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EFFECT OF MINERAL FERTILIZATION ON YIELD OF MAIZE CULTIVARS DIFFERING IN MATURITY SCALE

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Abstract. Field experiments were conducted in 2005-2007 at the Brody Experimental Station (52°26' N; 16°17' E) of the University of Life Sciences in Poznań with the following factors: 1) cultivars with different FAO number: 210, 240 and 260; 2) fertilization with K, Mg and Na: 0 (control), 150 kg K·ha^{-1}, 150 kg K + 16.3 kg Mg·ha^{-1}, 150 kg K + 16.3 kg Mg + 13.5 kg Na·ha^{-1}; 3) Zn application: 0 (control), 1.5 kg Zn·ha^{-1} after sowing and 1.5 kg Zn·ha^{-1} at the 3-4 leaf stage. It was found that the grain yield depended more on the course of weather conditions than did plant residues yield. Maize response to potassium fertilization depended on the vegetation season. In the year favorable for the establishment of a high maize yield, simultaneous K and Mg fertilization at rates 150 and 16.3 kg·ha^{-1} induced a significant grain yield increase. The influence of zinc fertilization on grain yield depended both on the vegetative period and cultivar. Early maturing cultivars responded positively to Zn and the optimal date for Zn foliar application was the 3-4 leaf stage. Maize response to sodium supplementation was not detected.

Key words: grain yield, magnesium, maize cultivars, potassium, sodium, yield components, zinc

INTRODUCTION

Maize is a crop plant characterized by a high potential of biomass and grain yield, especially in comparison with other cereal crops. The classical goals of maize cultivation are the production of silage for cows and grain to feed other animals, but it is also possible to produce biogas, bio-ethanol and solid fuels [Venturi and Venturi 2003]. Among many factors limiting grain yield, weather conditions during vegetation season are considered to exert a significant influence [Żarski et al. 2004]. Therefore, in Polish climate, the most important is to choose an adequate FAO cultivar [Górski 2004, Zaliwski and Hołaj 2006]. A production goal oriented at grain yield maximization must also take into account a sufficient supply of nutrients, with nitrogen being one of the most important nutrients [Kruczek 2005]. Nitrogen yield forming efficiency, expressed

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as the amount of nutrient necessary to produce one ton of grain with adequate top biomass, depends on many factors. According to Grzebisz [2004], particularly potassium affected positively the efficiency of nitrogen fertilization. In agricultural practice, potassium fertilization has a great importance because Polish soils were formed from sandy materials, which are naturally poor in this element [Fotyma and Gosek 2000]. The metabolism of nitrogen in plants depends also on soil magnesium availability [Kirbky and Mengel 1976]. On the one hand, when the supply of potassium is insufficient, the rate of magnesium uptake by plants is also decreased, but on the other hand, too excessive doses of potassium fertilizers negatively influence nutrient balance in the plant. It was found, for example, that fertilization with potassium decreased magnesium uptake by plants [Jacobsen 1993].

Among micronutrients, maize is especially sensitive to zinc deficiency [Rehm and Schmitt 1997]. According to Grzebisz et al. [2008b], zinc foliar fertilization increased both nitrogen uptake and grain yield of maize. However, it has been reported [Bukvić et al. 2003] that zinc application can also lead to a decrease in grain yield. This may be attributed to the different response of maize genotypes, doses of Zn, as well as soil conditions, especially pH and organic matter content [Fecenko and Ložek 1998, Leach and Hameleers 2001, Furlani et al. 2005, Singh et al. 2005].

Little is known about the response of maize cultivars to potassium fertilization and especially to its interaction with magnesium, sodium and zinc, when applied simultaneously. Hence, the present experiment was undertaken to provide relevant information on these details by using three maize cultivars with different FAO numbers. It was hypothesized that plants well supplied simultaneously with potassium, magnesium, sodium and zinc are in a position to increase nitrogen use efficiency, and consequently produce higher grain yield.

MATERIAL AND METHODS

Field trials were conducted in the consecutive years 2005, 2006 and 2007 at the Brody Experimental Station of the University of Life Sciences in Poznań (52°26’ N; 16°17’ E). The experiments were carried out in split-block design with 4 replications and the following treatments:

- cultivars with different number: Laurelis – FAO 210, Veritis – FAO 240 and Splendis – FAO 260;
- before sowing fertilization of K, Mg and Na: control (0), 150 kg K·ha^{-1} (K), 150 kg K + 16.3 kg Mg·ha^{-1} (K + Mg), 150 kg K + 16.3 kg Mg + 13.5 kg Na·ha^{-1} (K + Mg + Na);
- top dressing application of Zn: control (0), 1.5 kg Zn·ha^{-1} after sowing (ZnI), 1.5 kg Zn·ha^{-1} at the 3-4 leaf stage (ZnII).

