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Effects of application of different nitrogen fertilizer forms and magnesium on dynamics of dry matter accumulation in two maize (*Zea mays* L.) hybrids in their early growth stages

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Abstract. The paper presents results of field studies, examining the effects of application of different forms of nitrogen fertilizers and magnesium on the dynamics of dry matter accumulation in the early growth stages of two hybrid types of maize. The experiment determined dry matter yield at the 5–6 leaf stage, absolute growth rate (AGR) of dry matter, macronutrient contents and their uptake. It was shown that the type of nitrogen fertilizer and the dose of magnesium do not significantly differentiate the dynamics of the early growth in maize expressed by the amount of dry matter and absolute growth rate for dry matter. It was found that the stay-green cultivar ES Paroli had a significantly higher dry matter yield at the 5–6 leaf stage than the conventional cv. ES Palazzo.

keywords: maize; stay-green; nitrogen fertilizer; magnesium; absolute growth rate

INTRODUCTION

Maize (*Zea mays* L.) due to its origin is a thermophyte. For appropriate growth and rapid development it needs more heat in the vegetative period than other cereals (Aitken, 1977; Sowiński, 2000). The effect of temperature is manifested – among other things – in the dynamics of dry matter accumulation and early growth rate (Szulc and Kruczek, 2008). Low soil and air temperature at sowing and in the early development stage are the primary causes of yield reductions. Additionally, cold spells in the spring, occurring at seedling development, result in their inhibited growth. Thus the identification of optimal nutrition during the early vegetative period may have a positive effect on yields in maize. It was reported by Fageria and Baligar (2005) and Potarzycki (2011) that maize is highly sensitive to nutrient deficiencies, particularly at the early growth stages. In a greenhouse experiment Subedi and Ma (2005) found that inadequate nitrogen nutrition in maize from sowing to BBCH 18 stage caused reduction in ear size and seed yield.

Slow early growth caused by too low temperatures, as it has been shown by recent studies, results from reduced uptake of water and nutrients, particularly nitrogen and phosphorus (Arnon, 1975; Kruczek and Szulc, 2006; Mozafar et al., 1993). These problems may be overcome using several cultivation practices, such as selection of adequate fertilizer (its form), method of fertilizer application (Murphy, 1984; Uhart and Andrade, 1995; Yanai et al., 1996) and a specific cultivar. This is connected with the fact that maize hybrids exhibit diverse sensitivity to temperature conditions and varied dynamics of nodal root system development required for adequate nutrient and water uptake. The aim of the field experiments was to examine the dynamics of early growth in two different types of maize cultivars expressed by dry matter accumulation in response to different types (forms) of nitrogen fertilizers and magnesium.

MATERIAL AND METHODS

Field experiment

The field experiment was conducted at the Experimental Station at Swadzim of the Department of Agronomy, the Poznań University of Life Sciences in the years 2009–2011. The experiments were conducted in a split-plot × split-block design with three experimental factors in four replications. The first-order factor included six different forms of nitrogen fertilizers, i.e. with no fertilizer applied, ammonium nitrate [NH_4NO_3], ammonium sulfate [$(NH_4)_2SO_4$)], urea [$CO(NH_2)_2$], Canwil nitro-chalk

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$[NH_4NO_3+CaCO_3+MgCO_3]$, ammonium nitrate (50% dose of N) + urea (50% dose of N) $[NH_4NO_3 + CO(NH_2)_2]$, the second-order factor comprised two doses of magnesium, i.e. 0 kg MgO ha^{-1} and 25 kg MgO ha^{-1}, and the third-order factor included two different types of maize cultivars: ES Palazzo and the stay-green 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 in the amount of 120 kg N ha^{-1} (in accordance with the level of the first-order factor), 80 kg P_2O_5 ha^{-1} (35.2 kg P ha^{-1}) in the form of pelleted triple superphosphate 46% P_2O_5, 120 kg K_2O ha^{-1} (99.6 kg K ha^{-1}) as 60% potash salt. Magnesium was applied as kieserite (25% MgO, 50% SO_3 – 20% S, sulfate sulfur).

According to the FAO international soil classification (FAO, 1977), the soils may be classified as Phaeozems or – according to the US Soil Taxonomy (Soil Survey Staff, 1951) – as Mollisols. Concentrations of basic macronutrients as well as soil pH in individual years of the study are given in Table 1.

Table 1. Nutrient status of soil at Swadzim.

Specification	Years		
	2009	2010	2011
P [mg P kg^{-1} of soil]	31.7	36.1	16.7
K [mg K kg^{-1} of soil]	97.1	45.6	63.9
Mg [mg Mg kg^{-1} of soil]	69.0	34.0	62.0
pH [in 1 mol dm^{-3} KCl]	5.3	7.6	5.1

The assessment of the content of macroelements, pH was conducted according to research procedures/standards (the Regional Chemical and Agricultural Station in Poznań):
P_2O_5 – PB.64 ed. 6 of 17.10.2008
K_2O – PB.64 ed. 6 of 17.10.2008
Mg – PB.65 ed. 6 of 17.10.2008
pH – PB.63 ed. 6 of 17.10.2008

For more details see Szulc and Bocianowski (2012).

Methods

At the 5–6 leaf stage (BBCH 15-16) plant samples were collected from two middle rows of each plot and next roots were separated from the aboveground parts and dry matter content and dry weight of a single plant were determined.

The content of mineral components in dry matter (DM) in the 5–6 leaf stage was analyzed at the laboratory of the Department of Agronomy, Poznań University of Life Sciences, according to the methods described by Gawęcki (1994). Furthermore, potassium and calcium were determined using a Flapho 40 flame spectrophotometer, while phosphorus and magnesium were measured using a Spekol 11 colorimeter. In the study nitrogen content in dry matter in the 5–6 leaf stage was determined using the Kjeldahl method with a Kjeltec™ 2200 FOSS apparatus.

Absolute growth rate (AGR) for dry matter accumulation was calculated using a formula presented by Grzebisz (2008):

$$AGR = (W_2 - W_1) / (T_2 - T_1)$$

where:
AGR – absolute growth rate [g $plant^{-1}$ d^{-1}, kg ha^{-1} d^{-1}],
W_1 – initial dry matter [g $plant^{-1}$, kg ha^{-1}],
W_2 – dry matter at a given date [g $plant^{-1}$, kg ha^{-1}],
T_2 - T_1 – interval in days between determinations of W_1 and W_2.

Uptake (accumulation) of individual macroelements was calculated from dry matter yield at the 5–6 leaf stage (BBCH 15-16) using a formula:

$$\text{Uptake} = (\text{dry matter yield} \cdot \text{content of nutrients})/1000$$

where:
Uptake – in kg ha^{-1},
dry matter yield – in kg ha^{-1},
content of nutrients – in g kg^{-1}.

Unit uptakes of individual macroelements were calculated from dry matter yield of a single plant at the 5–6 leaf stage (BBCH 15-16) using the following formula:

$$\text{Unit uptake} = \text{dry matter of a single plant} \cdot \text{content of nutrient}$$

where:
Uptake – in mg $plant^{-1}$,
dry matter of a single plant – in g,
content of nutrients – in g kg^{-1}.

Thermal and humidity conditions

Thermal and humidity conditions in the period from sowing to the 5–6 leaf stage (BBCH 15-16) are presented in Table 2.

Table 2. Weather conditions in the period from sowing to the BBCH 15-16 stage.

