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Efficiency of nitrogen fertilization based on the fertilizer application method and type of maize cultivar (*Zea mays* L.)

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ABSTRACT

This article demonstrates the influence of the method using application of 100 kg N/ha of nitrogen fertilizer and hybrid types of maize (*Zea mays* L.) on selected efficiency indicators used for this macroelement. It was shown that in comparison to traditional broadcast fertilization, fertilization in rows or fertilization in rows combined partly with top dressing increased the values of such characteristics as nitrogen uptake and use, percentage of fertilizer nitrogen in the total nitrogen uptake as well as the agricultural and physiological effectiveness of the nitrogen. All the studied nitrogen effectiveness factors for maize (apart from physiological effectiveness) were significantly higher for the stay-green cultivar. In relation to a traditional cv. ES Palazzo, the cv. ES Paroli stay-green was characterised by poorer use of the nitrogen uptake regardless of the nitrogen fertilizer application method, which was visible in the lower values of physiological effectiveness.

Keywords: macronutrient; grain; method of nitrogen fertilization; N application effectiveness factors

Nitrogen (N) is a primary nutrient and has a decisive role in the intensification of crop production. Current activities aimed at the increase of world grain production, including maize production, must focus on the more efficient use of the nitrogen found in mineral fertilizers. The increase in crop yield per unit of used N is especially important due to concerns about the negative influence of excessive nitrogen use on the natural environment (Chen et al. 2004, Rahimizadeh et al. 2010). This is confirmed also by Cassman et al. (2003), who state that the loss of nitrogen from farmland may have a significant impact on the condition of the environment. The key factor in this aspect may be played by the increasing capability of the plants to uptake (Peng et al. 2010) and use (Niu et al. 2007) nitrogen contained in each dose of mineral fertilizer. Therefore, determining biologically and at the same time economically justified optimal doses of nitrogen, taking into consideration the factors influencing the uptake and use of this nutrient from mineral fertilizers, is a continuous direction for research into the role of nitrogen in shaping crop production.

While the literature on the subject includes papers on maize fertilization with different forms of nitrogen fertilizers (Hammad et al. 2011), there are no articles on the comparison of responses of individual types of maize cultivar to different forms of nitrogen fertilizer application. From the scientific point of view, this is very important because, as demonstrated by Szulc et al. (2012), stay-green type cultivars exhibit a negative nitrogen remobilization index, which means that soil sources of this macroelement are of decisive importance during generative yield development. Hence the fertilization system for stay-green type maize cultivars should imply the use of slow-acting nitrogen fertilizers as being the most suited to the dynamics of plant demand for this element (Szulc and Bocianowski 2012). Scientifically, an interesting solution is the use of fast-acting nitrogen

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fertilizers, such as ammonium nitrate or nitro-chalk, but applied using an alternative method in the cultivation of maize cultivars having different genetic profiles.

The aim of the field experiments was to assess the influence of nitrogen use and method of application on selected indicators of fertilization efficiency for two types of maize hybrids cultivated for grain in the Wielkopolska region.

MATERIAL AND METHODS

Field experiment. The field experiments were performed at the Department of Agronomy of the Poznan University of Life Sciences, in the fields of the Institute for Education and Experiment in Swadzim, in the years 2009–2011. They were conducted as 3-factor experiments using the split-split-plot system (random sub-blocks method), in 4 repetitions. The studied factors were: type of nitrogen fertilizer: ammonium nitrate (NH_4NO_3), Canwil nitro-chalk ($NH_4NO_3 + CaCO_3 + MgCO_3$); method of fertilizer application: broadcast (entire nitrogen dose before corn sowing), row (entire nitrogen dose at the time of corn sowing), row supplemented with top dressing (50 kg N/ha of row fertilization at the time of corn sowing + 50 kg N/ha of top dressing during the 5–6 leaves phase (15/16 BBCH)); and corn cultivar types: traditional ES Palazzo (FAO 230–240) and stay-green ES Paroli (FAO 250). In each year of the study before setting up the experimental culture, identical mineral fertilizers were applied to the entire field in the following amounts: 100 kg N/ha (fertilizer in accordance with the 1st degree factor), 35.2 kg P/ha as triple-granulated 46% superphosphate P_2O_5, and 99.6 kg K/ha as 60% potassium salt. The content of humus in the arable layer (0–25 cm) in the study period ranged from 1.41% (2009) to 1.46% (2010). The gross size of the test plot was 28 m^2 (4 rows of maize of length 10 m and spacing 70 cm). The net size of the plot for harvesting was 14 m^2 (with two external rows used to form a protective belt).