The soil used for this experiment is classified according to FAO/WRB as albic luvisols originating from loamy sands underlined by loam. The experimental site was characterized by pH 5.3-5.6 and a high content of available phosphorus, potassium, magnesium and zinc (Table 1). For each experimental year, triticale was the forecrop for maize. Potassium, sodium and magnesium fertilizers were applied before sowing as KCl, NaCl, $MgSO_4{\cdot}H_2O$. Zinc was used in the ZnO form. Nitrogen fertilizers (ammonium nitrate, 34%) were applied at two separate dates, first one week before seeding (80 kg N·ha^{-1}) and the second one at the 3-4 leaf growth stage (40 kg N·ha^{-1}). Phosphorus fertilizer (superphosphate, 20% P) was applied in autumn at doses of 26.2

kg P·ha^{-1}. The area of the experimental plot was 14 m^2 (5m x 2.8m). Plants were harvested at technical maturity (October), from an area of 7 m^2. Climatic conditions during maize growth are presented in Table 2. It can be observed that the two years (2005, 2007) were characterized by best weather conditions for maize as compared with the year 2006, with drought which was established in June and July.

Table 1. Agrochemical properties of soil
Tabela 1. Właściwości agrochemiczne gleby

Year Rok	Soil layer Warstwa gleby m	pH $_{KCl}$	P^A	K^A	Mg^B	Zn^C	Mn^C	Cu^C
			mg·kg^{-1}					
2005	0.0-0.3	5.6	66.3	156.0	62.1	34.6	264.3	7.7
	0.3-0.6	5.9	32.8	102.3	70.2	30.6	227.5	6.0
2006	0.0-0.3	5.3	72.5	139.8	89.1	73.4	231.0	9.7
	0.3-0.6	5.7	44.1	85.9	95.3	57.8	249.8	7.5
2007	0.0-0.3	5.3	65.3	151.8	84.2	42.1	260.6	6.5
	0.3-0.6	5.6	38.5	92.1	83.6	35.4	210.7	6.9

^{A} – extract solution – lactate buffer pH 3.55 – roztwór ekstrakcyjny – bufor mleczanowy pH 3,55
^{B} – extract solution – 0.0125 M $CaCl_2$ – roztwór ekstrakcyjny – 0,0125 M $CaCl_2$
^{C} – extract solution – 1 M HCl – roztwór ekstrakcyjny – 1 M HCl

Table 2. Weather conditions during maize vegetation period
Tabela 2. Warunki meteorologiczne podczas wegetacji kukurydzy

Month Miesiąc	2005		2006		2007		1957-2004	
	Temperature Temperatura °C	Rainfall Opady mm	Temperature Temperatura °C	Rainfall Opady mm	Temperature Temperatura °C	Rainfall Opady mm	Temperature Temperatura °C	Rainfall Opady mm
January Styczeń	2.1	48.5	-0.3	17.1	4.7	118.9	-1.8	36.5
February Luty	-1.5	66.4	-1.2	26.8	1.2	71.8	-0.6	30.6
March Marzec	1.8	22.9	0.5	36.8	6.5	71.9	2.8	38.8
April Kwiecień	8.8	19.2	8.7	47.2	10.5	4.8	7.7	38.0
May Maj	12.8	86.2	13.7	41.4	14.5	149.8	13.1	54.7
June Czerwiec	16.4	39.8	19.9	7.7	19.2	55.6	16.3	65.7
July Lipiec	19.7	126.5	24.4	9.9	18.6	96.2	17.8	77.6
August Sierpień	16.9	81.6	17.4	188.7	18.1	70.9	17.4	62.0
September Wrzesień	15.6	37.5	16.3	24.5	13.2	48.8	13.1	50.3
October Październik	10.2	6.4	11.1	31.3	8.2	21.3	8.5	41.8
November Listopad	3.0	15.4	6.5	68.6	2.9	67.7	3.4	44.7
December Grudzień	0.1	114.9	4.7	49.4	1.3	49.7	-0.2	47.1
Mean/total Średnia/suma	8.8	665.3	10.1	549.4	118.9	827.4	8.1	587.8

Data were elaborated by using analysis of variance for each year separately and for interaction year x treatments, using computer software STATISTICA 7. For F-test showing significant differences, Tukey's test (HSD) at the probability level $\alpha = 0.05$ was additionally performed to compare mean values. Correlation coefficients, stepwise variable selection and multiple regression fittings were determined in order to find out relationships between grain yield of maize cultivar and yield components.

RESULTS

Meteorological conditions prevailing during the growing season highly influenced the growth and final yield of maize (Table 2). In the years 2005 and 2007, characterized by similar weather conditions, the mean grain yield of maize amounted to 12.2 and 10.1 t·ha^{-1}, and that of crop residues 10.6 and 9.3 t·ha^{-1}, respectively (Table 3, 4).

