*Original Research*

# The Effects of Soil Supplementation with Different Nitrogen Fertilizers on Select Fertilization Indices in Two Types of Maize Hybrids (*Zea mays* L.) and on Mineral Nitrogen ($N_{min}$) Contents in Soil

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**Abstract**

This paper presents the effects of soil supplementation with different forms of nitrogen fertilizers on select fertilization efficiency indices in two types of maize hybrids and on changes in contents of mineral nitrogen in soil after maize harvest. Nitrogen content in grain of maize and its uptake with grain yield and utilization were significantly higher for slow-release fertilizers in comparison to quick-release nitrogen fertilizers. The application of 25 kg MgO·ha$^{-1}$ significantly increased nitrogen uptake with grain yield and its utilization in comparison to the object with no application of this macronutrient. Better indices of nitrogen use efficiency were recorded for the stay-green hybrid cv. ES Paroli in comparison to the traditional cv. ES Palazzo. Irrespective of the tested experimental factors, the percentage of nitrogen absorbed from the fertilizer in the total amount of nitrogen uptake was less than 25%. The advantage of the stay-green hybrid in comparison to the traditional cultivar in terms of nitrogen content in grain, the uptake of nitrogen with grain yield, and utilization of nitrogen were significantly higher for slow-release nitrogen fertilizers. The combined application of ammonium sulphate in fertilization with 25 kg MgO·ha$^{-1}$ caused a negative increment in nitrogen uptake and utilization in relation to other nitrogen fertilizers. Significantly less mineral nitrogen ($N_{min}$) in soil after maize harvest was detected in objects on which slow-release fertilizers (e.g. ammonium sulphate and urea) were used in comparison to quick-release fertilizers (e.g. ammonium nitrate). The application of 25 kg MgO·ha$^{-1}$ in comparison to the object, where this macronutrient was not used, is a cultivation measure causing lower burden of this biogen for the natural environment. The stay-green hybrid ES Paroli in relation to cv. ES Palazzo reduced nitrogen eutrophication of the natural environment with mineral nitrogen. Only nitrate nitrogen was highly correlated with total mineral nitrogen in soil at each depth of soil sample collection. The use of nitrogen fertilizers caused an increase in the contents of nitrate nitrogen in the total amount of mineral nitrogen in the 0-30 cm and 30-60 cm soil profiles. In turn, the application of magnesium and the stay-green cultivar reduced the amount of N-$NO_3$ in the total amount of $N_{min}$ in the period after the maize harvest.

**Keywords:** maize, stay-green, nitrogen fertilizers, magnesium, uptake N, utilization N, $N_{min}$

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## Introduction

Nitrogen is a basic plant component, playing a decisive role in the intensification of plant production [1]. The best increment in yields is obtained under the influence of nitrogen fertilization and an adequate supply of plants in the other nutrients. However, excessive doses of nitrogen fertilizers may have an adverse effect on the quality of plant biomass and the natural environment. Excessive nitrogen content in soil causes an inappropriately high uptake of this macronutrient by plants, which may result in inadequate growth and development due to the accumulation of nitrogen compounds in plant tissues [2]. On the other hand, excessive accumulation of mineral nitrogen forms in soil poses a risk of water pollution as a result of nitrate leaching by precipitation [3]. As reported by Andraski et al. [4], the application of nitrogen doses that precisely meet the requirement of a crop may as a consequence contribute to the formation of lower $NO_3^-$ amounts in soil available for leaching and affect quality of the natural environment. Thus a long-term direction in studies on the role of nitrogen in the modification of plant production is to identify biologically and economically justified optimal doses of nitrogen, taking into consideration factors modifying uptake and utilization of this nutrient from mineral fertilizers. According to Szulc [2] and Potarzycki [5], the utilization of nitrogen from a mineral fertilizer to a considerable degree depends on the balancing of its dose with phosphorus and potassium, as well as availability of several other elements, including magnesium. Apart from magnesium a decisive role in the utilization of nitrogen from the dose of a mineral fertilizer is also played by an appropriate selection of the hybrid to be grown [6, 7]. This is related to the fact that for several years now stay-green hybrids have been available in maize growing, in which grain ripening occurs at full greenness of whole plants [8]. Chevalier and Schrader [9] and Bertin and Gallais [10] reported that nitrogen uptake and utilization vary considerably among traditional maize hybrids. In turn, in their field experiment Ma and Dwyer [11] observed that the stay-green cultivar showed higher efficiency of nitrogen uptake that the rapidly aging traditional hybrid. For the production of generative yield, i.e. grain in maize growing, nitrogen is collected from two sources, N absorbed from soil and N remobilized from vegetative tissues [12]. As shown by Szulc et al. [13], a stay-green hybrid is characterized by a negative nitrogen remobilization index. This indicates that the soil resources are the main sources of nitrogen accumulation in the phase of generative growth. Such a behavior of stay-green plants should imply a system of fertilization based on slow-release nitrogen fertilizers [13].

Thus the aim of the field experiments was to assess soil supplementation with different forms of nitrogen fertilizers (slow- and quick-release fertilizers) on select indices of fertilization efficiency for two types of maize hybrids grown for grain. Moreover, the study evaluated the effect of nitrogen fertilizer forms, magnesium doses, and type of maize hybrid in terms of nitrogen eutrophication of the natural environment expressed in the contents of mineral nitrogen ($N_{min}$) in the period after maize harvest.

## Material and Methods

### Field Experiment

The field experiment was conducted at the Department of Agronomy, Poznań University of Life Sciences, on the fields of the Teaching and Experimental Station in Swadzim in 2009-11. It was performed in the split-split-plot design with three experimental factors, in four field replications. The 1st order factor comprised forms of nitrogen fertilizers at six levels: no fertilization applied, ammonium nitrate ($NH_4NO_3$), ammonium sulfate ($(NH_4)_2SO_4$), urea ($CO(NH_2)_2$), Canwil nitrochalk ($NH_4NO_3 + CaCO_3 + MgCO_3$), and ammonium nitrate at 50% N dose + 50% dose of urea ($NH_4NO_3 + CO(NH_2)_2$). The 2nd degree factor was doses of magnesium at two levels: 0 kg MgO·ha$^{-1}$ and 25 kg MgO·ha$^{-1}$, and the 3rd degree factor – types of maize cultivars, i.e. ES Palazzo and ES Paroli SG.

In each year of the study prior to the establishment of the experiment identical mineral fertilization was applied at 120 kg N·ha$^{-1}$ (according to the level of the 1st degree 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$^{-1}$) in the form of 605 potassium salt. Magnesium was applied in the form of kieserite (25% MgO, 50% $SO_3$ – 20% S, sulphate sulphur).