The experiment was conducted on luvisol, with a granulometric composition of shallow, light clay sand on light clay, belonging to the good rye soil class (IUSS Working Group WRB 2006). The basic macroelement content and pH of the soil in individual years of the study are presented in Table 1.

Thermal and humidity conditions. The profile of the climatic conditions present during the study was based on data from a meteorological station belonging to the Department of Agronomy, located at the site of the Institute for Education and Experiment in Swadzim (Table 2).

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

The nitrogen use per dose of the mineral fertilizer was calculated using the formula (Potarzycki 2010):

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

Where: N – use of nitrogen (%); N_f – nitrogen uptake by fertilized plants (kg/ha); N_c – nitrogen uptake by plants in the control (unfertilized) plot (kg/ha); D – nitrogen rate (100 kg N/ha).

Agricultural effectiveness was calculated using the following formula:

$$A_e = (GY_N - GY_0)/100$$

Where: A_e – agricultural effectiveness (kg DM (dry matter)/kg N in fertilizers); GY_N – grain yield in the field with applied nitrogen (t/ha); GY_N – grain yield in the field without applying nitrogen (t/ha).

Physiological effectiveness was calculated using the following formula:

$$P_e = ((GY_N - GY_0)/(N_f - N_c)) \times 100$$

Where: P_e – physiological effectiveness (kg DM/kg N in fertilizers); GY_N – grain yield in the field with applied nitrogen (t/ha); GY_N – grain yield in the field without applying nitrogen (t/ha); N_f – nitrogen uptake by fertilized plants (kg/ha); N_c – nitrogen uptake by plants in the control (unfertilized) plot (kg/ha).

Statistical analysis. The obtained results underwent one-way analysis of variance for orthogonal factorial experiments, and then a synthesis for multi-year experiments was performed. The significance of differences was estimated for $\alpha = 0.05$. The statistical analysis of the data was performed using the Statpaku software.

Table 1. Soil conditions in Swadzim

Specification	2009	2010	2011
P (mg P/kg of soil)	63.1	39.0	42.2
K (mg K/kg of soil)	89.0	91.3	83.3
Mg (mg Mg/kg of soil)	42.0	37.0	44.0
pH (1 mol/L KCl)	5.5	5.5	5.4

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Table 2. Air temperature and precipitation in vegetation seasons in Swadzim

	IV	V	VI	VII	VIII	IX	X	Mean–sum
Temperature (°C)								
2009	12.9	14.0	16.0	20.3	20.1	15.8	7.6	15.2
2010	9.3	12.2	18.4	22.6	19.2	13.0	7.0	14.5
2011	12.4	15.5	19.9	18.5	19.5	15.9	9.8	15.9
Rainfall (mm)								
2009	19.2	109.9	113.8	75.4	26.2	48.6	59.2	452.3
2010	26.8	110.5	43.4	97.5	143.5	69.9	9.1	500.7
2011	9.8	22.5	66.5	218.7	50.5	28.5	27.7	424.2

RESULTS AND DISCUSSION

For all the studied features, the direction of change under the experimental factors was similar in all years of the study and the statistically confirmed interaction resulted only from differences in their intensity each year. Therefore, to present the correlations more clearly, values averaged over the whole study period were used to show the influence of the type of nitrogen fertilizer and the manner of its application as well as the type of maize cultivar on the parameters.

The content of nitrogen in maize grain was significantly shaped by the type of cultivar (Table 3). The cv. ES Paroli SG was characterised by significantly greater values of these features in comparison to the classic cv. ES Palazzo. The difference between the studied cultivars was 2.41 g/kg DM.

