Original Research

Effects of Soil Supplementation with Urea and Magnesium on Nitrogen Uptake, and Utilization by Two Different Forms of Maize (*Zea mays* L.) Differing in Senescence Rates

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Abstract

This paper presents the effect of soil supplementation with urea and magnesium on nitrogen uptake and its utilization by two different types of hybrid maize cultivars. Based on the results of 3-year fertilization studies, it was shown that for average volume of grain yield of maize, nitrogen content in grain dry matter and nitrogen uptake with its yield was significantly determined by the doses of nitrogen and magnesium, as well as by the type of maize cultivar. Joint N+Mg fertilization of maize increased the efficiency of nitrogen applied in the mineral fertilizer, whose evident effect was to obtain a higher yield of grain, nitrogen uptake, and utilization in comparison to N application alone. The SG hybrid ES Paroli was characterized by a significantly greater nitrogen uptake with yield of grain and utilization of nitrogen from the dose of mineral fertilizer for each nitrogen dose in comparison to the traditional cultivar ES Palazzo. With an increase in the level of nitrogen fertilization the utilization of nitrogen from the mineral fertilizer dose was reduced significantly. The application of 25 kg MgO·ha^{-1} caused a significant increase in contents of mineral nitrogen N-NH_4 in the 0-30 cm and 30-60 cm soil horizins, while it reduced the amount of N-NO_3 in both soil horizons in relation to the 0 kg dose of MgO·ha^{-1}. The content of mineral nitrogen NH_4NO_3 after maize harvest was increased significantly with an increase in the dose of nitrogen in each of the soil horizon sampling variants. In comparison to the traditional cultivar ES Palazzo the SG cultivar ES Paroli was the hybrid causing lower eutrophication of the soil medium in the autumn period. Calculated correlation coefficients between observed characteristics of mineral nitrogen in the soil showed that only the N-NO_3 form was highly correlated with total mineral nitrogen in the soil, and it was so in each soil horizon.

Keywords: maize, stay-green, urea, magnesium, nitrogen uptake and utilization

Introduction

The application of nitrogen fertilizers has greatly contributed to an increase in agricultural production worldwide. However, irrespective of the profits and benefits, excessive use of nitrogen fertilizers is always connected with a risk of environmental pollution [1, 2]. This adverse effect of nitrogen occurs mainly after its optimal doses in either mineral fertilizers or organic manures are exceeded [3, 4]. In such a situation considerable amounts of mineral nitrogen forms are accumulated in the soil, thus leading to nitrogen eutrophication of the environment. Baker and

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Timmons [5] reported that in the first year after the application of fertilizer, losses of $N\text{-}NO_3$ as a result of leaching amounted to 13%, while in the second and third years it was 9% and 4%, respectively. For this reason considerable nutrient requirements of maize in relations to nitrogen in the sustainable farming system are considered a negative trait. Thus, multifaceted studies and analyses are conducted on the potential enhancement of efficiency for mineral fertilization in growing maize [6, 7], and rationalization of nitrogen relations in this crop [8]. One of the methods causing greater utilization of nitrogen from the dose of mineral fertilizer is to balance its dose with phosphorus and potassium and other elements, including magnesium and sulfur [9-12]. In turn, breeding is attempting to obtain lines of cultivars and hybrids with a lower nitrogen requirement. Cultivars with a lower requirement of nitrogen are characterized by a higher capacity to utilize this macroelement from mineral fertilizers, while their ability to remobilize nitrogen to grain is similar to that in traditional cultivars.

A slightly different dependence is found in stay-green cultivars. The remobilization index, transfer of nitrogen, phosphorus, and magnesium is negative, while for potassium it is positive [8]. This shows that soil resources are the main source of accumulation for these macroelements at the phase of generative growth for maize. In contrast, for traditional cultivars the remobilization index (transfer) of organic compounds is positive, i.e. at the phase of generative growth (grain filling) this cultivar uses only the resources accumulated at the vegetative growth phase [8]. On the basis of the above statement it may be assumed that since the stay-green hybrid absorbs nutrients from soil for a longer period, the final effect of such a situation may be their lower amount in soil after harvest. A novelty in this study in comparison with two earlier literature reports concerning the same scientific problem, i.e. eutrophication of natural environment with nitrogen [12, 13], is that the author presented simple correlation coefficients between the examined traits of N_{min} in the soil after maize harvest. In addition, coefficients of variation (CV) for the analyzed traits were determined.

Studies concerning the effect of fertilization on the purity state of soil and ground waters, as well as open waters, have become intensified after the 1991 Nitrate Directive [14]. In this directive the upper limit was established for the content of nitrates (50 mg NO_3 or 11.3 mg $N\text{-}NO_3$ in 1 dm^3 water) in potable water [15].

The hypothesis of the experiment assumed that cultivation measures such as nitrogen or magnesium fertilization, or the type of cultivar, may significantly determine the volume of nitrogen uptake and utilization from the dose of the mineral fertilizer.