Maize sowing rate in all the fertilizer combinations was the same and amounted to 7.93 pcs·m$^{-2}$ (79.300 pcs·ha$^{-1}$). Each year of research, the field experiment was established in mid-April. The size of the plot for harvesting was 15.4 m$^2$. Maize harvesting for grain was carried out at the full maturity stage with a Wintersteiger plot combine.

The field experiment was conducted on podsolic soil, light clay sand grade, shallowly deposited on the light clay belonging to a good rye complex. According to the FAO international soil classification [14], the examined soils are classified as Phaeozems or as Mollisols – according to US Soil Taxonomy [15].

Soil resources of basic macronutrients and soil pH in individual years of the experiment are given in Table 1.

### Thermal and Humidity Conditions

Temperature and humidity conditions during vegetation in the years of the experiments were highly varied for growth and development of maize. The effect of temperature and

Table 1. Soil conditions 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 |

humidity factors is most comprehensively presented by the hydrothermal water supply coefficient [K] according to Sielianinow [16] (Fig. 1). Optimal value of this coefficient is 1. Values below 1 indicate a drought period, while above 1 – relative humidity.

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

## Methods of Analyses

In the present study nitrogen content in grain was assessed using the Kjeldahl method with the Kjeltec™ 2200 FOSS apparatus.

Nitrogen uptake with yield of grain was calculated based on the following formula [2]:

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

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

Utilization of nitrogen from a dose of mineral fertilizer was calculated based on the following formula [5]:

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

...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$^{-1}$).

Agricultural efficiency was calculated based on the following formula:

$$Er = (GY_N - GY_0)/120$$

...where: $Er$ – agricultural efficiency (kg dm·kg N in fertilizers), $GY_N$ – yield of grain from object with nitrogen dose (dt·ha$^{-1}$), $GY_0$ – yield of grain from object with no nitrogen applied (dt·ha$^{-1}$).

## Collection of Soil Samples

Contents of mineral nitrogen in soil after maize harvest were assessed for two profiles (0-30 cm, 30-60 cm) according to the research 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.

## Statistical Analysis

Recorded results were analyzed statistically, applying the analysis of variance for orthogonal factorial experiments and the analysis of variance in the split-split-plot system. Significance of variation of results was determined at the confidence level P = 0.95. The coefficient of variation of analyzed parameters of mineral nitrogen was calculated from formula [2]:

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

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

## Results and Discussion

In this study nitrogen content in grain dry matter was significantly determined by the type of nitrogen fertilizer and the type of maize hybrid (Table 2). Significantly, the lowest nitrogen content in maize grain was recorded in the object with no nitrogen fertilizer applied (12.88 g·kg$^{-1}$ dm), while it was the highest in the objects fertilized with ammonium sulphate (14.68 g·kg$^{-1}$ dm) and urea (14.60 g·kg$^{-1}$ dm), for which the value of the discussed trait was statistically the same (Table 2). In turn, when investigating the effect of the type of maize hybrid on the value of the discussed trait it was shown that the stay-green cultivar (ES Paroli) was characterized by significantly higher contents of nitrogen in grain dry matter in comparison to the other analyzed cultivar, i.e. ES Palazzo (Table 2). The difference between the analyzed types of cultivars was 2.24 g·kg$^{-1}$ dm. Also, in other field experiments Szulc and Bocianowski [17], when

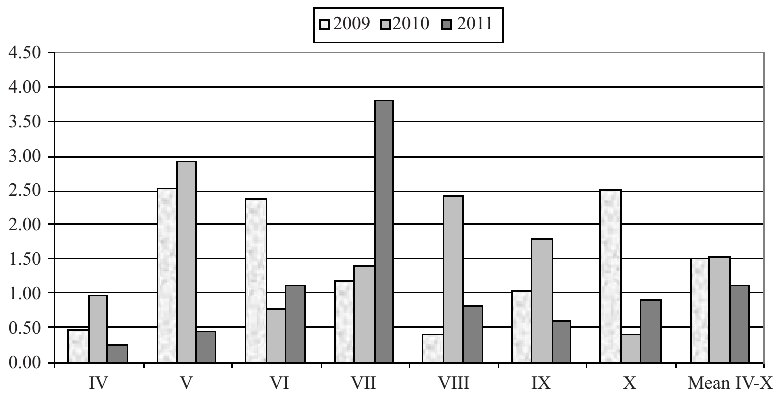



Fig. 1. Values of the hydrothermal water supply coefficient [K] according to Sielianinow.

Table 2. The effects of the type of nitrogen fertilizer, magnesium dose and maize type hybrid on content, uptake, utilization, and agricultural efficiency of nitrogen in relation to grain yield (2009-11).

| Factor<br>Levels of factor | | Nitrogen content | Nitrogen uptake | Utilization of nitrogen | Agricultural efficiency |
|---|---|---|---|---|---|
| | | $g \cdot kg^{-1}$ dm | $kg \cdot ha^{-1}$ | % | kg d.m·kg N in fertilizers |
| Type of nitrogen fertilizer | No fertilizer | 12.88 | 96.56 | - | - |
| | $NH_4NO_3$ | 13.90 | 121.97 | 21.16 | 10.41 |
| | $(NH_4)_2SO_4$ | 14.68 | 130.87 | 28.58 | 11.35 |
| | $CO(NH_2)_2$ | 14.60 | 130.58 | 28.34 | 11.65 |
| | $NH_4NO_3 + CaCO_3 + MgCO_3$ | 14.20 | 124.12 | 22.96 | 10.12 |
| | $NH_4NO_3$+ $CO(NH_2)_2$ | 14.22 | 128.29 | 26.43 | 12.29 |
| $LSD_{0.05}$ | | 0.398 | 4.612 | 2.866 | ns |
| Dose of $MgO \cdot ha^{-1}$ | 0 | 14.03 | 120.99 | 24.23 | 11.23 |
| | 25 | 14.13 | 123.14 | 26.76 | 11.10 |
| $LSD_{0.05}$ | | ns | 1.770 | 1.781 | ns |
| Type of hybrid | ES Palazzo | 12.96 | 105.43 | 18.74 | 9.94 |
| | ES Paroli "stay-green" | 15.20 | 138.70 | 32.25 | 12.38 |
| $LSD_{0.05}$ | | 0.223 | 1.854 | 1.883 | 1.493 |

n-s.d. – non-significant difference

applying a dynamic approach, found a significantly higher content of nitrogen in grain dry matter in the stay-green cultivar in relation to the traditional hybrid. This difference at day 130 from the sowing date amounted to 2.45 $g \cdot kg^{-1}$ dm between the investigated cultivars, at day 144 from the sowing date it was 3.40 $g \cdot kg^{-1}$ dm, while at the end of the vegetation period (at day 158 from the sowing date) it was 3.39 $g \cdot kg^{-1}$ dm. In this study an interaction was shown between the type of nitrogen fertilizer with the type of maize hybrid in the modification of nitrogen contents in grain dry matter (Fig. 2). For each of the analyzed nitrogen fertilizers significantly higher contents of nitrogen in grain were found in the stay-green hybrid in comparison to the traditional cultivar. The difference between the investigated types of cultivars ranged from 1.25 $g \cdot kg^{-1}$ dm (ammonium nitrate) to 2.86 $g \cdot kg^{-1}$ dm (ammonium sulphate). In slow-release fertilizers such as ammonium sulphate and urea, as well as the Canwil nitro-chalk and ammonium nitrate at 50% N dose + 50% urea dose, the advantage of the stay-green cultivar was significantly greater than in the objects with no nitrogen fertilizer applied and with ammonium nitrate applied (Fig. 2).

