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SOIL ABUNDANCE IN N_{min} AND FORMATION OF MAIZE GRAIN YIELD COMPONENTS

Summary

The study presents the results of 3-year field experiments aimed at assessing the effect of nitrogen dose balanced on the basis of N_{min} content, depending on the distribution in the soil profile and recognizing the effect of the type of nitrogen fertilizer on the formation of maize grain yield components. Nitrogen applied in the form of mineral fertilizer was characterized by greater efficiency in comparison to N_{min} contained in the soil, as evidenced by a significantly higher grain number in the ear and 1000 grain weight. It was shown that mineral nitrogen (N_{min}) present in soil in maize rooting zone significantly influenced the number of production ears per area unit. Inclusion of the pool of the component contained in the soil in the algorithm for calculating nitrogen dose significantly improves the quantitative status of the ears. It is sufficient to collect soil samples from two levels, i.e., 0-30 cm and 0-60 cm, to determine nitrogen dose based on the soil abundance in mineral nitrogen (N_{min}).
***Key words**: maize, nitrogen, residual nitrogen (N_{res}), yield components*

ZASOBNOŚĆ GLEBY W N_{min} A KSZTAŁTOWANIE KOMPONENTÓW PLONU ZIARNA KUKURYDZY

Streszczenie

Przedstawiono wyniki trzyletnich badań polowych, których celem była ocena wpływu wielkości dawki azotu bilansowanej w oparciu o zawartość N_{min}, zależnie od rozmieszczenia w profilu glebowym oraz rozpoznanie wpływu rodzaju nawozu azotowego na kształtowanie komponentów plonu ziarna kukurydzy. Azot zastosowany w formie nawozu mineralnego w porównaniu do azotu N_{min} zawartego w glebie charakteryzował się większą efektywnością, o czym świadczyła istotnie większa liczba ziaren w kolbie oraz masa 1000 ziaren. Wykazano, że azot mineralny (N_{min}) zawarty w glebie w strefie ukorzeniania się kukurydzy istotnie kształtuje liczbę kolb produkcyjnych na jednostce powierzchni. Uwzględnienie w algorytmie wyliczenia dawki azotu puli składnika zawartego w glebie istotnie poprawia stan ilościowy kolb. W celu wyznaczenia dawki azotu w oparciu o zasobność gleby w azot mineralny (N_{min}) wystarczy pobrać próby glebowe z dwóch poziomów, tzn. 0-30 cm i 0-60 cm.
***Słowa kluczowe:** kukurydza, azot, azot rezydualny (N_{res}), komponenty plonowania*

1. Introduction

Nitrogen is one of the basic nutrients that are decisive in the intensification of plant production [2, 6]. Proper and rational nitrogen application increases not only the height and stability of crop yielding, but also improves the biological and technological value of crops, soil chemical fertility and does not cause negative effects in the natural environment [1]. Hence, ensuring the optimal level of plant growth factors, including nutrient availability, guarantees the utilization of yielding potential. Maize is characterized by a high natural capacity to take up nutrients [9], which are utilized on a regular basis, however, high yields cannot be expected without increasing soil fertility level and simultaneously regulating pH. Therefore, doses of mineral fertilizers, including nitrogen, should correspond to nutritional needs, taking into account the amount of components that can be taken up from the soil [12]. Nitrogen in maize cultivation should be used at a maximum dose for production purposes, but at the same time as minimum as possible in order to fulfill the tasks resulting from environmental protection principles [10]. The hypothesis of the experiment assumed that the type of nitrogen fertilizer, the amount of nitrogen dose and soil N_{min} content in spring could have an impact on the formation of grain yield structure elements. Therefore, field studies were conducted to find out the effect of the type of nitrogen fertilizer, the amount of nitrogen dose and N_{min} content in three soil profiles on the formation of: (i) number of production ears per unit area, (ii) number of grains in the ear and (iii) thousand grain weight.

