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Morphological traits in maize cultivars at varied N and Mg fertilization rates

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Abstract. Field experiments were conducted at the Teaching and Experimental Station in Swadzim near Poznań in the years 2009-2011. They were carried out in the split-split-plot design with three experimental factors in four replications. Analyses were conducted to investigate four nitrogen fertilization rates and two magnesium fertilization rates on morphological traits of plants and ears in two types of maize cultivars differing in their genetic profiles. The aim of the conducted field tests was the evaluation of the effect of application of magnesium in maize cultivation, which would increase effectiveness of nitrogen fertilization. A visible symptom of that may be a modification of morphological features of the plant. The properties analyzed in this paper (plant height) can have significant effect on shaping plant photosynthetic surface area that determines productivity. It was shown that the number of plants was inversely proportional to the applied nitrogen rate. The stay-green hybrid was characterised by a greater number of plants both after emergence and during harvest. The significantly shortest plants were found for the dose of 0 kg N ha^{-1} in comparison to three other levels of application of this ingredient, for which the value of this property was significantly at the same level.

Regardless of the nitrogen and magnesium dose, the „stay-green" ES Paroli variety was characterized by shorter plants, a lower height of ear setting, a shorter length and diameter of the ears and the smaller volume of a ears compared with the ES Palazzo hybrid. Under conditions of this study it was ineffective to apply magnesium, as evidenced by the lack of effect of this macroelement on the analysed traits.

keywords: *Zea mays* L.; stay-green; fertilization; morphological traits

INTRODUCTION

Next to watering, nitrogen fertilization in maize (*Zea mays* L.) is the basic cultivation factor determining the level and quality of the crop (Szulc and Bocianowski, 2011). Application of high nitrogen rates in market economy-oriented management systems has to be justified economically and at the same time should be environmentally sound (Al-Kaisi and Yin, 2003; Schulte Auf'm Erley et al., 2005). Moreover, adequate growth and development of maize in the opinion of Machul (1995) requires appropriate cultivation measures, which in the period of its intensive growth should provide maximum photosynthesis productivity, contributing to high yields and the simultaneous good quality. Cultivation factors such as nitrogen fertilization (Szulc et al., 2013), application of magnesium (Szulc et al., 2011), plant density or pesticides may significantly limit the appropriate course of photosynthesis. The maize has worse indicators of use of nutrients from mineral fertilizers, especially of nitrogen in comparison with other crops. The literature data indicates that the use of nitrogen depends greatly on balancing its dose with phosphorus and potassium, as well as the availability of number of other elements, including magnesium. Photosynthesis, although considerably modified under the influence of cultivation conditions, is determined genetically and it is a species- and cultivar-specific trait of plants (Thomas and Smart, 1993). Most new maize cultivars in comparison to their older counterparts exhibit increased lodging resistance and improved health of plants (Meghji et al., 1984; Szulc, 2013). They are the so-called stay-green hybrids. These cultivars are characterized by leaves remaining green up to the physiological maturity stage (Craft-Brandner et al., 1984; Szulc et al., 2013).

Thus the aim of the conducted field experiments was to assess morphological traits of plats in maize cultivars differing in genetic profiles depending on applied nitrogen and magnesium rates.

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MATERIAL AND METHODS

Field experiments

The field experiments were performed at the Department of Agronomy, the Poznań University of Life Sciences, on the fields of the Teaching and Experimental Station in Swadzim in the years 2009–2011. They were run in the split-split-plot design with three experimental factors in four field replications. The experiment was conducted to analyze the effect of four urea application rates (0, 50, 100, 150 kg N ha^{-1}) and two magnesium rates (0, 25 kg MgO ha^{-1} applied as kieserite) on morphological traits of plants and ears in two types of maize cultivars, i.e. ES Palazzo [FAO 230-240] and the stay-green (SG) ES Paroli [FAO 250].

