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Original Research

Effects of Differentiated Levels of Nitrogen Fertilization and the Method of Magnesium Application on the Utilization of Nitrogen by Two Different Maize Cultivars for Grain

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Abstract

A field experiment was carried out at the Didactic and Experimental Farm in Swadzim near Poznań in 2004-07. Two maize cultivars were studied, six nitrogen doses and magnesium doses. The effects of the mentioned factors exerted on the utilization of nitrogen from the applied mineral fertilizer and on the nitrogen harvest index were studied. The impact of nitrogen fertilization on the mineral intake of traditional maize cultivars has been widely presented in national and foreign literature. However, there are a limited number of papers comparing the volume of mineral intake and use between the traditional and the "stay-green"-types of cultivars. Moreover, according to the "minimum" principle, the component most deficient in the soil determines harvest volume. Magnesium is obviously one of the ingredients whose deficiency has been found in most of the soils in Poland, and this justifies research focusing on improving the precision of the technology concerning "stay-green"-type maize cultivar fertilization with nitrogen and magnesium, including the environmental aspects. The hybrid LG 2244 "stay-green"-type utilized to a higher degree nitrogen from the applied mineral fertilizer and showed a higher nitrogen harvest index, as compared with a traditional hybrid cultivar: Anjou 258. Increasing levels of nitrogen fertilization decreased N utilization by the plants and the nitrogen harvest index. The application of 15 kg Mg·ha^{-1} both broadcast and in rows caused increased nitrogen utilization from the mineral fertilizer, which was distinctly shown by the smaller amount of N_{min} in the soil after the maize harvest.

Keywords: cultivar type, maize, nitrogen, magnesium, Mg application method, N utilization, nitrogen harvest index, N_{min}

Introduction

The basic task of prosperous agriculture is balanced fertilization, and this should take into consideration all the nutritive components necessary for correct growth and development of plants [1, 2]. Compliance with this requirement will contribute to the realization of the yield-creating potential present in the genotype of each species [3]. Maize, because of the quantity and quality of the produced biomass, belongs to the group of plants with high nutritive needs. The high level of fertilization that is required due to the above-mentioned reasons qualifies maize to the intensive plant group [4]. The component that distinctly limits the biomass of such plants is nitrogen, the price of which has recently caused a significant increase in the costs of cultivation. One of the methods that can improve plant cultivation payability

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is to reduce the nitrogen fertilization costs. This can be achieved by the improved effectiveness of nitrogen utilization of the applied mineral fertilizer, and by the application of nitrogen in combination with other nutritive components, including magnesium [5, 6]. A better utilization of nitrogen from the applied fertilizer will improve the effectiveness of maize cultivation as well as contribute to environmental protection against excessive eutrophication. As reported by Andarski et al. [7] the application of nitrogen doses that correspond exactly to the real demands of the grown plant can as a consequence effect a smaller development of NO_3^- available in the soil for leaching, thereby exerting an effect on the quality of the natural environment.

The hypothesis of our experiment assumed that magnesium, whose deficiency has recently been reported in a majority of soils in Poland, can exert an influence on the total yield of high production plants, including maize. Additionally, it can contribute to better utilization of nitrogen from the supplied mineral fertilizers and, in effect, decrease the content of mineral nitrogen remaining in the soil after the maize harvest (N_{min}).

The above reasons prompted us to undertake studies aimed at investigating the effect of the method of magnesium application on the utilization of nitrogen and on the nitrogen harvest index in the cultivation of two maize cultivars for grain, depending on the differentiated level of N fertilization.