Thus the aim of the conducted field trials was to asses the effect of soil supplementation with urea and magnesium on the uptake of nitrogen and its utilization by two types of maize cultivars differing in senescence rate. Additionally, the study determined the effect of analyzed experimental factors on nitrogen eutrophication of the natural environment expressed in the amount of N_{min} left in soil after harvest.

Material and Methods

Experimental Field

The field trial was conducted in 2009-11 at the Department of Agronomy, the Poznań University of Life Sciences, on fields of the Teaching and Experimental Station in Swadzim. The trials were conducted in the split-split-plot design with three experimental factors in four field replications. The experiment investigated the effect of four urea doses (N_1 – 0, N_2 – 50, N_3 – 100, N_4 – 150 kg $N\cdot ha^{-1}$) and two magnesium doses (Mg_1 – 0, Mg_2 – 25 kg $MgO\cdot ha^{-1}$) in the form of kieserite on the uptake and utilization of nitrogen by two types of maize cultivars differing in their senescence rates (Fig. 1) – (ES Palazzo [FAO 230-240], and the stay-green (SG) type ES Paroli [FAO 250]).

Fig. 1. The difference in senescence rates in two types of maize hybrids in the maturing stage.

Table 1. Soil conditions in Swadzim.

Specification	Years		
	2009	2010	2011
P, mg P·kg^{-1} of soil	36.1	37.6	61.2
K, mg K·kg^{-1} of soil	121.2	97.1	54.8
Mg, mg Mg·kg^{-1} of soil	44.0	40.0	81.0
pH in 1 mol·dm^{-3} KCl	5.2	5.5	5.1

Phosphorus at a dose of 80 kg P_2O_5·ha^{-1} was applied in the form of 46% pelleted triple superphosphate P_2O_5, while potassium was applied at 120 kg K_2O·ha^{-1} in the form of 60% K_2O potassium salt. Nitrogen was applied according to the experimental scheme. Nitrogen, phosphorus, and potassium fertilizers and kieserite were broadcasted before maize sowing.

Cultivation measures and the other cultivation elements were performed in accordance with the recommendations for maize growing in grain technology.

Thermal and Humidity Conditions

The effects of thermal and humidity factors are most comprehensively described by the hydrothermal index of water supply [K] (Fig. 2) according to Sielianinow [16]:

$$K = \frac{10 \times \text{monthly precipitation total [mm]}}{\text{number of days} \times \text{mean daily air temperature in a month [°C]}}$$

Adequate water supply of plants is found when the value of this coefficient is 1.

Collection of Soil Samples

The content of mineral nitrogen in soil after maize harvest was evaluated in two horizons (0-30 cm, 30-60 cm) according to the experimental procedure/standard (the Regional Chemical and Agricultural Station in Poznań):

$N\text{-}NH_4$ – PB.50 ed. 6 of 17.10.2008

$N\text{-}NO_3$ – PB.50 ed. 6 of 17.10.2008

Plant Material

Maize was harvested using a plot combine harvester by Wintersteiger. After harvest the yield of grain was calculated in terms of dry matter (dt·ha^{-1} dry matter).

In the present study nitrogen content in grain was assessed by the Kjeldahl method using a Kjeltec™ 2200 FOSS device.

Nitrogen uptake with the yield of grain was calculated based on the following formula:

$$\text{Uptake} = \frac{\text{grain yield} \times \text{content of nutrients}}{100}$$

...where: Uptake in kg·ha^{-1}, grain yield in kg·ha^{-1}, and content of nutrients – in %.

Utilization of nitrogen from the dose of mineral fertilizer was calculated based on the following formula [9]:

$$N\ (\%) = (N_f - N_c) \times 100/D$$

...where:
N – utilization of nitrogen (%)
N_f – nitrogen uptake by fertilized plants (kg·ha^{-1})
N_c – nitrogen uptake by plants in the control (unfertilized plot) (kg·ha^{-1})
D – nitrogen rate (kg·ha^{-1})

Statistical Analysis

The obtained results were statistically evaluated with the use of analysis of variance for orthogonal factor experiments and split-split-plot analysis of variance. Significance of result variation was assessed at the confidence level P = 0.95. The analyses of variance were supplemented with analyses of linear and quadratic regression.

The coefficient of variation for the analyzed traits of mineral nitrogen was calculated according to the formula:

$$CV = (S/X) \times 100\%$$

...where:
CV– coefficient of variation (%)
S – standard deviation
X – arithmetic mean

Results and Discussion

Recorded results indicate the significance of weather conditions varying between the years of the study on the volume of grain yield (Table 2). On average the lowest

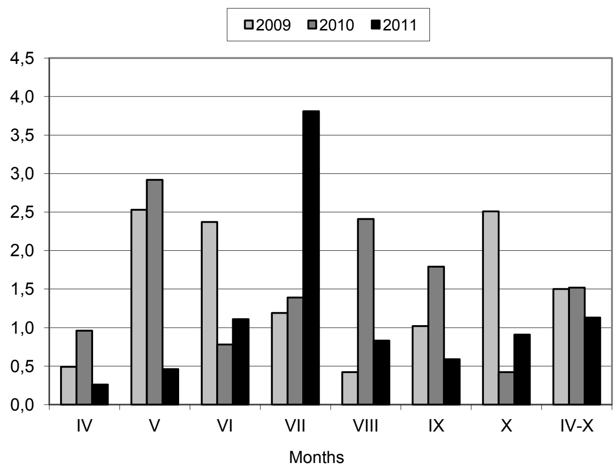

Fig. 2. Values of coefficient [K] in vegetation periods of maize.