Phosphorus at a dose of 80 kg P_2O_5 ha^{-1} was used in the form of granular triple superphosphate 40% P_2O_5, and potassium at a dose of 120 kg K_2O ha^{-1} as potassium salt 60% K_2O. Nitrogen was applied according to the scheme of the experiment. Soil resources of phosphorus, potassium and magnesium in individual years of the experiments were as follows in: 2009 (36.1 mg P kg^{-1} of soil; 121,2 mg K kg^{-1} of soil; 44.0 mg Mg kg^{-1} of soil), 2010 (37.8 mg P kg^{-1} of soil; 97.1 mg K kg^{-1} of soil; 40.0 mg Mg kg^{-1} of soil), 2011 (61.2 mg P kg^{-1} of soil; 54.8 mg K kg^{-1} of soil; 81.0 mg Mg kg^{-1} of soil).

Thermal and humidity conditions

The course of temperature and humidity conditions in the maize vegetation seasons was presented in an earlier study (Szulc et al., 2013).

The plant material

Biometric measurements of plant height and production ear setting prior maize harvest were carried out using wooden ruler graduated in cm. Plant height was measured from the ground level to the top of maize panicle. Whereas, the height of productive ear setting was measured from the ground level to the ear attachment point.

After emergence the number of plants was counted in each plot, followed by the count of plants per 1 m^2. Analogously the number of plants was determined before harvest. Counting the number of plants twice during their vegetation period made it possible to determine plant losses. In the harvest season, 10 ears were collected from each plot and their length and diameter was measured using an electronic caliper. Plant height and ear setting height were recorded only in 2009 and 2010. Ear volume (V) was calculated using the formula $V = \pi \cdot r^2 \cdot D$, where r denotes ½ ear diameter, D – ear length.

Statistical analysis

Firstly, the normality of distributions for studied traits was tested using the Shapiro-Wilk normality test (Shapiro and Wilk, 1965). A four-way analysis of variance (ANOVA) was performed to verify the hypothesis of a lack of effects of years (Y), nitrogen application rates (N), magnesium rates (M) and hybrids (H) and hypotheses about a lack of interaction between: Y×N, Y×M, Y×H, N×M, N×H, M×H, Y×N×M, Y×N×H, Y×M×H, N×M×H, Y×N×M×H) on plant height, ear setting height, ear length, ear diameter, ear volume, the number of plants after emergence, the number of plants before harvest and plant loss rates in the vegetation period. Mean values and standard deviations of individual characteristics were calculated. Least significant differences (LSDs) were calculated for individual characteristics.

RESULTS AND DISCUSSION

All studied traits have a normal distribution. The results indicate that the impact of weather conditions varied between years for all the observed traits ($P<0.001$) (Tables 1, 2). Markedly taller maize plants were observed in 2009 than in 2010 (Table 3). Nitrogen fertilization rates constituted a factor significantly determining plant height (Table 1). The Y×N interaction statistically significantly determined plant height (Table 1). Significantly the lowest maize plants were recorded for the fertilization rate of 0 kg N ha^{-1} (217.13 cm), while the plants were tallest for the fertilization rate of 150 kg N ha^{-1} (234.28 cm) (Table 3). Szulc (2009) showed that plant height increased significantly within the range of fertilization rates from 0 kg N ha^{-1} to 120 kg N ha^{-1}. In these studies the application of nitrogen at a rate of 150 kg N ha^{-1} caused a reduction of this trait. Also Kruczek (1997) in the experiment with a high number of nitrogen application rates from 30 to 270 kg N ha^{-1} showed

Table 1. Mean squares from analysis of variance for plant height and ear setting height.

Source of variation	Degrees of freedom	Plant height	Ear setting height
Blocks	3	57	13.24
N	3	2939.3**	29.55
Residual 1	9	299.7	43.17
MgO (M)	1	64.9	38.31
N×M	3	25.8	27.66
Residual 2	12	315.1	69.12
Hybrid (H)	1	107.6	269.39**
N×H	3	30	4.88
M×H	1	16.3	0.58
N×M×H	3	107.8	2.07
Residual 3	24	57	22.36
Year (Y)	1	64489.9***	1309.12***
Y×N	3	1970.9***	14.03
Y×M	1	0.8	4.63
Y×H	1	226.8	104.49*
Y×N×M	3	38.2	12.17
Y×N×H	3	22.9	19.64
Y×M×H	1	0	13.36
Y×N×M×H	3	105.2	34.25
Residual 4	48	119.8	24.54

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

Table 2. Mean squares from analysis of variance for ear length, ear diameter, ear volume, number of plants after emergence and number of plants before harvest.