Specification	Years		
	2009	2010	2011
Sowing date	14 April	21 April	21 April
Date of reaching 5–6 leaf stage	30 May	7 June	23 May
Number of days from sowing to 5–6 leaf stage [days]	46	48	32
Total precipitation from sowing to 5–6 leaf stage [mm]	129.1	142.3	21.3
Mean air temperature from sowing to 5–6 leaf stage [°C]	14.5	13.9	14.8
Mean soil temperature at a depth of 10 cm from sowing to 5–6 leaf stage [°C]	12.6	10.5	11.4

Statistical analysis

Firstly, the normality of distribution for the specific traits (dry matter of a single plant, dry matter yield, dry matter content, absolute growth rate for dry matter of a single plant, absolute growth rate for dry matter from a unit area, contents of N, P, K, Mg, Ca and Na in dry matter of plants, unit uptake from unit area for N, P, K, Mg, Ca and Na) were tested using the Shapiro-Wilk's normality test (Shapiro and Wilk, 1965). The four-way analysis of variance (ANOVA) was carried out to determine the effects of years, type of nitrogen fertilizer, dose of magnesium, cultivar type, and all of interactions on the variability of the analyzed traits. Least significant differences (LSDs) were calculated for each trait. The relationships between the traits were estimated using correlation coefficients.

RESULTS AND DISCUSSION

Results indicate the significance of weather conditions varying between the years of the study on the volume of dry matter of a single plant ($F_{2.144}$ = 100.82, P < 0.001) (Table 3), dry matter yield ($F_{2.144}$ = 83.76, P < 0.001) (Table 4) as well as its contents ($F_{2.144}$ = 132.31, P < 0.001) (Table 5) at the 5–6 leaf stage. Averaged across the years of the study, the highest dry matter of a single plant and dry matter yield, irrespective of the investigated experimental factors, was recorded in 2009 (1.78 g and 130.1 kg ha^{-1}, respectively), while they were lowest in 2010 (0.90 g and 69.4 kg ha^{-1}, respectively). In the case of dry matter content the lowest value was recorded in 2010 (13.1%), while the highest in 2011 (16.5%). The year 2010, in which maize was characterized by the slowest vigour in early growth, in the period from sowing to the 5–6 leaf stage was the coolest and most humid. In that period precipitation was

Table 3. Dry matter of a single plant at the BBCH 15-16 stage [g] ± standard deviation.

Factor		Years			Mean
		2009	2010	2011	
Form of nitrogen fertilizer	no fertilizer	1.71 ±0.47	0.79 ±0.27	1.20 ±0.36	1.23 ±0.53
	NH_4NO_3	1.77 ±0.39	0.92 ±0.24	1.60 ±0.60	1.43 ±0.56
	$(NH_4)_2SO_4$	1.58 ±0.40	0.99 ±0.38	1.62 ±0.56	1.40 ±0.53
	$CO(NH_2)_2$	1.84 ±0.31	0.94 ±0.42	1.40 ±0.40	1.39 ±0.53
	$NH_4NO_3 + CaCO_3 + MgCO_3$	1.86 ±0.36	0.86 ±0.20	1.16 ±0.36	1.30 ±0.53
	$NH_4NO_3 + CO(NH_2)_2$	1.93 ±0.23	0.90 ±0.27	1.33 ±0.52	1.39 ±0.56
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.
Dose of magnesium [kg MgO ha^{-1}]	0	1.85 ±0.36	0.88 ±0.29	1.36 ±0.52	1.37 ±0.56
	25	1.72 ±0.38	0.92 ±0.32	1.41 ±0.47	1.35 ±0.52
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.
Hybrid type	ES Palazzo	1.80 ±0.40	0.86 ±0.29	1.32 ±0.49	1.33 ±0.55
	ES Paroli SG	1.77 ±0.35	0.94 ±0.32	1.45 ±0.50	1.39 ±0.52
$LSD_{0.05}$		n-s.d.	0.046	0.118	0.058
Mean		1.78 ±0.37	0.90 ±0.31	1.38 ±0.50	-

n-s.d. – non-significant difference at P = 0.05

Table 4. Dry matter yield of maize at the BBCH 15-16 stage [kg ha^{-1}] ± standard deviation.

Factor		Years			Mean
		2009	2010	2011	
Form of nitrogen fertilizer	no fertilizer	127.4 ±34.3	61.9 ±21.1	93.2 ±28.8	94.2 ±38.9
	NH_4NO_3	125.8 ±30.0	70.5 ±18.5	124.0 ±45.7	106.8 ±41.7
	$(NH_4)_2SO_4$	115.4 ±30.2	75.4 ±28.3	125.3 ±43.1	105.4 ±40.2
	$CO(NH_2)_2$	133.3 ±21.4	72.3 ±32.1	108.7 ±31.1	104.7 ±37.8
	$NH_4NO_3 + CaCO_3 + MgCO_3$	136.5 ±27.4	66.8 ±15.7	90.4 ±27.7	97.9 ±37.7
	$NH_4NO_3 + CO(NH_2)_2$	141.8 ±16.5	69.7 ±21.6	103.1 ±39.9	104.9 ±40.4
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.
Dose of magnesium [kg MgO ha^{-1}]	0	135.2 ±26.7	68.2 ±22.4	106.3 ±40.5	103.2 ±41.2
	25	124.9 ±28.5	70.7 ±24.4	108.6 ±36.3	101.4 ±37.6
$LSD_{0.05}$		5.17	n-s.d.	n-s.d.	n-s.d.
Hybrid type	ES Palazzo	127.8 ±29.4	64.5 ±20.5	100.2 ±36.9	97.5 ±39.3
	ES Paroli SG	132.3 ±26.5	74.4 ±25.1	114.7 ±38.7	107.2 ±39.0
$LSD_{0.05}$		n-s.d.	3.81	11.29	4.47
Mean		130.1 ±27.9	69.4 ±23.3	107.5 ±38.3	-

n-s.d. – non-significant difference at P = 0.05

Table 5. Dry matter content at the BBCH 15-16 stage [%] ± standard deviation.

Factor		Years 2009	2010	2011	Mean
Form of nitrogen fertilizer	no fertilizer	16.3 ±1.33	13.0 ±1.12	16.9 ±1.74	15.4 ±2.22
	NH_4NO_3	16.2 ±1.86	12.8 ±1.26	17.5 ±1.85	15.5 ±2.56
	$(NH_4)_2SO_4$	16.2 ±1.18	13.1 ±1.19	16.5 ±1.32	15.3 ±1.95
	$CO(NH_2)_2$	15.7 ±1.43	14.2 ±2.53	16.1 ±1.23	15.3 ±1.97
	$NH_4NO_3 + CaCO_3 + MgCO_3$	16.1 ±1.69	12.8 ±1.37	16.0 ±1.28	15.0 ±2.10
	$NH_4NO_3 + CO(NH_2)_2$	15.9 ±1.37	12.6 ±1.40	15.8 ±1.49	14.8 ±2.07
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.
Dose of magnesium [kg MgO ha^{-1}]	0	16.4 ±1.53	12.9 ±1.09	16.3 ±1.50	15.2 ±2.13
	25	15.8 ±1.35	13.3 ±1.98	16.6 ±1.66	15.2 ±2.19
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.
Hybrid type	ES Palazzo	16.8 ±1.23	13.2 ±1.48	16.4 ±1.65	15.5 ±2.17
	ES Paroli SG	15.4 ±1.33	13.0 ±1.72	16.5 ±1.52	14.9 ±2.11
$LSD_{0.05}$		0.41	n-s.d.	n-s.d.	0.23
Mean		16.1 ±1.47	13.1 ±1.60	16.5 ±1.58	-

n-s.d. – non-significant difference at P = 0.05

142.3 mm and mean air temperature was 13.9°C. Also soil temperature at a depth of 10 cm was low (10.5°C) (Table 2). This confirms earlier literature reports concerning temperature requirements of maize (Aitken, 1977; Sowiński, 2000). Low soil and air temperatures at sowing and at the early growth stages of maize were the primary causes reducing its yields (Sowiński and Maleszewski, 1989). The hybrids differed significantly in mean dry matter of a single plant for the years of the study ($F_{1.144}$ = 4.16, P = 0.049), dry matter yield ($F_{1.144}$ =17.84, P < 0.001) and its content at the 5–6 leaf stage ($F_{1.144}$ = 21.55, P < 0.001). In contrast, no significant effect was shown of the type of nitrogen fertilizer ($F_{5.144}$ = 1.81, P = 0.171, $F_{5.144}$ = 1.55, P = 0.233 and $F_{5.144}$ = 1.74, P = 0.187) or the dose of magnesium ($F_{1.144}$ = 0.53, P = 0.475, $F_{1.144}$ = 0.96, P = 0.341 and $F_{1.144}$ = 0.02, P = 0.897) on values of dry matter of a single plant, dry matter yield and dry matter contents. Uziak et al. (1993) reported that maize fertilized with $N\text{-}NO_3$ and $N\text{-}NH_4$ showed a similar growth rate in the juvenile stage. Maize fertilized with nitrates showed a slightly higher weight of underground parts than when ammonium nitrogen was applied. In contrast, yield of roots was practically identical, thus the mean weight of whole plants did not differ significantly, which was also confirmed in this study. In turn, a lack of an effect of magnesium application on dry matter of a single plant or dry matter yield at the 7–8 leaf stage was shown by Szulc et al. (2011). They stated that at the early growth stages of maize the foliar application of magnesium proved to be more advantageous, while at full maturity similar effects are provided by both magnesium application methods with a trend towards an advantage of spread application.

