Pak. J. Bot., 50(1): 189-198, 2018.

THE SIZE OF THE N_{MIN} SOIL POOL AS A FACTOR IMPACTING NITROGEN UTILIZATION EFFICIENCY IN MAIZE (*ZEA MAYS* L.)

PIOTR SZULC[1*], HUBERT WALIGÓRA[1], TADEUSZ MICHALSKI[1], JAN BOCIANOWSKI[2], MAGDALENA RYBUS-ZAJĄC[3] AND WIOLETTA WILCZEWSKA[1]

[1]Department of Agronomy, Poznań University of Life Sciences, Dojazd 11, 60-632 Poznań, Poland
[2]Department of Mathematical and Statistical Methods, Poznań University of Life Sciences, Wojska Polskiego 28, 60-637 Poznań, Poland,
[3]Department of Plant Physiology, Poznań University of Life Sciences, Wołyńska 35, 60-637 Poznań,
[*]Corresponding Corresponding author's email: pszulc@up.poznan.pl, Phone: +48618487515

Abstract

The article presents the results of 3-year field tests aimed at evaluating the effect of the nitrogen dose balance based on the N_{min} content. N_{min} was evaluated in the context of the distribution in the soil profile and the effect of the type of nitrogen fertilizer on production efficiency indicators and the use of nitrogen in maize grain. In order to verify the assumptions, we determined the amount of nitrogen collected with grain yield, N_{min} **percentage in total nitrogen uptake with grain yield**, agricultural and physiological efficiency and utilization of nitrogen and nitrogen N_{min} content in the autumn after maize harvest. It has been shown that developing maize accumulates mineral nitrogen (N_{min}) present in the soil in the rooting zone, especially during dry years. Incorporating nitrogen dose in the algorithm of the soil component pool significantly improves the performance indicators of the component application. It is possible for a fertilizer to exceed 100% of nitrogen utilization when nitrogen contained in the whole profile of maize rooting in the N pool is included. A significant increase in nitrogen accumulation in maize grain in the sulfur variant indicates that this element is a factor limiting the use of maize production potential in the test plot. Including the use of nitrogen-sulfur (N+S) fertilizer in maize and balancing the N dose based on N_{min} reduces nitrogen eutrophication of the environment.

Key words: *Zea mays* L., nitrogen, residual nitrogen (N_{res}), nitrogen fertilizers, nitrogen fertilizer efficiency

Introduction

Nitrogen (N) supplied to the soil as a fertilizer (organic or mineral) is not completely utilized by the crops (Harun 2017; Kawsar *et al*., 2017; Szulc *et al*., 2016). Its mineral forms are absorbed by plants, and those that remain in the soil after harvest create a pool of residual nitrogen (N_{res}), posing a potential threat to ecosystems adjacent to agricultural fields (Gastal & Lemaire, 2002). In order to reduce the production of excessive amounts of mineral nitrogen in the soil (N_{res}), it is necessary to determine correct doses of nitrogen fertilizers, taking into account nutritional requirements of the plants and the type of fertilizer (Dessureault-Rompré *et al*., 2010; Fan & Li, 2010). Achieving a sufficiently high efficiency of the applied mineral nitrogen fertilizers is not easy, because plants absorb nitrogen in the form of nitrate or ammonium ions. Ammonia nitrogen, in contrast to nitrate, can be bound by the soil. In the growing season, microorganisms and plants compete for ammonium nitrogen, already present in the soil (N_{min}) or applied as fertilizer (Schimel & Bennet, 2004). This phenomenon has a significant impact on the selection of the dose and nitrogen fertilizer. In the current agricultural practice, fertilizer doses, including nitrogen fertilizer are determined by the nutritional needs of plants, without considering the available forms of the component in the soil (Bocianowski *et al*., 2016; Szulc *et al*., 2016). This practice leads to an imbalance of nitrogen resources in plant growth environment during the growing season, resulting in a deficiency or more frequently – an excess of nitrogen. This leads to an increase in the pool of residual nitrogen (N_{res}), which on the one hand, reduces the efficiency of the component application, and on the other hand, burdens the environment with this biogen (Sharifi *et al*., 2011). According to Donner & Kucharika (2003), elevating nitrogen dose above 30% of its optimum, increases maize yield only by 4%, while the amount of nitrogen lost by leaching amounts to 53%. Therefore, determining the correct level of nitrogen doses, which guarantees the utilization of maize productive potential, is a key challenge in the cultivation technology of this plant (Zebarth *et al*., 2009). Rationalization of the use of nitrogen fertilizers in maize cultivation is an important issue for sustainable agriculture, because it can reduce the negative impact of agriculture on the environment.

The hypothesis of the experiment assumed that nitrogen dose and N_{min} content in the spring in the soil, before maize sowing, and the type of nitrogen fertilizer shape the performance indicators of production and utilization of nitrogen fertilizers. Therefore, field tests were conducted to assess the impact of nitrogen dose in relation to N_{min} content, depending on the distribution in the soil profile and the effect of nitrogen fertilizer on production efficiency indicators and nitrogen utilization in maize grain.

Materials and Methods

Experimental field: The field experiment was performed at the Department of Agronomy at the University of Life Sciences in Poznan, in the fields of the Experimental and Didactic Department in Swadzim (52º26' N; 16º45' E) in 2012-2014. The study was conducted in randomized blocks (split-split-plot) with three research factors in 4 field replications. The experiment examined the effect of four nitrogenous fertilizers [ammonium nitrate (NH_4NO_3), urea ($CO(NH_2)_2$), ammonium sulfate ($(NH_4)_2SO_4$), calcium nitrate ($Ca(NO_3)_2$], two nitrogen doses [150 kg N·ha^{-1} (N_f) and 150 kg N ha^{-1} reduced by the abundance of N_{min} in the soil (sum of NH_4 + NO_3) (150-N_{min})] and N_{min} content in soil profiles (0-0.3 m, 0-0.6 m, 0-0.9 m) on the performance indicators of nitrogen fertilization of maize grown on the grain. Mineral nitrogen content (N_{min}) was determined seven days before maize sowing. The same level of fertilization supplementation (70 kg P_2O_5 ha^{-1} and 130 kg K_2O ha^{-1}) was assumed for all experimental facilities. Mineral fertilizers were applied in early spring. Phosphorus was applied in the form of granular triple superphosphate, potassium in the form of potassium salt. Nitrogen dose of 150 kg N ha^{-1} in the form of fertilizer prepared in accordance with the levels of the first order factor. The content of mineral nitrogen in the soil in the spring was measured at three levels (layers) before establishing the experiment. N_f doses were established on this basis, as shown in Table 1. In the experiment, the maize Euralis Semences strain called Fortran (FAO 210-220; hybrid single S.C.; flint grain type) was used. Tillage, fertilization and other elements of agricultural technology were implemented in accordance with the recommendations of maize grain technology. Field experiment was conducted on deer soil, a type of clay lightweight sand, shallow defaulting on light clay. Basic macronutrients (P, K, Mg) in the soil in the individual years of research were determined at the medium level, and its reaction measured in 1 M KCl ranged from 5.4 in 2012 to 6.0 in 2014.