Table 2. Grain yield of maize [$dt \cdot ha^{-1}$ dry matter].

Experimental factor Factor levels		Years			Mean
		2009	2010	2011	
Dose of nitrogen kg $N \cdot ha^{-1}$	0	61.09	65.43	83.53	70.01
	50	75.19	72.63	89.96	79.26
	100	81.20	75.23	89.96	82.13
	150	85.97	71.72	92.44	83.38
$LSD_{0.05}$		4.949	3.167	3.605	2.084
Dose of magnesium kg $MgO \cdot ha^{-1}$	0	73.36	71.37	88.23	77.65
	25	78.36	71.14	89.71	79.74
$LSD_{0.05}$		4.337	ns	ns	1.695
Type of cultivar	ES Palazzo	72.91	66.34	85.57	74.94
	ES Paroli SG	78.82	76.17	92.37	82.45
$LSD_{0.05}$		4.922	1.801	1.769	1.780
Mean		75.86	71.25	88.97	-

ns – non-significant difference

yield of grain was recorded in 2010 (71.25 $dt \cdot ha^{-1}$), while it was highest in 2011 (88.97 $dt \cdot ha^{-1}$). When presented in a synthetic form for the period of three years of the experiment the volume of grain yield was significantly determined by the doses of nitrogen, magnesium, and the type of maize hybrid (Table 2). Significantly, the lowest yield of grain was obtained for the dose of 0 kg $N \cdot ha^{-1}$ (70.01 $dt \cdot ha^{-1}$), while it was highest for the dose of 150 $N \cdot ha^{-1}$ (83.38 $dt \cdot ha^{-1}$). However, it needs to be stressed that the volume of maize grain yield for doses of 100 kg $N \cdot ha^{-1}$ and 150 kg $N \cdot ha^{-1}$ was statistically identical. In the case of magnesium doses it was found that the application of 25 kg $MgO \cdot ha^{-1}$ resulted in a significant increase in grain yield by 2.09 $dt \cdot ha^{-1}$ in comparison to the dose of 0 kg $MgO \cdot ha^{-1}$ (Table 2). Rational crop nutrition with magnesium is a key task of contemporary agriculture, since this element plays an extremely important role in plant metabolism and – what is more – it has a direct effect on the quality of plant products [17]. Ciećko and Wyszkowski [18] reported that an adequate supply of crops with this nutrient has an advantageous effect on yield volume, which was shown in this study. In turn, when analyzing the effect of maize hybrid type it was shown that the SG cultivar ES Paroli had significantly higher yields (by 7.51 $dt \cdot ha^{-1}$) than the traditional cultivar ES Palazzo. Also, in earlier studies by the author [19, 20] it was shown that the stay-green hybrid was characterized by a significantly greater yield of grain in relation to the traditional cultivar. The volume of grain yield in this study also was determined by the interaction of the dose of nitrogen with the dose of magnesium (Fig. 3). These dependencies were described by 2º equations, whereas for the SG hybrid ES Paroli this dependence was at a higher level in relation to cv. ES Palazzo. The result recorded in this study confirms earlier literature reports on the advantageous interaction of N and Mg in the modification of grain yield level in maize [7, 19]. Another advantageous effect of magnesium fertilization in maize expressed in an increase of grain yield was confirmed by Fazekas et al. [21]. In turn, Marska [22] reported that insufficient levels of magnesium in soil result in a situation when plants may not appropriately use other elements required for their growth and development. In turn, Grzebisz and Gaj [23] stated that an increase in maize grain yield requires an optimized uptake of nitrogen, phosphorus, sulfur and zinc, which is dependent on better plant nutrition with magnesium.

Statistical analysis of the recorded results showed the significance of years in the modification of nitrogen content in dry matter of maize grain. However, proving the significance of the effect of analyzed experimental factors on the value of the analyzed trait tested in terms of the (years × factors) interaction indicates a strong direct effect of the analyzed factors and provides generalized conclusions. On average for years of the study the content of nitrogen in

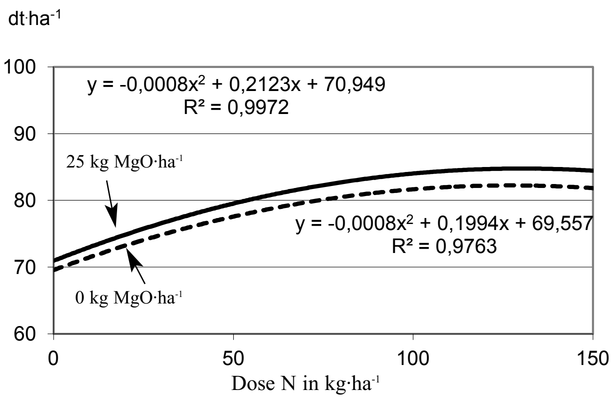

Fig. 3. Interaction of the nitrogen dose with the magnesium dose in modification of grain yield of maize (2009-11).