Material and Methods

The field studies were carried out at Didactic and Experimental Farm in Swadzim near Poznań in 2004-07. The experiment was carried out using a "split-plot" design with 3 factors in 4 field replications. Two cultivars were studied: Anjou 258 and LG 2244 (the "stay-green"-type); six nitrogen doses were used: 0 kg N·ha^{-1}, 30 kg N·ha^{-1}, 60 kg N·ha^{-1}, 90 kg N·ha^{-1}, 120 kg N·ha^{-1}, and 150 kg N·ha^{-1}; and three magnesium doses: 0 kg Mg·ha^{-1}, 15 kg Mg·ha^{-1} (in rows) and 15 kg Mg·ha^{-1} (broadcast), in the form of kieserite. Fertilization with P and K was performed before the sowing of maize in the doses: 80 kg P_2O_5·ha^{-1} (35.2 kg P·ha^{-1}) in the form of Polifoska 6 and 120 kg K_2O·ha^{-1} (99.6 kg K·ha^{-1}) in the form of a 60% potassium salt.

The soil and meteorological conditions relevant to the precision field tests have been presented in a previous paper by the author [5].

The utilization by plants of nitrogen from the supplied mineral fertilizer and the nitrogen harvest index were taken from formulas contained in a paper by Fotyma [8].

$$W_N = \frac{Y_Z N}{Y_Z N + Y_S N}$$

...where:
W_N – coefficient of nitrogen harvest;
$Y_Z N$ – N uptake with grain yield in kg·ha^{-1};
$Y_S N$ – N uptake with stover yield in kg·ha^{-1}.

Table 1. Harvest index of nitrogen and its utilization in reference to grain yield.

Specification		Harvest index of N	N utilization in reference to grain yield
		-	%
Cultivars	Anjou 258	0.71	43.2
	LG 2244	0.75	47.3
	$LSD_{0.05}$	0.022	3.94
Dose of N kg·ha^{-1}	0	0.73	-
	30	0.74	80.1
	60	0.74	48.1
	90	0.74	40.6
	120	0.73	29.3
	150	0.72	28.1
	$LSD_{0.05}$	0.017	7.73
Dose of Mg kg·ha^{-1}	0	0.73	42.4
	15 in rows	0.74	47.4
	15 broadcast	0.73	46.0
	$LSD_{0.05}$	ni	3.23

ni – non significant differences

$$U = \frac{P_{Ni} - P_{No}}{N_i}$$

...where:
U – nitrogen utilization in %;
P_{Ni} – nitrogen uptake with plant yield in a plot with N_i;
P_{No} – nitrogen uptake with plant yield in a control plot (0 kg N·ha^{-1});
N_i – N dose.

The study results were subject to one-variable analysis of variance followed by a synthesis of multiple experiments. The significant differences were estimated at $\alpha = 0.05$.

Results and Discussion

On average, for the 3-year study period, the degree of nitrogen utilization by plants from the nitrogen fertilizer (i.e. the proportion of N uptaken from the soil to the nitrogen applied in the fertilizer) depended on the cultivar type, on the size of nitrogen dose and on the dose and the method of magnesium application (Table 1). A higher N utilization from the fertilizer, independent of its dose level, was found in the cultivar LG 2244 "stay-green"-type in comparison with the traditional cultivar Anjou 258, the difference being 4.1 point % (Table 1). The result obtained in our studies confirms the earlier reports of Ma and Dwyer [9]. These authors, on the basis of their own field studies, found that the "stay-green" cultivar showed more effective utilization

of nitrogen from the mineral fertilizer than the earlier aging traditional hybrid Anjou 258. A higher nitrogen utilization from mineral fertilizer by cultivars of the "stay-green"-type in relation to traditional hybrids is caused by the longer period of nitrogen uptake from the soil by these hybrids (phenotypes showing retarded aging) and by a secondary remobilization of the nitrogen from vegetative tissues to the grain [10].

An analysis of the nitrogen dose size showed that the nitrogen utilization index decreased with changes in size of nitrogen dose from 30 kg N·ha^{-1} to 150 kg N·ha^{-1}, and from 80.1% to 28.1% (Table 1). Also Kruczek [11] found a drop in N utilization with an increase in nitrogen dose from 45 to 180 kg N·ha^{-1} and from 54.8% to 23% in reference to grain yield. Nielsen et al. [12] found that the nitrogen utilization in field conditions most frequently was 40 to 60%, confirmed by field experiments.