2. Methods

2.1. Experimental field

The field experiment was carried out at the Department of Agronomy of Poznań University of Life Sciences, on the fields of the Experimental and Educational Unit in Swadzim in the years 2012-2014. The experiments were conducted in a split-split-plot design with three experimental factors, in 4 field replicates. The experiment investigated the influence of four nitrogen carriers (ammonium nitrate, urea, ammonium sulphate, calcium nitrate), two nitrogen doses (150 kg $N \cdot ha^{-1}$ and 150 kg $N \cdot ha^{-1}$ reduced by soil abundance in N_{min}) and N_{min} content in soil samples (0-30 cm, 0-60 cm, 0-90 cm) on the structure of maize grain yield. The same level of phosphorus and potassium fertilization was adopted for all experimental objects: 70 kg P_2O_5 ha^{-1} and 130 kg K_2O ha^{-1}. Mineral fertilizers were applied in early spring. Phosphorus was applied in the form of triple granulated superphosphate, potassium in the form of potassium salt. The nitrogen dose of 150 kg in the form of fertilizer was applied according to the levels of the 1st order factor. The experiment used the cultivar Fortran (FAO 210-200, single hybrid S.C.) from Euralis Semences. Plot size: 24.5 m^2 (length - 8.75 m, width - 2.8 m). The net plot area for harvesting was 12.25 m^2. The sowing density of maize was 7.95 psc.·m^{-2}. The field experiment was carried out on gray-brown podzolic soil, a kind of light loamy sands, shallowly deposited on light clay, belonging to the good rye complex. Soil abundance in basic macronutrients (P, K, Mg) in individual years of the study was on the average level, while its pH ranged from 5.4 in 2012 to 6.0 in 2014. Mineral nitrogen content at three soil levels in spring, before establishing the experiments, is shown in Table 1.

2.2. Determination of yield components

- Number of ears [pcs·m^{-2}]: all developed ears were counted in two middle rows of each plot. Their number was divided by the size of the plot intended for harvesting.
- Number of grains in the ear [pcs.]: grain number in a row and row number were counted on each of 10 randomly selected ears. Grain number in the ear was obtained by calculating the product of these two values.
- Thousand seed weight [g]: this value was calculated by summing up the results of two randomly collected samples containing 500 seeds each.

2.3. Thermal and humidity conditions

Thermal and humidity conditions during the growing season in the years of research were very diverse for maize growth and development (Table 2). Total precipitation in the IV-IX period was 473.6 mm in 2012, 397.4 mm in 2013 and 351.8 mm in 2014. The average daily air temperature measured at a height of 2 m ranged from 15.4°C in 2012 to 16.1°C in 2014.

2.4. Soil chemical analyses

The assessment of macronutrient contents, pH and mineral nitrogen in the soil was carried out in accordance with the research procedure/standard (District Chemical and Agriculture Station in Poznań) before establishing the experiment (0-30 cm, 0-60 cm, 0-90 cm): 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 N_{min} kg ha^{-1} = N_{min} content in mg 100 g^{-1} dry weight * 45 [8], where: 45 – coefficient for light soil.

2.5. Statistical analysis

One-year results were subjected to a univariate analysis of variance, followed by synthesis for multiple experiments. The significance of the differences was estimated at the level of α = 0.05 using Student's t-test.

Table 1. Nitrogen fertilization scheme employed in the experiment
Tab. 1. Schemat nawożenia azotowego w doświadczeniu