Table 3. Nitrogen uptake with grain yield of maize [kg·ha^{-1}].

Experimental factor Factor levels		Years			Mean
		2009	2010	2011	
Dose of nitrogen kg N·ha^{-1}	0	77.79	81.95	109.12	89.62
	50	107.63	103.93	128.78	113.45
	100	123.20	110.17	134.11	122.49
	150	131.68	102.67	136.87	123.74
$LSD_{0.05}$		7.666	4.062	5.562	3.116
Dose of magnesium kg MgO·ha^{-1}	0	105.35	99.55	125.51	110.14
	25	114.80	99.80	128.93	114.51
$LSD_{0.05}$		6.245	ns	ns	2.442
Type of cultivar	ES Palazzo	99.12	85.99	113.32	99.48
	ES Paroli SG	121.03	113.36	141.13	125.17
$LSD_{0.05}$		7.375	2.458	2.698	2.648
Mean		110.07	99.68	127.22	-

ns – non-significant difference

grain dry matter was significantly modified by the doses of nitrogen and magnesium, as well as by the type of maize hybrid (Fig. 4). Significantly, the lowest content of nitrogen in grain dry matter was obtained for 0 kg N·ha^{-1} (12.81 g·kg^{-1} dm), while it was highest for the doses of 100 kg N·ha^{-1} and 150 kg N·ha^{-1}, for which the value of the trait was statistically identical. In the case of the dose of magnesium it was found that the application of 25 kg MgO·ha^{-1} caused a significant increment in the content of nitrogen in grain by 0.26 g·kg^{-1} dm in comparison to the dose of 0 kg MgO·ha^{-1} (Fig. 4). In turn, the SG hybrid ES Paroli had a significantly higher content of nitrogen in grain dry matter (by 1.85 g·kg^{-1} dm) in comparison to the other tested cultivar. In another study by this author [24], no significant effect of the type of maize hybrid was shown on the content of nitrogen in dry matter of maize grain. The only observed trend was

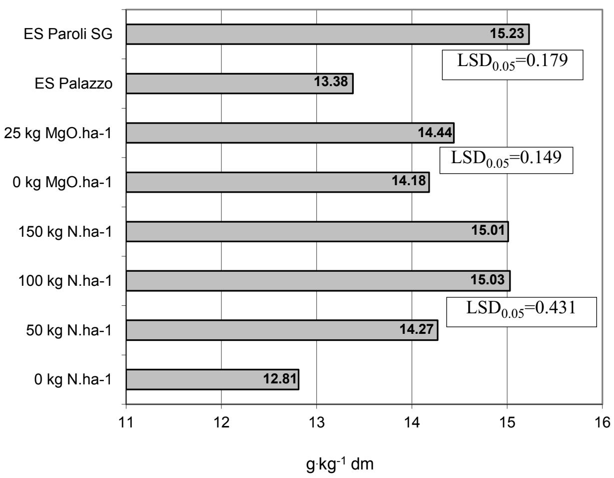

Fig. 4. Nitrogen content in grain dry matter (2009-11).

for a higher concentration of this element in grain of the stay-green hybrid in comparison to the traditional cultivar.

Nitrogen uptake with the yield of dry matter in maize grain in this study was significantly determined by varied weather conditions between the years of the analyses (Table 3). In terms of years, the highest nitrogen uptake with grain yield was found in 2011 (127.22 kg N·ha^{-1}), while it was lowest in 2010 (99.68 kg N·ha^{-1}). When treated jointly for the period of three years of the study, nitrogen uptake with the generative yield of maize was significantly modified by the volume of nitrogen and magnesium doses, as well as the type of maize hybrid (Table 3). Nitrogen uptake increased in the range of doses from 0 kg N·ha^{-1} (89.62 kg N·ha^{-1}) to 150 kg N·ha^{-1} (123.74 kg N·ha^{-1}). The value of the discussed trait for doses of 100 kg N·ha^{-1} and 150 kg N·ha^{-1} was statistically the same. In the case of magnesium doses it was found that the application of 25 kg MgO·ha^{-1} resulted in a significant increase in nitrogen uptake with the yield of grain from 4.37 kg N·ha^{-1} in comparison to the dose of 0 kg MgO·ha^{-1} (Table 3).

When analyzing the effect of the type of maize hybrid, it was shown that the SG cultivar ES Paroli accumulated significantly greater amounts of nitrogen (by 25.69 kg N·ha^{-1} more) in relation to the traditional cultivar ES Palazzo (Table 3). The result recorded in this study corresponds with earlier findings [24]. In this study a significantly greater nitrogen uptake with the yield of grain also was shown for the stay-green hybrid in comparison with the other tested cultivar. The difference between the analyzed cultivar types was 11.53 kg N·ha^{-1}. In turn, Ta and Weiland [25] explained the greater nitrogen uptake by stay-green cultivars in relation to the conventional cultivars by the absorption of this nutrient from two sources, i.e. from nitrogen absorbed from soil and remobilized from the vegetative

Table 4. Utilization of nitrogen from the dose of mineral fertilizer in relation to grain yield [%].