Nitrogen uptake in the grain yield significantly depended on the manner of application of the fertilizer and the type of maize hybrid (Table 3). The application of nitrogen in rows, with or without top dressing, caused a significant increase in nitrogen uptake in the grain yield in comparison

Table 3. Nitrogen (N) content and uptake, nitrogen utilization and percentage of fertilizer nitrogen uptake in the total nitrogen uptake (2009–2011)

Experimental factor		N content (g/kg DM)	N uptake (kg N/ha)	N utilization	Percentage of fertilizer nitrogen uptake in the total nitrogen uptake
				(%)	
Type of nitrogen fertilizer	ammonium nitrate	14.68	126.3	31.5	33.0
	Canwil nitro-chalk	14.80	126.2	31.9	33.1
$LSD_{0.05}$		ns	ns	ns	ns
Method of fertilization	broadcast	14.87	124.0	29.0	30.9
	in rows	14.72	127.8	33.5	34.7
	in rows + top-dressing	14.64	126.9	32.6	33.6
$LSD_{0.05}$		ns	2.182	1.358	2.366
Cultivar	ES Palazzo	13.54	110.8	22.9	26.3
	ES Paroli stay-green	15.95	141.7	40.5	39.8
$LSD_{0.05}$		0.331	2.943	2.458	2.954
Control (0 kg N/ha)	ES Palazzo	12.77	90.18	–	–
	ES Paroli stay-green	14.19	102.61	–	–

ns – non-significant differences; *LSD* – least significant difference

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to broadcast application. The cv. ES Paroli SG was characterised by a significantly higher nitrogen uptake in the grain yield (141.7 kg/ha) than the cv. ES Palazzo (110.8 kg/ha). The results obtained in our own study confirm the earlier statements in the literature that stay-green cultivars have higher nitrogen uptakes in the grain yield than their classic counterparts (Borrell and Hammer 2000). Ta and Weiland (1992) attribute the higher nitrogen uptake by stay-green cultivars in comparison to their classic counterparts to their uptake of this nutrient from two sources – soil nitrogen and nitrogen remobilised from the vegetative tissues of the plant.

Cultivation methods aimed at increasing the crop production must include the application of nitrogen fertilizers and improvements in their use (Potarzycki 2010). In our own study, the use of nitrogen per dose of mineral fertilizer was modified by the manner of fertilizer application and type of cultivar (Table 3). Application of nitrogen in rows, with and without top dressing, was associated with significantly better use of nitrogen in comparison to broadcast application. The cv. ES Paroli SG was characterised by a significantly higher value of this parameter than the cv. ES Palazzo (Table 3), the difference amounting to 17.60 pp. A smaller (by 4.1 pp) but also significantly greater use of nitrogen by the stay-green cultivar in comparison to the classic cultivar was also shown in an earlier paper (Szulc 2010).

Interest in the determination of genotypic differences from the perspective of nitrogen use grew in 1980s, when this feature was considered to be one of the methods enabling the minimisation of nitrogen dose application in maize cultivation, simultaneously minimising the eutrophication of the environment due to nitrogen. That is why the new cultivars, including the stay-green maize cultivars, are more efficient in nitrogen use, as the physiological traits related to nitrogen management in these cultivars are continuously improved in a comprehensive way (Mi et al. 2010). The use of nitrogen per dose of mineral fertilizer depended significantly on the combination of application method and maize cultivar type (Figure 1). The cv. ES Paroli SG was characterised by a higher value of the parameter than the classic cv. ES Palazzo, regardless of the fertilizing manner. However, in examining the increase of nitrogen use, it was proved that the value was statistically greater for application in rows, with or without top dressing, in comparison to broadcast application (Figure 1).

The highest percentage of fertilizer nitrogen utilisation in the formation of grain yield was observed in relation to the manner of fertilizer application and type of maize cultivar (Table 3). The highest significant value of this parameter was obtained for application in rows, with or without top dressing, in comparison to traditional broadcast application. The stay-green cultivar was characterised by a higher percentage of fertilizer nitrogen in the total nitrogen uptake than the traditional cultivar, a difference amounting to 13.5%. However, it must be noted that the percentage of fertilizer nitrogen in the total nitrogen accumulated in the maize grain was about 30% regardless of the studied factors. Also Kruczek and Szulc (2000) stated that the percentage of nitrogen absorbed from the fertilizer for the formation of grain and cobs was 27.6% on average, over 2.5 times less