Nitrogen uptake with the yield of grain in this study presented synthetically for the 3-year period of the study was significantly determined by all three experimental factors (Table 2). When analyzing the type of nitrogen fertilizer it was found that, significantly, the lowest uptake of nitrogen with the yield of grain was recorded in the object with no nitrogen fertilizer applied (96.56 $kg \cdot ha^{-1}$), while significantly the highest uptake was observed in the case of slow-release fertilizers, i.e. ammonium sulphate (130.87 $kg \cdot ha^{-1}$) and urea (130.58 $kg \cdot ha^{-1}$), as well as ammonium nitrate at 50% N dose + urea 50% dose (128.29 $kg \cdot ha^{-1}$) – Table 2. In turn, when analyzing the level of magnesium dose it was stated that at the application of 25 kg $MgO \cdot ha^{-1}$ a significantly

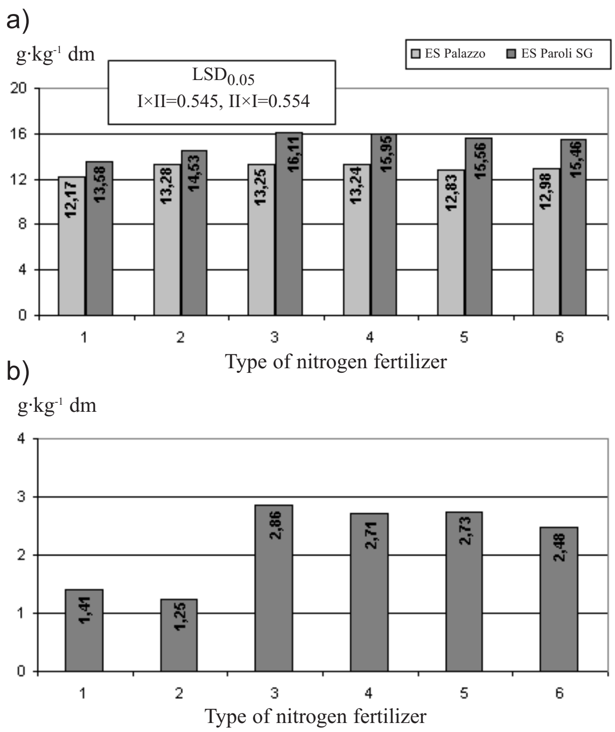



Fig. 2. Interaction of the type of nitrogen fertilizer with the type of maize hybrid in modification of nitrogen content in grain (a), and (b) increment in nitrogen content in grain (2009-11).

higher nitrogen uptake with the yield of grain was recorded in relation to the object with no application of this macronutrient. The difference between magnesium doses was 2.15 $kg\cdot ha^{-1}$ (Table 2). Grzebisz [18] reported that the primary and at the same time expected effect of magnesium is an increase in the useful yield of a crop. The influence of this nutrient is manifested in an increase of nitrogen productivity, resulting from increased nitrogen uptake as well as effective conversion of absorbed nitrogen by crops into a yield of biomass, which was shown in this study. In the case of the type of maize hybrid a significantly greater nitrogen uptake was recorded, by as much as 33.27 $kg\cdot ha^{-1}$ for the hybrid ES Paroli in relation to the hybrid ES Palazzo (Table 2). The result stated in this study confirms earlier literature sources, reporting higher nitrogen uptake by stay-green cultivars in comparison to their traditional equivalents [19, 20]. In turn, Ta and Weiland [12] explained greater nitrogen uptake by stay-green cultivars in relation to conventional cultivars by the absorption of this nutrient from two sources, i.e. from nitrogen absorbed from soil and that remobilized from vegetative tissues of the plant. In this study it also was shown that the volume of nitrogen uptake with the yield of grain in maize also was determined by the interaction of the type of nitrogen fertilizer with the dose of magnesium (Fig. 3). In each of the tested nitrogen fertilizers, except for the control object (with no nitrogen applied) and for ammonium sulphate, the application of 25 kg $MgO\cdot ha^{-1}$ resulted in an increase of nitrogen uptake in relation to the object, on which this nutrient was not applied.

By broadcasting urea and the Canwil nitro-chalk with 25 kg $MgO\cdot ha^{-1}$, a significantly positive increment was

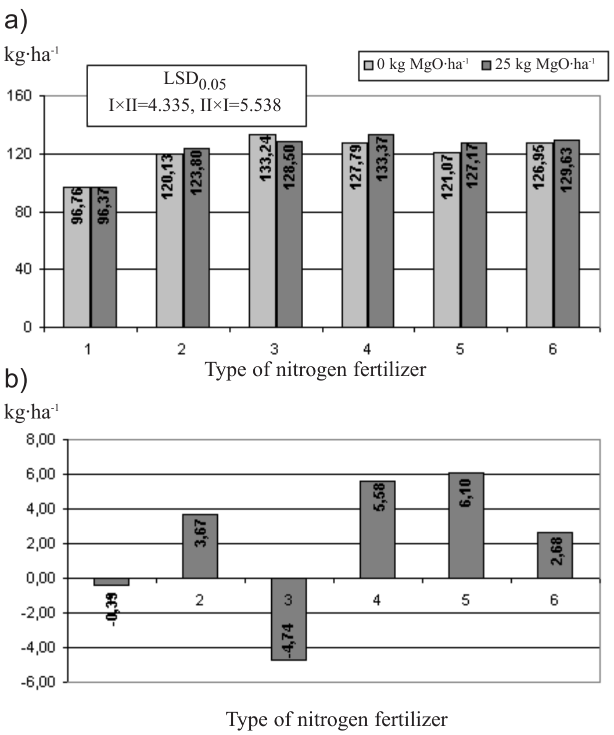



Fig. 3. Interaction of the type of nitrogen fertilizer with magnesium dose in the modification of nitrogen uptake with yield of grain (a) and (b) increment in nitrogen uptake with yield of grain (2009-11).