Thermal and humidity conditions: Temperature and humidity during the growing season of maize greatly varied in the study period of maize growth and development (Table 2). Rainfall in the April-September period amounted to 473.6 mm in 2012, 397.4 mm in 2013 and 351.8 mm in 2014. The average daily air temperature measured at 2 m above the ground surface ranged from 15.4°C in 2012 to 16.1°C in 2014. In general, it can be assumed that in two growing seasons, i.e., 2012 and 2013, the temperature and humidity conditions for growth and development of maize were favorable. In the third year of tests (2014), moisture conditions were worse due to the lower rainfall during maize growing season. At the same time, with less total rainfall, the highest average daily air temperature (16.1°C) was recorded that year.

Table 1. Nitrogen fertilization scheme in the present study

Factor – Factor levels		Soil depth m	Years, N_f - N_{min}		
			2012	2013	2014
Ammonium nitrate	Dose of N kg·ha^{-1}	0.0-0.3	150	150	150
		0.0-0.6	150	150	150
		0.0-0.9	150	150	150
		0.0-0.3	150 - 63.8	150 - 65.5 N_{min}	150 - 61.5 N_{min}
		0.0-0.6	150 - 99.3	150 - 103.7 N_{min}	150 - 98.7 N_{min}
		0.0-0.9	150 - 135.2	150 - 134.3 N_{min}	150 - 137.7 N_{min}
Urea	Dose of N kg·ha^{-1}	0.0-0.3	150	150	150
		0.0-0.6	150	150	150
		0.0-0.9	150	150	150
		0.0-0.3	150 - 63.8 N_{min}	150 - 65.5 N_{min}	150 - 61.5 N_{min}
		0.0-0.6	150 - 99.3 N_{min}	150 - 103.7 N_{min}	150 - 98.7 N_{min}
		0.0-0.9	150 - 135.2 N_{min}	150 - 134.3 N_{min}	150 - 137.7 N_{min}
Ammonium sulphate	Dose of N kg·ha^{-1}	0.0-0.3	150	150	150
		0.0-0.6	150	150	150
		0.0-0.9	150	150	150
		0.0-0.3	150 - 63.8 N_{min}	150 - 65.5 N_{min}	150 - 61.5 N_{min}
		0.0-0.6	150 - 99.3 N_{min}	150 - 103.7 N_{min}	150 - 98.7 N_{min}
		0.0-0.9	150 - 135.2 N_{min}	150 - 134.3 N_{min}	150 - 137.7 N_{min}
Calcium nitrate	Dose of N kg·ha^{-1}	0.0-0.3	150	150	150
		0.0-0.6	150	150	150
		0.0-0.9	150	150	150
		0.0-0.3	150 - 63.8 N_{min}	150 - 65.5	150 - 61.5 N_{min}
		0.0-0.6	150 - 99.3 N_{min}	150 - 103.7	150 - 98.7 N_{min}
		0.0-0.9	150 - 135.2 N_{min}	150 - 134.3	150 - 137.7 N_{min}

Table 2. Mean monthly air temperature and monthly sum of precipitation in Swadzim in 2012–2014.

Years	Temperature [ºC]							
	IV	V	VI	VII	VIII	IX	X	Mean – Sum
2012	9.3	16.3	17.0	20.0	19.8	15.0	8.6	15.4
2013	8.9	15.6	18.4	22.0	20.2	13.2	10.8	15.6
2014	11.4	14.6	17.9	23.2	18.8	16	11.2	16.1
Years	**Rainfall [mm]**							
2012	17.4	84.4	118.1	136.2	52.7	28.4	36.4	473.6
2013	10.5	95.5	114.9	52.9	32.4	75.9	15.3	397.4
2014	50.3	80.7	44.6	51.5	56.5	39.2	29.0	351.8

Chemical analyses of soil: The evaluation of macronutrient contents, pH and mineral nitrogen (N_{min}) in the soil before the experiment and after the harvest was performed according to the test procedure/standard (OSCHR in Poznan): P_2O_5 – PB.64 ed. 6 from 17.10.2008; K_2O – PB.64 ed. 6 from 17.10.2008; Mg – PB.65 ed. 6 from 17.10.2008; pH – PB.63 ed. 6 from 17.10.2008; N-NH_4 – PB.50 ed. 6 from 17.10.2008; N-NO_3 – PB.50 ed. 6 from 17.10.2008.

Quantity of N_{min} kg ha^{-1} = content of N_{min} w mg 100 g^{-1} dry matter * 45 (Szulc 2012), where:

45 – light soil factor.

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

The uptake of nitrogen in the grain yield was calculated with the following formula:

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

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

The recovery of the nitrogen fertilizer was calculated with the formula:

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

where:
R_N –nitrogen fertilizer recovery (%),
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.

The apparent N use efficiency was calculated based on the equation:

$$ANE = (Y_i - Y_0)/N_f,\ \text{kg grain kg}^{-1}\ N_f;$$

where:
Y_i – yield of grain harvested from the plot with the fixed rate of N, kg ha^{-1},
Y_0 – yield of grain harvested from the absolute control plot, kg ha^{-1},
N_f – nitrogen fertilizer rate, kg N ha^{-1},

Physiological nitrogen use efficiency was calculated with the following formula:

$$PNUE = ((Y_i - Y_0) / (N_f - N_c)) * 100$$

where:
PNUE - physiological nitrogen use efficiency (kg dm kg N in fertilizers)
Y_i - yield of grain harvested from the plot with the fixed rate of N, kg ha^{-1},
Y_0 - yield of grain harvested from the absolute control plot, kg ha^{-1},
N_f - nitrogen uptake by fertilized plants (kg ha^{-1}),
N_c - nitrogen uptake by control plants (unfertilized) plot (kg ha^{-1}),

Statistical analysis: The obtained results were subjected to one-way analysis of variance for orthogonal factorial experiments, followed by synthesis for many-year experiments. The significance of differences was estimated for α = 0.05. Statistical analysis of the data was performed using STATPAKU software.