Factor and factor levels			Years		
			2012	2013	2014
Ammonium nitrate	Dose of N kg·ha^{-1}	0-30 cm	150	150	150
		0-60 cm			
		0-90 cm			
		0-30 cm	150 – 63.8 N_{min}	150 – 65.5 N_{min}	150 – 61.5 N_{min}
		0-60 cm	150 – 99.3 N_{min}	150 – 103.7 N_{min}	150 – 98.7 N_{min}
		0-90 cm	150 – 135.2 N_{min}	150 – 134.3 N_{min}	150 – 137.7 N_{min}
Urea	Dose of N kg·ha^{-1}	0-30 cm	150	150	150
		0-60 cm			
		0-90 cm			
		0-30 cm	150 – 63.8 N_{min}	150 – 65.5 N_{min}	150 – 61.5 N_{min}
		0-60 cm	150 – 99.3 N_{min}	150 – 103.7 N_{min}	150 – 98.7 N_{min}
		0-90 cm	150 – 135.2 N_{min}	150 – 134.3 N_{min}	150 – 137.7 N_{min}
Ammonium sulphate	Dose of N kg·ha^{-1}	0-30 cm	150	150	150
		0-60 cm			
		0-90 cm			
		0-30 cm	150 – 63.8 N_{min}	150 – 65.5 N_{min}	150 – 61.5 N_{min}
		0-60 cm	150 – 99.3 N_{min}	150 – 103.7 N_{min}	150 – 98.7 N_{min}
		0-90 cm	150 – 135.2 N_{min}	150 – 134.3 N_{min}	150 – 137.7 N_{min}
Calcium nitrate	Dose of N kg·ha^{-1}	0-30 cm	150	150	150
		0-60 cm			
		0-90 cm			
		0-30 cm	150 – 63.8 N_{min}	150 – 65.5	150 – 61.5 N_{min}
		0-60 cm	150 – 99.3 N_{min}	150 – 103.7	150 – 98.7 N_{min}
		0-90 cm	150 – 135.2 N_{min}	150 – 134.3	150 – 137.7 N_{min}

Source: own study / Źródło: opracowanie własne

Table 2. Mean monthly air temperature and monthly sum of precipitation in Swadzim in 2012-2014
Tab. 2. Średnia miesięczna temperatura powietrza i miesięczna suma opadu atmosferycznego w Swadzimiu w latach 2012-2014

Years	Temperature [°C]							
	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	Precipitation [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

Source: own study / Źródło: opracowanie własne

3. Discussion

The number of ears per unit area of single-ear cultivars is determined before maize sowing, during the planning of crop density. Formation of the basic component of grain yield, i.e. the ear starts in maize already from the 3-leaf stage (BBCH 13) and lasts to the 5-leaf stage (BBCH 15). The number of leaves and ears with spikelet primordia is determined during this period [11]. Potentially, maize can develop up to 8 ears simultaneously. The number of developing ears depends on the genotype and the availability of water and nutrients, mainly nitrogen [5]. Usually, only the top 1-2 ears become dominant and develop further. The number of production ears per area unit, depended on average for the years of research on mineral nitrogen content in the soil profile (Table 3). The number of production ears decreased with the increase of mineral nitrogen in the soil (lower dose of mineral fertilizer). It should be noted that the value of the discussed trait for N_{min} soil content in the 0-60 cm and 0-90 cm profile, was statistically at the same level (Table 3). A decrease in the number of ears per area unit with an increase in nitrogen fertilization level was also demonstrated in previous studies [7]. The number of production ears is very strongly correlated with plant quantitative status. As reported by Borowiecki and Koter [4], poor plant emergence, inhibition of their growth in objects with high nitrogen doses, including urea was caused by a high concentration of ammonium nitrogen in the soil, as a result of this fertilizer hydrolysis. This can also explain the lower number of production ears per area unit with increasing doses of nitrogen fertilizers.

In the present study, thousand seed weight (Table 4) and the number of grains in the ear (Table 5) in synthetic terms, for the years of research, significantly depended solely on the amount of nitrogen dose. Maize fertilized with 150 kg N·ha^{-1}, compared to the nitrogen dose balanced by its content in mineral nitrogen (150-N_{min}), was characterized by significantly better developed kernels and their higher number in the flask. The difference was 15.83 g and 17.97 pcs, respectively. The obtained result in the current study proved the higher efficiency of nitrogen applied in the fertilizer compared to nitrogen N_{min}. Nitrogen availability shapes grain yield from the ear by affecting the number of formed grains and preventing their reduction after fertilization [3], which was clearly demonstrated in the study. Thousand grain yield during harvest was also significantly modified by the interaction of the type of nitrogen fertilizer with nitrogen dose (Fig. 1). For each of the tested nitrogen fertilizers, sowing full nitrogen dose in the form of mineral fertilizer significantly increased the value of the discussed trait, compared to nitrogen dose reduced by the amount of N_{min} in the soil. Significantly greater increase in 1000 grain weight between two nitrogen doses was found for ammonium nitrate, in relation to urea, ammonium sulphate and calcium nitrate (Fig. 1).