Table 3. Effect of K, Mg and Na fertilization on the grain yield of maize cultivars in relation to vegetation seasons, t·ha^{-1}

Tabela 3. Wpływ nawożenia potasem, magnezem i sodem na plon ziarna odmian kukurydzy w zależności od sezonu wegetacyjnego, t·ha^{-1}

Year Rok	Cultivar Odmiana	Treatment of fertilization – Wariant nawożenia				Mean – Średnia
		O	K	K + Mg	K + Mg + Na	
2005	Laurelis	11.2	10.5	11.6	10.7	11.0
	Veritis	12.6	11.8	13.3	13.6	12.8
	Splendis	11.7	11.7	14.3	13.9	12.9
	Mean – Średnia	11.8	11.3	13.1	12.7	12.2
	LSD$_{0.05}$ – NIR$_{0,05}$	A 0.95	B 1.18	A x B ns – ni		
2006	Laurelis	4.2	4.6	4.3	4.6	4.4
	Veritis	3.7	3.9	4.7	3.9	4.1
	Splendis	3.9	4.8	3.6	3.8	4.0
	Mean – Średnia	3.9	4.4	4.2	4.1	4.2
	LSD$_{0.05}$ – NIR$_{0,05}$	A ns – ni	B ns – ni	A x B ns – ni		
2007	Laurelis	9.1	9.8	9.6	10.3	9.7
	Veritis	10.1	10.0	10.2	10.3	10.1
	Splendis	10.3	11.1	10.2	10.8	10.6
	Mean – Średnia	9.8	10.3	10.0	10.5	10.1
	LSD$_{0.05}$ – NIR$_{0,05}$	A 0.79	B ns – ni	A x B ns – ni		
Mean Średnia	Laurelis	8.1	8.3	8.5	8.5	8.4
	Veritis	8.8	8.6	9.4	9.3	9.0
	Splendis	8.6	9.2	9.4	9.5	9.2
	Mean – Średnia	8.5	8.7	9.1	9.1	8.8
	LSD$_{0.05}$ – NIR$_{0,05}$	A 0.57	B 0.59	A x B ns – ni		

A – cultivar – odmiana

B – pre-sowing fertilization with K, Mg and Na – przedsiewne nawożenie K, Mg i Na

ns – ni – non significant difference – różnica nieistotna

In contrast to the above years, June and July 2006 were characterized by very poor precipitation. Therefore, in that year the mean yield of grain decreased to 4.2 t·ha^{-1}, but crop residues yield increased, even to 11.4 t·ha^{-1} (Table 4). For the years 2005 and 2007, the highest yields were mostly related to the Splendis cultivar, with significant differences (17% and 9%, respectively) as compared to the Laurelis cultivar. No significant differences were obtained in 2006 between the tested cultivars; however, a distinct tendency for a greater yield was obtained for the earlier maturing cultivar (Laurelis). In that year the mean differences between cultivars amounted to *ca* 8.6% (Table 3).

Table 4. Effect of zinc fertilization on the grain and crop residues yield of maize cultivars, t·ha^{-1}
Tabela 4. Wpływ nawożenia cynkiem na plon ziarna i resztek pożniwnych odmian kukurydzy, t·ha^{-1}

Cultivar Odmiana	Year – Rok									Mean Średnia		
	2005			2006			2007					
	O	Zn/ I	Zn/ II	O	Zn/ I	Zn/ II	O	Zn/ I	Zn/ II	O	Zn/ I	Zn/ II
Grain yield – Plon ziarna												
Laurelis	10.8	10.9	11.4	4.5	4.7	4.0	9.1	9.8	10.1	8.1	8.4	8.5
Veritis	12.5	13.0	12.9	3.8	3.8	4.6	10.1	9.9	10.4	8.8	8.9	9.3
Splendis	13.1	13.2	12.4	3.8	4.1	4.2	11.2	10.3	10.2	9.3	9.2	8.9
$LSD_{0.05}$ – $NIR_{0,05}$	A x C ns – ni			A x C ns – ni			A x C 0.95			A x C ns – ni		
Crop residue yield – Plon resztek pożniwnych												
Laurelis	10.2	9.7	10.3	11.6	10.5	10.9	8.7	9.8	9.7	10.1	10.0	10.3
Veritis	10.3	11.0	10.7	10.7	10.3	11.6	9.3	8.4	9.1	10.1	9.9	10.5
Splendis	10.6	11.6	11.2	12.8	11.4	12.6	9.2	10.3	9.1	10.9	11.1	11.0
$LSD_{0.05}$ – $NIR_{0,05}$	A x C ns – ni			A x C ns – ni			A x C ns – ni			A x C ns – ni		

A – cultivar – odmiana
C – zinc application – nawożenie cynkiem
ns – ni – non-significant difference – różnica nieistotna