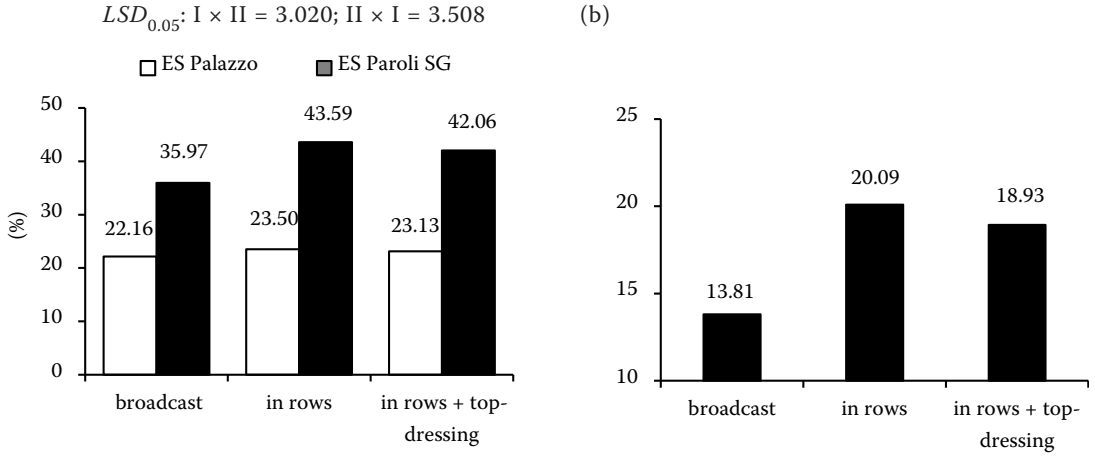

Figure 1. (a) Combined effect of fertilizer application method and type of maize cultivar on nitrogen utilization of mineral fertilizer dose, and (b) the difference between the two types of cultivar (2009–2011)

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Table 3. Nitrogen (N) content and uptake, nitrogen utilization and percentage of fertilizer nitrogen uptake in the total nitrogen uptake (2009–2011)

Experimental factor		N content (g/kg DM)	N uptake (kg N/ha)	N utilization	Percentage of fertilizer nitrogen uptake in the total nitrogen uptake
					(%)
Type of nitrogen fertilizer	ammonium nitrate	14.68	126.3	31.5	33.0
	Canwil nitro-chalk	14.80	126.2	31.9	33.1
$LSD_{0.05}$		ns	ns	ns	ns
Method of fertilization	broadcast	14.87	124.0	29.0	30.9
	in rows	14.72	127.8	33.5	34.7
	in rows + top-dressing	14.64	126.9	32.6	33.6
$LSD_{0.05}$		ns	2.182	1.358	2.366
Cultivar	ES Palazzo	13.54	110.8	22.9	26.3
	ES Paroli stay -green	15.95	141.7	40.5	39.8
$LSD_{0.05}$		0.331	2.943	2.458	2.954
Control (0 kg N/ha)	ES Palazzo	12.77	90.18	–	–
	ES Paroli stay -green	14.19	102.61	–	–

ns – non-significant differences; *LSD* – least significant difference

than for soil nitrogen. Therefore, in spite of the fact that the generative yield of maize was formed during the greatest nitrogen demand and uptake period, it was nitrogen from the soil reserves and not from fertilizers that played the decisive role in the formation of generative yield (Kruczek and Szulc 2000). The percentage of fertilizer nitrogen in the general nitrogen uptake in the grain yield also depended on the combination of fertilizer application method and maize cultivar type (Figure 2). In each studied fertilizing manner, the cv. ES Paroli SG was characterised by a significantly higher percentage of fertilizer nitrogen in the general nitrogen uptake in the grain yield in comparison to the classic cv. ES Palazzo. The value was statistically greater for application in rows, with or without top dressing, in comparison to broadcast application (Figure 2).