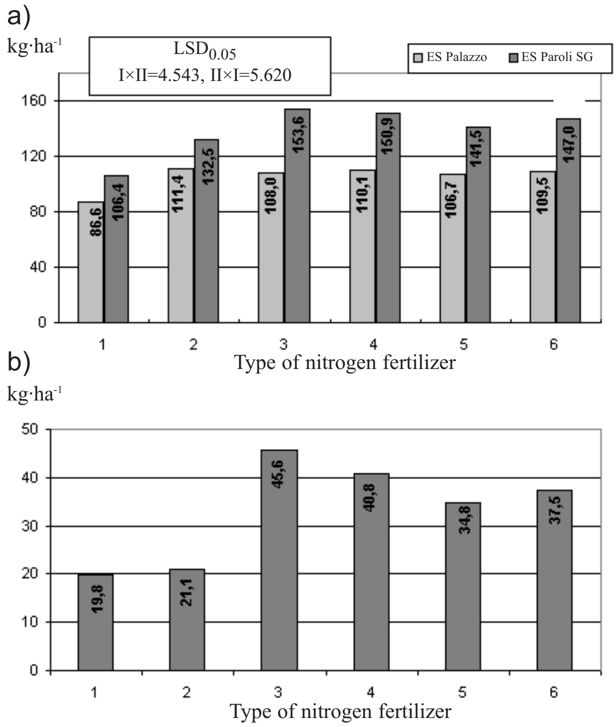


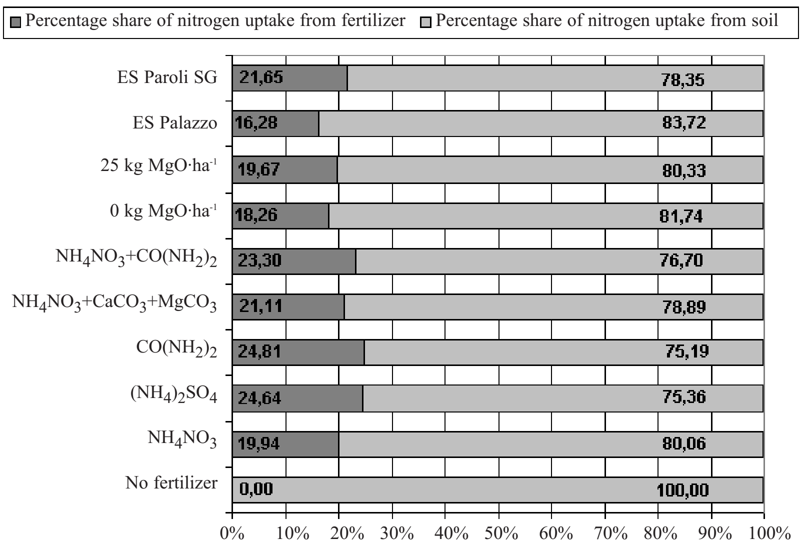

Fig. 4. Interaction of the type of nitrogen fertilizer with the type of maize hybrid in the modification of nitrogen uptake with yield of grain (a) and (b) increment in uptake volume with yield of grain (2009-11).

obtained for nitrogen uptake in comparison to the other fertilizer objects. The presence of ammonium nitrogen in soil causes a considerable reduction of magnesium absorption. The uptake of nitrogen in the form of the ammonium cation by plants leads to a strong acidification of the rhizosphere, which as a consequence causes a limitation of cation uptake with a simultaneous accumulation of chloride, sulphate, and phosphate anions. As a consequence, a strong deficit of basic anions ($Mg^{2+}$, $K^{+}$), particularly calcium ions ($Ca^{2+}$), is observed, which leads to the production of organic cations in order to maintain constant pH in the cytoplasm. As a result the production of organic acids is reduced, leading to a limitation of plant growth rate [21].

Moreover, in this study an interaction was shown between the type of nitrogen fertilizer with the type of maize hybrid in the modification of the volume of nitrogen uptake with the yield of grain (Fig. 4). In each of the tested nitrogen fertilizers a significantly greater nitrogen uptake was observed in the stay-green hybrid in comparison to the traditional cultivar. The difference between the tested cultivars ranged from 19.8 $kg\cdot ha^{-1}$ (with no nitrogen applied) to 45.6 $kg\cdot ha^{-1}$ (ammonium sulphate applied) – Fig. 4. In the case of slow-release fertilizers the advantage of the stay-green cultivar in comparison to the other tested cultivar was significantly greater in terms of the values of the discussed trait than for quick-release fertilizers. The classical model of nitrogen accumulation stipulates that plants accumulate 85-100% required nutrient at the phase of vegetative growth, while during the grain filling (ripening) phase nitrogen organic compounds are remobilized from resources accumulated at the vegetative growth phase at a slight uptake from soil resources [18]. Szulc et al. [13] showed that a classical example (model) of nitrogen accumulation is provided by a cultivar which is not a stay-green hybrid. The index of remobilization for organic compounds for such a hybrid is positive, i.e. at the generative growth phase (grain filling) this cultivar uses resources accumulated at the vegetative growth phase. In turn, the stay-green cultivar is characterized by a negative nitrogen remobilization index. This shows that the primary source of N accumulation at the generative growth phase is provided by soil resources [13]. For this reason in this study the advantage of the stay-green cultivar over the traditional cultivar in the amount of accumulated nitrogen in the yield of grain in case of slow-release fertilizers needs to be explained by the negative remobilization index for this macronutrient. When using slow-release fertilizers in maize, growing plants are provided with this macronutrient in accordance with the dynamics of its requirement.

Moreover, the percentage proportions of nitrogen absorbed from the fertilizer and from soil in the total uptake of this macronutrient with the yield of grain also were calculated in this study (Fig. 5). It was stated that in the case of slow-release fertilizers, i.e. ammonium sulphate and urea, nitrogen absorbed from the fertilizer accounts for approximately 25%, while 75% nitrogen is absorbed from soil resources (Fig. 5). For the other nitrogen fertilizers the percentage share of nitrogen absorbed from soil in the total amount of nitrogen uptake was markedly lower. In the case of a magnesium dose it was shown that the application of 25 kg $MgO \cdot ha^{-1}$ increases the percentage proportion of nitrogen absorbed from fertilizer in the total nitrogen uptake in relation to the object with no magnesium application. The difference between magnesium doses was 1.41% points (Fig. 5). The stay-green hybrid ES Paroli was characterized by a significantly higher percentage share of nitrogen absorbed from fertilizer (21.65%) in the total amount of absorbed N in relation to cv. ES Palazzo (16.28%). Thus it needs to be assumed that the percentage proportion of nitrogen absorbed from fertilizer in the total amount of nitrogen accumulated in maize grain, irrespective of the analyzed experimental factors, was below 25%. Also, Kruczek and Szulc [22] stated that the percentage of nitrogen absorbed from fertilizer for the production of grain and ears for the 9 fertilizer combinations on average amounted to 27.6%, i.e. it was more than 2.5-times lower than the share of soil nitrogen. Thus, despite the fact that generative yield of maize is formed in the period of the greatest nitrogen requirement and in the period of its most intensive uptake, a decisive role in the production of generative yield was played by nitrogen absorbed from soil resources rather than from fertilizers.