Results and Discussion

The trend of nitrogen content in maize grain under the influence of experimental factors was similar in all years, and the statistically confirmed interactions resulted only from the differences in the strength of their impact in subsequent years. Hence, the study shows the influence of experimental factors on the value of this feature by using the average values from successive research years. The nitrogen content of maize grain depended essentially only on nitrogen (Fig. 1). A substantially larger amount of nitrogen was found in maize grain for the full N_f dose compared to that calculated from the equation: 150 – N_{min}. The difference between doses was on average 1.21 g/kg DM. This difference indicated the presence of the phenomenon termed „dilution effect" in the fertilizing variant 150 – N_{min} (Potarzycki & Grzebisz, 2009). Regardless of the tested factors, the variable temperature and humidity conditions in the maize growing seasons (Tab. 2) shaped the nitrogen content in maize grain. In 2012, the nitrogen content of maize grain amounted to 15.84 g/kg DM (9.9% of protein), 16.21 g/kg DM (10.13% of protein) in 2013 and 16.03 g/kg DM (10.02% of protein) in 2014. The lowest nitrogen content (protein) in maize grain was found in 2012, with the highest total rainfall (473.6 mm) and cold compared to the other two years of experiments. Prokszáné Paplogó *et al*., (1995) showed that the protein content of maize grain was greater in dry years compared to the wet period, also as demonstrated in this study. In addition, Szulc *et al.* (2013) demonstrated that, the protein content of maize grain increased with increasing air temperature and decreased with an increase in the total rainfall.

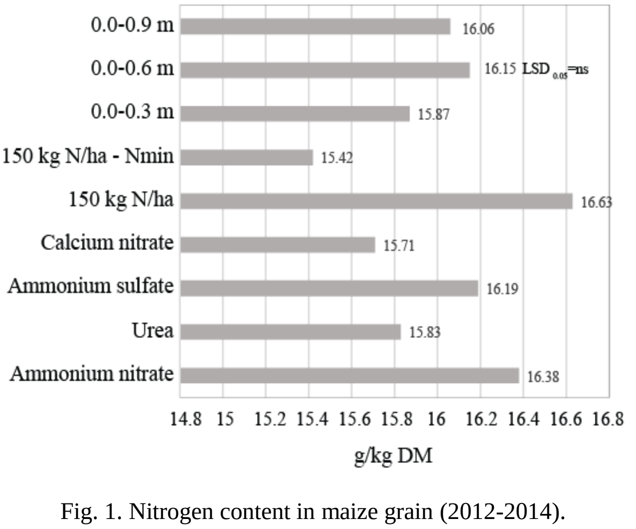

Fig. 1. Nitrogen content in maize grain (2012-2014).

Table 3. Nitrogen collected with grain yield (kg N·ha^{-1})

Factor – Factor levels		Years 2012	Years 2013	Years 2014	Mean
Type of nitrogen fertilizer	Ammonium nitrate	156.50	143.92	92.28	130.90
	Urea	155.59	140.04	93.74	129.79
	Ammonium sulphate	154.50	156.78	102.82	138.04
	Calcium nitrate	141.88	139.98	87.55	123.14
LSD $_{0.05}$		5.705	ns	ns	8.024
Dose of N_f kg·ha^{-1}	150	165.80	156.32	99.55	140.56
	150 - N_{min}	138.43	134.04	88.65	120.37
LSD $_{0.05}$		6.021	4.761	4.883	2.823
Content of N_{min} kg·ha^{-1}	0-0.3 m	141.59	150.11	96.06	129.25
	0-0.6 m	153.18	150.33	97.19	133.56
	0-0.9 m	161.58	135.10	89.04	128.58
LSD $_{0.05}$		3.683	4.730	4.188	2.396
Mean		152.12	145.18	94.10	130.47
Control 0 kg N·ha^{-1}		102.94	86.92	46.65	78.83

ns – difference non-significant

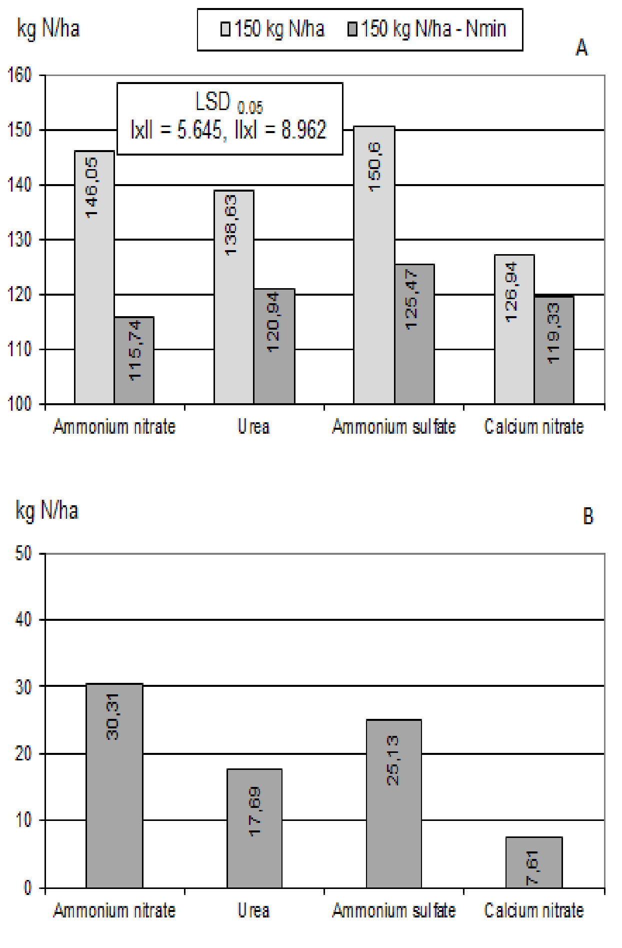

Fig. 2. Effect of nitrogen fertilizer and nitrogen doses on nitrogen accumulated in grain yield (A); difference between nitrogen doses (B) – (2012-2014)