A significantly greater dry matter of a single plant and dry matter yield was found for ES Paroli SG. This difference amounted to 0.06 g and 9.7 kg ha^{-1}. Also in an earlier study Szulc et al. (2008) reported that a stay-green cultivar was characterized by a significantly greater vigour of early growth expressed by the accumulation of dry matter in comparison to a conventional hybrid. In the case of dry matter content it was significantly higher by 0.6% in cv. ES Palazzo (Table 5).

Analysis of plant growth is the basic tool in the overall evaluation of factors responsible for the accumulation of dry matter. When taking measurements on a regular basis we determine plant weight or the area of assimilating organs. Such accumulation of dry matter in plants is informative about the actual level of biomass production by a given genotype of plants under conditions dependent on environmental and cultivation factors (Grzebisz, 2008). For this purpose, in this study absolute growth rate (AGR) was determined for dry matter in the period from sowing to the 5–6 leaf stage (Table 6). This index was used for the assessment of the rate of early growth, expressed by the accumulation of dry matter. In this study the absolute growth rate (AGR) for dry matter accumulation was determined by temperature and humidity conditions in the investigated period in the years of the study ($F_{2.144}$ = 126.01, P < 0.001 for a single plant and $F_{2.144}$ = 123.87, P < 0.001 for unit area). The greatest daily increase in dry matter both from unit area and a single plant, irrespective of the experimental factors was observed in 2011 (0.043 g $plant^{-1}$ d^{-1}; 3.35 kg ha^{-1} d^{-1}, respectively), while it was lowest in 2010 (0.018 g $plant^{-1}$ d^{-1}; 1.44 kg ha^{-1} d^{-1}, respectively) (Table 6). Mean annual absolute growth rate for maize expressed by dry matter accumulation from sowing to the 5–6 leaf stage was determined solely by the cultivar type factor ($F_{1.144}$ = 4.11, P = 0.049 for a single plant and $F_{2.144}$ = 15.12, P < 0.001 for unit area). ES Paroli SG hybrid exhibited sig-

Table 6. Absolute growth rate (AGR) for dry matter of a single plant and dry matter yield at the BBCH 15-16 stage ± standard deviation.

Factor		Years 2009		Years 2010		Years 2011		Mean	
		$g\ plant^{-1}\ d^{-1}$	$kg\ ha^{-1}\ d^{-1}$	$g\ plant^{-1}\ d^{-1}$	$kg\ ha^{-1}\ d^{-1}$	$g\ plant^{-1}\ d^{-1}$	$kg\ ha^{-1}\ d^{-1}$	$g\ plant^{-1}\ d^{-1}$	$kg\ ha^{-1}\ d^{-1}$
Form of nitrogen fertilizer	no fertilizer	0.037 ±0.010	2.77 ±0.75	0.016 ±0.006	1.29 ±0.44	0.037 ±0.011	2.91 ±0.90	0.030 ±0.013	2.32 ±1.02
	NH_4NO_3	0.038 ±0.008	2.73 ±0.65	0.019 ±0.005	1.47 ±0.38	0.050 ±0.019	3.87 ±1.43	0.036 ±0.018	2.69 ±1.35
	$(NH_4)_2SO_4$	0.034 ±0.009	2.50 ±0.66	0.020 ±0.008	1.57 ±0.59	0.050 ±0.017	3.91 ±1.35	0.035 ±0.017	2.66 ±1.33
	$CO(NH_2)_2$	0.040 ±0.007	2.89 ±0.46	0.019 ±0.009	1.50 ±0.67	0.044 ±0.012	3.39 ±0.97	0.034 ±0.014	2.60 ±1.08
	$NH_4NO_3 + CaCO_3 + MgCO_3$	0.040 ±0.008	2.96 ±0.60	0.018 ±0.004	1.39 ±0.33	0.036 ±0.011	2.82 ±0.87	0.032 ±0.013	2.39 ±0.95
	$NH_4NO_3 + CO(NH_2)_2$	0.042 ±0.005	3.08 ±0.36	0.018 ±0.006	1.45 ±0.45	0.041 ±0.016	3.22 ±1.25	0.034 ±0.015	2.58 ±1.12
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.
Dose of magnesium [kg MgO ha^{-1}]	0	0.040 ±0.008	2.93 ±0.58	0.018 ±0.006	1.42 ±0.47	0.042 ±0.016	3.32 ±1.27	0.033 ±0.015	2.56 ±1.18
	25	0.037 ±0.008	2.71 ±0.62	0.019 ±0.007	1.47 ±0.51	0.044 ±0.015	3.39 ±1.14	0.033 ±0.015	2.52 ±1.13
$LSD_{0.05}$		0.0014	0.112	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.
Hybrid type	ES Palazzo	0.039 ±0.009	2.77 ±0.64	0.018 ±0.006	1.34 ±0.43	0.041 ±0.015	3.13 ±1.15	0.032 ±0.015	2.41 ±1.11
	ES Paroli SG	0.038 ±0.008	2.87 ±0.58	0.020 ±0.007	1.55 ±0.52	0.044 ±0.015	3.58 ±1.21	0.035 ±0.015	2.67 ±1.18
$LSD_{0.05}$		n-s.d.	n-s.d.	0.001	0.079	n-s.d.	0.352	0.0017	0.127
Mean		0.038 ±0.008	2.82 ±0.61	0.018 ±0.006	1.44 ±0.49	0.043 ±0.015	3.35 ±1.20	-	-

n-s.d. – non-significant difference at P = 0.05

Table 7. Contents of macronutrients in dry matter of maize at the BBCH 15-16 stage ± standard deviation (2009–2011).

Factor		N	P	K	Ca	Mg	Na
		g kg^{-1} of dry matter					
Form of nitrogen fertilizer	no fertilizer	34.02 ±5.5	3.08 ±1.4	44.12 ±5.9	0.97 ±0.70	2.40 ±0.58	0.64 ±0.31
	NH_4NO_3	35.71 ±5.3	3.01 ±1.3	40.94 ±4.5	0.98 ±0.70	2.49 ±0.51	0.77 ±0.43
	$(NH_4)_2SO_4$	36.34 ±4.3	3.15 ±1.3	42.58 ±6.6	0.85 ±0.53	2.67 ±0.43	0.80 ±0.26
	$CO(NH_2)_2$	35.56 ±4.4	3.26 ±1.5	44.31 ±7.2	0.89 ±0.63	2.55 ±0.46	0.78 ±0.45
	NH_4NO_3 + $CaCO_3$ + $MgCO_3$	35.20 ±3.6	3.12 ±1.4	43.58 ±7.0	0.82 ±0.51	2.53 ±0.33	0.87 ±0.46
	NH_4NO_3 + $CO(NH_2)_2$	35.46 ±5.0	3.13 ±1.3	44.35 ±4.6	0.86 ±0.59	2.47 ±0.48	0.76 ±0.39
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.
Dose of magnesium [kg MgO ha^{-1}]	0	35.22 ±5.0	3.06 ±1.3	42.68 ±5.4	0.90 ±0.62	2.46 ±0.50	0.74 ±0.35
	25	35.54 ±4.2	3.20 ±1.4	43.94 ±6.5	0.89 ±0.58	2.57 ±0.43	0.80 ±0.39
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.	0.098	n-s.d.
Hybrid type	ES Palazzo	35.72 ±4.9	3.15 ±1.4	42.68 ±5.8	0.92 ±0.62	2.41 ±0.45	0.76 ±0.39
	ES Paroli SG	35.04 ±4.4	3.10 ±1.3	43.94 ±6.1	0.87 ±0.58	2.62 ±0.45	0.78 ±0.36
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.	0.111	n-s.d.

n-s.d. – non-significant difference at P = 0.05

nificantly higher daily increase in single plant dry matter and per unit area in comparison with ES Palazzo cultivar. The difference between the examined hybrids was respectively: 0.003 g plant^{-1} d^{-1} and 0.26 kg ha^{-1} d^{-1} (Table 6).

