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REGULAR ARTICLE

A comparative analysis of growth in maize (*Zea mays* L.) hybrids of different genetic profiles depending on type of nitrogen fertilizer and magnesium dose

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ABSTRACT

The paper presents results of 3-year field trials (2009-2011), aiming at a comparative analysis of growth in maize cultivars of different genetic profiles depending on the type of nitrogen fertilizer and magnesium dose at the cob flowering stage (BBCH 67). Investigations were conducted at the Department of Agronomy, the Poznań University of Life Sciences, in the fields of the Teaching and Experimental Station in Swadzim. A comparative analysis of maize (*Zea mays* L.) growth was based on the assimilating area of a single plant and the following indexes: SLA (specific leaf area), LWF (leaf weight fraction), SWF (stem weight fraction), EWF (ear weight fraction), LAI (leaf area index) and LAR (leaf area ratio). No significant differences were noticed between the tested types of nitrogen fertilizers in terms of values of discussed traits. These values differed significantly in relation to the treatment with no nitrogen application. It was shown that the application of magnesium had no significant effect on the analyzed growth parameters in the tested types of maize cultivars. The stay-green hybrid turned out to be a leafy cultivar, as evidenced by the greater number of leaves per ha, assimilating area of a single plant, leaf area index (LAI), leaf weight and the proportion of leaves in plant mass. Cultivar ES Paroli SG was characterized by a more efficient transport of assimilates, as determined by the value of specific leaf area (SLA).

Key Words: *maize; stay-green; type of nitrogen fertilizer; magnesium; SLA; LWF; SWF; EWF; LAI; LAR.*

Abbreviations: SG – *stay-green;* SLA – *specific leaf area;* LWF – *leaf weight fraction;* SWF – *stem weight fraction;* EWF – *ear weight fraction;* LAI – *leaf area index;* LAR - *leaf area ratio*

INTRODUCTION

Availability of nitrogen constitutes the primary limitation to productivity of crop plants (Amanullah et al. 2007), since most parameters determining their growth are limited by its deficit (Godwin and Jones 1991). Nitrogen, as an essential component of enzymes regulating the process of photosynthesis, determines the development of leaf area and leaf ageing rate (Li et al. 2006). This macronutrient may be absorbed directly from soil through absorption of nitrate or the ammonium ion, or can be re-utilized from older parts of plants (Ta and Weiland 1992). Bertin and Gallais (2000) reported that uptake of nitrogen and its utilization varies greatly among traditional maize cultivars. Apart from conventional cultivars, for some time stay-green hybrids have been used in selection of cultivars for cultivation, as in those cultivars grain ripening occurs at full greenness of the entire plant (Chen et al. 2010). As it was shown by Szulc et al. (2012), such a hybrid is characterized by a negative coefficient of nitrogen remobilization. This shows that soil resources are the main sources of nitrogen accumulation at the phase of generative growth for such cultivars. Such a behavior of stay-green plants should imply the fertilization system using slow-release nitrogen fertilizers (Szulc et al. 2012, Szulc and Bocianowski 2012). Since for the formation of generative yields (grain) slow-release nitrogen fertilizers are optimal, it would be of interest to clarify the effect of applying different nitrogen fertilizers on the development of foliage in such cultivars. Individual variation in different cultivar types of maize (*Zea mays* L.), and their response to specific habitat and growth conditions have been investigated for many years at the Department of Agronomy, the Poznań University of Life Sciences (Szulc et al. 2008, Szulc 2009a, 2010, Szulc et al. 2012, Szulc et al. 2013).

The experimental hypothesis proposed that the type of nitrogen fertilizer as well as the application of magnesium may significantly modify growth in maize cultivars having different genetic profiles. For this reason the aim of this study was to assess growth in two different types of maize depending on the type of nitrogen fertilizer and Mg application doses.

MATERIALS AND METHODS

EXPERIMENTAL FIELD

The field experiment was conducted at the Department of Agronomy, the Poznań University of Life Sciences, in the fields of the Teaching and Experimental Station in Swadzim in the years 2009 – 2011. Trials were performed in the split-split-plot design with three experimental factors in four field replications. The 1st factor comprised forms of nitrogen fertilizers: no nitrogen fertilizer applied, ammonium nitrate, ammonium sulfate, urea, Canwil nitrochalk (27% N), ammonium nitrate (50% N dose) + urea (50% N dose), while the 2nd factor included magnesium dose at two levels: 0 kg MgO ha^{-1} and 25 kg MgO ha^{-1}, whereas the 3rd factor comprised types of maize cultivars: ES Palazzo and ES Paroli SG.