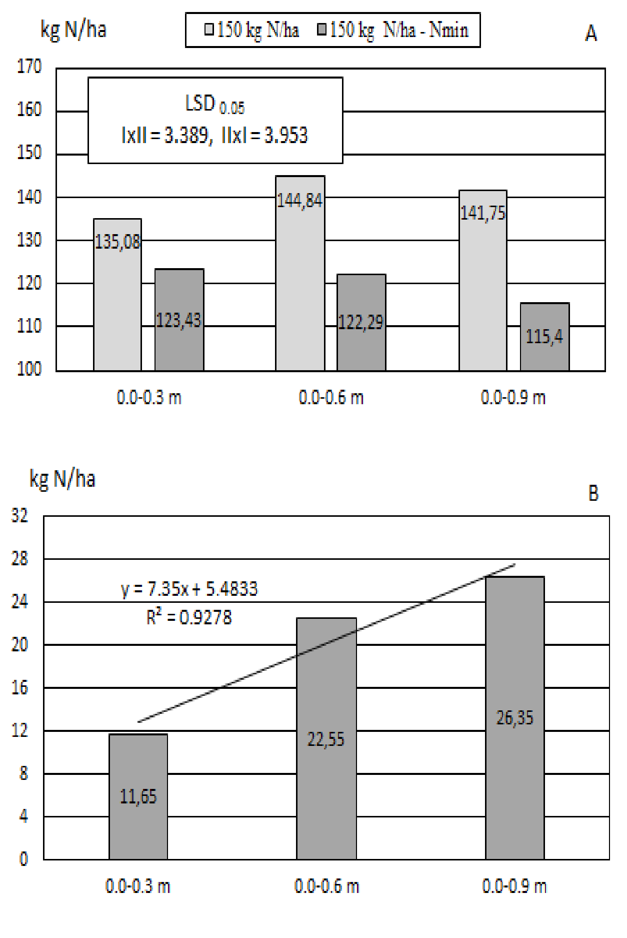

Fig. 3. Effect of nitrogen and N_{min} content in the soil profile on nitrogen collected with grain yield (A); difference between the dose and N_{min} content in soil profiles (B) – (2012-2014)

The amount of nitrogen from maize grain yield significantly depended on the type of nitrogen fertilizer, nitrogen dose and N_{min} content in the soil (Table. 3). The significantly greatest accumulation of nitrogen was found for ammonium sulfate, and the lowest for calcium nitrate. The negative trend observed for calcium nitrate occurred in all years of the experiment. The positive trend, recorded for ammonium sulfate, was observed in years with lower rainfall. The average increase in the accumulation of nitrogen in the variant with ammonium nitrate was 14.9 kg N/ha. Such a large increase in nitrogen accumulation resulted from the presence of sulfur in the fertilizer, which pointed to this element as a factor limiting the growth and yield of maize (Szulc & Bocianowski, 2012). The average dry grain yield for the three years of tests was at the following levels: ammonium nitrate – 79.40 dt/ha, urea – 81.73 dt/ha, ammonium sulphate – 85.19 dt/ha, calcium nitrate – 78.35 dt/ha. On the other hand, considering nitrogen inputs, significantly greater accumulation of N with grain yield was recorded for the N_f dose in comparison to the 150-N_{min} dose. Significantly higher accumulation of nitrogen in maize grain yield was observed for N_{min} content in the 0-0.6 m soil profile compared to 0-0.3 m and 0-0.9 m (Table. 3). It follows that the layer of the 0-0.6 m soil profile was the main factor determining the supply of nitrogen to corn. The result confirmed the latest scientific reports showing that maize grown in soil efficiently utilized nitrogen when minerals with low mobility (magnesium, phosphorus) were available in the whole rooting profile (Łukowiak *et al*., 2016a, Łukowiak *et al*., 2016b). Nitrogen uptake in the current study significantly depended on the interaction between the type of nitrogen fertilizer and nitrogen dose (Fig. 2). For each of the nitrogen fertilizer application of 150 kg N/ha resulted in a significantly higher value of this feature compared to the nitrogen dose minus N_{min} in the soil. The difference ranged from 7.61 kg N/ha (nitrate of lime) to 30.31 kg N/ha (ammonium nitrate). Nevertheless, significant differences in N uptake between the two nitrogen doses were recorded for ammonium nitrate and ammonium sulphate (Fig. 2). The conclusion is that the presence of sulfur in the mineral fertilizer was a factor differentiating the value of this feature. This component stimulated nitrogen uptake in decreasing N dose of the mineral fertilizer. According to Jackson (2000) and Gryffiths *et al*., (1995), supplying crops with sulfur is economical and ecological, because its deficiency reduces the efficiency of nitrogen fertilizers, which in turn increases the quantity of N_{res}, which is a potential threat to the environment. In our own research, the accumulation of nitrogen with maize grain yield was also caused by an interaction of nitrogen dose with N_{min} content in the soil (Fig. 3). There was a linear trend observed in the difference between the accumulation of N for the N_f dose and 150-N_{min} with increasing N_{min} content in the soil (Fig. 3).

The percentage of mineral nitrogen (N_{min}) in the total amount of nitrogen in the grain yield in the present experiments significantly depended on the type of nitrogen fertilizer, nitrogen rate and the content of mineral nitrogen in the soil (Table 4). The significantly lowest percentage of N_{min} in the total accumulation of this component was observed for ammonium sulfate (57.06%), whereas the highest for calcium nitrate (63.88%). This indicates that the presence of sulfur in nitrogen fertilizer increases the utilization of nitrogen fertilizer dose. Salvagiotti & Miralles (2008) showed an increase in grain yield of wheat due to the use of nitrogen and sulfur, which was reflected in the effectiveness of the applied nitrogen fertilizer. Concerning the dose of nitrogen, it was shown that the use of full (N_f) doses resulted in a significantly lower percentage of mineral nitrogen in the total amount of N collected with grain yield compared to the reduced dose (150-N_{min}). Significantly lower percentage of N_{min} in the total amount of nitrogen acquired from the grain yield was observed in the 0-0.6 m soil profile compared to 0-0.3 m and 0-0.9 m profiles. Much more interesting are considerations taking into account the influence of the weather factor. In the humid year (2012), the percentage of N_{min} was at a significantly higher level than in dry years. Simultaneously, arable layer clearly dominated (0.0-0.3 m) only in this year, while in others – the deep subsoil layer (0.6-0.9 m). The percentage of N_{min} in the total amount of nitrogen acquired from the grain yield also depended on the interaction of nitrogen dose and N_{min} content in the soil (Fig. 4). The difference in the proportion between the N_f dose and 150-N_{min} was significantly elevated with the increase of the quantity and N_{min} included in the algorithm of fertilizer nitrogen dose. These values amounted to: 0.0-0.3 m (5.8%), 0.0-0.6m (9.40%), 0.0-0.9 m (13.5%) (Fig. 4). This relationship indicates that maize extracts nitrogen resources from the soil occurs at least to a depth of 0.9 m.