In the studies by the author, the agricultural and physiological effectiveness were significantly

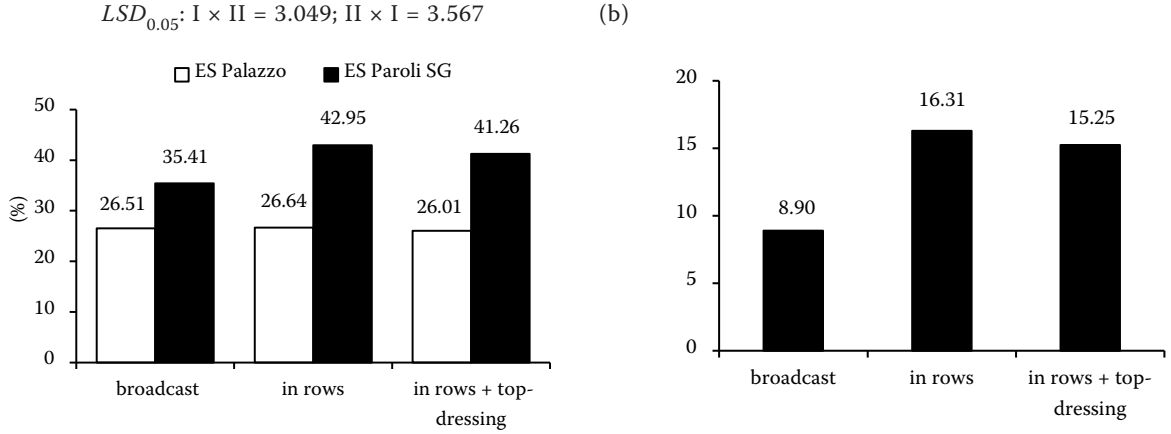

Figure 2. (a) Combined effect of fertilizer application method and type of maize cultivar on percentage of fertilizer nitrogen uptake in the total amount of nutrient uptake with grain yield, and (b) the difference between the two types of cultivar (2009–2011)

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Table 4. Agricultural and physiological effectiveness of nitrogen (N) use (2009–2011)

Experimental factor		Agricultural effectiveness (kg DM kg N in fertilizers)	Physiological effectiveness (kg DM kg N in uptake)
Type of nitrogen fertilizer	ammonium nitrate	15.2	50.70
	Canwil nitro-chalk	14.9	47.96
$LSD_{0.05}$		ns	2.258
Method of fertilization	broadcast	12.7	44.11
	in rows	16.3	53.75
	in rows + top-dressing	16.1	50.13
$LSD_{0.05}$		1.824	2.067
Cultivar	ES Palazzo	12.8	56.89
	ES Paroli stay -green	17.2	41.78
$LSD_{0.05}$		1.143	1.338
Control (0 kg N/ha)	ES Palazzo	–	–
	ES Paroli stay -green	–	–

ns – non-significant differences; *LSD* – least significant difference; DM – dry matter

determined by the manner of fertilizer application and type of cultivar (Table 4). In comparison to broadcast application, greater increases of grain yield per kilogram of fertilizer nitrogen and per kilogram of absorbed nitrogen were found in the case of application in rows, with or without top dressing. In-row fertilization increased the soil-fertilizer contact by means of putting nitrogen in a soil zone having a higher root concentration, leading to the higher efficiency of this method of applying this nutrient (Kruczek and Szulc 2006). In the study, the stay-green cultivar exhibited higher agricultural effectiveness and lower physiological effectiveness of nitrogen in comparison to the traditional cultivar. The difference between the studied cultivars was: 4.40 kg DM/kg of N from the fertilizer and 15.11 kg DM/kg of the N uptake.

The agricultural effectiveness observed in the study depended partly on the combination of fertilization method and type of maize cultivar (Figure 3). In each studied nitrogen application method, the cv. ES Paroli SG was characterised by a higher agricultural effectiveness of nitrogen than cv. ES Palazzo. As far as the value of increase in grain yield per kilogram of fertilizer nitrogen was concerned, it was shown that the value was