The application of 15 kg Mg·ha^{-1} (in rows or broadcast) significantly increased N utilization in relation to the objects without magnesium. Between the two methods of magnesium application, no significant difference in this value was found (Table 1).

The experiment showed the joint action of the N dose with the fodder maize cultivar type as exerted on the size of nitrogen utilization from the applied nitrogen fertilization (Fig. 1). These mutual dependences have been described by a first-degree equation, where for the hybrid LG 2244 "stay-green"-type the resulting curve plotted at a higher level than for the traditional cultivar Anjou 258. For each applied 1 kg N·ha^{-1}, the N utilization in the cultivar LG 2244 "stay-green"-type decreased by 0.45%, while in Anjou 258 it decreased by 0.42% (Fig. 1).

Nitrogen utilization from the mineral fertilizer also depended on the interaction between the N fertilization level and the magnesium dose and method of its application (Fig. 2). These dependences have been described by first-degree equations. The application of 15 kg Mg·ha^{-1} applied broadcast or in rows caused an increase in N utilization from the applied mineral fertilizer (plotted at a higher level) in relation to the objects where Mg was not applied. An increase in fertilization by 1 kg N·ha^{-1} caused a decrease of N utilization in cases of N doses applied without magnesium by 0.36%, while in cases of Mg application (broadcast), the nitrogen utilization decreased by 0.37%. On the other hand, for nitrogen doses with magnesium application (in rows), the decrease was by 0.41% (Fig. 2). As reported by Potarzycki [13], the presence of magnesium in multicomponent fertilizers significantly increased the utilization of nitrogen from ammonium saltpeter and contributed to the increased payability of fertilization and, at the same time, meeting the requirements of good agricultural practice. Potarzycki [13] obtained a return of nitrogen in his fertilization variant NPK + Mg 91%, while normally after NPK application, the nitrogen return was 74%.

The nitrogen harvest index is an indicator of the uptaken component transformed into the biomass of the usable plant organs. This index always has a higher value than the yield harvest index, caused by a higher percentage of N content in the grain than in the stover of maize.

In our field experiment, the value of the nitrogen harvest index was modified significantly by the fodder maize cultivar type and by the level of N fertilization (Table 1). A significantly higher value of this index (by 0.04) was shown by the cultivar LG 2244 "stay-green"-type in comparison with the traditional hybrid Anjou 258. The higher value of the nitrogen harvest index obtained by this hybrid was a consequence of the obtained higher grain yield (by 0.8 t·ha^{-1}) in comparison with the Anjou 258 cultivar [5].

The effect of the differentiated level of maize fertilization with nitrogen on the value of the nitrogen harvest index was significant, in spite of the small differences obtained in the values of this feature (Table 1). An increase in nitrogen dose above 120 kg·ha^{-1} in relation to N doses in the range from 30 to 90 kg·ha^{-1} significantly decreased the value of this index.

The effectiveness of the transformation of the uptaken nutritive component (nitrogen harvest index) into the biomass of the plant's useful organs also depended on the relationship between N dose and the different cultivar types of fodder maize (Fig. 3). These dependences have been described by first-degree equations, where for the cultivar LG 2244 "stay-green"-type the dependence increased with increases in nitrogen dose, while for the hybrid Anjou 258

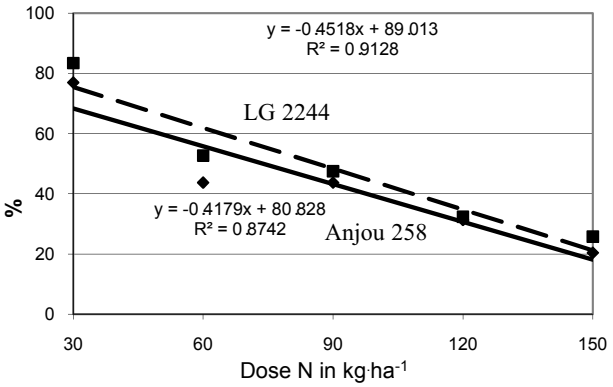

Fig. 1. Nitrogen utilization in reference to grain yield depending on cultivar type and nitrogen dose size.