Over the entire experimental field in each year of the study prior to the establishment of the experiment identical mineral fertilization was applied, amounting to 120 kg N·ha^{-1} (according to levels of the 1st factor), 80 kg P_2O_5 ha^{-1} (35.2 kg P ha^{-1}) as pelleted triple superphosphate (46% P_2O_5), 120 kg K_2O ha^{-1} (99.6 kg K ha^{-1}) in the form of potash salt (60% K_2O). Magnesium was applied as kieserite (25% MgO, 50% SO_3 – 20% S, sulfate sulfur).

The field experiment was performed on loessive soil, of light loamy sands, lying in a shallow layer and belonging to the good rye complex (IUSS Working Group WRB 2006).

Temperature and moisture conditions as well as macronutrient resources of soil prior to the establishment of the experiment were presented in a study by Szulc and Bocianowski (2012).

THE PLANT MATERIAL

Samples for analysis were collected each year at the cob flowering stage (BBCH 67). Each experimental plot consisted of four rows. Samples for analysis were taken from two middle rows of each plot.

Assimilation surface area of a single plant was calculated on the basis of the formula given in the study by Borowiecki and Filipiak (1992):

PL = -3.550 + 3.774 · x,

where PL is assimilation surface area of a single plant, and x is the sum of the surface areas of the fifth and sixth leaf.

The surface area of the 5th and 6th leaf was determined using Montgomery's formula (quoted after Borowiecki and Filipiak [1992]): leaf length along the main nerve multiplied by the width determined in the widest place and the result multiplied by the coefficient of 0.75.

SLA = LA / LW, (Grzebisz 2008)

where SLA is specific leaf area ($cm^2 \cdot g^{-1}$), LA is leaf area (cm^2), and LW is leaf blade weight (g).

WF = (W/TW) · 100 [%], (Grzebisz 2008)

where WF is weight fraction of leaves (LWF), stems (SWF), ears (EWF) – [in %]; W is weight of leaves, or stems, or cobs (g); and TW is total plant weight (g).

LAI = (LA * LR) / 10000,

where LAI is leaf area index, LA is leaf area of a single plant (cm^2), and LR is plant density per 1 m^2 ($plants \cdot m^{-2}$).

LAR = LA / TW, (Amanullah et al. 2007)

where LAR is leaf area ratio ($cm^2 \cdot g^{-1}$), LA is leaf area (cm^2), and TW is total plant weight (g).

STATISTICAL ANALYSIS

Results recorded for individual years were subjected to univariate analysis of variance, and next a synthesis was conducted for multi-annual experiments. Significance of differences was estimated at α = 0.05 using t-Student's test.

RESULTS AND DISCUSSION

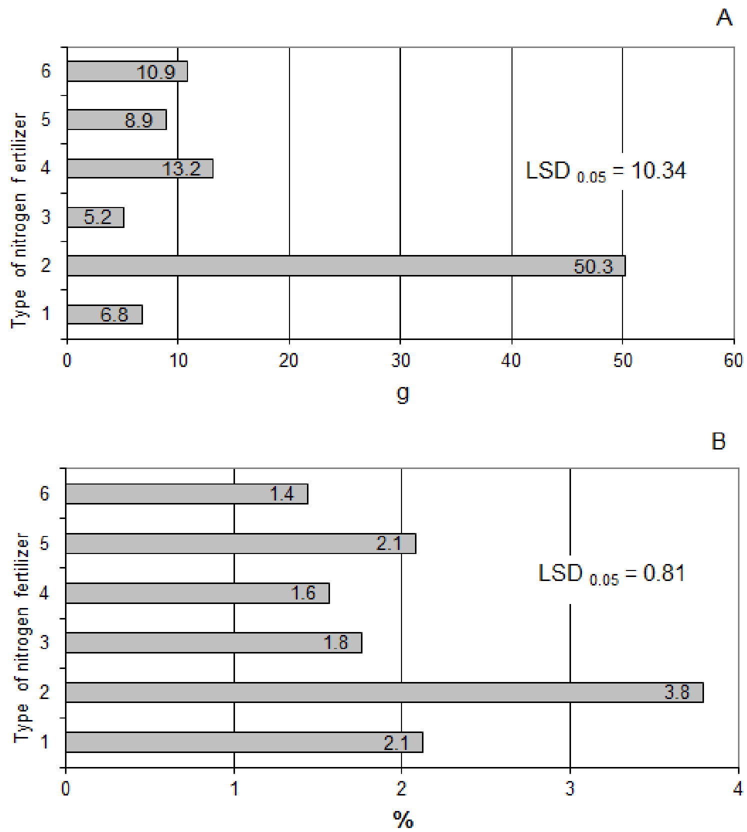
Leaf area and the number of leaves per plant are important elements in the evaluation of photosynthesis of maize genotypes (Boote et al. 1996). This study showed a significant effect of the type of nitrogen fertilizer and the type of maize hybrid on the number of leaves formed on the plant (Tab. 1). Significantly fewer leaves were recorded at no application of nitrogen fertilizer in comparison to the other nitrogen variants, for which the number of formed leaves on a plant was statistically comparable (10.6 per plant). The stay-green hybrid was characterized by a lower number of formed leaf blades; however, per 1 ha their number was greater by 18,274 (tab. 1) than in the case of the conventional cultivar. The results recorded in this study are in concordance with previous literature reports (Pandey et al. 2000), indicating that maize genotypes differ in the number of formed leaves, growth rate and the production of biomass at varied amounts of available water and nitrogen. The above statement was also confirmed by Keating and Wafla (1992). Assimilation area of a single plant and the level of LAI in this study were significantly influenced by the type of nitrogen fertilizer and the type of maize hybrid (tab. 1). The lowest values of these characteristics (3747.96 cm^2 and 2.82, respectively) were recorded in treatments with no nitrogen fertilization in comparison to the other nitrogen variants. No significant differences were found among the tested types of nitrogen fertilizers. Considering the impact of maize hybrid type, a significantly greater assimilation area of a single plant and the level of LAI were recorded for the stay-green cultivar in relation to the conventional cultivar. The difference between the tested cultivars amounted to 6.94% and 11.85%, respectively. Also Szulc (2009b) showed that the stay-green cultivar was characterized by a greater value of LAI in comparison to the conventional cultivar.