One of the most important criteria for evaluating the effectiveness of nitrogen fertilizers is to determine their productivity using performance indicators. In this study, the agricultural effectiveness, in terms of synthetic scope, significantly depended on the N_{min} content in the soil profile, N fertilizer dose and the type of nitrogen fertilizer (Table. 5). Significantly, the highest average increase in grain yield per 1 kg of N applied in fertilizer was found for ammonium sulphate (40.07 kg s.m. kg N_f), while the lowest for calcium nitrate (32.92 kg s.m. kg N applied). The obtained result confirmed previous studies of Fotyma (2003), who indicated that the efficiency of agricultural and physiological nitrogen fertilization of crops was higher after the application of fertilizers containing sulfur than those without it. Considering the amount of mineral nitrogen, it has been shown that the application rate of N_f in the form of fertilizer resulted in an average of more than 3-fold increase of N used in the fertilizer, as compared to the full dose of nitrogen fertilizer 150-N_{min} (Table 5). The significantly highest agricultural efficiency of nitrogen was found for the 0-0.9 m soil profile when compared to 0.0-0.3 m and 0.0-0.6 m profiles. This observation confirmed the results of Łukowiak *et al*. (2016 and 2016b) about the role of sub-soil as an important source of minerals for maize. High nitrogen accumulation, and thus high efficiency of nitrogen fertilizer can occur only at the optimum content of all major components (Table. 3). The agricultural effectiveness also significantly depended on the interaction of nitrogen dose and N_{min} content in the soil (Fig. 6). The agricultural effectiveness of the applied dose of nitrogen fertilizer significantly increased with the increase of N_{min} in the soil. These values were as follows: 0.0-0.3 m (5.89 kg s.m. kg N applied), 0.0-0.6 m (22.9 kg s.m. kg N applied), 0.0-0.9 m (91.79 kg s.m. kg N applied) (Fig. 5).

None of the experimental factors significantly influenced the effectiveness of physiological fertilization (Table 6). The size of this indicator was determined only by the weather conditions in the growing seasons. Regardless of the experimental factor, the highest physiological efficiency was recorded in dry 2014 (47.23 kg s.m. kg N applied), and the lowest in 2012 (35.89 kg s.m. kg N applied). It should be noted that the effectiveness of the 150-N_{min} dose of physiological nitrogen was significantly increased in dry years and reduced in wet years. This was another signal confirming the role of the subsoil in the supply of nitrogen to corn.

Table 4. Percentage of total N_{min} in the amount of nitrogen collected together with grain yield. In brackets - the percentage of nitrogen fertilizer (N_f) in total nitrogen obtained from grain yield.

Factor – Factor levels		Years 2012	Years 2013	Years 2014	Mean
Type of nitrogen fertilizer	Ammonium nitrate	67.50 (32.50)	62.17 (37.83)	51.91 (48.09)	60.53 (39.47)
	Urea	66.97 (33.03)	63.72 (36.28)	51.33 (48.67)	60.67 (39.33)
	Ammonium sulphate	67.98 (32.02)	56.42 (43.58)	46.80 (53.20)	57.06 (42.94)
	Calcium nitrate	73.33 (26.66)	63.22 (36.78)	55.07 (44.93)	63.88 (36.12)
$LSD_{0.05}$		2.559	ns	ns	4.413
Dose of N_f kg·ha^{-1}	150	62.74 (37.26)	56.41 (43.59)	48.10 (51.90)	55.75 (44.25)
	150 - N_{min}	75.15 (24.84)	66.35 (33.65)	54.43 (45.53)	65.32 (34.68)
$LSD_{0.05}$		2.913	2.356	3.056	1.500
Content of N_{min} kg·ha^{-1}	0-0.3 m	74.30 (25.70)	58.69 (41.31)	49.98 (50.02)	60.99 (39.01)
	0-0.6 m	68.37 (31.63)	59.04 (40.96)	49.43 (50.57)	58.95 (41.05)
	0-0.9 m	64.18 (35.82)	66.41 (33.59)	54.41 (45.59)	61.67 (38.33)
$LSD_{0.05}$		1.692	2.097	2.429	1.898
Mean		68.95 (31.05)	61.38 (38.62)	51.28 (48.72)	60.54 (39.46)
Control 0 kg N·ha^{-1}		100.00	100.00	100.00	100.00

ns – difference non-significant

Table 5. Agricultural efficiency of nitrogen fertilization (kg d.m. kg N in fertilizers)

Factor – Factor levels		Years 2012	Years 2013	Years 2014	Mean
Type of nitrogen fertilizer	Ammonium nitrate	32.80	31.59	40.65	35.01
	Urea	34.75	35.84	42.73	37.77
	Ammonium sulphate	40.71	36.12	43.40	40.07
	Calcium nitrate	30.09	30.83	37.83	32.92
$LSD_{0.05}$		ns	ns	ns	2.952
Dose of N_f kg·ha^{-1}	150	16.36	16.47	16.20	16.35
	150 - N_{min}	52.82	50.71	66.10	56.54
$LSD_{0.05}$		8.810	11.963	15.719	6.711
Content of N_{min} kg·ha^{-1}	0-0.3 m	11.64	22.15	22.75	18.85
	0-0.6 m	21.28	31.88	31.95	28.37
	0-0.9 m	70.85	46.75	68.75	62.11
$LSD_{0.05}$		8.945	9.386	12.748	5.959
Mean		34.59	33.59	41.15	36.44
Control 0 kg N·ha^{-1}		-	-	-	-

ns – difference non-significant

Table 6. Effectiveness of physiological nitrogen fertilization (kg d.m. kg N in uptake)

Factor – Factor levels		Years 2012	Years 2013	Years 2014	Mean
Type of nitrogen fertilizer	Ammonium nitrate	33.17	35.17	45.42	37.92
	Urea	33.66	43.76	49.30	42.24
	Ammonium sulphate	40.29	34.75	48.35	41.13
	Calcium nitrate	36.44	35.70	45.85	39.33
$LSD_{0.05}$		3.495	ns	ns	ns
Dose of N_f kg·ha^{-1}	150	39.04	34.91	44.79	39.58
	150 - N_{min}	32.74	39.78	49.67	40.73
$LSD_{0.05}$		4.686	2.914	2.358	r.n.
Content of N_{min} kg·ha^{-1}	0-0.3 m	34.68	36.31	49.03	40.01
	0-0.6 m	36.55	37.79	47.66	40.67
	0-0.9 m	36.44	37.94	45.01	39.79
$LSD_{0.05}$		ns	ns	2.228	ns
Mean		35.89	37.35	47.23	40.16
Control 0 kg N·ha^{-1}		-	-	-	-