Experimental factor Factor levels		Years			Mean
		2009	2010	2011	
Dose of nitrogen kg N·ha^{-1}	50	64.46	43.96	39.31	49.24
	100	45.40	28.22	24.98	32.87
	150	35.92	13.81	18.49	22.74
$LSD_{0.05}$		14.576	6.797	6.930	5.012
Dose of magnesium kg MgO·ha^{-1}	0	47.65	29.24	23.98	33.62
	25	49.54	28.09	31.20	36.28
$LSD_{0.05}$		ns	ns	6.455	ns
Type of cultivar	ES Palazzo	45.98	19.18	18.01	27.72
	ES Paroli SG	51.21	38.14	37.18	42.18
$LSD_{0.05}$		ns	6.227	3.610	3.710
Mean		48.60	28.66	27.59	-

ns – non-significant difference

plant tissues. The level of nitrogen uptake with the yield of grain was significantly modified by the interaction of the dose of nitrogen with the dose of magnesium (Fig. 5a) and the dose of nitrogen with the type of maize hybrid (Fig. 5b). The interaction of nitrogen with magnesium was described by 2° equations, while for the joint application of N+Mg this dependence occurred at a higher level in comparison with the curve describing the application of N only. In turn, the interaction of the dose of nitrogen with the type of maize hybrid was described by a linear equation. For the SG hybrid ES Paroli the increase in the dose of nitrogen by 1 kg N·ha^{-1} resulted in an increase of nitrogen uptake with the yield of grain by 0.25 kg N·ha^{-1}, while for ES Palazzo it was by 0.19 kg N·ha^{-1} (Fig. 5b).

The type of management aimed at increasing plant production has to include the application of nitrogen fertilizers and improve its utilization. Utilization of nitrogen from mineral fertilizers as an equivalent of nitrogen recovery is a measure of effectiveness of its uptake by plants [26]. The coefficient of nitrogen utilization from mineral fertilizers, interesting from both practical and theoretical points of view, so far has been determined mainly by the differential method [27]. At some research centers the isotope method is applied. In literature sources on the subject it is stressed that both methods do not give similar values of the coefficients of nitrogen utilization from mineral fertilizer. When using the differential method higher values of the coefficient of nitrogen utilization from fertilizers are obtained than when using the isotope method [28]. On average for the years of the study the highest nitrogen utilization from mineral fertilizer was recorded in 2009 (48.60%), while it was lowest in 2011 (27.59%). Jointly for the three years of the study nitrogen utilization from the dose of mineral fertilizer was significantly modified by the volume of nitrogen dose and the type of maize hybrid (Table 4). Nitrogen utilization from mineral fertilizer was significantly reduced with an increase in the dose of nitrogen from 50 kg N·ha^{-1} to 150 kg N·ha^{-1} (from 49.24% to 22.74%). In turn, when investigating the effect of the type of maize hybrid in terms of effectiveness of nitrogen utilization by

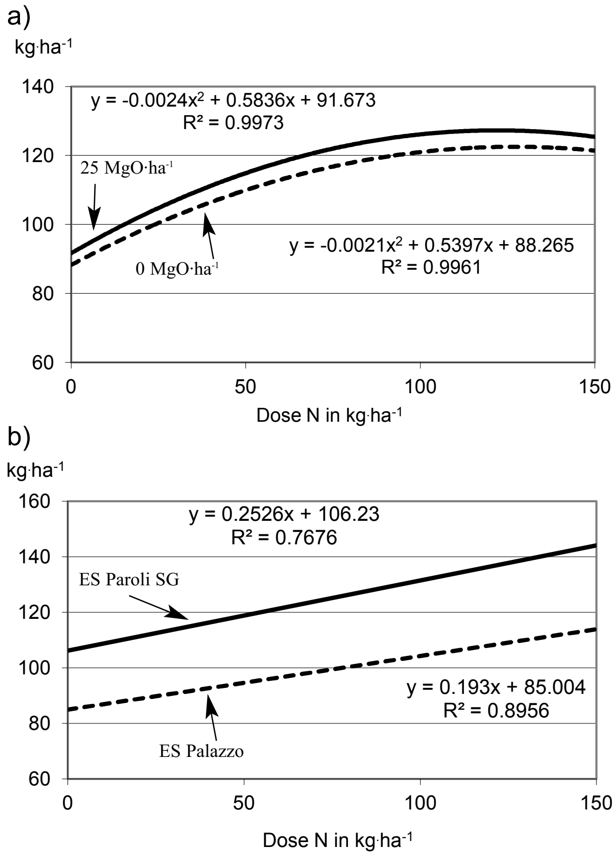

Fig. 5. Interaction of the nitrogen dose with the magnesium dose (A), and the nitrogen dose with maize hybrid type (B) in the modification of nitrogen uptake with grain yield (2009-11).

Table 5. Variation of analyzed mineral nitrogen contents in soil, irrespective of analyzed experimental factors.