Source of variation	d.f.	Ear length	Ear diameter	Ear volume	Number of plants after emergence	Number of plants before harvest
Blocks	3	1.60	0.04	821.3	0.27	0.14
N (N)	3	18.57***	0.08*	7842.1***	0.92***	0.66**
Residual 1	9	1.11	0.01	494.7	0.07	0.07
MgO (M)	1	0.10	0.03**	500.4	0.09	0.08
N×M	3	0.66*	0.03***	985.1***	0.09	0.06
Residual 2	12	0.13	0.002	66.7	0.08	0.05
Hybrid (H)	1	14.48***	0.81***	26862.2***	11.38***	10.18***
N×H	3	2.26**	0.01	534	0.26**	0.11
M×H	1	0.0002	0.01	272.9	0.11	0.18
N×M×H	3	0.62	0.01	347.1	0.05	0.03
Residual 3	24	0.34	0.01	330.9	0.04	0.06
Year (Y)	2	128.94***	1.36***	86315.5***	3.60***	6.34***
Y×N	6	3.81***	0.05**	2016***	0.17**	0.13*
Y×M	2	0.002	0.01	145.5	0.02	0.02
Y×H	2	22.06***	0.08**	3465.5***	1.22***	1.18***
Y×N×M	6	0.68	0.02	646.4	0.02	0.02
Y×N×H	6	0.62	0.01407	576	0.15258**	0.17845**
Y×M×H	2	0.0487	0.01256	258.4	0.00968	0.002
Y×N×M×H	6	0.3659	0.01208	360.9	0.0281	0.03755
Residual 4	96	0.6382	0.01438	439.8	0.05027	0.05543

* P<0.05, ** P<0.01, *** P<0.001

Table 3. Mean values (± standard deviations) of plant height and ear setting height on a plant.

Experimental factor		Plant height [cm]			Ear setting height [cm]		
		years		mean	years		mean
		2009	2010		2009	2010	
Nitrogen rate [kg N ha^{-1}]	0	228.2 ±14.6	206.1 ±8.6	217.1 ±16.3	73.2 ±5.3	81.3 ±4.4	77.3 ±6.3
	50	253.7 ±15.4	206.7 ±5.2	230.2 ±26.4	75.4 ±5.1	82.2 ±5.6	78.8 ±6.3
	100	260.0 ±8.4	205.6 ±7.0	232.8 ±28.7	75.3 ±4.5	80.7 ±3.9	78.0 ±5.0
	150	262.3 ±10.0	206.2 ±6.9	234.3 ±29.7	74.5 ±5.5	79.8 ±5.3	77.1 ±6.0
$LSD_{0.05}$		12.34	ns	7.99	ns	ns	ns
Magnesium rate [kg MgO ha^{-1}]	0	251.7 ±18.0	206.6 ±7.7	229.2 ±26.5	75.3 ±4.5	81.3 ±4.9	78.3 ±5.6
	25	250.4 ±18.8	205.6 ±6.0	228.0 ±26.5	73.9 ±5.5	80.8 ±4.9	77.4 ±6.2
$LSD_{0.05}$		ns	ns	ns	ns	ns	ns
Type of cultivar	ES Palazzo	248.9 ±18.7	206.7 ±6.2	227.8 ±25.4	74.9 ±5.78	83.1 ±4.9	79.0 ±6.7
	ES Paroli SG	253.1 ±17.9	205.6 ±7.6	229.3 ±27.6	74.3 ±4.3	78.9 ±3.8	76.6 ±4.6
$LSD_{0.05}$		3.76	ns	ns	ns	1.94	1.41
Mean		251.0 ±18.3	206.1 ±6.9	-	74.6 ±5.0	81.0 ±4.8	-

ns – non-significant difference

Table 4. Mean values (± standard deviation) of ear morphological traits.