The effect of K, Mg and Na fertilization on grain yield depended on the vegetation seasons. Potassium increased grain yield for each experimental year, but a significant increase in comparison with the control was recorded in 2005. In spite of seasonal variability, the highest mean grain yield was harvested on the K + Mg and K + Mg + Na treatments. The obtained yield increase (7.0%) was significant in comparison with that observed for maize growing on the controls. Furthermore, a smaller yield was harvested from the K treatments in comparison with K + Mg and K + Mg + Na treatments and the difference was 2.3%. In the case of the current investigations, no significant interactions were obtained between the tested cultivars and potassium fertilization systems; however, a distinct tendency for greater potassium efficiency was observed in Splendis cultivar (Table 3).

The effect of zinc application depended both on vegetation seasons and cultivars (Table 4). In the last investigated year, zinc applied at the 3-4 leaf stage increased significantly the grain yield of cv. Laurelis, but decreased that of cv. Splendis, which were characterized by +11.0% and -8.9%, respectively as compared with control treatments. A similar tendency in yielding of cultivars was also observed in the first year. As a result, the highest mean grain yield of two earlier cultivars (Laurelis and Veritis) was recorded in the treatment Zn/II and exceeded the yields obtained in the controls by 4.9 and 5.7%, respectively.

The structure of yield of crop residues depended on interactions between plant cultivar and treatments of K, Mg and Na fertilization. The Splendis cultivar produced the highest mean yield of vegetative biomass (stalk), irrespective of chemical composition of fertilizers and weather conditions throughout years of experimentation (Table 5). The obtained differences between cultivars were a result of higher stalk biomass, leaves as well as corn rachis. The effect of K, Mg and Na fertilization on the total yield of crop residues (stalk yield) depended both on the vegetation season and the cultivar. Generally, the highest dry matter (averaged across the cultivar) of all investigated plant organs was produced by plants fertilized in the K + Mg + Na systems. However, a significant difference between the control and K + Mg + Na treatments was found in respect of the yield of cob covering leaves, only. On the other hand, harvested yields of leaves and stems depended on the interaction between investigated factors. The Laurelis cultivar on control plots produced significantly lower biomass of those plant organs than Splendis cultivar fertilized with K + Mg + Na. In respect of total dry matter, the effect of interaction cultivar x K treatments was more complicated. The highest crop residues yield of the Laurelis cultivar was produced by plants fertilized with K + Mg, Veritis with K and Splendis with K + Mg + Na (Table 5).

Table 5. Effect of cultivar and K, Mg and Na fertilization on the yield structure of crop residues, t·ha^{-1} (mean 2005-2007)

Tabela 5. Wpływ odmiany oraz nawożenia potasem, magnezem i sodem na strukturę plonu resztek pożniwnych, t·ha^{-1} (średnia 2005-2007)

Characteristics Cechy	Cultivar Odmiana	Treatment of fertilization – Wariant nawożenia				Mean Średnia
		O	K	K + Mg	K + Mg + Na	
Corn rachis Osadki kolbowe	Laurelis	1.66	1.35	1.53	1.49	1.51
	Veritis	1.39	1.72	1.61	1.74	1.61
	Splendis	1.77	1.78	1.77	1.75	1.77
	mean – średnia	1.60	1.62	1.64	1.66	1.63
	LSD$_{0.05}$ – NIR$_{0,05}$		A 0.22	B ns – ni	A x B 0.35	
Cob covering leaves Liście okrywowe	Laurelis	1.18	1.34	1.70	1.65	1.47
	Veritis	1.14	1.43	1.06	1.36	1.25
	Splendis	1.47	1.32	1.35	1.47	1.40
	mean – średnia	1.26	1.36	1.37	1.49	1.37
	LSD$_{0.05}$ – NIR$_{0,05}$		A 0.13	B 0.24	A x B 0.42	
Liście Leaves	Laurelis	2.06	2.30	2.46	2.32	2.28
	Veritis	2.27	2.37	2.20	2.33	2.29
	Splendis	2.59	2.40	2.46	2.68	2.53
	mean – średnia	2.31	2.36	2.37	2.44	2.37
	LSD$_{0.05}$ – NIR$_{0,05}$		A 0.24	B X	A x B 0.55	
Łodygi Stems	Laurelis	4.55	4.76	5.40	4.79	4.88
	Veritis	4.96	5.39	4.41	5.22	5.00
	Splendis	4.80	5.11	5.43	5.78	5.28
	mean – średnia	5.10	4.92	4.91	5.26	5.05
	LSD$_{0.05}$ – NIR$_{0,05}$		A 0.21	B X	A x B 1.10	
Total crop residues Ogółem resztki pożniwne	Laurelis	9.45	9.75	11.09	10.25	10.14
	Veritis	9.76	10.91	9.28	10.65	10.15
	Splendis	10.63	10.61	11.01	11.68	10.98
	mean – średnia	9.95	10.42	10.46	10.86	10.42
	LSD$_{0.05}$ – NIR$_{0,05}$		A 0.75	B X	A x B 0.90	

ns – ni – non significant difference – różnica nieistotna
X – values dependent on years – wartości zależne od roku
A – cultivar – odmiana
B – pre-sowing fertilization with K, Mg and Na – przedsiewne nawożenie K, Mg i Na