For contents of N, P, K, Mg, Ca and Na in dry matter of maize plants at the 5–6 leaf stage the direction of changes influenced by the analyzed levels of factors was similar in all the years, while the statistically confirmed interaction resulted only from differences in the degree of effects of factors in individual years. Thus in order to provide a more comprehensible presentation of the dependence it was decided in this study to present the effect of the type of nitrogen fertilizer, dose of magnesium and the type of maize hybrid using mean values (Table 7). Averaged across the years, none of the investigated experimental factors significantly modified contents of N, P, K, Ca or Na in dry matter of plants (Table 7). Also Kruczek and Sulewska (2005), when investigating the effect of urea, ammonium nitrate and Hydrofoska did not record a significant effect of the nitrogen fertilizers on the contents of P, Mg, Ca and Na in dry matter of maize at early growth. In the case of magnesium content in this study a significant effect was observed for the dose of magnesium and the type of maize hybrid on values of the discussed parameter ($F_{1.144}$ = 5.34, P = 0.028 and $F_{1.144}$ = 37.77, P < 0.001, respectively). The application of 25 kg MgO ha^{-1} caused a significant increase in magnesium contents in plant dry matter by 0.11 g kg^{-1} dry matter in relation to the treatment with no application of that macroelement. In the case of stay-green hybrid it was found that the stay-green cultivar was characterized by a significantly higher content of magnesium in dry matter in comparison to the traditional cultivar. This difference was 0.21 g kg^{-1} dry matter (Table 7).

Averaged across the three years of the study, none of the experimental factors had a significant effect on the amount of accumulated phosphorus, calcium and sodium in dry matter of a single plant or dry matter yield in maize at the 5–6 leaf stage (Table 8). Accumulation of nitrogen was significantly affected by the type of the nitrogen fertilizer ($F_{5.144}$ = 4.05, P = 0.016 for N uptake and $F_{5.144}$ = 4.33, P = 0.012 for unit N uptake) and the type of maize hybrid ($F_{1.144}$ = 13.09, P < 0.001 for N uptake and $F_{1.144}$ = 5.58, P = 0.017 for the uptake of unit N uptake). Significantly the lowest elemental uptake as well as the uptake from unit area was found in the treatment with no nitrogen fertilizer applied in comparison to treatments with the application of ammonium nitrate, ammonium sulfate, urea or ammonium nitrate used together with urea (Table 8). In case of ES Paroli SG significantly greater unit uptake and uptake from unit area were recorded in comparison to cv. ES Palazzo. This difference amounted to 1.8 mg N plant^{-1} and 0.31 kg N ha^{-1}. Averaged across the years, potassium accumulation in this study was significantly varied only by the cultivar factor ($F_{1.144}$ = 29.48, P < 0.001 for K uptake and $F_{1.144}$ = 10.31, P = 0.003 for unit K uptake). A significantly greater amount of accumulated potassium was recorded for ES Paroli SG (Table 8). with the difference amounting to 4.09 mg K plant^{-1} and 0.53 kg K ha^{-1} (Table 8). Accumulation of magnesium in terms of dry matter content in a single plant as well as per unit area was significantly modified by all the three experimental factors (for dry matter of a single plant: fertilizer – $F_{5.144}$ = 6.16, P = 0.003, magnesium – $F_{1.144}$ = 4.75, P = 0.029, cultivar type – $F_{1.144}$ = 63.79, P < 0.001; for dry matter from unit area: fertilizer – $F_{5.144}$ = 5.79, P = 0.004, magnesium – $F_{1.144}$ = 6.24, P = 0.019, cultivar type – $F_{1.144}$ = 56.55, P < 0.001). Sig-

Table. 8. Macronutrient uptake by maize on dry matter basis at the BBCH 15-16 stage ± standard deviation (2009–2011).

Factor		N		P		K		Mg		Ca		Na	
		mg plant^{-1}	kg ha^{-1}	mg plant^{-1}	kg ha^{-1}	mg plant^{-1}	kg ha^{-1}	mg plant^{-1}	kg ha^{-1}	mg plant^{-1}	kg ha^{-1}	mg plant^{-1}	kg ha^{-1}
Form of nitrogen fertilizer	no fertilizer	40.55 ±14.51	3.09 ±1.11	4.24 ±3.35	0.31 ±0.25	56.56 ±28.88	4.29 ±2.12	2.81 ±1.04	0.21 ±0.08	1.31 ±0.98	0.09 ±0.075	0.78 ±0.51	0.05 ±0.038
	NH_4NO_3	50.15 ±19.60	3.75 ±1.52	4.61 ±3.13	0.33 ±0.22	59.82 ±26.63	4.44 ±1.95	3.49 ±1.48	0.26 ±0.12	1.58 ±1.31	0.11 ±0.101	1.08 ±0.65	0.07 ±0.046
	$(NH_4)_2SO_4$	50.73 ±20.40	3.82 ±1.58	4.57 ±2.71	0.34 ±0.20	60.29 ±25.18	4.53 ±1.91	3.78 ±1.70	0.28 ±0.13	1.33 ±0.98	0.10 ±0.075	1.13 ±0.59	0.08 ±0.042
	$CO(NH_2)_2$	48.37 ±19.73	3.63 ±1.19	5.03 ±3.66	0.37 ±0.26	64.32 ±31.98	4.79 ±2.25	3.53 ±1.35	0.26 ±0.10	1.35 ±1.01	0.10 ±0.077	1.14 ±0.86	0.08 ±0.061
	$NH_4NO_3 + CaCO_3 + MgCO_3$	44.56 ±15.31	3.36 ±1.10	4.56 ±3.51	0.33 ±0.25	58.89 ±30.80	4.41 ±2.20	3.20 ±1.11	0.24 ±0.08	1.14 ±0.77	0.08 ±0.058	1.19 ±0.87	0.08 ±0.063
	$NH_4NO_3 + CO(NH_2)_2$	47.58 ±16.34	3.60 ±1.21	4.82 ±3.53	0.35 ±0.25	63.15 ±29.13	4.75 ±2.10	3.30 ±1.20	0.25 ±0.09	1.29 ±0.94	0.09 ±0.071	1.07 ±0.72	0.08 ±0.053
$LSD_{0.05}$		6.864	0.517	n-s.d.	n-s.d.	n-s.d.	n-s.d.	0.482	0.036	n-s.d.	n-s.d.	n-s.d.	n-s.d.
Dose of magnesium [kg MgO ha^{-1}]	0	46.74 ±17.48	3.53 ±1.32	4.60 ±3.30	0.34 ±0.24	59.86 ±28.91	4.50 ±2.09	3.28 ±1.34	0.24 ±0.10	1.34 ±1.05	0.10 ±0.080	1.04 ±0.72	0.07 ±0.052
	25	47.24 ±17.31	3.55 ±1.31	4.68 ±3.33	0.34 ±0.24	61.15 ±28.62	4.58 ±2.08	3.42 ±1.37	0.26 ±0.11	1.32 ±0.98	0.09 ±0.074	1.09 ±0.72	0.08 ±0.051
$LSD_{0.05}$		n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	n-s.d.	0.14	0.010	n-s.d.	n-s.d.	n-s.d.	n-s.d.
Hybrid type	ES Palazzo	46.09 ±17.37	3.39 ±1.27	4.63 ±3.49	0.33 ±0.24	58.46 ±29.42	4.27 ±2.07	3.13 ±1.33	0.23 ±0.10	1.33 ±1.02	0.09 ±0.076	1.04 ±0.75	0.07 ±0.053
	ES Paroli SG	47.89 ±17.38	3.70 ±1.34	4.64 ±3.14	0.35 ±0.23	62.55 ±27.96	4.80 ±2.06	3.57 ±1.35	0.28 ±0.11	1.33 ±1.01	0.10 ±0.078	1.08 ±0.68	0.08 ±0.051
$LSD_{0.05}$		0.978	0.164	n-s.d.	n-s.d.	2.523	0.192	0.155	0.012	n-s.d.	n-s.d.	n-s.d.	n-s.d.