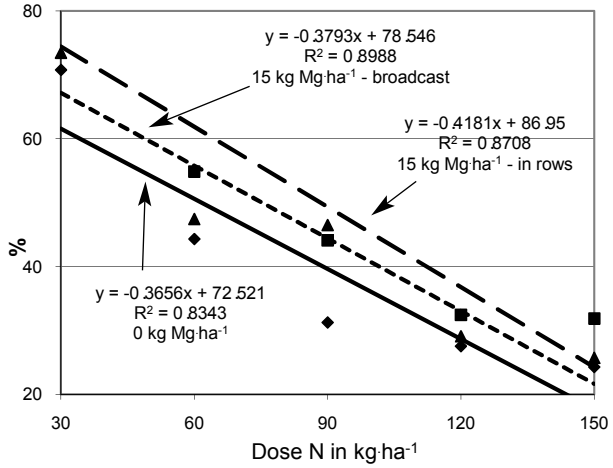

Fig. 2. Effect of magnesium dose and of the method of its application on the utilization of nitrogen in reference to grain yield.

the dependence decreased. In the case of the hybrid "stay-green"-type, the increase in N dose by 1 kg N·ha^{-1} caused an increment in the nitrogen harvest index by 0.0001, while in the traditional cultivar this index value decreased by 0.0003 (Fig. 3). Such a difference in the reaction of fodder maize cultivar types to increases in the level of nitrogen fertilization testifies that the "stay-green"-type hybrid is more useful to be grown for grain; it better transforms the nitrogen into a generative yield in comparison with the traditional cultivar, as demonstrated in an earlier paper by the present authors [5].

The value of the nitrogen harvest index also depended on the relationship between nitrogen fertilization and the Mg dose with its application method (Fig. 4). In the case of nitrogen doses used without Mg application, there was no significant effect on the value of this feature. The mean value of the nitrogen harvest index for six doses of nitrogen was 0.71 (Fig. 4). These dependences were shown for a dose of 15 kg Mg·ha^{-1} (broadcast) and for a dose of 15 kg Mg·ha^{-1} (in rows). Both the resulting curves are described by second-degree equations. In the case of the Mg dose applied in rows, the maximal value of this index (0.75) was obtained for a nitrogen dose of 50 kg N·ha^{-1}, while for the same Mg dose applied, the maximal value of this index was 0.73.

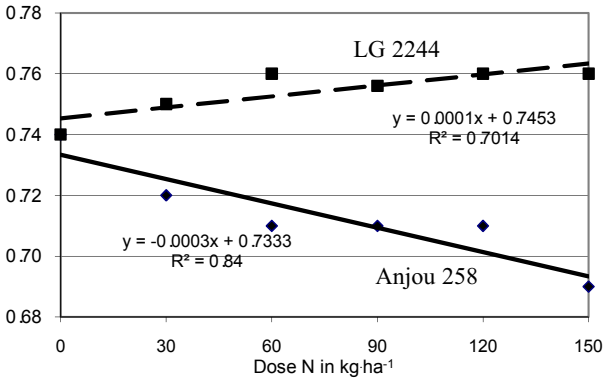

Fig. 3. N harvest index depending on cultivar type and N dose.

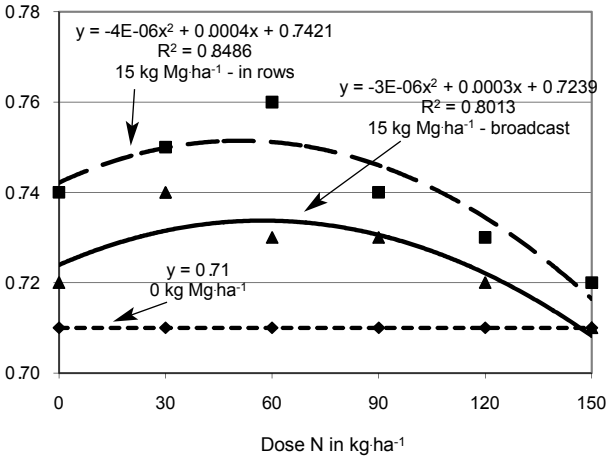

Fig. 4. N harvest index depending on nitrogen dose and the method of magnesium application.