Experimental factor		Ear length [cm] 2009	Ear length [cm] 2010	Ear length [cm] 2011	Ear length [cm] mean	Ear diameter [cm] 2009	Ear diameter [cm] 2010	Ear diameter [cm] 2011	Ear diameter [cm] mean
Nitrogen rate [kg N ha^{-1}]	0	15.4 ±1.6	17.9 ±1.3	19.4 ±0.5	17.6 ±2.0	3.9 ±0.2	4.1 ±0.1	4.3 ±0.2	4.1 ±0.2
	50	17.3 ±1.0	18.2 ±0.9	20.1 ±0.5	18.5 ±1.4	4.1 ±0.2	4.1 ±0.1	4.4 ±0.2	4.2 ±0.2
	100	17.7 ±0.6	18.4 ±1.2	20.1 ±0.7	18.7 ±1.4	4.1 ±0.2	4.1 ±0.1	4.4 ±0.1	4.2 ±0.2
	150	18.1 ±0.6	18.8 ±1.3	20.2 ±0.5	19.0 ±1.2	4.2 ±0.1	4.1 ±0.1	4.4 ±0.2	4.2 ±0.2
$LSD_{0.05}$		1.045	ns	0.35	0.40	0.14	ns	ns	0.06
Magnesium rate [kg MgO ha^{-1}]	0	17.2 ±1.4	18.4 ±1.2	19.9 ±0.6	18.5 ±1.6	4.1 ±0.2	4.1 ±0.1	4.3 ±0.2	4.2 ±0.2
	25	17.1 ±1.5	18.3 ±1.2	19.9 ±0.7	18.4 ±1.7	4.1 ±0.2	4.1 ±0.1	4.3 ±0.1	4.2 ±0.2
$LSD_{0.05}$		ns	ns	ns	ns	ns	ns	ns	0.02
Type of cultivar	ES Palazzo	17.1 ±1.1	19.3 ±0.8	19.8 ±0.5	18.7 ±1.4	4.1 ±0.2	4.2 ±0.1	4.5 ±0.1	4.2 ±0.2
	ES Paroli SG	17.1 ±1.7	17.4 ±0.7	20.1 ±0.8	18.2 ±1.8	4.1 ±0.1	4.0 ±0.1	4.2 ±0.1	4.1 ±0.1
$LSD_{0.05}$		ns	0.32	0.24	0.20	n.s	0.05	0.05	0.03
Mean		17.1 ±1.4	18.3 ±1.2	19.9 ±0.6	-	4.1 ±0.2	4.1 ±0.1	4.3 ±0.1	-

ns – non-significant difference

an increase in plant height under the influence of varied fertilization with this macronutrient.

Marketable ear setting height on plants was determined by the hybrids, years and the Y×H interaction (Table 1). The highest values were observed in the 2010 (Table 3). A greater marketable ear setting height on plants was observed in cv. ES Palazzo than in ES Paroli SG (Table 3). The result recorded in this study confirmed earlier literature reports (Szulc, 2009). In those studies the stay-green cultivar was characterized by a lower setting of marketable ears on plants in comparison to the conventional hybrid.

Ear length was determined by nitrogen fertilisation rates, cultivars, years and interactions of N×M, N×H, Y×N and Y×H (Table 2). The longest ears were produced after fertilisation at the greatest nitrogen rate of 150 kg N ha^{-1} (19.04 cm), while they were shortest for the application of 0 kg N ha^{-1} (17.59 cm) (Table 4). In each of the three years (and averaged across years) the increase in ear length was directly proportional to the applied nitrogen rates (Fig. 1). Averaged across years, ears were longer in cv. ES Palazzo than in ES Paroli SG (Table 4).