The relationship between crop residues and grain yields depended on year and cultivars (Table 6). In the two years of study (2005 and 2007) the highest correlation coefficient between grain and crop residues yield was found for Veritis, and lowest for Splendis cultivars. Among all investigated plant parts, a significant and positive correlation was obtained particularly for leaves in 2005 and corn rachis in 2007. On the basis of the first plant organ, and irrespective of the vegetation season, the order of cultivars response was as follows: Splendis < Veritis < Laurelis (Table 6).

Table 6. Correlation coefficients between grain yield and crop residue structure components in relation to vegetation seasons and maize cultivar
Tabela 6. Współczynniki korelacji między plonem ziarna a elementami struktury resztek pożniwnych w zależności od sezonu wegetacyjnego oraz odmiany kukurydzy

Plant organ Organ rośliny	2005			2006			2007		
	Laurelis	Veritis	Splendis	Laurelis	Veritis	Splendis	Laurelis	Veritis	Splendis
Corn rachis Osadki kolbowe	0.358*	0.378*	0.294*	0.379*	0.251	0.352*	0.500***	0.560***	0.443**
Cob covering leaves Liście okrywowe	0.342*	0.322*	0.075	0.271	-0.013	0.160	0.380*	0.489**	0.135
Liście Leaves	0.525**	0.445**	0.345*	0.429**	0.266	0.195	0.386*	0.264	0.161
Łodygi Stems	0.452**	0.434**	0.352*	0.239	-0.097	0.126	0.364*	0.441**	0.084
Total Ogółem	0.558***	0.575***	0.340*	0.237	0.000	0.204	0.476**	0.565***	0.177

*, **, *** significant for $p \leq 0.05$; 0.01; 0.001 respectively – istotne odpowiednio dla $p \leq 0,05$; 0,01; 0,001
n = 48

The values of yield components were influenced mainly by the course of weather conditions during vegetation seasons. For example, the acute drought in 2006 decreased significantly the weight of 1000 kernels and number of kernels per cob (Table 7). The second factor which significantly affected yield components was the maize genotype. Three of seven studied yield components, i.e., number of cob per plant, number of rows per cob, and number of kernels per cob had the highest values on plots with the Splendis cultivar, whereas the highest weight of 1000 kernels and plant density were obtained for Veritis.

Table 7. Yield structure of maize in relation to vegetation seasons
Tabela 7. Struktura plonu kukurydzy w zależności od sezonu wegetacyjnego

Rok Year	Plant density $No \cdot ha^{-1}$ Obsada $szt. \cdot ha^{-1}$	Number of cobs per plant Liczba kolb na roślinie	Number of rows per cob Liczba rzędów na kolbie	Number of kernels per row Liczba ziarniaków w rzędzie	Number of kernels per cob Liczba ziarniaków z kolby	Weight of 1000 kernels Masa tysiąca nasion g	Harvest index Indeks zbioru
2005	66776	1.17	15.0	39.9	599.1	330.9	53.5
2006	68477	0.94	13.2	23.3	312.5	245.8	26.8
2007	71652	0.99	14.8	30.1	451.7	323.0	52.2
$LSD_{0.05}$ $NIR_{0,05}$	3507.2	0.181	1.22	6.11	88.65	35.33	10.40

Among all investigated yield components, treatments of K, Mg and Na fertilization significantly affected the number of kernels per cob only. The following order was obtained: control < K < K + Mg + Na < K + Mg. The effect of interactions between cultivars and before sowing fertilization depended on vegetation seasons, except for plant density, number of kernels per row and cob (Table 8). The application of Zn did not significantly affect the values of yield components.