Table 3. Number of production ears per area unit [pc.m^{-2}]
Tab. 3. Liczba kolb produkcyjnych na jednostce powierzchni

Factor - Factor levels		Years			Mean
		2012	2013	2014	
Type of nitrogen fertilizer	Ammonium nitrate	9.09	8.29	7.68	8.35
	Urea	9.13	8.25	7.65	8.34
	Ammonium sulphate	9.91	7.98	7.20	8.36
	Calcium nitrate	8.93	8.39	7.30	8.21
LSD $_{0.05}$		0.320	0.213	n.s.	n.s.
Dose of N kg·ha^{-1}	150	9.72	8.13	7.14	8.33
	150 – N_{min}	8.81	8.32	7.78	8.30
LSD $_{0.05}$		0.191	0.153	0.248	n.s.
Content of N_{min} in soil samples kg·ha^{-1}	0-30 cm	9.11	8.13	7.36	8.20
	0-60 cm	9.29	8.32	7.51	8.37
	0-90 cm	9.39	8.24	7.51	8.38
LSD $_{0.05}$		n.s.	n.s.	n.s	0.116
Mean		9.26	8.23	7.46	8.32
Control 0 kg N·ha^{-1}		8.80	8.11	7.21	8.04

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne

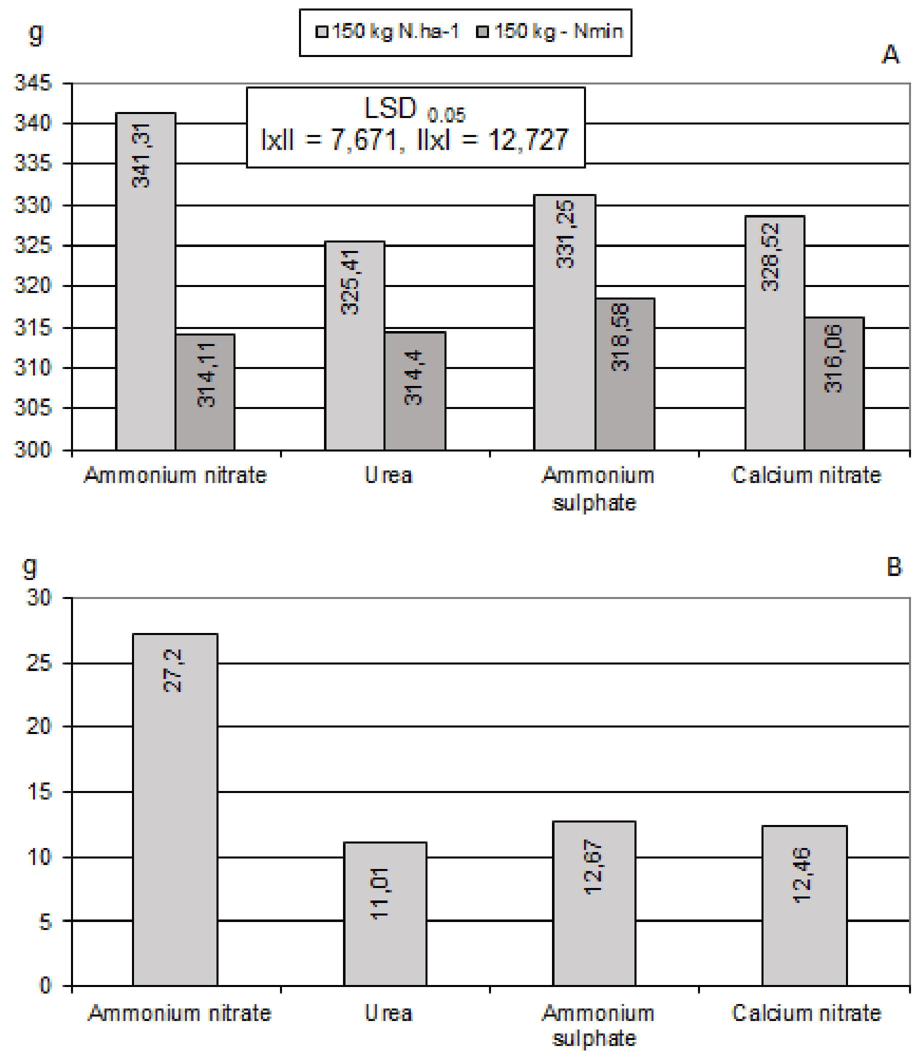
Table 4. Thousand grain weight [g]