n-s.d. – non-significant difference at P = 0.05

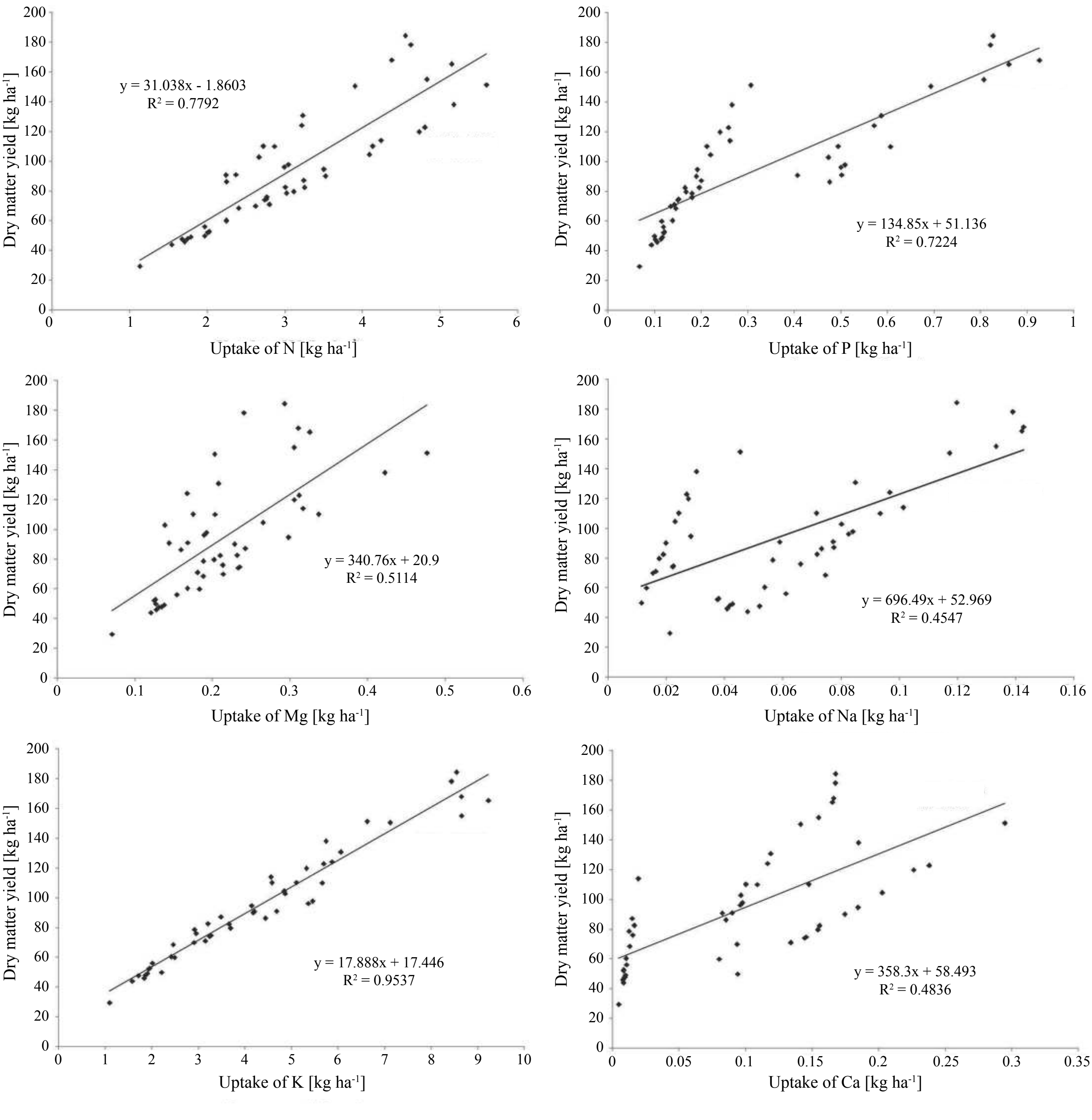

Fig. 1. The relationship between dry matter yield in maize at the BBCH 15-16 stage and the uptake of individual macronutrients at the absence of nitrogen fertilization irrespective of magnesium dose and type of hybrid (2009–2011).