ns – difference non-significant

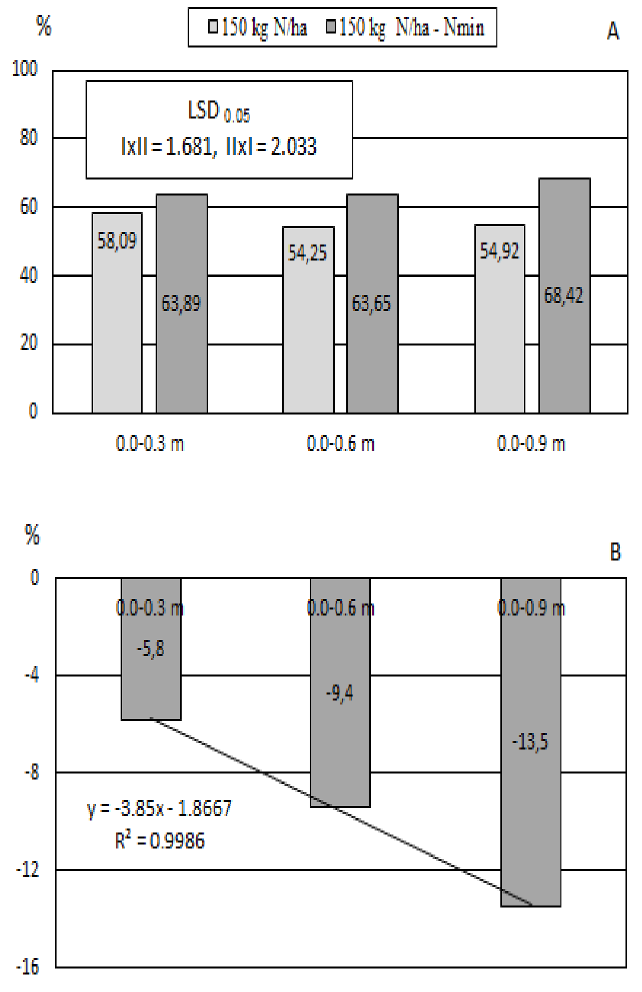

Fig. 4. Effect of nitrogen and N_{min} content in the soil profile on N_{min} percentage in total nitrogen collected with grain yield (A); difference between the dose and N_{min} content in soil profiles (B) – (2012-2014).

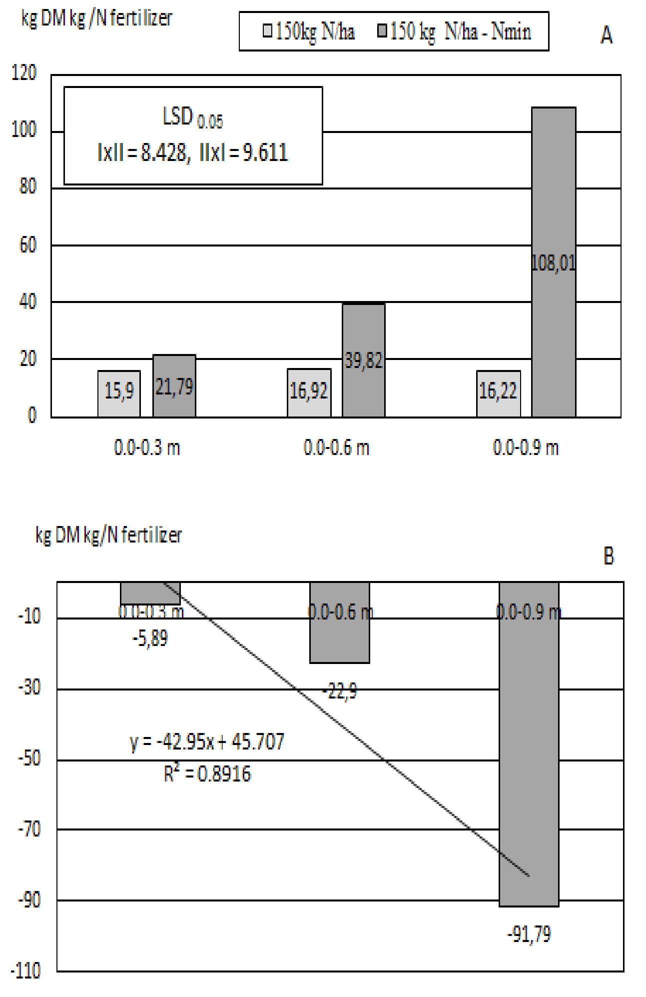

Fig. 5. Effect of nitrogen and N_{min} content in soil profiles on agricultural nitrogen effectiveness (A); difference between the dose and N_{min} content in soil profiles (B) – (2012-2014).

Table 7. Nitrogen utilization (%)

Factor – Factor levels		Years			Mean
		2012	2013	2014	
Type of nitrogen fertilizer	Ammonium nitrate	94.74	77.43	82.03	84.73
	Urea	96.27	73.29	81.04	83.53
	Ammonium sulphate	95.9	107.98	92.17	98.70
	Calcium nitrate	84.89	78.84	77.22	80.32
LSD 0.05		ns	ns	ns	10.639
Dose of N_f kg·ha^{-1}	150	41.91	46.27	35.26	41.14
	150 - N_{min}	144.02	122.50	130.98	132.50
LSD 0.05		13.809	17.432	23.82	10.113
Content of N_{min} kg·ha^{-1}	0-0.3 m	31.11	58.12	44.57	44.60
	0-0.6 m	56.17	79.88	62.71	66.25
	0-0.9 m	191.60	115.15	142.07	149.61
LSD 0.05		14.060	13.61	19.426	9.038
Mean		92.96	84.38	83.12	86.82
Control 0 kg N·ha^{-1}		-	-	-	-

ns – difference non-significant

Table 8. N_{min} content after maize harvest (kg N_{min} ha^{-1}) - (2012-2014)