Table 8. Effect of K, Mg and Na fertilization on the yield structure of maize cultivars
Tabela 8. Wpływ nawożenia potasem, magnezem i sodem na strukturę plonu odmian kukurydzy

Characteristic Cecha	Cultivar Odmiana	Treatment of fertilization – Wariant nawożenia				Mean Średnia
		O	K	K + Mg	K + Mg + Na	
Plant density, No·ha^{-1} Obsada, szt.·ha^{-1}	Laurelis	68238	67399	69144	69614	68599
	Veritis	71380	69548	68265	71003	70049
	Splendis	69386	68146	67947	67550	68257
	mean – średnia	69668	68364	68452	69389	68968
	LSD$_{0.05}$ – NIR$_{0,05}$	A	X	B ns – ni	A x B ns – ni	
Number of cobs per plant Liczba kolb na roślinie	Laurelis	0.93	0.94	0.94	1.07	0.97
	Veritis	1.03	1.04	1.03	0.99	1.02
	Splendis	1.09	1.08	1.11	1.14	1.11
	mean – średnia	1.01	1.02	1.02	1.07	1.03
	LSD$_{0.05}$ – NIR$_{0,05}$	A	0.045	B ns – ni	A x B X	
Number of rows per cob Liczba rzędów na kolbie	Laurelis	14.2	13.4	13.4	14.5	14.2
	Veritis	14.2	14.6	14.6	14.2	14.2
	Splendis	14.4	14.8	14.8	15.0	14.9
	mean – średnia	14.2	14.3	14.3	14.6	14.4
	LSD$_{0.05}$ – NIR$_{0,05}$	A	0.75	B ns – ni	A x B X	
Number of kernels per row Liczba ziarniaków w rzędzie	Laurelis	29.7	30.8	31.8	31.7	31.0
	Veritis	29.6	30.9	30.3	31.2	30.5
	Splendis	31.5	31.3	33.0	31.4	31.8
	mean – średnia	30.3	31.0	31.7	31.4	31.1
	LSD$_{0.05}$ – NIR$_{0,05}$	A	ns – ni	B ns – ni	A x B ns – ni	
Number of kernels per cob Liczba ziarniaków z kolby	Laurelis	425.7	427.8	466.7	463.8	446.0
	Veritis	422.9	450.1	428.1	447.2	437.1
	Splendis	458.4	470.0	505.7	486.9	480.3
	mean – średnia	435.7	449.3	466.8	466.0	454.4
	LSD$_{0.05}$ – NIR$_{0,05}$	A	40.2	B 30.3	A x B ns – ni	
Weight of 1000 kernels Masa tysiąca nasion g	Laurelis	297.4	295.4	294.2	282.6	292.4
	Veritis	309.5	314.2	308.7	311.3	310.9
	Splendis	283.3	299.7	309.1	293.7	296.5
	mean – średnia	296.7	303.1	304.0	295.8	299.9
	LSD$_{0.05}$ – NIR$_{0,05}$	A	9.78	B ns – ni	A x B X	
Harvest index Indeks zbioru %	Laurelis	46.3	45.9	43.4	45.4	45.3
	Veritis	47.4	44.0	50.4	46.5	47.1
	Splendis	42.6	47.7	47.1	44.8	45.5
	mean – średnia	45.4	45.9	47.0	45.6	46.0
	LSD$_{0.05}$ – NIR$_{0,05}$	A	1.5	B ns – ni	A x B X	

ns – ni – non significant difference – różnica nieistotna
X – values dependent on years – wartości zależne od roku
A – cultivar – odmiana
B – pre-sowing fertilization with K, Mg and Na – przedsiewne nawożenie K, Mg i Na

In 2005, plant density and number of kernels per row were significantly and positively correlated with the grain yield. However, the first parameter played the strongest role for cv. Laurelis, while the second one for cv. Splendis. In 2007, the relationships between investigated characteristics were more complex. For earlier maturing cultivars, plant density and number of cob per plant were the most important, whereas for Splendis, number of cob per plant, number of kernels per row as well as weight of 1000 kernels. However, in both years (i.e., 2005 and 2007), the highest direct effect (*BETA* coefficient) on grain yield was exerted by the number of kernels per row (Table 9). Regression equations describing the above mentioned relationships are reported in Table 10. It appeared that the grain yield should be better forecasted by the analysis of most of yield components, of which plant density and number of kernels per row were found to be the most important. For the year with disturbed plant growth as a result of drought effect, the values of R^2 were below 0.50 and not significant.

Table 9. Dependency of grain yield on the yield structure components; correlation (r) and beta (*B*) coefficients
Tabela 9. Zależność plonu ziarna od elementów struktury plonu; współczynniki korelacji (r) oraz beta (*B*)