The utilization of nitrogen from mineral fertilizers, as an equivalent of nitrogen recovery, is a measure of effectiveness of its uptake by plants [23]. In this study its volume is significantly determined by the type of nitrogen fertilizer, magnesium dose, and type of maize hybrid (Table 2). Significantly greater utilization of mineral nitrogen was observed from slow-release fertilizers, i.e. ammonium sulphate, urea, and for ammonium nitrate at 50% N dose + 50% urea dose in comparison to both ammonium nitrate and the Canwil nitro-chalk. Crassman and Dobermann [24] reported that the utilization of nitrogen from mineral and organic fertilizers by crops depends on numerous environmental factors, the dynamics of nitrogen uptake by plants and on chemical properties of fertilizer. In turn, at the application of 25 kg $MgO \cdot ha^{-1}$ a significantly higher utilization of nitrogen by 2.53% points was recorded in comparison to the object with no application of this macronutrient. As it was reported by Grzebisz and Härdter [25], the primary yield-forming task of magnesium and sulphate is to provide an increase in the yield of grain thanks to a more efficient utilization of fertilizer nitrogen. Both these mineral nutrients by effectively balancing nitrogen make it possible to considerably enhance the utilization of fertilizer nitrogen. Also the stay-green cv. ES Paroli in this study was characterized




$LSD_{0.05}$ from fertilizer **3.212**, $LSD_{0.05}$ from dose MgO **1.130**, $LSD_{0.05}$ from coltivar type **1.112**

Fig. 5. Percentage share of nitrogen uptake from fertilizer and from soil in total uptake with yield of grain (2009-11).

Table 3. The effects of nitrogen fertilizer type and magnesium dose on utilization of nitrogen in relation to grain yield (2009-11).

| Dose of MgO·ha$^{-1}$ | Type of nitrogen fertilizer | | | | |
|---|---|---|---|---|---|
| | $NH_4NO_3$ | $(NH_4)_2SO_4$ | $CO(NH_2)_2$ | $NH_4NO_3$ + $CaCO_3$ + $MgCO_3$ | $NH_4NO_3$+ $CO(NH_2)_2$ |
| 0 | 19.47 | 30.39 | 25.86 | 20.26 | 25.16 |
| 25 | 22.85 | 26.77 | 30.83 | 25.66 | 27.71 |
| $LSD_{0.05}$ | I x II = 3.982. II x I = 4.018 | | | | |
| Difference | + 3.38 | - 3.62 | + 4.97 | + 5.6 | + 2.55 |

Table 4. The effects of nitrogen fertilizer type and maize hybrid type on utilization of nitrogen in relation to grain yield (2009-11).

| Type of hybrid | Type of nitrogen fertilizer | | | | |
|---|---|---|---|---|---|
| | $NH_4NO_3$ | $(NH_4)_2SO_4$ | $CO(NH_2)_2$ | $NH_4NO_3$ + $CaCO_3$ + $MgCO_3$ | $NH_4NO_3$+ $CO(NH_2)_2$ |
| ES Palazzo | 20.61 | 17.79 | 19.56 | 16.67 | 19.06 |
| ES Paroli “stay-green” | 21.71 | 39.37 | 37.12 | 29.24 | 33.81 |
| $LSD_{0.05}$ | I x II = 4.210. II x I = 4.132 | | | | |
| Difference | + 1.1 | + 21.58 | + 17.56 | + 12.57 | + 14.75 |

by a significantly greater utilization of nitrogen from nitrogen fertilizer in comparison to the hybrid ES Palazzo. The difference between both types of cultivars was 13.51% points (Table 2). A slightly lower (by 4.1% points), but significantly greater utilization of nitrogen by the stay-green hybrid in comparison to the traditional cultivar was reported by the author in an earlier study [6]. According to Hirel et al. [26], an increase in the absorption of solar radiation by plants grown on poorer soils contributes indirectly to an increase in the efficiency of nitrogen utilization. Stay-green hybrids have a greater assimilation area than their traditional equivalents [27]. This may indirectly explain a greater utilization of nitrogen by such hybrids. In the investigations conducted by the author the utilization of nitrogen also was dependent on the interaction of the type of nitrogen fertilizer with the dose of magnesium (Table 3).

For all the analyzed fertilizers, except for ammonium sulphate, the application of magnesium increased the utilization of nitrogen from nitrogen fertilizer. The utilization of nitrogen in the conducted field experiment also was determined by the interaction of the type of nitrogen fertilizer with the type of maize hybrid (Table 4). For each of the used nitrogen fertilizers the stay-green hybrid ES Paroli was characterized by a greater utilization of nitrogen from the dose of mineral fertilizer in comparison to the traditional hybrid ES Palazzo. The difference between the examined cultivars ranged from 1.1% (ammonium nitrate) to 21.58% (ammonium sulphate). For slow-release fertilizers the advantage of the stay-green cultivar was significantly greater than for slow-release fertilizers in terms of values of the discussed trait. The utilization of nitrogen from the dose of nitrogen fertilizer also was modified by an interaction of magnesium dose with the type of maize hybrid (Fig. 6). Irrespective of the volume of magnesium dose, the stay-green hybrid ES Paroli was characterized by a significantly greater utilization of nitrogen from the dose of nitrogen fertilizer in comparison to cv. ES Palazzo. For the traditional cultivar the dose of magnesium did not determine to a significant degree the utilization of nitrogen from mineral fertilizer. In the case of the stay-green hybrid ES Paroli the application of 25 kg MgO·ha$^{-1}$ significantly increased the utilization of nitrogen in comparison to the object with no magnesium application (Fig. 6).