Factor – Factor levels		0.0-0.3 m	0.0-0.6 m	0.0-0.9 m
Type of nitrogen fertilizer	Ammonium nitrate	27.43	37.86	76.00
	Urea	26.13	37.40	72.38
	Ammonium sulphate	22.63	30.63	65.26
	Calcium nitrate	26.03	41.53	86.23
$LSD_{0.05}$		ns	9.976	ns
Dose of N_f kg·ha^{-1}	150	28.41	41.35	83.47
	150 - N_{min}	22.70	32.36	66.46
$LSD_{0.05}$		ns	8.091	12.106
Content of N_{min} kg·ha^{-1}	0-0.3 m	38.50	49.51	103.55
	0-0.6 m	26.00	37.30	73.09
	0-0.9 m	12.17	23.75	48.27
$LSD_{0.05}$		9.031	8.276	18.717
Mean		25.55	36.85	74.96
Control 0 kg N·ha^{-1}		10.19	29.47	32.58

ns – difference non-significant

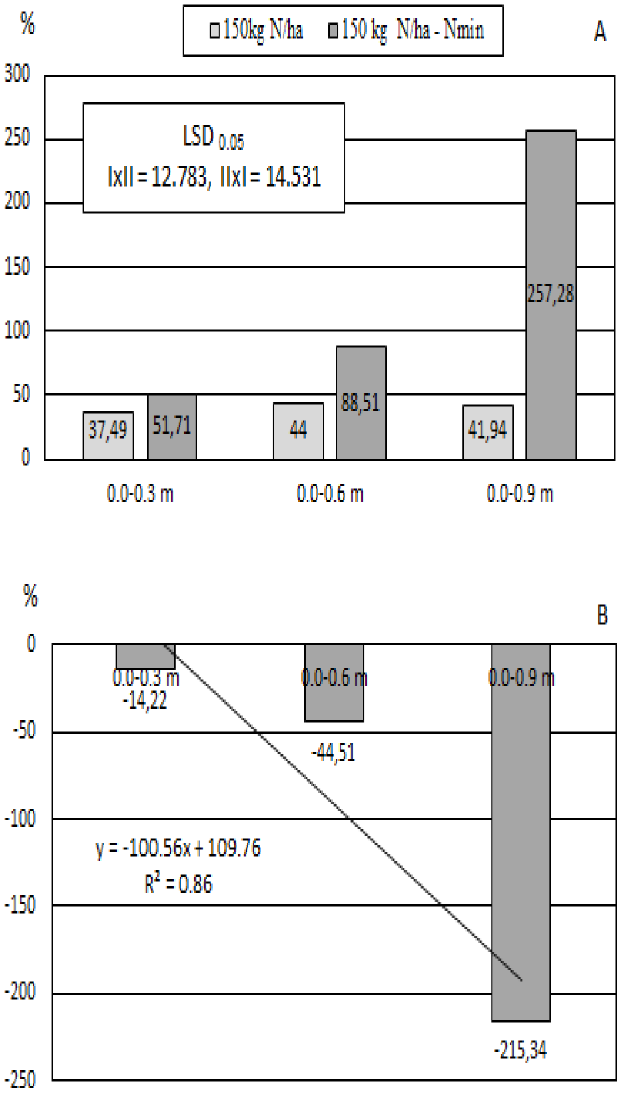

Fig. 6. Effect of nitrogen and N_{min} content in soil profiles on nitrogen utilization (A); difference between the dose and N_{min} content in soil profiles (B) – (2012-2014).

The results indicated a significant effect of weather conditions between successive years of the experiment on the volume of nitrogen utilization from the dose of mineral fertilizer (Table 7). The highest value of this index was recorded in 2012 (92.96%), which was characterized by the highest total rainfall, while values were lower in drier years, i.e., 2013 (84.38%) and 2014 (83.12%). The result obtained in the present test shows that the dose of nitrogen fertilizer can be reduced in humid years, because the utilization of N_{min} nitrogen from the soil reserves increases in such conditions (pool of residual nitrogen – N_{res}) (Table 4). The result obtained in the this test confirmed previous reports in the literature regarding the influence of environmental conditions (humidity) on the use of nitrogen from mineral fertilizer dose (Mi *et al*., 2010, Niu *et al*., 2007, Peng *et al*., 2010). The synthetic scope of the use of nitrogen from mineral fertilizer for three years of the current experiment significantly depended on the type of nitrogen fertilizer, nitrogen dose and N_{min} content in the soil profile (Table 7). Significantly, the highest use of nitrogen fertilizer was found for ammonium sulfate (98.70%), and the lowest for calcium nitrate (80.32%). The use of nitrogen was significantly greater for the 150-N_{min} nitrogen dose compared to the N_f dose. The difference between the two doses of nitrogen was up to 82.36% (Table 7). The utilization of nitrogen from the mineral fertilizer increased linearly from 44.60% (0.0-0.3 m) to 149.61% (0.0-0.9 m) with the increase of N_{min} (Table 7). A number of indices suggested the dominant role of the 0.6-0.9 m soil in nitrogen utilization. The use of nitrogen from the mineral fertilizer dose also significantly depended on the interaction of of nitrogen dose with N_{min} content in the soil (Fig. 6). Nitrogen utilization from the mineral fertilizer dose was significantly higher with the increase of N_{min} in the soil, and this relationship was linear. The difference amounted to: 0.0-0.3 m (14.22%), 0.0-0.6 m (44.51%) and 0.0-0.9 m (215.345). The use of nitrogen from the N_f pool, irrespective of the N_{min} in the soil, was statistically at the same level (Fig. 6).

Evaluation of mineral nitrogen content in the soil is used to improve the fertilizer efficiency of this component, however, it is considered also an indicator of environmental hazards resulting from its excessive concentration in the soil (Rahimizadeh *et al*., 2010). Too high concentration of residual nitrogen (N_{res}) remaining in the soil after harvest of plants is a potential threat to the environment. Fertilizer nitrogen (N_f) pool, which is not used by the cultivated plant, migrates beyond the cultivated field; this phenomenon has become one of the most important environmental issues in recent years (Erisman *et al*., 2007). Therefore, the main aim of modern agriculture should be to reduce the pool of (N_{res}) and nitrogen dispersed in the environment (NI), which should lead to an increase in the productivity of nitrogen fertilizer. The current study demonstrates that maize fertilization with ammonium sulfate (N+S), balancing nitrogen dose based on the abundance of this component in the soil, significantly reduces the amount of N_{res} (Table 8). Müller & Görlitz (1990) drew attention to the danger of excessive amounts of nitrogen N_{res} in the soil after harvest and reported that the average content of this form of nitrogen was 107 kg N_{min} ha^{-1} in the loamy sand soil in the autumn, in the 0.0-0.6 m layer. In the present study, the residual nitrogen content after maize harvest was below the upper limit.