Ear diameter was statistically significantly influenced by nitrogen fertilization rates, magnesium fertilization rates, cultivars, years as well as interactions of N×M, Y×N, Y×H (Table 2). Significantly the smallest diameter of the ear were obtained for 0 kg N ha^{-1} compared with the dose

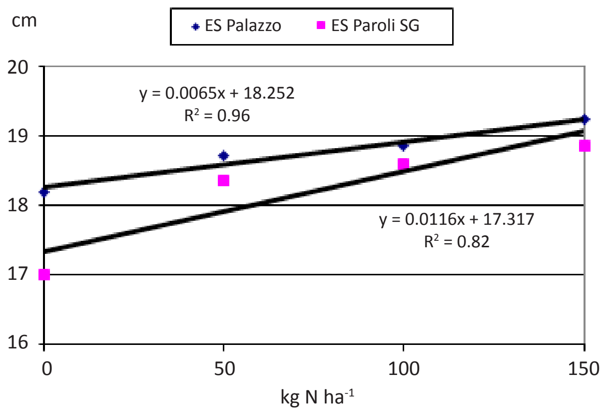

Fig. 1. The effect of nitrogen fertilization rate and type of maize hybrid on ear length (2009–2011).

of nitrogen in the range of 50 to 100 N ha^{-1}, for which the value of the properties was statistically at the same level. Ears in cv. ES Palazzo were characterized by a greater diameter than those of cv. ES Paroli SG (Table 4).

Ear volume varied depending on nitrogen rates, cultivars, years and interactions of N×M, Y×N and Y×H (Table 2). Ear volume was smallest in the first year of observations (mean 226.4 cm^3), while it was greatest in 2011 (mean

Table 5. Mean values (± standard deviation) of ear volume [cm³]

Experimental factor		Years			Mean
		2009	2010	2011	
Nitrogen rate [kg N ha⁻¹]	0 (control)	191.7 ±33.9	239.7 ±25.1	281.3 ±25.6	237.6 ±46.3
	50	228.0 ±26.9	236.2 ±20.0	300.8 ±22.3	255.0 ±40.0
	100	237.9 ±18.2	245.7 ±25.8	299.0 ±17.7	260.9 ±34.2
	150	247.8 ±19.2	249.1 ±31.6	305.1 ±22.3	267.3 ±36.4
$LSD_{0.05}$		17.7	ns	8.7	12.1
Magnesium rate [kg MgO ha⁻¹]	0	229.1 ±32.1	245.2 ±25.1	296.6 ±22.9	256.9 ±39.4
	25	223.6 ±33.5	240.2 ±26.8	296.5 ±24.4	253.4 ±42.2
$LSD_{0.05}$		ns	ns	ns	ns
Type of cultivar	ES Palazzo	230.7 ±32.6	261.7 ±20.9	308.6 ±18.5	267.0 ±40.5
	ES Paroli SG	222.0 ±32.7	223.6 ±13.1	284.4 ±21.9	243.4 ±37.6
$LSD_{0.05}$		ns	6.8	5.5	10.07
Mean		226.4 ±32.7	242.7 ±25.9	296.5 ±23.5	-

ns – non-significant difference

Table 6. Mean values (±standard deviation) for the number of plants for studied factors

Experimental factor		After emergence [plants m⁻²]				Before harvest [plants m⁻²]			
		years			mean	years			mean
		2009	2010	2011		2009	2010	2011	
Nitrogen rate [kg N ha⁻¹]	0 (control)	7.4 ±0.2	7.5 ±0.3	7.7 ±0.2	7.5 ±0.3	7.01 ±0.2	7.2 ±0.3	7.5 ±0.2	7.3 ±0.3
	50	7.4 ±0.3	7.5 ±0.4	7.7 ±0.3	7.5 ±0.3	7.0 ±0.3	7.1 ±0.4	7.5 ±0.2	7.2 ±0.4
	100	7.3 ±0.3	7.4 ±0.4	7.8 ±0.1	7.5 ±0.4	7.0 ±0.3	7.0 ±0.5	7.6 ±0.1	7.2 ±0.4
	150	7.0 ±0.4	7.1 ±0.8	7.6 ±0.3	7.2 ±0.6	6.7 ±0.3	6.8 ±0.7	7.5 ±0.3	7.0 ±0.6
$LSD_{0.05}$		0.3	0.3	0.1	0.1	0.2	0.3	ns	0.1
Magnesium rate [kg MgO ha⁻¹]	0	7.2 ±0.3	7.4 ±0.5	7.7 ±0.2	7.5 ±0.4	6.9 ±0.3	7.1 ±0.5	7.5 ±0.2	7.2 ±0.4
	25	7.2 ±0.3	7.3 ±0.5	7.7 ±0.3	7.4 ±0.4	6.9 ±0.3	7.0 ±0.5	7.5 ±0.3	7.1 ±0.5
$LSD_{0.05}$		ns	ns	ns	ns	ns	ns	ns	ns
Type of cultivar	ES Palazzo	7.1 ±0.3	7.0 ±0.5	7.5 ±0.2	7.2 ±0.4	6.8 ±0.2	6.6 ±0.5	7.4 ±0.3	6.9 ±0.5
	ES Paroli SG	7.4 ±0.3	7.7 ±0.1	7.9 ±0.1	7.7 ±0.3	7.1 ±0.2	7.4 ±0.2	7.6 ±0.1	7.4 ±0.3
$LSD_{0.05}$		0.1	0.1	0.1	0.1	0.1	0.1	ns.	0.1
Mean		7.2 ±0.3	7.4 ±0.5	7.7 ±0.2	-	6.9 ±0.3	7.0 ±0.5	7.5 ±0.2	-