A major stage in the evaluation of effectiveness of fertilization is connected with the determination of its efficiency. According to Bock [28], agricultural efficiency is a measure for such an evaluation in studies on the assessment of the effect of nitrogen. Agricultural (cultivation) efficiency is expressed by an increment in the yield of grain per unit of nitrogen applied in mineral fertilizer. In this study agricultural efficiency was significantly determined only by the

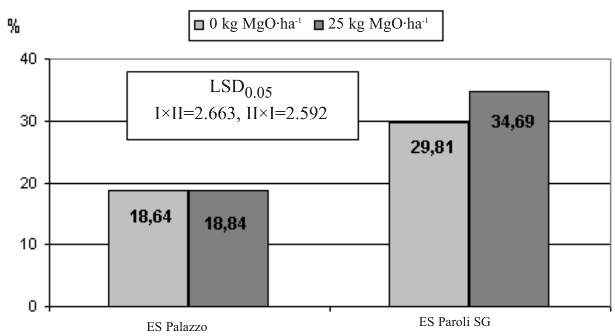



Fig. 6. The effect of magnesium dose and type of maize hybrid on the modification of nitrogen utilization from mineral fertilizer dose in relation to grain yield (2009-11).

Table 5. Variation of mineral nitrogen contents in soil irrespective of analyzed experimental factors (2009-11).

| Parameter | Value of parameter kg·ha$^{-1}$ minimum | maximum | mean | Standard deviation | Coefficient of variation % |
|---|---|---|---|---|---|
| $N\text{-}NH_4$ [0-30 cm] | 7.65 | 25.42 | 16.28 | 4.544 | 27.91 |
| $N\text{-}NH_4$ [30-60 cm] | 6.30 | 24.07 | 16.58 | 3.885 | 23.43 |
| $N\text{-}NO_3$ [0-30 cm] | 7.87 | 54.90 | 25.96 | 16.722 | 64.39 |
| $N\text{-}NO_3$ [30-60 cm] | 6.52 | 70.87 | 26.75 | 21.795 | 81.46 |
| $NH_4NO_3$ [0-30 cm] | 20.02 | 77.62 | 42.25 | 17.833 | 42.21 |
| $NH_4NO_3$ [30-60 cm] | 16.87 | 84.37 | 43.34 | 22.608 | 52.16 |
| $NH_4NO_3$ [0-60 cm] | 39.15 | 157.95 | 85.59 | 39.552 | 46.21 |

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

| 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 |
|---|---|---|---|---|---|---|---|---|
| | | $N_{min}$ kg·ha$^{-1}$ | | | | | | |
| Type of nitrogen fertilizer | No fertilizer | 17.38 | 17.43 | 13.78 | 10.46 | 31.16 | 27.90 | 59.06 |
| | $NH_4NO_3$ | 19.35 | 18.61 | 41.40 | 39.82 | 60.75 | 58.44 | 119.19 |
| | $(NH_4)_2SO_4$ | 13.16 | 11.30 | 19.91 | 17.15 | 33.07 | 28.46 | 61.53 |
| | $CO(NH_2)_2$ | 18.95 | 21.26 | 25.31 | 25.25 | 44.26 | 46.51 | 90.78 |
| | $NH_4NO_3 + CaCO_3 + MgCO_3$ | 11.36 | 13.44 | 30.03 | 30.82 | 41.40 | 44.26 | 85.66 |
| | $NH_4NO_3 + CO(NH_2)_2$ | 17.49 | 17.43 | 25.36 | 37.01 | 42.86 | 54.45 | 97.31 |
| $LSD_{0.05}$ | | ns | ns | 14.377 | 12.101 | 15.107 | 14.907 | 19.448 |
| Dose of MgO·ha$^{-1}$ | 0 | 17.41 | 16.91 | 28.44 | 28.95 | 45.86 | 45.86 | 91.72 |
| | 25 | 15.15 | 16.25 | 23.49 | 24.56 | 38.64 | 40.81 | 79.46 |
| $LSD_{0.05}$ | | ns | ns | 3.974 | 3.213 | 5.614 | 3.211 | 8.489 |
| Type of hybrid | ES Palazzo | 16.95 | 17.08 | 37.08 | 39.50 | 54.03 | 56.58 | 110.62 |
| | ES Paroli "stay-green" | 15.61 | 16.08 | 14.85 | 14.01 | 30.46 | 30.09 | 60.56 |
| $LSD_{0.05}$ | | ns | ns | 12.222 | 17.734 | 13.653 | 18.957 | 21.871 |

ns – non-significant difference

cultivar factor (Table 2). Significantly greater agricultural efficiency of nitrogen was found for the stay-green hybrid in comparison to the traditional cultivar. The difference between the tested cultivars was 2.44 kg d.m.·kg N in the applied fertilizer.

Variation in the analyzed traits concerning the 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 observed for the $N\text{-}NO_3$ form in comparison to the $N\text{-}NH_4$ form, and it was both at a depth of 0-30 cm (the coefficient of variation 64.39%) and a depth of 30-60 cm ($CV$ = 81.46%).

The $N\text{-}NH_4$ form of mineral nitrogen was not significantly modified, either in the 0-30 cm or 30-60 cm profiles, at any of the tested levels of the experimental factors (Table 6). In the case of the nitrate form the type of nitrogen fertilizer, the dose of magnesium, and the type of maize hybrid significantly modified the amount of this form of mineral nitrogen in soil in the period after maize harvest, and it was the case in both profiles of soil sample collection for chemical analyses (Table 6). Significantly lower amounts of nitrate nitrogen were determined in the objects, in which slow-release fertilizers (e.g. ammonium sulphate and urea) were applied in comparison to quick-release fertilizers such

Table 7. Correlation coefficients between observed parameters (2009-11).

| Specification | N-$NH_4$ [0-30 cm] | N-$NH_4$ [30-60 cm] | N-$NO_3$ [0-30 cm] | N-$NO_3$ [30-60 cm] | $NH_4NO_3$ [0-30 cm] | $NH_4NO_3$ [30-60 cm] | $NH_4NO_3$ [0-60 cm] |
|---|---|---|---|---|---|---|---|
| N-$NH_4$ [0-30 cm] | 1 | | | | | | |
| N-$NH_4$ [30-60 cm] | 0.712** | 1 | | | | | |
| N-$NO_3$ [0-30 cm] | 0.116 | 0.139 | 1 | | | | |
| N-$NO_3$ [30-60 cm] | 0.187 | 0.123 | 0.898** | 1 | | | |
| $NH_4NO_3$ [0-30 cm] | 0.364 | 0.312 | 0.967** | 0.890** | 1 | | |
| $NH_4NO_3$ [30-60 cm] | 0.302 | 0.291 | 0.890** | 0.985** | 0.911** | 1 | |
| $NH_4NO_3$ [0-60 cm] | 0.337 | 0.307 | 0.945** | 0.964** | 0.972** | 0.982** | 1 |