Feature	Value of feature			Standard deviation	Coefficient of variation %
	minimum	maximum	mean		
	kg·ha^{-1}				
N-NH_4 [0-30 cm]	10.35	18.45	14.23	2.162	15.19
N-NH_4 [30-60 cm]	12.15	18.22	15.42	1.995	12.94
N-NO_3 [0-30 cm]	15.52	44.10	27.18	9.329	34.32
N-NO_3 [30-60 cm]	14.17	36.00	22.26	6.504	29.22
NH_4NO_3 [0-30 cm]	31.95	56.47	41.41	8.809	21.27
NH_4NO_3 [30-60 cm]	28.80	49.50	37.68	6.869	18.23
NH_4NO_3 [0-60 cm]	61.65	105.30	79.10	15.397	19.47

maize, it was stated that the SG hybrid ES Paroli was characterized by a significantly greater value of the discussed trait in comparison with cv. ES Palazzo (Table 4). This difference was 14.46% points. Slightly lower (by 4.1% points), but still significantly greater utilization of nitrogen by the stay-green hybrid in comparison with the traditional cultivar was shown by the author in an earlier study [12].

Utilization of nitrogen in relation to the yield of grain in this study was significantly modified by the interaction of the nitrogen dose with the magnesium dose (Fig. 6a), and the nitrogen dose with the type of maize hybrid (Fig. 6b).

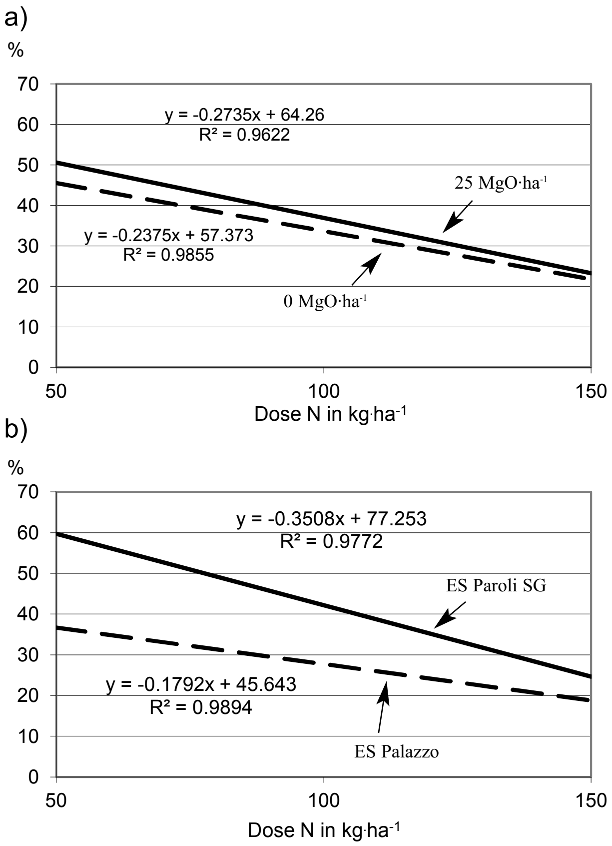

Fig. 6. Interaction of the nitrogen dose with the magnesium dose (A), and the nitrogen dose with maize hybrid type (B) in the modification of nitrogen utilization in relation to grain yield (2009-11).

Interaction of the nitrogen dose with the magnesium dose was described by a 1° equation, while for the joint N+Mg application this curve was plotted at a higher level in comparison to the curve describing the application of N alone. Greater utilization of nitrogen with the dose of mineral fertilizer as a result of combined N+Mg application was previously shown by Szulc [12] and Potarzycki [9]. Also, the interaction of the dose of nitrogen with the type of maize hybrid was described by a 1° equation, while for each used kg of nitrogen the SG hybrid ES Paroli reduced the utilization of this nutrient by 0.35%, and for cv. ES Palazzo it was by 0.17%. The above-mentioned statement also was presented by the author in an earlier study [12].

Mineral nitrogen (N_{min}) is found in soil in the form of ammonia and nitrate ions accounting for 1% and up to 5% total nitrogen content [29]. However, in view of the dynamics of changes in this nutrient as well as its effect on plant nutrition, it constitutes the most important pool of total soil nitrogen resources [30]. However, in soil there is a constant depletion of this nitrogen form caused by crops, as well as its losses by leaching to ground waters [31]. Evaluation of the content of mineral nitrogen in soil is used to improve the effectiveness of fertilization with this nutrient, but it also is used as an indicator of environmental threat resulting from its excessive concentration in soil [12, 13]. A too high concentration of mineral nitrogen left in soil after harvest constitutes a potential threat for the natural environment. Variation in the analyzed characteristics of contents of mineral nitrogen (N_{min}) in the autumn after maize harvest, irrespective of the analyzed experimental factors, is presented in Table 5. Greater variation was found for the N-NO_3 form in comparison with N-NH_4 and this was both at a depth of 0-30 cm and 30-60 cm. In the case of NH_4NO_3 content, greater fluctuations were found for the 0-30 cm horizon than 30-60 cm (the coefficients of variation were 21.27% and 18.23%, respectively). In this study the direction of changes under the influence of the examined factors was similar in all years, while the statistically confirmed interaction resulted only from the difference in the power of their action in individual years of the field trials. Thus in this study, in order to illustrate the dependencies more com-

Table 6. Content of N_{min} in soil after maize harvest (2009-11).