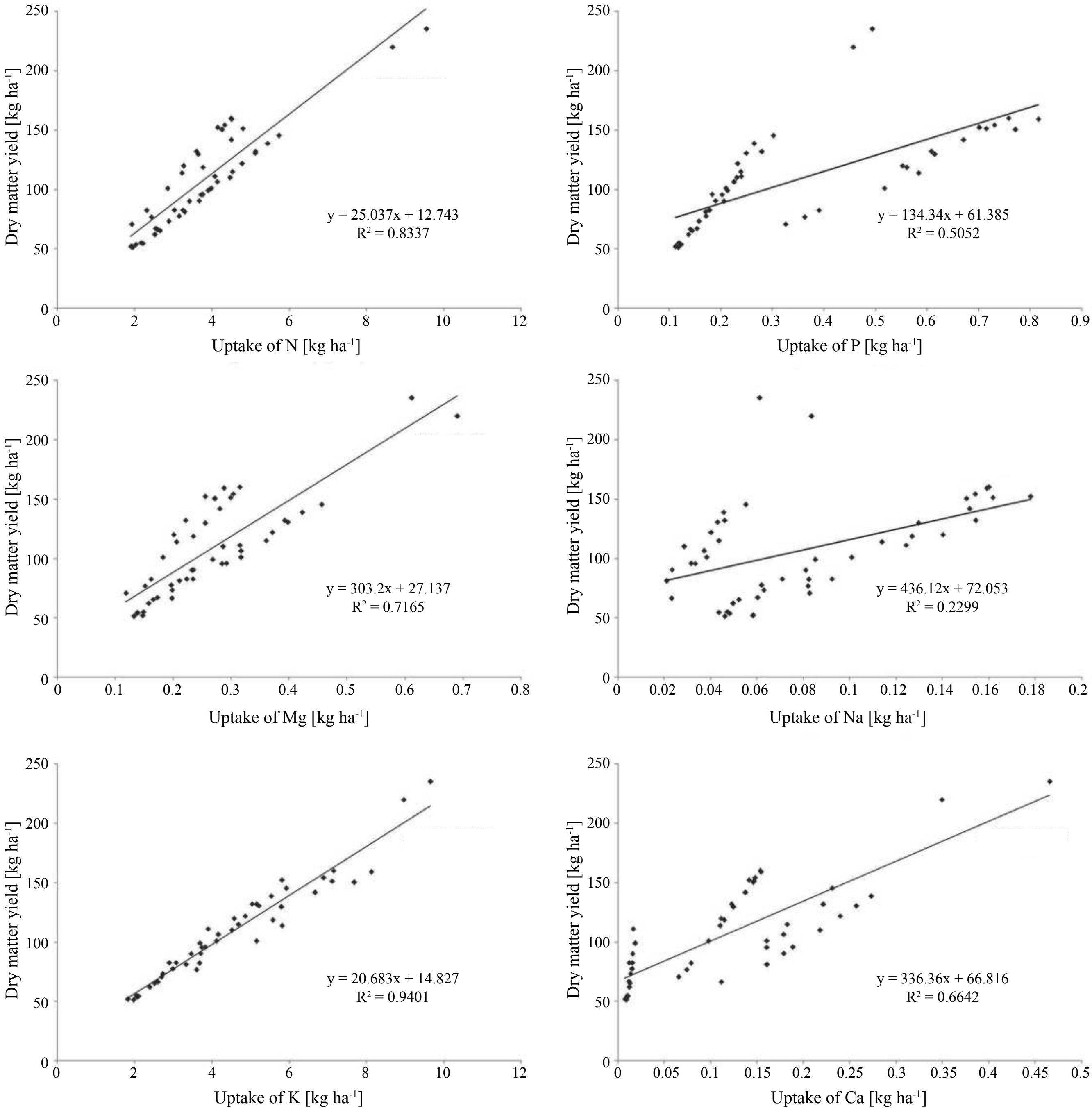

Fig. 2. The relationship between dry matter yield at the BBCH 15-16 stage and the uptake of individual macronutrients at fertilization with ammonium nitrate [NH_4NO_3], irrespective of magnesium dose and hybrid type (2009–2011).

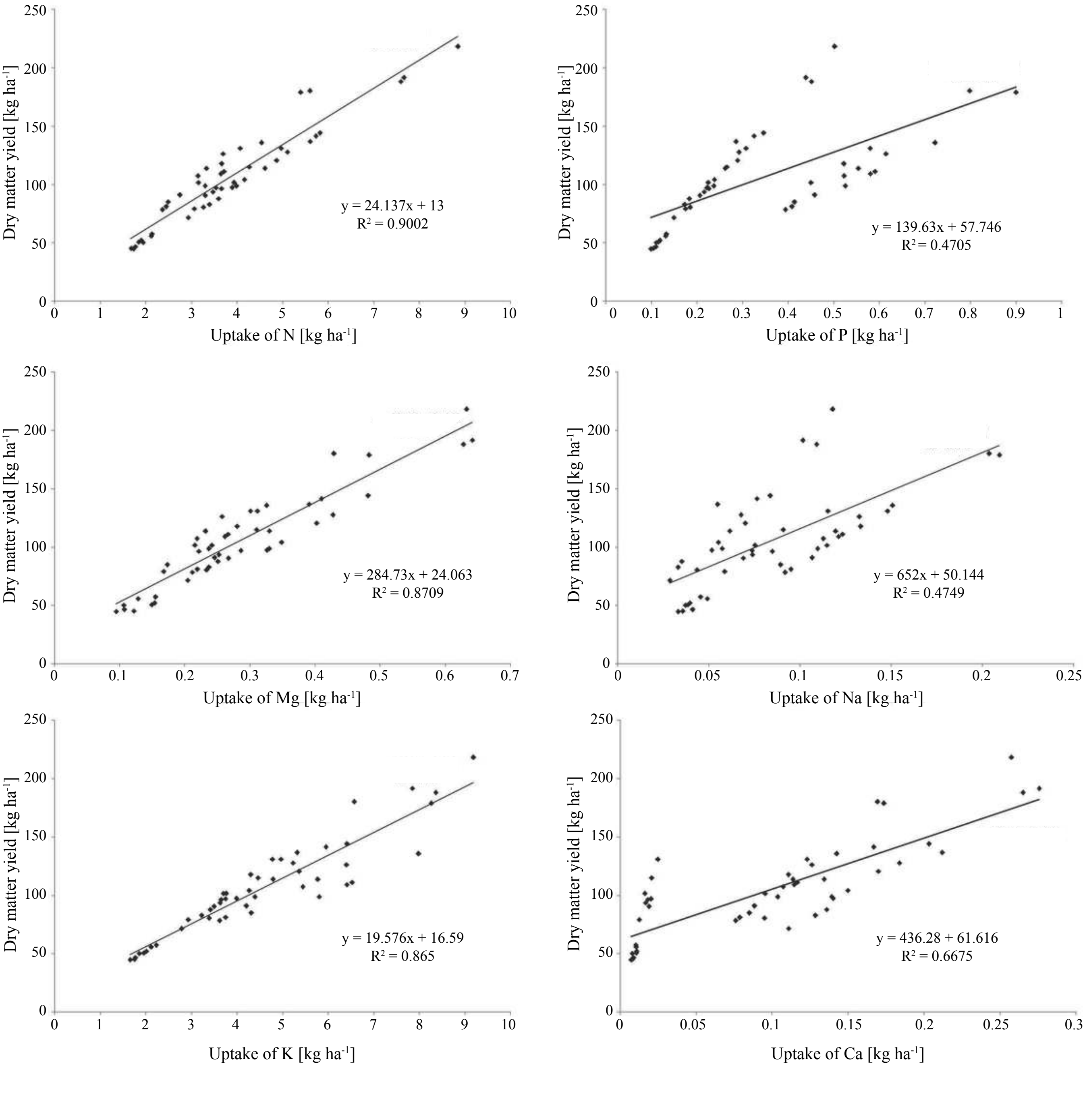

Fig. 3. The relationship between dry matter yield in maize at the BBCH 15-16 stage and the uptake of individual macronutrients at fertilization with ammonium sulfate [$(NH_4)_2SO_4$)], irrespective of magnesium dose and hybrid type (2009–2011).