ns – non-significant difference

296.5 cm³). Ear volume was greatest after the application of the greatest nitrogen fertilization rate of 150 kg N ha⁻¹. Cultivar ES Paroli SG had ears with markedly smaller volume than those of cv. ES Palazzo (Table 5).

The number of plants after emergence and the number of plants before harvest were determined by nitrogen fertilization rates, cultivars, years of observations and interactions of Y×N, Y×H and Y×N×H (Table 2). Moreover, the number of plants after emergence was influenced by the N×H interaction (Table 2). Health status of plants both after emergence and before harvest was better in the stay-green hybrid than in cv. ES Palazzo. Values of both the above mentioned traits were inversely proportional to the applied nitrogen fertilization rate (Table 6, Fig. 2). As it was reported by Borowiecki and Koter (1983), poor plant emergence rates and inhibition of their growth in treatments with

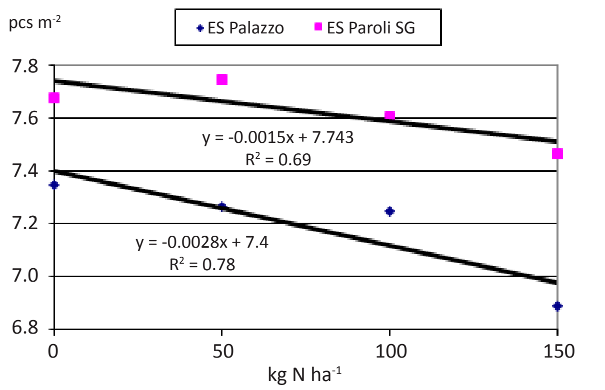

Fig. 2. The effect of nitrogen fertilization rate and type of maize hybrid on the number of plants after emergence (2009–2011).

high urea application rates are caused by a considerable concentration of ammonium nitrogen in soil resulting from hydrolysis of urea. In this study this could explain the reduced plant densities after emergence and before harvest with an increase in maize fertilization with this fertilizer.

Plant loss rates were determined only by the years of observations. The highest plant loss rates were observed in the 2010 of the observations (mean 4.56%), while they were lowest in 2011, being 2.37%.

CONCLUSIONS

1. The number of plants after emergence and before harvest was inversely proportionally to the applied nitrogen fertilization rate.
2. Cultivar ES Paroli (the stay-green type) was characterized by a significantly higher number of plants after emergence and before harvest in relation to hybrid ES Palazzo. This probably resulted from a greater tolerance of this hybrid to a high concentration of ammonia nitrogen in soil as a result of hydrolysis of urea.
3. Cultivar ES Paroli (the stay-green type) was characterized by bigger plant height, lower ear setting height, lesser length and diameter of ears and smaller ear volume in relation to hybrid ES Palazzo.
4. Under the conditions which the field tests were carried out, the usage of the magnesium as a component assisting the collecting and nitrogen utilization was quite inefficient. Only a significant effect on the ear diameter and the interaction with N for the diameter and the length ears has been found.

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