Experimental factor Factor levels		N_{min} kg·ha^{-1}						
		N-NH$_4$		N-NO$_3$		NH$_4$NO$_3$		
		cm						
		0-30	30-60	0-30	30-60	0-30	30-60	0-60
Dose of nitrogen kg N·ha^{-1}	0	14.28	14.28	23.51	20.58	37.80	34.87	72.67
	50	13.33	15.46	25.81	21.82	39.15	37.29	76.44
	100	16.59	17.15	28.06	21.88	44.66	39.03	83.70
	150	12.71	14.79	31.33	24.75	44.04	39.54	83.58
$LSD_{0.05}$		ns	ns	ns	ns	1.015	1.837	2.716
Dose of magnesium kg MgO·ha^{-1}	0	13.02	14.79	28.91	23.23	41.93	38.02	79.95
	25	15.44	16.05	25.45	21.29	40.89	37.35	78.24
$LSD_{0.05}$		1.557	1.207	2.007	1.538	ns	ns	ns
Type of cultivar	ES Palazzo	13.86	15.66	35.04	27.67	48.90	43.34	92.25
	ES Paroli SG	14.59	15.18	19.32	16.84	33.91	32.03	65.95
$LSD_{0.05}$		ns	ns	5.519	4.521	5.542	4.151	9.026

ns – non-significant differences

prehensively, the effect of individual experimental factors on the value of this trait was presented using mean values from the years of the study (Table 6). Contents of the ammonia form (N-NH$_4$) in the 0-30 cm as well as 30-60 cm horizons were significantly modified only by the dose of magnesium. Significantly higher amounts of the ammonia form of mineral nitrogen were found on the object, where 25 kg MgO·ha^{-1} were applied in comparison with the object with no magnesium application. This difference was 2.42 kg N-NH$_4$·ha^{-1} in the 0-30 cm horizon, while at a depth of 30-60 cm it was 1.26 kg N-NH$_4$·ha^{-1}. The presence of ammonia nitrogen in soil causes a strong limitation of magnesium uptake and vice versa. Uptake of nitrogen in the form of the ammonia cation by plants leads to strong acidification of the rhizosphere, which as a consequence causes a reduction of cation uptake with a simultaneously high accumulation of chloride, sulfate, and phosphate anions. As a result, the production of organic acids is reduced, which as a consequence decreases plant growth rate [32]. Such a situation results in an increased content of this form of mineral nitrogen in soil. Contents of the nitrate form (N-NO$_3$) in the 0-30 cm and in 30-60 cm horizons in this study were significantly modified by the dose of magnesium and by the type of maize hybrid (Table 6). Significantly lower amounts of the nitrate form of mineral nitrogen were found for the object, where 25 kg MgO·ha^{-1} were applied in comparison with the object with no magnesium application. This difference in the 0-30 cm horizon was 3.46 kg N-NO$_3$·ha^{-1}, while in the 30-60 cm horizon it was 1.94 kg N-NO$_3$·ha^{-1}. In turn, when investigating the effect of the type of maize hybrid on the content of nitrate nitrogen in soil, it was shown that after harvest of the SG hybrid ES Paroli a significantly smaller amount of this nitrogen form was left in the 0-30 cm and 30-60 cm horizons in comparison with cv. ES Palazzo. This difference was 15.72 kg N-NO$_3$·ha^{-1} (0-30 cm) and 10.83 kg N-NO$_3$·ha^{-1} (30-60 cm), respectively. The content of mineral nitrogen NH$_4$NO$_3$ at depths of 0-30 cm, 30-60 cm, and 0-60 cm in this study was significantly modified by the dose of nitrogen and the type of maize hybrid. Content of N_{min} in soil after maize harvest increased linearly with an increase in the applied nitrogen doses (Table 6).

The results recorded in this study confirm earlier literature reports [25]. In these studies the content of N_{min} determined during the maize vegetation period increased with an increase in the doses of nitrogen fertilization from 0 to 270 kg N·ha^{-1}. A dependence between the content of mineral nitrogen in soil and applied doses of mineral fertilizers was described by equations of linear regression. In turn, the SG cultivar ES Paroli turned out to be the hybrid-reducing nitrogen eutrophication of the environment in this study in the autumn period, after the harvest of which a significantly lower amount of N_{min} was left in soil in comparison with the traditional cv. ES Palazzo. The recorded results in this study correspond with earlier results obtained by Szulc [12]. This author, when investigating the response of two different types of maize cultivars, showed a lower amount of mineral nitrogen after harvest in the 0-60 cm harvest by 28.1 kg N_{min}·ha^{-1} to the advantage of the stay-green cultivar. Thus, in view of ecological considerations and the potential to produce generative yield grown for grain, it is best to choose a stay-green hybrid [31]. Müller and Görlitz [33]

Table 7. Correlation coefficients between observed traits.