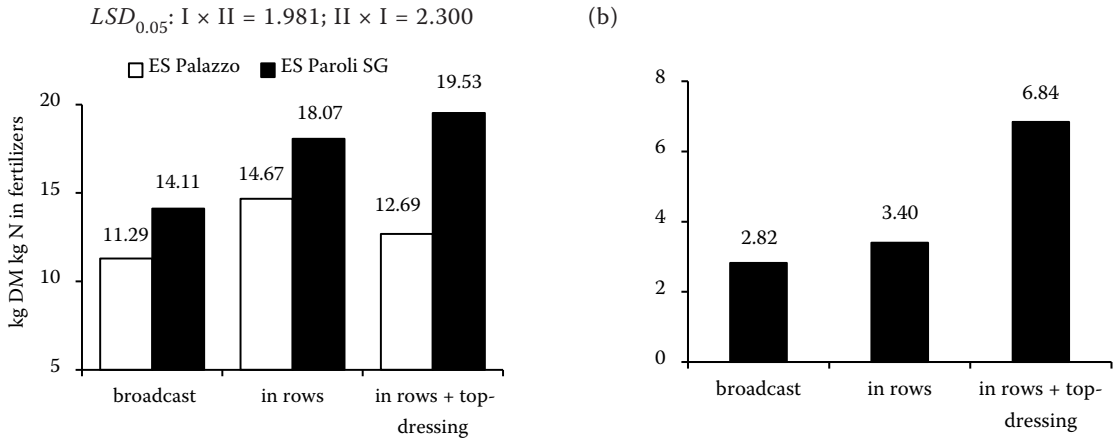

Figure 3. (a) Combined effect of fertilizer application method and type of maize cultivar on agricultural effectiveness of nitrogen, and (b) the difference between the two types of cultivar (2009–2011)

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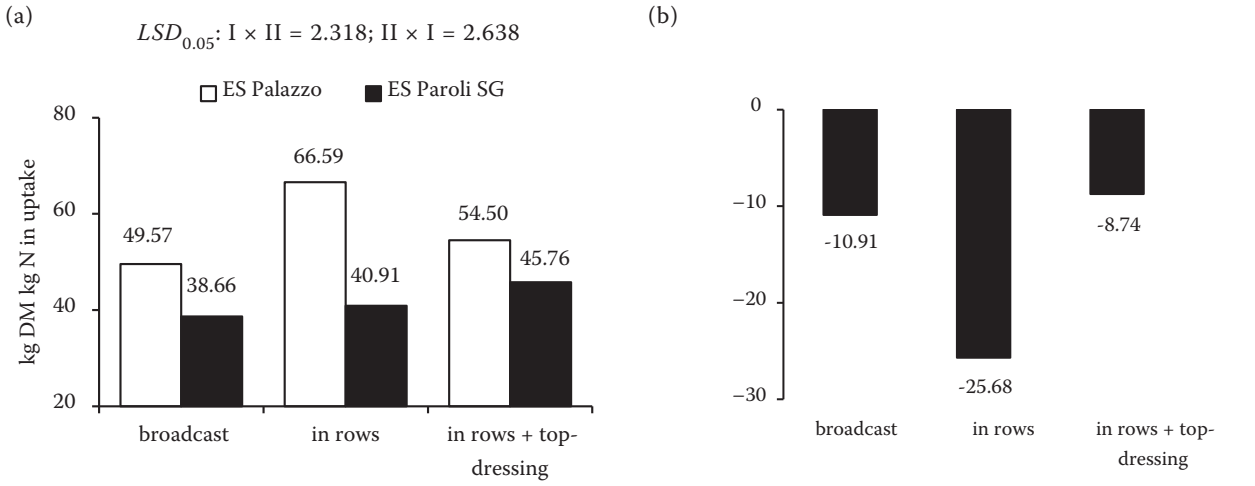

Figure 4. (a) Combined effect of fertilizer application method and type of maize cultivar on physiological effectiveness of nitrogen, and (b) the difference between the two types of cultivar (2009–2011)

statistically significantly greater for application in rows combined with top dressing than for application only in rows or broadcast application. Therefore, it seemed that the classic cultivar had a poorer reaction to the division of the nitrogen dose. The stay-green cultivar behaved differently, which resulted mainly from the different nitrogen accumulation time (Szulc et al. 2012).

Both the physiological and the agricultural effectiveness depended on the combination of fertilizer application method and type of cultivar (Figure 4). In each fertilizer application method, the classic cultivar was characterised by a significantly higher increase in grain yield per unit of absorbed nitrogen in comparison to the stay-green cultivar. The stay-green cultivar absorbed more nitrogen, which resulted in lower unit productivity for this nutrient. The latter was also characterised by a higher grain yield (Szulc 2013), which clearly showed its higher yield capacity in comparison to the classic cultivar. There was also a suggestion that for the studied stay-green cultivar, the dose of nitrogen could be reduced by at least the difference between the two cultivars and still obtain the same effect in terms of crop yield.