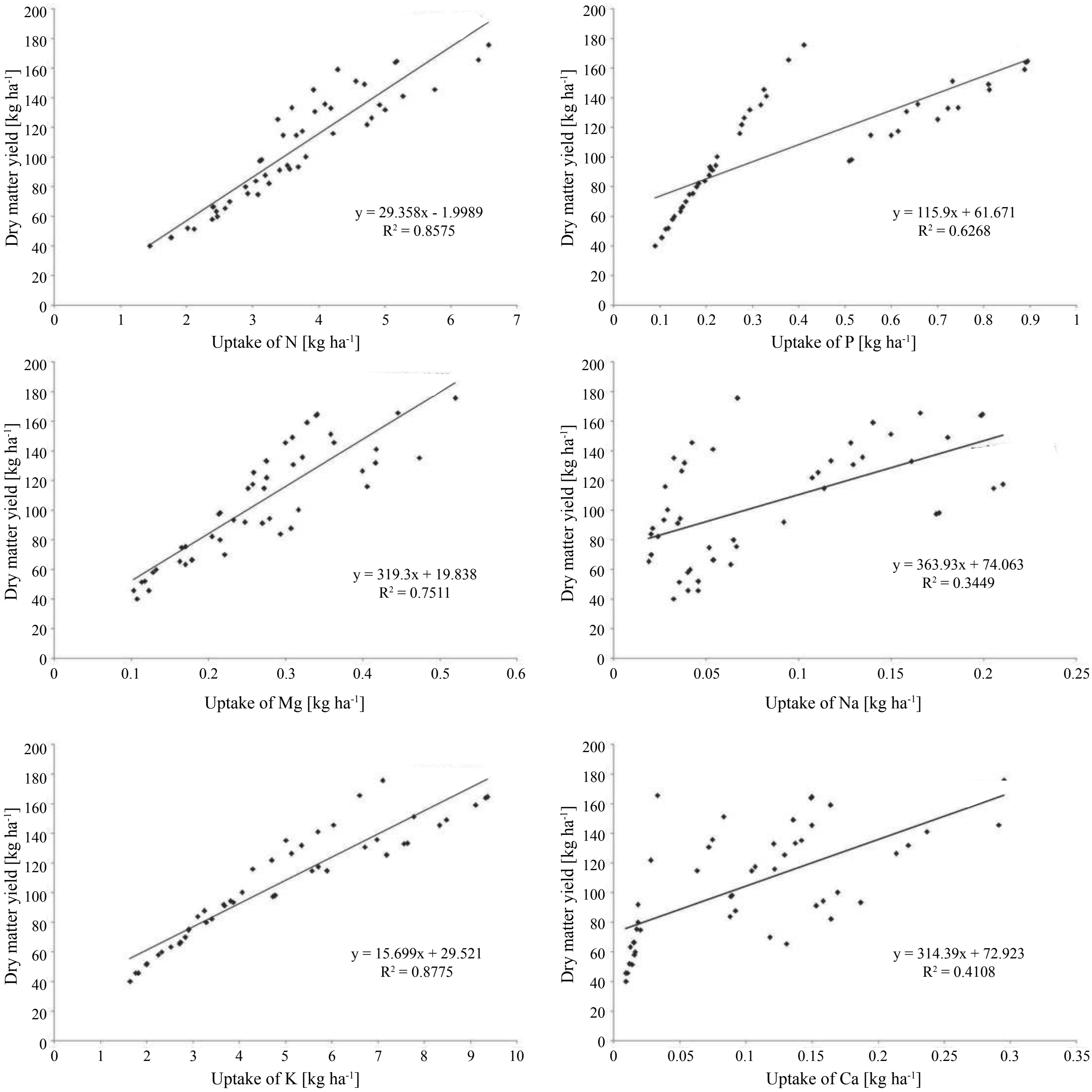

Fig. 4. The relationship between dry matter yield in maize at the BBCH 15-16 stage and the uptake of individual macronutrients at fertilization with urea [$CO(NH_2)_2$], irrespective of magnesium dose and hybrid type (2009–2011).

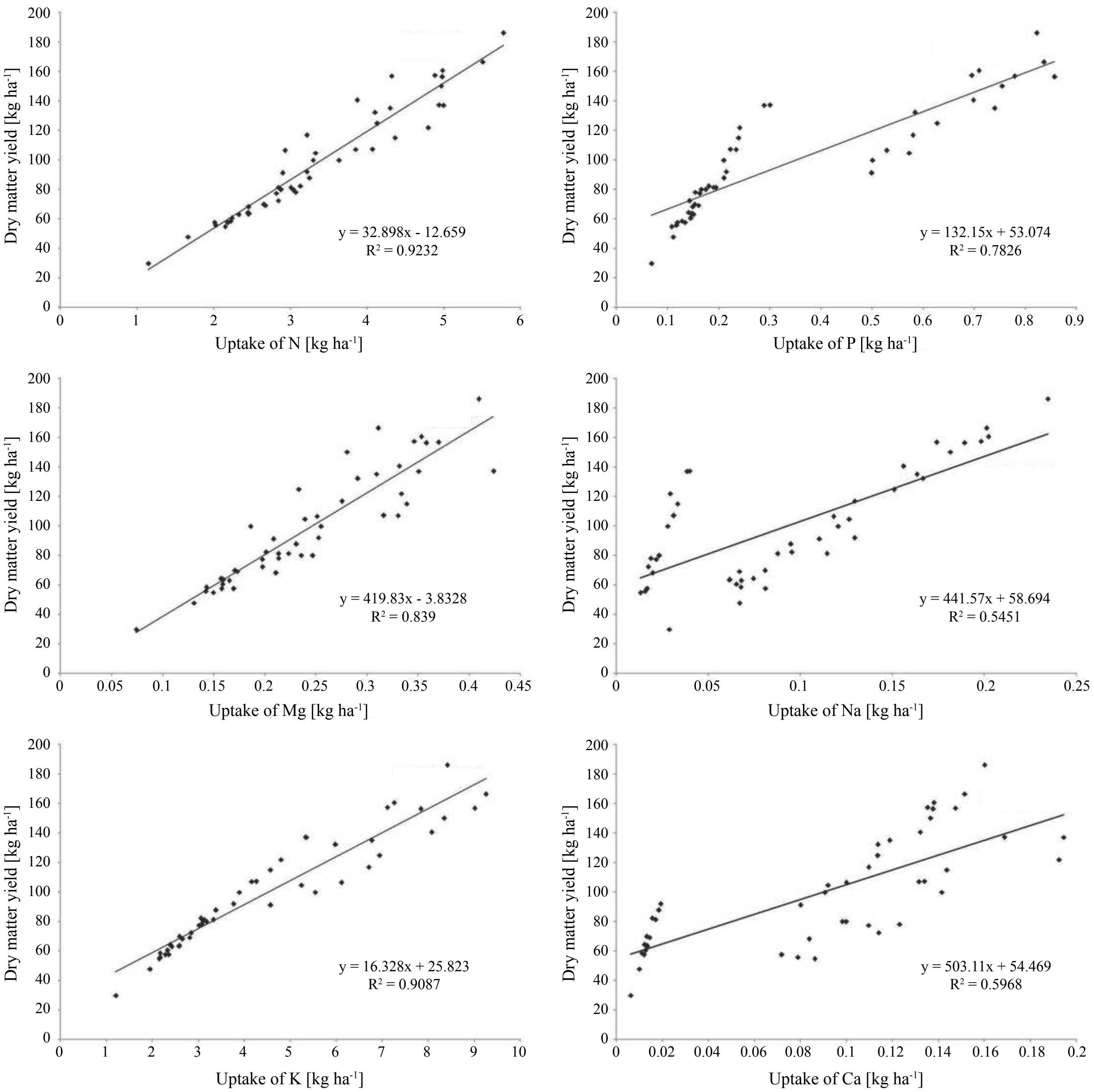

Fig. 5. The relationship between dry matter yield in maize at the BBCH 15-16 stage and the uptake of individual macronutrients at fertilization with Canwil nitro-chalk [NH_4NO_3+$CaCO_3$+$MgCO_3$], irrespective of magnesium dose and hybrid type (2009–2011).