Specification	$N\text{-}NH_4$ [0-30 cm]	$N\text{-}NH_4$ [30-60 cm]	$N\text{-}NO_3$ [0-30 cm]	$N\text{-}NO_3$ [30-60 cm]	NH_4NO_3 [0-30 cm]	NH_4NO_3 [30-60 cm]	NH_4NO_3 [0-60 cm]
$N\text{-}NH_4$ [0-30 cm]	1						
$N\text{-}NH_4$ [30-60 cm]	0.524	1					
$N\text{-}NO_3$ [0-30 cm]	-0.349	0.082	1				
$N\text{-}NO_3$ [30-60 cm]	-0.332	0.034	0.939**	1			
NH_4NO_3 [0-30 cm]	-0.124	0.215	0.973**	0.913**	1		
NH_4NO_3 [30-60 cm]	-0.162	0.323	0.913**	0.956**	0.927**	1	
NH_4NO_3 [0-60 cm]	-0.143	0.267	0.964**	0.949**	0.986**	0.976**	1

**significance at P=0.01

also pointed to the danger of excessive amounts of mineral nitrogen in soil after harvest, and reported that the average content of this nitrogen form in the autumn in loamy sand soil in the 0-60 cm horizon is 107 kg $N_{min}\cdot ha^{-1}$. In this study the content of mineral nitrogen after maize harvest was below that upper value. We need to stress here the consistency of differences in nitrogen uptake with the yield of grain by the tested maize cultivar types and the amount of nitrogen N_{min} remaining in soil at a depth of 0-60 cm. The difference in absorbed nitrogen between the tested cultivar types was 25.69 kg $N\cdot ha^{-1}$, while in terms of mineral nitrogen content it was 26.3 kg $N_{min}\cdot ha^{-1}$.

Calculated correlation coefficients between observed characteristics of mineral nitrogen in soil showed that only the $N\text{-}NO_3$ form is highly correlated with total mineral nitrogen in soil, and it was so at each depth of soil sample collection (Table 7).

Conclusions

The significantly lowest yield of grain dry matter, content of nitrogen in grain dry matter, and nitrogen uptake were obtained for the dose of 0 kg $N\cdot ha^{-1}$, while the highest values of these traits were found for the dose of 150 kg $N\cdot ha^{-1}$. The difference in values of the discussed parameters for doses of 100 kg $N\cdot ha^{-1}$ and 150 kg $N\cdot ha^{-1}$ was statistically at the same level. The application of 25 kg $MgO\cdot ha^{-1}$ resulted in a significant increase in yield of grain dry matter, nitrogen content in grain, and nitrogen uptake in comparison to the object with no application of this macronutrient. Significantly greater yield of grain dry matter, nitrogen content in grain, and nitrogen uptake were found for the stay-green hybrid ES Paroli in comparison with hybrid ES Palazzo. Utilization of nitrogen from mineral fertilizer (urea) was significantly reduced with an increase in its dose. The stay-green cv. ES Paroli was characterized by a significantly greater utilization of nitrogen from the dose of urea in comparison with cv. ES Palazzo. A combined application of nitrogen with magnesium (N+Mg) resulted in a higher yield of grain, nitrogen uptake, and utilization in comparison with the application of N only. At each soil horizon where nitrogen was applied, the SG hybrid Es Paroli accumulated more nitrogen with the yield of grain and exhibited better utilization of nitrogen in relation to grain yield in comparison with cv. ES Palazzo. The application of 25 kg $MgO\cdot ha^{-1}$ resulted in a significant increase in ammonia nitrogen ($N\text{-}NH_4$), while it reduced the amount of nitrate nitrogen ($N\text{-}NO_3$) in the 0-30 cm and 30-60 cm horizons in comparison with the object with no magnesium application. Significantly less nitrate nitrogen ($N\text{-}NO_3$) in soil at a depth of 0-30 cm and 30-60 cm was found after harvest of the stay-green hybrid ES Paroli in comparison with the other analyzed cultivar ES Palazzo. Content of mineral nitrogen in the soil horizons (0-30 cm, 30-60 cm, and 0-60 cm) was significantly increased for the range of nitrogen doses from 0 kg $N\cdot ha^{-1}$ to 100 kg $N\cdot ha^{-1}$. The increase in N_{min} content in soil after the application of the 50 kg $N\cdot ha^{-1}$ dose of nitrogen was statistically non-significant. The stay-green hybrid ES Paroli turned out to be the cultivar with a significantly lower impact on the environment caused by nitrogen eutrophication after harvest in relation to cv. ES Palazzo. Additionally, the research demonstrated that the difference in nitrogen uptake between the analyzed maize cultivars and the content of NH_4NO_3 (N_{min}) in the soil layer of 0-60 cm was almost the same (26.30 kg $N\cdot ha^{-1}$; 25.69 kg N_{min}). Only the nitrate nitrogen form ($N\text{-}NO_3$) was highly correlated with total mineral nitrogen in soil at each sampling depth.

Abbreviations

SG – stay-green
N_{min} – mineral nitrogen

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