** significant at P=0.01

as ammonium nitrate. Also, the application of 25 kg MgO·$ha^{-1}$, in comparison to the object with no fertilization using this macronutrient, is a cultivation measure causing a lower burden of this biogen for the natural environment (Table 6). Selection of a stay-green hybrid as opposed to traditional cultivars reduces nitrogen eutrophication of the natural environment with nitrate nitrogen. The difference between the analyzed cultivar types in this study amounted to 22.23 kg N-$NO_3$·$ha^{-1}$ (0-30 cm) and 25.49 kg N-$NO_3$·$ha^{-1}$ (30-60 cm). In the case of mineral nitrogen content (N-$NH_4$ and N-$NO_3$) the same effect of the analyzed experimental factors was observed as for the nitrate form (Table 6). It needs to be stressed that after maize harvest in the 0-60 cm soil profile the content of mineral nitrogen ($NH_4NO_3$) in the object with ammonium nitrate applied was 119.19 kg $N_{min}$·$ha^{-1}$, at the initial dose of this fertilizer of 120 kg N·$ha^{-1}$.

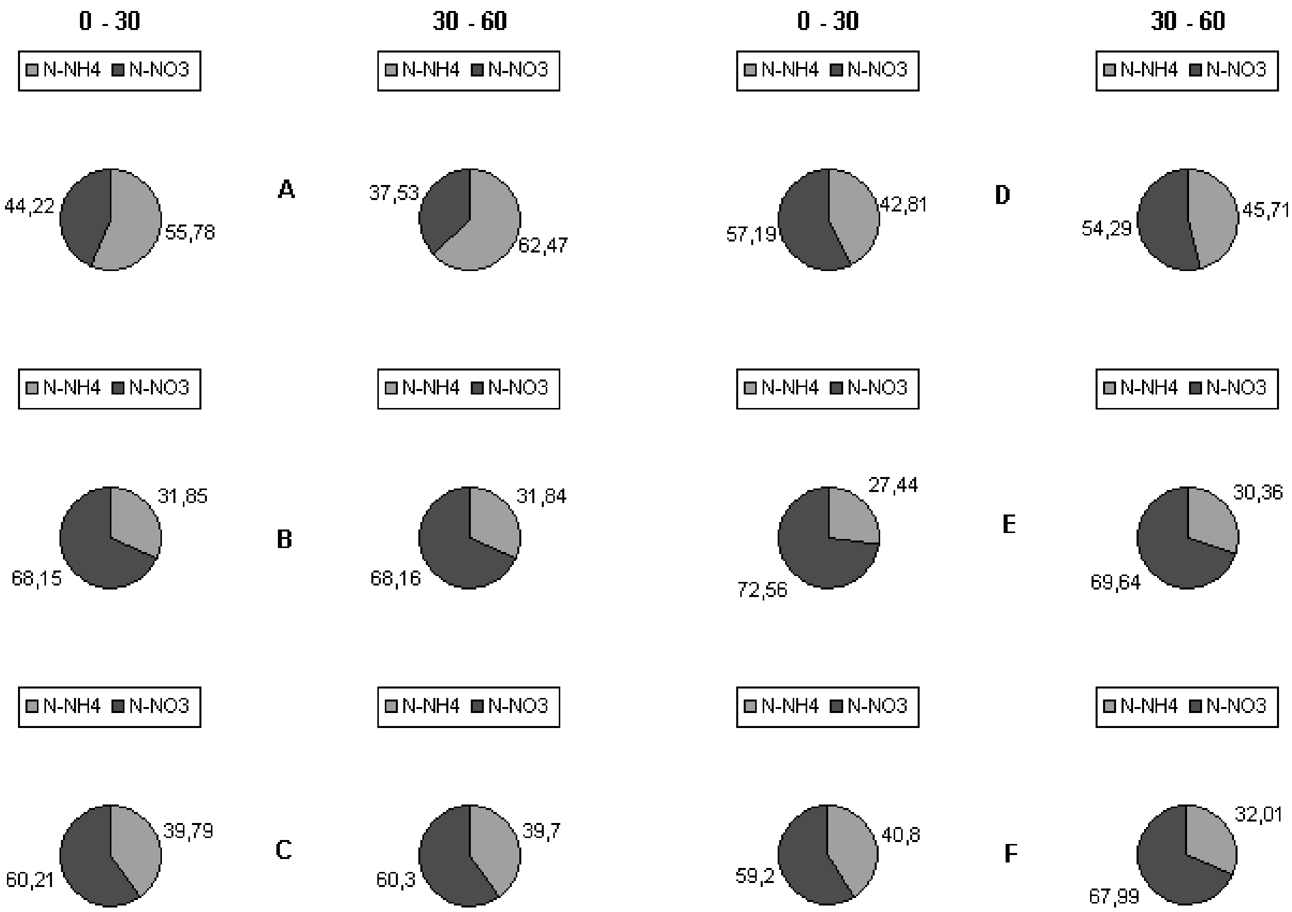



Fig. 7. Percentage shares of N-$NH_4$ and N-$NO_3$ in total mineral nitrogen ($N_{min}$) after harvest of maize plants (2009-11) (A – no fertilizer, B – ammonium nitrate, C – ammonium sulphate, D – urea, E – Canwil nitro-chalk, F – ammonium nitrate at 50% N dose + urea at 50% dose).

Calculated coefficients of correlation between the observed characteristics of mineral nitrogen in soil showed that only the N-$NO_3$ nitrogen form was highly correlated with total mineral nitrogen in soil, and that remained the case for all depths of soil sampling (Table 7).

In this research paper another investigated aspect was connected with the percentage shares of N-$NH_4$ and N-$NO_3$ in the total amount of mineral nitrogen ($N_{min}$) after maize harvest (Figs. 7 and 8). When analyzing the type of nitrogen fertilizer, it was shown that in the control object (with no nitrogen application) in the 0-30 cm profile the nitrate form accounted for 44.22%, while the ammonium nitrogen form comprised 55.78%. In the 30-60 cm profile the amount of the nitrate form was reduced (37.53%) at the expense of the ammonium form (62.47%). As a result of the application of ammonium nitrate, ammonium sulphate, urea, the Canwil nitro-chalk, and ammonium nitrate at a 50% N dose + 50% dose of urea, irrespective of the soil sampling depth, the nitrate form predominated over the ammonium form (Fig. 7). Still, the highest amounts of the N-$NO_3$ form in the 0-30 cm and 30-60 cm profiles were recorded after the application of slow-release nitrogen fertilizers, i.e. ammonium nitrate (68.15% and 68.16%) and the Canwil nitro-chalk (72.56% and 69.64%, respectively). Taking into consideration the dynamics of maize requirement for this nutrient as well as ecological concerns (eutrophication of the environment), the application of quick-release nitrogen fertilizers is not recommended in maize growing.