The application of 15 kg Mg·ha^{-1} in rows gave an increase in the nitrogen harvest index of 0.02 in comparison with the magnesium application broadcast (with the same level of nitrogen fertilization). The application of 15 kg Mg·ha^{-1} (in rows) and 15 kg Mg·ha^{-1} (broadcast) increased the nitrogen harvest index, in comparison with N doses without magnesium, by 0.02 and 0.04, respectively (Fig. 4).

In our experiment, the value of the nitrogen harvest index was significantly modified by the relationship between the cultivar type with the Mg dose and the method of its application (Fig. 5). In the case of the traditional cultivar Anjou 258, the size of the Mg dose and the method of its application did not exert any significant effect on the value of this feature, the LG 2244 "stay-green"-type obtained the highest value of nitrogen harvest index (10.76) on plots where a dose of 15 kg Mg·ha^{-1} was applied in rows in comparison with the object where this macrocomponent was not applied (0.74). Between the magnesium application methods of the dose (15 kg Mg·ha^{-1}), no significant differences were found in reference to this hybrid (the LG 2244 "stay-green"-type). It must be stressed, however, that LG 2244 in each combination of Mg fertilization showed a significantly higher value of nitrogen harvest index in comparison with Anjou 258 cultivar (Fig. 5).

In order to determine the amounts of mineral nitrogen remaining in the soil in autumn after the maize harvest, the N_{min} method was used. An excessive nitrogen amount in the soil is, during this time, not desirable because during the winter period this component may be dislocated to groundwater and cause its eutrophication [14]. In the synthetic analysis, for the three-year study period, the content of mineral nitrogen in the soil (N_{min}) after the maize harvest increased with the increasing N doses applied in the mineral fertilizer for maize cultivation (Table 2). This refers both to the nitrate and the ammonic forms in the 0-30 cm and 30-60 cm soil profiles. In the case of the sum of both these nitrogen forms in the soil after the maize harvest, the cultivar type and the nitrogen dose were found to exert a significant effect on the mineral nitrogen content in the soil. Significantly less nitrogen was found in the soil after the harvest of the LG 2244 "stay-green"-type in comparison with the traditional hybrid Anjou 2588. This difference in

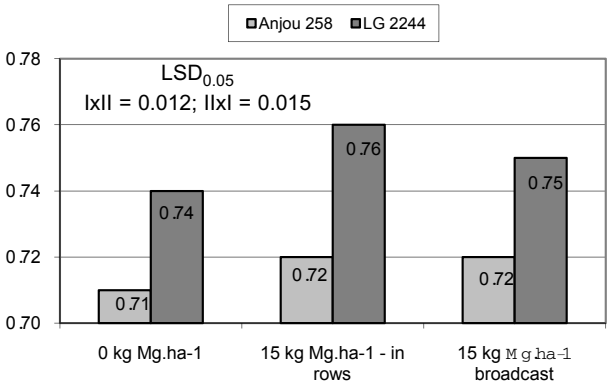

Fig. 5. N harvest index depending on cultivar type and the method of magnesium application.

Table 2. N_{min} in soil after maize harvest.