In conclusion, row fertilizer application of 100 kg/ha or partially combined with top-dressing (50 kg N/ha + 50 kg N/ha), in comparison to traditional broadcasting fertilization at the same nitrogen dose, increased the levels of such traits as protein yield, uptake and utilization of N, rate of fertilizer nitrogen in the total nitrogen uptake and the agronomical and physiological efficiency of the nitrogen. The stay-green cultivar was characterised by higher nitrogen content in the grain, higher uptake and use of fertilizer nitrogen as well as better capability of absorbing fertilizer nitrogen, expressed by higher agricultural effectiveness and percentage of fertilizer nitrogen in the total amount of absorbed nitrogen than the traditional cultivar. In all the studied fertilizing methods, the stay-green cultivar showed better use of fertilizer nitrogen, higher percentage of fertilizer nitrogen in the total amount of absorbed nitrogen and better agricultural effectiveness than the traditional cultivar. In relation to the traditional cultivar, the stay-green cultivar was characterised by poorer use of the nitrogen uptake, regardless of the nitrogen fertilizer application method, which is visible in the lower values of physiological effectiveness.

REFERENCES

Borrell A.K., Hammer G.L. (2000): Nitrogen dynamics and physiological basis of stay-green in sorghum. Crop Science, 40: 1295–1307.

Chen X.P., Zhou J.C., Wang X.R., Blackmer A.M., Zhang F.S. (2004): Optimal rates of nitrogen fertilization for a winter wheat-corn cropping system in Northern China. Communications in Soil Science and Plant Analysis, 35: 583–597.

Hammad H.M., Ahmad A., Wajid A., Akhter J. (2011): Maize response to time and rate of nitrogen application. Pakistan Journal of Botany, 43: 1935–1942.

doi: 10.17221/654/2015-PSE

Cassman K.G., Dobermann A., Walters D.T., Yang H. (2003): Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources, 28: 315–358.

IUSS Working Group WRB (2006): World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 103. Rome, FAO.

Kruczek A., Szulc P. (2000): The influence of foliar application of urea on N uptake and utilization by maize. Fragmenta Agronomica, 3: 18–29.

Kruczek A., Szulc P. (2006): Effect of fertilization method on the uptake and accumulation of mineral components in the initial period of maize development. International Agrophysics, 20: 11–22.

Mi G.H., Chen F.J., Zhang F.S. (2010): Physiological and genetic mechanisms for nitrogen-use efficiency in maize. Journal of Crop Sciences and Biotechnology, 10: 57–63.

Niu J.F., Chen F.J., Mi G.H., Li C.J., Zhang F.S. (2007): Transpiration, and nitrogen uptake and flow in two maize (*Zea mays* L.) inbred lines as affected by nitrogen supply. Annals of Botany, 99: 153–160.

Peng Y., Niu J., Peng Z., Hang F., Li Ch. (2010): Shoot growth potential driver N uptake in maize plants and correlates with root growth in the soil. Field Crops Research, 115: 85–93.

Potarzycki J. (2010): Improving nitrogen use efficiency of maize by better fertilizing practices. Review paper. Nawozy i Nawożenie/ Fertilizers and Fertilization, 39: 5–24.

Rahimizadeh M., Kashani A., Zare-Feizabadi A., Koocheki A.R., Nassiri-Mahallati M. (2010): Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. Australian Journal of Crop Science, 4: 363–368.

Szulc P. (2010): 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. Polish Journal of Environmental Studies, 19: 407–412.

Szulc P., Bocianowski J. (2012): The effect of soil supplementation with different forms of nitrogen fertilizer on modification of generative yield in two different types of maize (*Zea mays* L.) hybrids. Polish Journal of Agronomy, 11: 52–64.

Szulc P., Bocianowski J., Rybus-Zając M. (2012): Accumulation of N, P, K and Mg nutrient elements and nutrient remobilization indices in the biomass of two contrasting maize (*Zea mays* L.) hybrids. Fresenius Environmental Bulletin, 21: 2062–2071.

Szulc P. (2013): Effects of soil supplementation with urea and magnesium on nitrogen uptake, and utilisation by two different forms of maize (*Zea mays* L.) differing in senescence rates. Polish Journal of Environmental Studies, 22: 239–248.

Ta C.T., Weiland T.R. (1992): Nitrogen partitioning in maize during ear development. Crop Science, 32: 443–451.

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