Table 1. Number of maize leaves, assimilation area of a single plant and LAI at flowering phase in three-year field experiment (2009-2011).

Factor Level of factor		Number of leaves		Assimilation area of a single plant	LAI
		1 plant	1 ha		
		Number		cm^2	-
Type of nitrogen fertilizer	No fertilizer	10.33	772519	3747.96	2.82
	NH_4NO_3	10.59	779622	4239.56	3.12
	$(NH_4)_2SO_4$	10.60	780410	4062.31	3.01
	$CO(NH_2)_2$	10.68	789045	4164.61	3.09
	NH_4NO_3 + $CaCO_3$ + $MgCO_3$	10.62	786395	4137.06	3.08
	NH_4NO_3+ $CO(NH_2)_2$	10.60	789655	4154.75	3.11
LSD $_{0.05}$		0.187	Ns	128.765	0.104
Dose of MgO ha^{-1}	0	10.60	787854	4058.74	3.03
	25	10.54	778028	4110.01	3.05
LSD $_{0.05}$		ns	Ns	ns	ns
Type of hybrid	ES Palazzo	10.68	773804	3947.31	2.87
	ES Paroli SG	10.46	792078	4221.44	3.21
LSD $_{0.05}$		0.097	8151.1	38.084	0.032

ns – non-significant difference

Fresh mass of leaves, stems, cobs and that of the entire single plant at the cob flowering phase were significantly modified by the type of nitrogen fertilizer and the type of maize hybrid (tab. 2). Values of these characteristics were significantly smaller in the treatment with no nitrogen application in comparison to the tested nitrogen fertilizers, for which values of these characteristics were statistically the same. When investigating the effect of the type of maize hybrid on the above mentioned traits it was found that the stay-green cultivar was characterized by a significantly greater mass of leaf blades in comparison to the conventional cultivar. In the case of stems, ears and the whole plant mass the effect of hybrid type on these traits was different (tab. 2). This study also showed an interaction of the nitrogen fertilizer variant with the type of maize hybrid on the fresh mass of leaf blades per plant (Fig. 1A). For each of the tested nitrogen fertilizers a greater fresh mass of leaves per plant was recorded for the stay-green cultivar in comparison to the conventional cultivar. The difference between tested cultivar types ranged from 5.2 g to 50.3 g. Still the advantage of the stay-green cultivar was significantly greater in the case of the ammonium nitrate application (NH_4NO_3). Plants absorb nitrogen from soil in the nitrate and ammonium forms. When taken up by plants, nitrogen is transformed into amino acids, from which plants synthesize proteins. At an adequate plant nitrogen supply, a rapid increase in their mass and assimilation area can be observed together with a rapid transformation of carbohydrates and ammonia to protoplasm proteins. As a rule the nitrate form is absorbed faster, while the uptake of the ammonium form is slower (Ladha et al. 2005).