Year Rok	Elements of yield structure Elementy struktury plonu	Laurelis		Veritis		Splendis	
		r	*B*	r	*B*	r	*B*
2005	Plant density, No·ha^{-1} Obsada, szt.·ha^{-1}	0.537***	0.786***	0.450**	0.763***	0.386*	0.782***
	Number of cobs per plant Liczba kolb na roślinie	-0.125	0.502***	-0.210	0.653***	-0.045	0.742***
	Number of rows per cob Liczba rzędów na kolbie	0.015	0.447**	0.269	0.432**	0.013	0.384**
	Number of kernels per row Liczba ziarniaków w rzędzie	0.447**	0.821***	0.526***	0.984***	0.609***	0.826***
	Weight of 1000 kernels, g Masa tysiąca nasion	0.370*	0.168*	-0.027	-0.147*	0.035	0.141
2006	Plant density, No·ha^{-1} Obsada, szt.·ha^{-1}	0.003	0.027	0.127	0.173	0.439**	0.502**
	Number of cobs per plant Liczba kolb na roślinie	0.288	0.062	0.019	-0.060	-0.247	0.001
	Number of rows per cob Liczba rzędów na kolbie	0.326*	0.226	0.266	0.255	0.302	-0.374
	Number of kernels per row Liczba ziarniaków w rzędzie	0.599***	0.416**	0.426**	0.434**	0.369*	0.531***
	Weight of 1000 kernels, g Masa tysiąca nasion	0.371*	0.127	0.139	0.125	0.234	0.281
2007	Plant density, No·ha^{-1} Obsada, szt.·ha^{-1}	0.316*	0.858***	0.016	1.367***	0.190	0.666***
	Number of cobs per plant Liczba kolb na roślinie	0.329*	0.852***	0.061	1.090***	0.414**	0.741***
	Number of rows per cob Liczba rzędów na kolbie	-0.031	0.510***	0.048	0.516***	-0.277	0.415**
	Number of kernels per row Liczba ziarniaków w rzędzie	0.236	1.051***	0.351*	1.513***	0.435**	0.882***
	Weight of 1000 kernels, g Masa tysiąca nasion	0.291*	0.621***	0.262	1.065***	0.446**	0.633***

*, **, *** significant for $p \leq 0.05$; 0.01; 0.001 respectively – istotne odpowiednio dla $p \leq 0,05$; 0,01; 0,001
n = 48

DISCUSSION

The results of the present study showed that the course of weather conditions during vegetation seasons was the main factor which affected the grain yield. The acute drought in June and July 2006 influenced more negatively grain yield than the plant residues biomass. It was a result of plant regrowth after the drought. Losses of grain yield in 2006 were mainly attributed to the reduction in the number of kernels per cob and weight of kernels. The first feature resulted from the direct impact of drought on kernels initiation and the second one, from the insufficient transport of carbohydrates due to the delay of the vegetation [Subedi and Ma 2005]. Moreover, in 2006 the late maturing cultivars were infested by smut (*Ustilago maya*). For the dry year, the highest grain yield was harvested from the Laurelis variety. This is in agreement with the data reported by Górski [2004], who showed that the risk of maize cultivation for grain is lower in Poland when cropping earlier maturing maize varieties. In the other years the highest grain yield was harvested from the Splendis variety. This result confirms the high yield forming potential of late maturing varieties [Michalski *et al.* 2002, Zaliwski and Hołaj 2006].

In contrast to the type of cultivar, the effect of K, Mg and Na fertilization was nearly consistent, despite the seasonal weather variability. Potassium fertilization increased the average grain yield by 2.3% in comparison with the control treatments, but the significant effect was obtained under K + Mg treatments (7%). These results confirm those obtained by Kulczycki [2000], who reported that the addition of magnesium to potassium fertilization is very profitable. It should be pointed out that soils used for current fields trials were characterized by a high level of available potassium and magnesium. In spite of these characteristics, it was observed that maize responded positively to potassium and magnesium fertilization, since high yields induced greater plant nutritional requirements. This is confirmed by the highest grain yields harvested in 2005 with a simultaneous and significant effect of K and Mg fertilization. Potassium exhibits a great role in photosynthesis process, nitrogen metabolism, carbohydrates synthesis and increases plant resistance to water stress [Hampe and Marschner 1982, Grzebisz 2004]. Moreover, the optimal supply of potassium increases the rate of nitrate uptake by plants. It is very important because maize can fully activate its yielding potential only under conditions of good nitrogen supply before bloom stage [Subedi and Ma 2005]. The main role of magnesium, because of its essential role in the chlorophyll molecule, is to efficiently capture sun energy by the plant. Additionally, the production and activation of biochemical forms of energy (ATP) also require a well supply of magnesium [Kirkby and Mengel 1976].

The highest positive relationship between grain yield and yield components was found for the number of kernels per row and per cob. Similar data were reported by Elmore and Abendroth [2006]. Potassium and magnesium applied simultaneously increased significantly the number of kernels per cob. Westagate et al. [2003] reported that the number of kernels per cob is an indirect index of pollen vitality of maize. It can be concluded that in the present study, magnesium had the biggest influence on pollen vitality. Moreover, potassium and magnesium exerted a positive influence on the weight of 1000 kernels, since both elements participate in the transport of carbohydrates to the sink organs [Kirkby and Mengel 1976, Grzebisz 2004]. For some plant species sodium fertilization is one of the important yield factors. The reason for the beneficial effect of Na has been related to an improved drought resistance, when the water supply is limited

[Hampe and Marschner 1982]. According to Ohaishi et al. [1990], for C4 plant species such as maize and sorghum, sodium has not even been shown to be beneficial. In respect of the grain yield, this is confirmed by current investigations since no differences occurred between K + Mg and K + Mg + Na treatments. However, late maturing maize cultivars exhibited an increase trend of crop residues biomass under sodium fertilization.