Tab. 4. Masa tysiąca ziaren [g]

Factor - Factor levels		Years			Mean
		2012	2013	2014	
Type of nitrogen fertilizer	Ammonium nitrate	309.58	330.12	343.42	327.71
	Urea	313.29	324.02	322.42	319.91
	Ammonium sulphate	302.20	334.64	337.90	324.91
	Calcium nitrate	302.89	330.08	333.89	322.29
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.
Dose of N $kg \cdot ha^{-1}$	150	312.53	338.21	344.14	331.62
	150 – N_{min}	301.45	321.22	324.68	315.79
$LSD_{0.05}$		5.084	5.333	9.927	3.835
Content of N_{min} in soil samples $kg \cdot ha^{-1}$	0-30 cm	301.64	332.22	337.69	323.85
	0-60 cm	309.32	329.77	335.12	324.74
	0-90 cm	310.01	327.15	330.42	322.53
$LSD_{0.05}$		5.682	n.s.	n.s.	n.s.
Mean		306.99	329.72	334.41	323.71
Control 0 kg $N \cdot ha^{-1}$		300.95	308.35	314.25	307.85

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne



Source: own study / Źródło: opracowanie własne

Fig. 1. Influence of nitrogen fertilizer type and nitrogen dose on thousand grain weight (A), increase in thousand grain weight (B), (2012-2014)

Rys. 1. Wpływ rodzaju nawozu azotowego i dawki azotu na masę 1000 ziaren (A), przyrost masy 1000 ziaren (B), (2012-2014)

Table 5. Number of grains per ear [pcs.]
Tab. 5. Liczba ziaren w kolbie [szt.]

Factor - Factor levels		Years 2012	2013	2014	Mean
Type of nitrogen fertilizer	Ammonium nitrate	527.86	529.26	464.42	507.18
	Urea	527.64	526.26	459.93	504.61
	Ammonium sulphate	517.98	526,23	472.94	505.72
	Calcium nitrate	524.14	524.82	432.54	493.83
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.
Dose of N $kg \cdot ha^{-1}$	150	533.72	527.95	473.78	511.82
	150 – N_{min}	515.09	525.34	441.13	493.85
$LSD_{0.05}$		14.475	n.s.	26.224	10.386
Content of N_{min} in soil samples $kg \cdot ha^{-1}$	0-30 cm	510.43	526.62	465.20	500.75
	0-60 cm	525.09	530.11	457.42	504.20
	0-90 cm	537.70	523.19	449.76	503.55
$LSD_{0.05}$		14.497	n.s.	n.s.	n.s.
Mean		524.41	526.64	457.46	502.83
Control 0 kg $N \cdot ha^{-1}$		491.65	502.79	450.01	481.48

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne

4. Conclusions

1. Nitrogen applied in the form of mineral fertilizer was characterized by greater efficiency in comparison to N_{min} contained in the soil, as evidenced by a significantly greater grain number in the ear and 1000 grain weight.
2. It was shown that mineral nitrogen (N_{min}) present in soil in the maize rooting zone significantly influenced the number of production ears per area unit. Including in the algorithm the calculated nitrogen dose in the pool of the component contained in the soil significantly improves the quantitative state of the ears.
3. It is sufficient to collect soil samples from two levels, i.e. 0-30 cm and 0-60 cm to determine nitrogen dose based on the soil abundance in mineral nitrogen (N_{min}).

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