1– no fertilizer, 2 – NH_4NO_3, 3 – $(NH_4)_2SO_4$, 4 – $CO(NH_2)_2$, 5 – NH_4NO_3 + $CaCO_3$ + $MgCO_3$, 6 – NH4NO3 + $CO(NH_2)_2$

Figure 1. Interaction of the type of nitrogen fertilizer with the type of maize hybrid as a difference between tested types maize, expressed in increment of leaf mass (A) and leaf weight fraction (B) in three-year field experiment (2009-2011).

In the process of photosynthesis, apart from leaves, a considerable role may also be played by stems and cob covering leaves (Szulc et al. 2013). For this reason in this study the leaf weight fraction (LWF), stem weight fraction (SWF) and ear weight fraction (EWF) were determined. These values in this study were significantly modified solely by the cultivar factor (Tab. 3). In the total plant mass of the hybrid ES Paroli SG the share of leaf blades was greater, while that of stems was lower in comparison to cv. ES Palazzo. The share of ears (EWF), irrespective of the type of cultivar, accounted for approximately 35% of plant mass. Leaf weight fraction (LWF) in this study was modified by the interaction of the type of nitrogen fertilizer with cultivar type (Fig. 1B). For each of the tested nitrogen fertilizers a greater share of leaves in plant mass was observed for the stay-green hybrid in comparison to the conventional cultivar. The difference between the tested cultivars ranged from 1.4% to 3.8%. An advantage of the stay-green cultivar was significantly greater at the application of ammonium nitrate (NH_4NO_3).

Table 2. Fresh mass of maize leaves, stems, cobs and the whole plant at flowering phase in three-year field experiment (2009-2011).

Factor Level of factor		Mass of leaves	Mass of stems	Mass of ears*	Mass of entire plant
		g			
Type of nitrogen fertilizer	no fertilizer	105.21	311.70	232.07	648.98
	NH_4NO_3	142.95	364.03	270.55	777.54
	$(NH_4)_2SO_4$	117.50	346.29	269.42	733.23
	$CO(NH_2)_2$	124.44	367.08	265.73	757.26
	NH_4NO_3 + $CaCO_3$ + $MgCO_3$	124.54	375.40	267.13	767.09
	NH_4NO_3+ $CO(NH_2)_2$	124.62	364.95	267.01	756.59
$LSD_{0.05}$		28.856	26.002	22.528	55.342
Dose of MgO ha^{-1}	0	126.35	357.81	260.67	744.84
	25	120.07	352.01	263.30	735.38
$LSD_{0.05}$		ns	Ns	ns	ns
Type of hybrid	ES Palazzo	115.27	368.62	267.09	750.99
	ES Paroli SG	131.15	341.20	256.88	729.24
$LSD_{0.05}$		12.640	7.728	7.189	18.817

* - mass of husks, cob and set kernels
ns – non-significant difference

Table 3. Leaf weight fraction (LWF), stem weight fraction (SWF) and ear weight fraction (EWF) at maize flowering phase in terms of their share in plant mass in three-year field experiment (2009-2011)

Factor Level of factor		LWF	SWF %	EWF
Type of nitrogen fertilizer	no fertilizer	16.27	48.13	35.59
	NH_4NO_3	17.27	47.29	35.42
	$(NH_4)_2SO_4$	15.97	47.37	36.64
	$CO(NH_2)_2$	16.37	48.57	35.05
	NH_4NO_3 + $CaCO_3$ + $MgCO_3$	16.20	48.93	34.85
	NH_4NO_3+ $CO(NH_2)_2$	16.49	48.43	35.07
$LSD_{0.05}$		ns	ns	ns
Dose of MgO ha^{-1}	0	16.56	48.30	35.12
	25	16.29	47.94	35.75
$LSD_{0.05}$		ns	ns	ns
Type of hybrid	ES Palazzo	15.36	49.27	35.35
	ES Paroli SG	17.49	46.97	35.53
$LSD_{0.05}$		0.696	0.590	ns