Specification		N_{min} kg·ha^{-1}						
		$N\text{-}NO_3$		$N\text{-}NH_4$		NH_4NO_3		
		0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-60cm (100%)
Cultivars	Anjou 258	22.84	29.08	20.28	21.75	43.12 (45.9%)	50.84 (54.1%)	93.96
	LG 2244	19.20	20.16	10.56	15.95	29.76 (45.2%)	36.09 (54.8%)	65.85
	$LSD_{0.05}$	ni	ni	ni	ni	8.197	7.638	15.321
Dose of N kg·ha^{-1}	0	16.58	16.76	13.63	14.29	30.21 (49.3%)	31.05 (50.7%)	61.26
	30	16.94	17.95	15.07	17.08	35.01 (50.0%)	35.03 (50.0%)	70.04
	60	21.75	20.64	16.03	17.25	37.78 (49.9%)	37.89 (50.1%)	75.67
	90	21.95	20.84	16.12	19.03	38.07 (48.8%)	39.87 (51.2%)	77.94
	120	22.65	35.58	17.59	20.95	40.24 (41.6%)	56.53 (58.4%)	96.77
	150	26.24	35.97	18.34	24.33	44.58 (42.5%)	60.30 (57.5%)	104.88
	$LSD_{0.05}$	4.356	6.141	2.879	3.879	6.984	7.652	18.748
Dose of Mg kg·ha^{-1}	0	22.60	27.39	17.27	19.47	39.87 (46.0%)	46.86 (54.0%)	86.73
	15 in rows	22.51	21.84	13.74	18.15	36.25 (45.4%)	39.99 (52.5%)	76.24
	15 broadcast	17.94	24.63	15.25	18.90	33.19 (43.3%)	43.53 (56.7%)	76.72
	$LSD_{0.05}$	ni	ni	ni	ni	ni	ni	7.658

ni – non significant differences

the 0-30 cm soil layer amounted to 13.36 kg N_{min}·ha^{-1}, while in the 30-60 cm layer it was 14.75 kg N_{min}·ha^{-1} (Table 2). Together with the increase in the nitrogen fertilization level, the content of mineral nitrogen in the 0-30 and 30-60 cm soil layers increased linearly.

It must be stressed that over 50% of the NH_4NO_3 was found in the 30-60 cm soil layer (Table 2). All the studied factors in our own experiment modified significantly the N_{min} content in the 0-60 cm soil layer (Table 2). Significantly less nitrogen (by 28.11 N_{min}·ha^{-1}) was found in objects where the LG 2244 "stay-green"-type was grown as compared with the traditional Anjou 258 cultivar. With increasing doses of nitrogen, the N_{min} content in soil increased from 61.26 kg N_{min}·ha^{-1} (a dose of 0 kg N·ha^{-1}) to 104.88 kg N_{min}·ha^{-1} (a dose of 150 kg N·ha^{-1}). The application of 15 kg Mg·ha^{-1} (broadcast) and 15 kg Mg·ha^{-1} (in rows) decreased the N_{min} content in soil by over 10 kg N_{min}·ha^{-1}, in comparison with objects without magnesium application (Table 2).

Summary

The hybrid LG 2244 "stay-green"-type utilized to a higher degree nitrogen from the supplied mineral fertilizer, as compared with the traditional Anjou 258 cultivar. The increasing level of maize fertilization with nitrogen decreased the utilization of this nutritive component from the supplied mineral fertilizer. The application of 15 kg Mg·ha^{-1} broadcast and in rows caused an increased N utilization from the mineral fertilizer in relation to objects where this macronutrient was not applied. Utilization of nitrogen from the supplied fertilizer by the "stay-green" hybrid, for each of the five tested doses, took place at a higher level as compared to the traditional cultivar. Application of a dose of 15 kg Mg·ha^{-1} broadcast and in rows caused an increased utilization of nitrogen from the mineral fertilizer for each dose, independent of the cultivar type. The hybrid LG 2244 "stay-green"-type showed a higher nitrogen harvest index in relation to the traditional cultivar, ensuring that it is more suitable to be grown for grain. Under the influence of increasing levels of N fertilization, the value of the nitrogen harvest index for the "stay-green" cultivar increased, while in relation to the traditional hybrid it decreased.

In order to protect the natural environment against an excessive amount of N_{min} in the soil after the maize harvest, it is recommended to choose exclusively a "stay-green"-type hybrid and to apply nitrogen fertilization in combination with magnesium. Only such a procedure can limit the negative intensity of plant production in the natural environment.

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