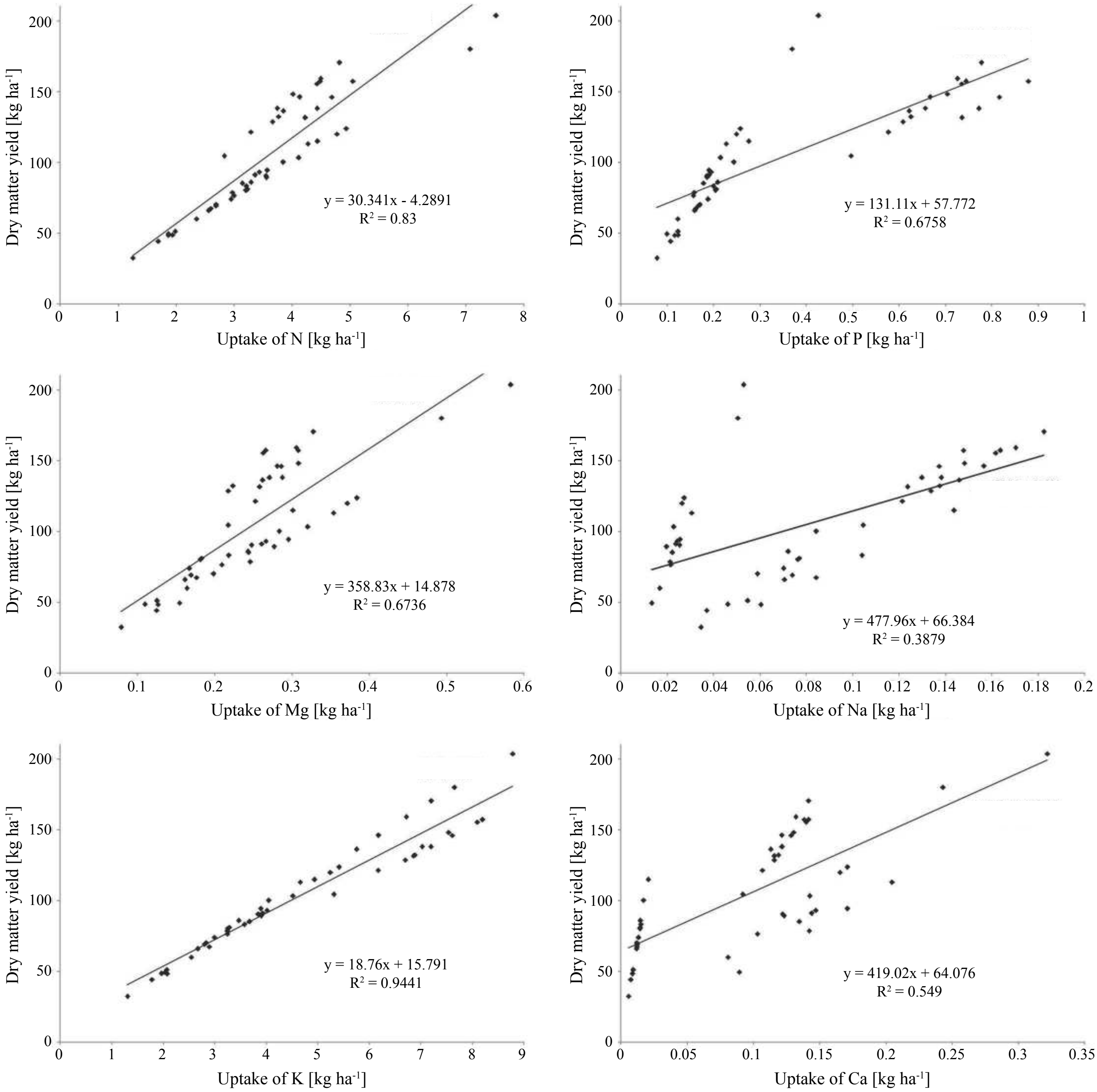

Fig. 6. The relationship between dry matter yield in maize at the BBCH 15-16 stage and the uptake of individual macronutrients at simultaneous fertilization with ammonium nitrate (50% N dose) and urea (50% N dose) [NH_4NO_3 + $CO(NH_2)_2$] (2009–2011).

Table 9. Correlation coefficients between analyzed maize traits (values given in bold in the text are not statistically significant).

Trait	DM of a single plant	DM yield	DM content	DM of a single plant increment	DM yield increment	N uptake	N unit uptake	P uptake	P unit uptake	Mg uptake	Mg unit uptake	Na uptake	Na unit uptake	K uptake	K unit uptake	Ca uptake
DM yield	0.99															
DM content	0.40	0.39														
DM of a single plant increment	0.90	0.92	0.52													
DM yield increment	0.86	0.90	0.50	0.99												
N uptake	0.88	0.92	0.36	0.95	0.95											
N unit uptake	0.92	0.94	0.38	0.95	0.94	0.99										
P uptake	0.83	0.79	0.31	0.55	0.49	0.50	0.57									
P unit uptake	0.82	0.77	0.31	0.53	0.47	0.48	0.55	1.00								
Mg uptake	0.80	0.84	0.36	0.92	0.94	0.95	0.92	0.40	0.38							
Mg unit uptake	0.84	0.87	0.38	0.94	0.94	0.95	0.94	0.47	0.45	0.99						
Na uptake	0.66	0.62	**0.02**	0.30	0.24	0.37	0.43	0.86	0.86	0.26	0.32					
Na unit uptake	0.66	0.61	**0.04**	0.30	0.24	0.35	0.42	0.87	0.87	0.24	0.31	1.00				
K uptake	0.96	0.95	0.40	0.82	0.79	0.80	0.83	0.90	0.88	0.71	0.75	0.70	0.70			
K unit uptake	0.95	0.93	0.40	0.79	0.75	0.76	0.81	0.92	0.91	0.67	0.72	0.73	0.73	0.99		
Ca uptake	0.72	0.74	0.64	0.91	0.92	0.79	0.78	0.41	0.39	0.79	0.79	**0.07**	**0.08**	0.67	0.64	
Ca unit uptake	0.74	0.76	0.65	0.92	0.91	0.79	0.79	0.44	0.43	0.78	0.79	**0.11**	0.12	0.69	0.67	1.00

DM – dry matter

nificantly the lowest unit uptake and uptake from unit area were found in the treatment with no nitrogen fertilizer applied in comparison to objects with the application of ammonium nitrate, ammonium sulfate, urea and ammonium nitrate applied jointly with urea (Table 8). When using 25 kg MgO ha^{-1} a significantly higher uptake was recorded for this macroelement in dry matter of plants in comparison to the treatment in which no magnesium was applied (Table 8). In the case of the cultivar type a significantly higher amount of accumulated magnesium was found for ES Paroli SG (Table 8). This difference amounted to 0.44 mg Mg plant^{-1} and 0.05 kg Mg ha^{-1}. The effect of uptake of individual macronutrients on dry matter yield for individual types of nitrogen fertilizers is presented in Figs. 1-6. In all cases a statistically significant linear relationship was observed. The most advantageous effect of N uptake on dry matter yield was recorded for nitro-chalk fertilization (Fig. 5), while the least advantageous (from among the tested variants) for fertilization with ammonium sulfate (Fig. 3). Uptake of P had the most advantageous effect on dry matter yield at ammonium sulfate fertilization (Fig. 3), in contrast to urea fertilization (Fig. 4), where this dependence was least advantageous. The effect of Mg uptake on dry matter yield was definitely the most disadvantageous at fertilization with ammonium sulfate (Fig. 3), while it was optimal at nitro-chalk fertilization (Fig. 5). Uptake of Na had the most effective influence on dry matter yield at the absence of nitrogen fertilization (Fig. 1), while the effect was definitely the weakest at urea fertilization (Fig. 4). Uptake of K had the most advantageous effect on dry matter yield when fertilization with ammonium nitrate was applied (Fig. 2), while it was weakest at urea fertilization (Fig. 4). In the case of urea fertilization (Fig. 4) dry matter yield responded the weakest to Ca uptake. In turn, the response was most marked at fertilization with nitro-chalk (Fig. 5). Summing up, the least advantageous variant in terms of the relationship between macronutrient uptake and dry matter yield turned out to be urea fertilization (Fig. 4), while nitro-chalk fertilization was the most advantageous (Fig. 5).

The analysis of correlations showed that a vast majority of trait pairs was statistically significantly correlated (Table 9).

Table 10. Relationship between dry matter of a single plant in the 5–6 leaf stage, dry matter yield in the 5–6 leaf stage and grain yield of maize. Grain yield of maize is provided in a study by Szulc and Bocianowski (2012).

Year	Dry matter of a single plant [g]	Dry matter yield [kg ha^{-1}]	Grain yield [dt ha^{-1}]
2009	1.78	138.10	107.0
2010	0.90	69.40	93.9
2011	1.38	107.50	103.0

Grain yield of maize depends on the dynamics of initial growth expressed as accumulation of dry matter in the 5–6 leaf stage (Table 10).

SUMMARY AND CONCLUSIONS

1. The type of nitrogen fertilizer and the dose of magnesium do not significantly differentiate the dynamics of early growth in maize manifested in the accumulation of dry matter.
2. Higher dynamics of dry matter accumulation and a greater daily increase in dry matter content (AGR) were found in stay-green ES Paroli than in the traditional hybrid ES Palazzo.
3. The application of 25 kg MgO ha^{-1} resulted in an increase of magnesium content in dry matter of maize at the 5–6 leaf stage.
4. Hybrid ES Paroli SG had a significantly higher content of magnesium in dry matter than cv. ES Palazzo.
5. The type of nitrogen fertilizer and the dose of magnesium do not differentiate significantly the accumulation of N, P, K, Ca and Na.
6. Hybrid ES Paroli SG exhibited a significantly higher uptake of N, K and Mg than the traditional cultivar ES Palazzo.
7. Grain yield of maize depends on the dynamics of initial growth expressed as accumulation of dry matter in the 5–6 leaf stage.

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