ns – non-significant difference

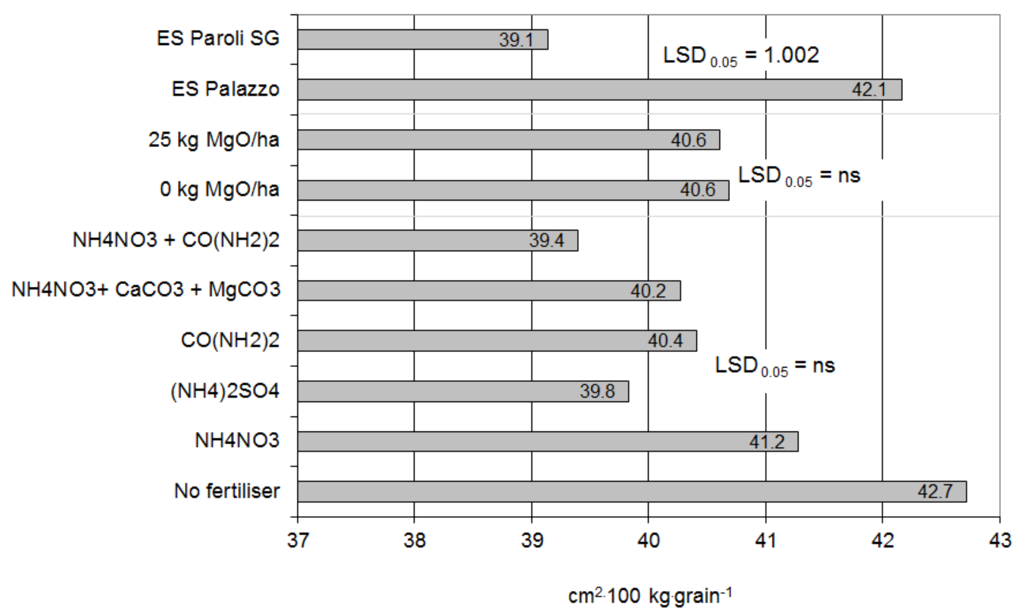
Growth analysis of a single plant according to Grzebisz (2008) covers several parameters, such as specific leaf area (SLA) and leaf area ratio (LAR). In this study significantly greater SLA and LAR values were found for the stay-green hybrid in comparison to the conventional cultivar (tab. 4). A greater value of specific leaf area indicates that cv. ES Paroli SG was characterized by thinner leaf blades. From the physiological point of view thinner leaf blades are more advantageous for plants, since the production and transport of assimilates are not hindered (Szulc et al. 2013). All produced assimilates in leaves are immediately transported to sink organs. The above statement is also confirmed by the fact that the SG cultivar needed 39.14 cm^2 leaf blades to produce 100 kg grain, while in the conventional cultivar it needed as much as 42.16 cm^2 leaf area (Fig. 2). Also the greater yielding potential of the SG hybrid in comparison to the conventional cultivar might be determined by the concentrations of chlorophyll a, a+b, and chlorophyll in terms of SPAD units at the cob flowering phase, as it was reported by Szulc and Rybus-Zając (2009).

In turn, the leaf area ratio (LAR) was also greater in the hybrid ES Paroli SG. On this basis it may be assumed that the accumulation of plant biomass in the case of the stay-green cultivar was definitely more efficient than in cv. ES Palazzo. We may also infer a highly efficient transport of assimilates in the stay-green cultivar, as evidenced by a lower leaf thickness (Szulc et al. 2013).

Table 4. Specific leaf area (SLA) and leaf area ratio (LAR) at maize flowering phase in three-year field experiment (2009-2011).

Factor		SLA	LAR
Level of factor		cm^2g^{-1}	
Type of nitrogen fertilizer	no fertilizer	36.12	5.90
	NH_4NO_3	36.04	5.72
	$(NH_4)_2SO_4$	36.33	5.65
	$CO(NH_2)_2$	35.71	5.67
	NH_4NO_3 + $CaCO_3$ + $MgCO_3$	35.15	5.56
	NH_4NO_3+ $CO(NH_2)_2$	34.94	5.63
$LSD_{0.05}$		Ns	ns
Dose of MgO ha^{-1}	0	35.88	5.62
	25	35.89	5.76
$LSD_{0.05}$		Ns	ns
Type of hybrid	ES Palazzo	35.38	5.39
	ES Paroli SG	36.47	5.99
$LSD_{0.05}$		0.939	0.497

ns – non-significant difference



ns - non-significant difference

Figure 2. Assimilation area of a single maize plant needed to produce 100 kg grain in three-year field experiment (2009-2011).

CONCLUSIONS

1. The type of nitrogen fertilizer as well as the application of Mg had no significant effect on the analyzed growth parameters in maize.
2. Analyses of the morphological structure of leaves in the stay-green hybrid based on the specific leaf area (SLA) indicates a highly efficient utilization of nitrogen, leading to a faster formation of leaves with a greater assimilation area, providing the basis for the effective absorption of solar radiation.

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