Conclusions

1. Mineral nitrogen (N_{min}) contained in the soil in the maize rooting zone significantly increases the accumulation of this component, especially during dry years.
2. Incorporating the pool of nitrogen contained in the soil into the algorithm calculating the dose of fertilizer nitrogen significantly improves the performance of fertilization indicators.
3. The agricultural efficiency of nitrogen fertilization is directly proportional to the amount of soil N_{min} included in the algorithm calculating the fertilizer dose of nitrogen.
4. Exceeding 100% of nitrogen utilization from mineral fertilizer is possible provided the nitrogen pool contained in the whole rooting maize profile is included.
5. Significant increase of nitrogen accumulation in the grain in the variant of applying nitrogen with sulfur points to this element as a factor limiting the use of the productive potential of maize in the test plot.
6. Incorporating mineral fertilizer containing nitrogen and sulfur (N+S), and balancing the dose of nitrogen based on the N_{min} in maize crop reduce eutrophication of the environment with this biogen.

References

Bocianowski, J., P. Szulc, A. Tratwal, K. Nowosad and D. Piesik. 2016. The influence of potassium to mineral fertilizers on the maize health. *J. Integ. Agri*.,. 15 (6): 1286-1292.

Dessureault-Rompré, J., B.J. Zebarth, D.L. Burton, M. Sharifi, J. Cooper, C.A. Grant and C.F. Drury. 2010. Relationships among mineralizable soil nitrogen, soil properties, and climatic indices. *Soil Sci. Soc. Amer. J.*, 74:1218-1227.

Donner, S.D., and J.A. Kucharik. 2003. Evaluating the impacts of land management and climate variability on crop production and nitrate export across the Upper Mississippi Basin. *Global Biogeochem. Cycle.* 17.

Erisman, J., A. Bleeker, J.N. Galloway and M. Sutton. 2007. Reduced nitrogen in ecology and the environment. *Environ. Pollut.*, 150: 140-149.

Fan, X.H., and Y.C. Li. 2010. Nitrogen release from slow-release fertilizers as affected by soil type and temperature. *Soil Sci. Soc. Amer. J*., 74:1635-1641.

Fotyma, E. 2003. The influence of sulphur fertilization on nitrogen use efficiency by arable crops. (in Polish). *Nawozy i Nawożenie*. 4:116-136.

Gastal, F., and G. Lemaire. 2002. N uptake and distribution in crops: An agronomical and ecophysiological perspective. *J. Exp. Bot*., 53:789-799

Griffiths, M.W., P.S. Kettlewell and T.J. Hocking. 1995. Effects of foliar-applied sulphur and nitrogen on grain growth, grain sulphur and nitrogen concentrations and yield of winter wheat. *J. Agric. Sci*., 125: 331-339.

Harun, Ö. 2017. Effects of shading and organic fertilizers on tomato yield and quality. *Pak. J. Bot*., 49(5): 1849-1855.

Jackson, G.D. 2000. Effects of nitrogen and sulphur on Canova yield and nutrient uptake. *Agron. J*., 92: 644-649.

Kawsar, A., A. Muhammad, S. Farooq, S. Aamir, M. Fazal, A.M. Ishaq and A.M. Afaq. 2017. Improvement in maize (*Zea mays* L) growth and quality through integrated use of biochar. *Pak. J. Bot*., 49(1): 85-94.

Łukowiak, R., W. Grzebisz and G.F. Sassenrath. 2016a. New insights into phosphorus management in agriculture – a crop rotation approach. *Scie Tot Environ*., 542: 1062-1077.

Łukowiak, R., W. Grzebisz and P. Barłóg. 2016b. Magnesium management in the soil-crop system – a crop rotation approach. *Plant Soil Environ*., 62(9): 395-401.

Mi, G., F. Chen and F. Zhang. 2010. Physiological and genetic mechanisms for nitrogen-use efficiency in maize. *J. Crop Sci. & Biotechnol.*, 10 (2): 57-63.

Müller, S., and H. Görlitz. 1990. The N_{min} method in GDR (In Polish). *Fragmenta Agronomica*. 1(25): 23-35.

Niu, J., F.J. Chen, G.H. Mi, C.J. Li and F.S. Zhang. 2007. Transpiration and nitrogen uptake and flow in two maize (*Zea mays* L.) Inbred Lines as Affected by nitrogen Supply. *Annal. Bot*., 99: 153-160.

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

Potarzycki, J., and W. Grzebisz. 2009. Effect of zinc foliar application on grain yield of maize and its yielding compone. *Plant soil Environ*., 55: 519-527.

Prokszáné Paplogó, Z., E. Széll and M. Kovácsné Komlós. 1995. The effect of N- fertilisationon the yield and on several traits of maize under different seasonal effects on meadow silty soil. *Növénytermelés*. 44: 33-42.

Rahimizadeh, M., A. Kashani, A. Zare-Feizabadi, A. Koocheki and M. Nassiri-Mahallati. 2010. Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. *Aust. J. Crop Sci.*, 4(5): 363-368.

Salvagotti, F., and D.J. Miralles. 2008. Radiation interception, biomass production and grain yield as affected by the interaction nitrogen and sulfur fertilization in wheat. *European J. Agron.*, 28(3): 282-290.

Schimel, J.P., and J. Bennet. 2004. Nitrogen mineralization: challenges of a changing paradigm. *Ecol.*, 85: 591-602.

Sharifi, M., B.J. Zebarth, D.L. Burton, V. Rodd and C.A. Grant. 2011. Long-term effects of semisolid beef manure application to forage grass on soil mineralizable nitrogen. *Soil Sci. Soc. Amer. J.*, 75: 649-658.

Szulc, P. 2012. Differences in the accumulation and redistribution of dry matter and N_{min} content in the cultivation of two different maize (*Zea mays* L.) cultivars for grain. *Pol. J. Environ. Stud*., 21 (4): 1039-1046.

Szulc, P., and J. Bocianowski. 2012. The effect of soil supplementation with different forms of nitrogen fertiliser on modification of generative yield in two different types of maize (Z*ea mays* L.) hybrids. *Pol. J. Agron.*, 11: 52-64.

Szulc, P., J. Bocianowski, A. Kruczek, G. Szymańska and R. Roszkiewicz. 2013. Response of two cultivar types of maize (*Zea mays* L.) expressed in protein content and its yield to varied soil resources of N and Mg and a form of nitrogen fertilizer. *Pol. J. Environ. Stud*., 22(6): 1845-1853.

Szulc, P., H. Waligóra, T. Michalski, M. Rybus-Zając and P. Olejarski. 2016. Efficiency of nitrogen fertilization based on the fertilizer application method and type of maize cultivar (*Zea mays* L.). *Plant Soil Environ*., 62 (3): 135-142.

Zebarth, B.J., C.F. Drury, N. Tremblay and A.N. Cambouris. 2009. Opportunities for improved fertilizer nitrogen management in production of arable crops in eastern Canada: A review. *Can. J. Soil Sci*., 89:113-132.

(Received for publication 9 January 2017)