Mainly nitrogen forms are leached from mineral soils (nitrate nitrogen to a much greater degree than ammonium nitrogen). Nitrates are absorbed by the soil sorption complex. Ammonium nitrogen undergoes exchangeable and non-exchangeable sorption, although some of it penetrates to deeper layers of the soil profile. Taking into consideration the behavior of both forms of mineral nitrogen in soil, most authors in their analyses include only nitrate nitrogen [24]. In turn, when investigating the effect of magnesium dose on the percentage shares of both mineral nitrogen forms in the total amount of $N_{min}$ in soil, it was found that the application of 25 kg MgO·ha$^{-1}$ results in a reduction of the amount of nitrate nitrogen in both soil profiles in comparison to the object with no magnesium application (Fig. 8). In contrast, interesting fluctuations are observed for the percentage shares of both mineral nitrogen forms in soil depending on the type of maize hybrid (Fig. 8). In the case of the hybrid ES Palazzo, both in the 0-30 cm and 30-60 cm profiles, the nitrate form accounts for approximately 70%, with the ammonium form constituting approximately 30%. Also, Trawczyński [29] showed that after the end of the vegetation period the share of the nitrate form in the 0-30 cm and 31-60 cm soil horizons was higher than in the plant vegetation period, constituting over 70% total amount of mineral nitrogen, which was also shown in this study. For the stay-green cv. ES Paroli, irrespective of the soil sampling depth, the ammonium form of mineral nitrogen constituted over 50%. This definitely shows that the stay-green cultivar is a hybrid posing as a lesser burden for the natural environment in terms of nitrate-nitrogen (N-$NO_3$) pollution.

## Conclusions

1. The application of ammonium sulphate and urea (slow-release fertilizers) increases significantly the content of nitrogen, its uptake and utilization in comparison to quick-release fertilizers, i.e. ammonium nitrate and the Canwil nitro-chalk.
2. The application of 25 kg MgO·ha$^{-1}$, in comparison to the dose of 0 kg MgO·ha$^{-1}$, significantly increases nitrogen uptake and its utilization.
3. The stay-green hybrid ES Paroli was characterized by a significantly higher nitrogen content in grain, nitrogen uptake, nitrogen utilization, and agricultural efficiency in comparison to the traditional cv. ES Palazzo.

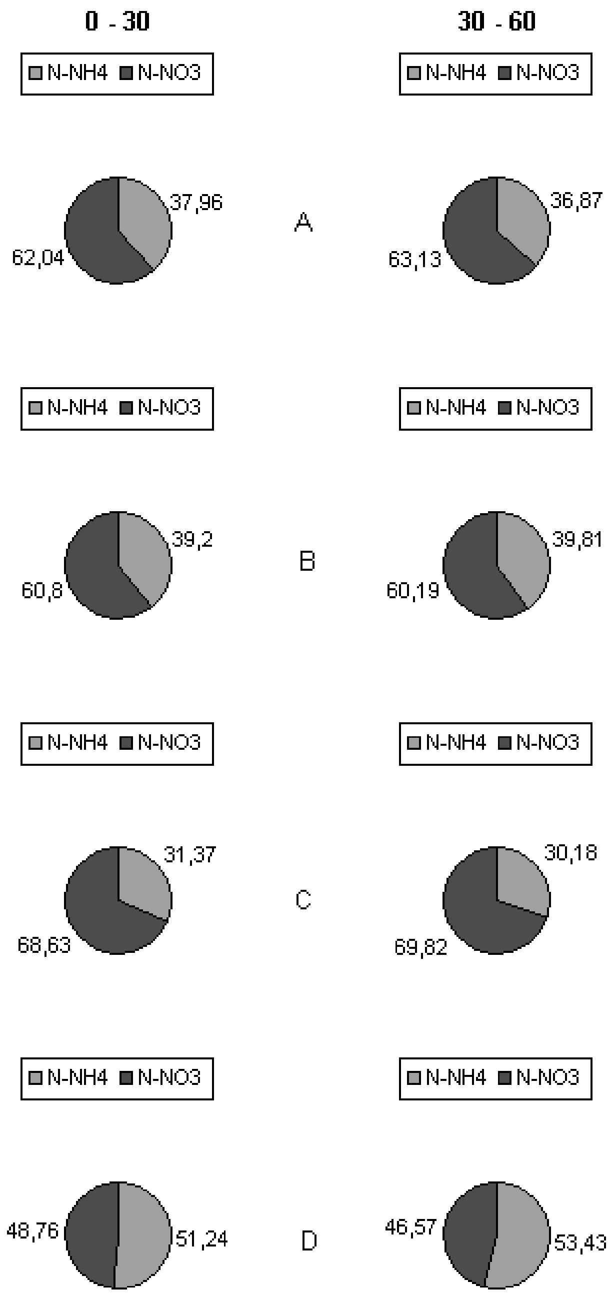



Fig. 8. Percentage shares of N-$NH_4$ and N-$NO_3$ in total mineral nitrogen ($N_{min}$) after harvest of maize plants (2009-11) (A – 0 kg MgO·ha$^{-1}$, B – 25 kg MgO·ha$^{-1}$, C – ES Palazzo, D – ES Paroli SG).

4. For each of the analyzed nitrogen fertilizers, except for ammonium sulphate, the application of 25 kg MgO·ha$^{-1}$ caused an increment in nitrogen uptake and its utilization in relation to the object with no magnesium applied. By broadcasting urea and the Canwil nitrochalk with 25 kg MgO·ha$^{-1}$ a significantly positive increment of nitrogen uptake and utilization was recorded in comparison to the other nitrogen fertilizers.
5. In the fertilization of the stay-green hybrid ES Paroli in comparison to the traditional cv. ES Palazzo, slow-release fertilizers proved to be more effective (such as ammonium sulphate and urea).
6. Irrespective of the investigated experimental factors, the percentage share of nitrogen absorbed from fertilizer in the total amount of nitrogen uptake was below 25%.
7. The type of nitrogen fertilizer, the dose of magnesium, and the type of maize hybrid did not differentiate significantly the contents of ammonium nitrogen in soil.
8. The application of slow-release fertilizers and magnesium in maize growing as well as the selection of stay-green cultivars reduce nitrogen eutrophication of soil.
9. The application of nitrogen fertilizers results in an increase in the contents of nitrate nitrogen in the total amount of mineral nitrogen in the 0-30 cm and 30-60 cm soil profiles. In turn, the use of magnesium and the stay-green cultivar reduce the amount of the N-$NO_3$ form in the total amount of $N_{min}$ in the period after maize harvest.

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