The effect of Zn application on maize grain yield depended on many factors. According to Fecenko and Ložek (1998) the high zinc dose (> 6 kg·ha^{-1}) resulted in a reduction in yield, while rates varying within 1.5-3.0 kg Zn·ha^{-1} were considered as optimal. According to Grzebisz et al. [2008a], zinc fertilization at the 5-6 leaf stage (1--1.5 kg Zn·ha^{-1}), irrespective of seasonal weather variability, increased the grain yield by 20%. The positive effect of zinc on maize yielding results in the fact that this nutrient stimulates the activity of several enzymes, including carbonic anhydrase. However, one of the most important functions relates to the activity of hormones, such as auxins [Rehm and Schmitt 1997, Singh et al. 2005]. In our field trials, the influence of Zn depended both on the vegetation season and cultivars. For years of favorable weather conditions, only early maturing maize cultivars responded positively to Zn, whereas for late maturing cultivars, a yield decrease was observed. From data reported by Furlani et al. [2005], it appeared that the differential response among the genotypes was found to be associated with their capability to exploit soil Zn and/or transport it to the shoot. A negative influence of Zn on yield dry biomass was obtained by Bukvić et al. [2003] who stated that the decrease of the P/Zn ratio in the leaves was the cause of the above mentioned response. The influence of Zn foliar application on maize yielding depended also on the application date. According to Leach and Hameleers [2001], the 4-leaf growth stage is the optimal period. Our data showed that the latter one was at the 3-4 leaf for the cultivars, which respond positively, but this stage is considered by Singh et al. [2005] as critical. The low increase in grain yield for years 2005 and 2006 resulted probably from the acidic soil pH and a simultaneous high zinc phytoavailability [Rehm and Schmitt 1997, Bukvić et al. 2003, Singh et al. 2005].

CONCLUSIONS

1. It was found that the grain yield depended more on the course of weather conditions than did plant residue yield.
2. A significant influence of potassium fertilization on grain yield of maize grown on a soil rich in nutrients was obtained during the year when maize plants could realize their genetic potential. A marked grain yield increase was reached owing to the application of both K and Mg at the rates 150 and 16.3 kg·ha^{-1}. Our data showed a tendency for the best utilization of potassium by the medium-late maturing maize cultivar.
3. The influence of zinc application on maize grain yield depended both on the vegetation season and maize genotype. Early maturing cultivars responded positively to Zn application and the 3-4 leaf stage was the optimal application time.
4. Maize response to sodium supplementation was not detected under potassium-magnesium fertilization.

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WPŁYW NAWOŻENIA MINERALNEGO NA PLON ODMIAN KUKURYDZY O RÓŻNEJ WCZESNOŚCI

Streszczenie. Doświadczenia polowe przeprowadzono w latach 2005-2007 w Stacji Doświadczalnej Brody (52°26’ N; 16°17’ E), należącej do Uniwersytetu Przyrodniczego w Poznaniu. Czynnikami doświadczalnymi były: 1) odmiany o różnej liczbie FAO: 220, 240 i 260; 2) warianty nawożenia potasem, magnezem i sodem: 0 (kontrola), 150 kg K·ha^{-1}, 150 kg K + 16,3 kg Mg·ha^{-1}, 150 kg K + 16,3 kg Mg + 13,5 kg Na·ha^{-1}; 3) nawożenie cynkiem: 0 (kontrola), 1,5 kg Zn·ha^{-1} po siewie i 1,5 kg Zn·ha^{-1} w fazie 3-4 liści. Od przebiegu pogody w większym stopniu zależał plon ziarna niż masa resztek pożniwnych. Reakcja kukurydzy na zastosowane warianty nawożenia potasem zależała od sezonu wegetacyjnego. W roku sprzyjającym wysokiemu poziomowi plonowania istotny przyrost plonu ziarna zapewniało jednoczesne nawożenie kukurydzy K i Mg (180 i 27 kg·ha^{-1}). Wpływ nawożenia kukurydzy cynkiem na plon ziarna zależał od sezonu wegetacyjnego oraz wczesności odmiany. Dodatnio na nawożenie cynkiem reagowały odmiany wcześniejsze, a optymalnym terminem ich dokarmiania była faza 3-4 liści. Nie stwierdzono reakcji kukurydzy na uzupełnienie sodem nawożenia mineralnego.

Słowa kluczowe: cynk, magnez, odmiany kukurydzy, plon ziarna, potas, sód, struktura plonu

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