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Received: 2021-11-16; Accepted: 2021-12-06

EFFECT OF THE DEPTH OF NITROGEN-PHOSPHORUS FERTILIZER APPLICATION ON THE NUTRITIONAL STATUS OF MAIZE PLANTS (*Zea mays* L.)

Summary

The study presents the results of a 4-year field study aimed at assessing the nutrition of maize plants in relation to the depth of two-component (NP) mineral fertilizer placement in the soil layer (0, 5, 10, 15 cm), the type of nitrogen fertilizer (ammonium nitrate, urea) and the date of its application (before sowing, BBCH 15/16). It was demonstrated that the initial phosphorus application elevated nitrogen content in the ear leaf with the increase in mineral fertilizer placing depth in soil, while zinc to the depth of 5 cm. DRIS analysis confirmed the significant impact of the depth of phosphorus fertilizer placement on the plants' nitrogen balance. Initial fertilization with phosphorus improved the plant nutritional status, indicating N as the main deficient nutrient at the BBCH 63 stage.
***Key words**: maize (Zea mays* L.*), plant nutrition, developmental stage*

WPŁYW GŁĘBOKOŚCI APLIKACJI NAWOZU AZOTOWO-FOSFOROWEGO NA STAN ODŻYWIENIA ROŚLIN KUKURYDZY (*Zea mays* L.)

Streszczenie

W pracy przedstawiono wyniki 4-letnich badań polowych, których celem była ocena odżywienia roślin kukurydzy w zależności od głębokości umieszczania nawozu mineralnego, dwuskładnikowego (NP) w warstwie gleby (0, 5, 10, 15 cm), rodzaju nawozu azotowego (saletra amonowa, mocznik) oraz terminu jego aplikacji (przed siewem BBCH 15/16). Wykazano, że startowa aplikacja fosforu powodowała wzrost zawartości azotu w liściu podkolbowym kukurydzy wraz ze wzrostem głębokości umieszczania nawozu mineralnego w glebie, natomiast cynku do głębokości 5 cm. Istotny wpływ głębokości umieszczenia nawozu fosforowego na gospodarkę azotową roślin potwierdziła analiza DRIS. Nawożenie startowe fosforem poprawiło stan odżywienia roślin, wskazując na N jako główny składnik pokarmowy, będący w stadium BBCH 63 w niedoborze.
***Słowa kluczowe**: kukurydza (Zea mays* L.*),, odżywienie roślin, faza rozwojowa*

1. Introduction

In Poland, maize is one of the basic fodder plants that enables energy and protein balance in the nutrition of all animal groups. In addition to the genetic factor (variety), the size of the yields is determined by nitrogen fertilization, of course in proportion to other mineral nutrients [1]. Maize has high nutritional and fertilizer demands, especially for nitrogen [2], yet it is rather insensitive to this nutrient overdose. Application of large doses of nitrogen fertilizers before sowing, with a long period from sowing to maize emergence, pose a risk of nitrogen leaching, especially in the occurrence of higher precipitation. Additionally, maize cultivation in wide inter-rows (approx. 75 cm) means that mineral nutrients applied superficially in mineral fertilizer are no longer available by the time the plant develops a deep root system that could take them up [3]. Księżak et al. [4] have reported that the application of high nitrogen doses, especially to light soils, poses a threat to the environment, as it may lead to soil nitrate concentration, groundwater contamination and water reservoir eutrophication. Hence, nutrients, including nitrogen, should be applied in such a way that their uptake by maize follows the rhythm of its growth in order to fully utilize the yield-forming potential of maize nitrogen fertilization in virtually all agricultural systems increases the content of protein (its yield) and chlorophyll, and thus increases leaf mass and its surface area, which accelerates photosynthesis and stimulates further yield increments [5]. The excess of applied nitrogen, in relation to other nutrients, decreases its effectiveness, especially in soils with insufficient potassium content [6, 7]. Plantations over-fertilized with nitrogen have denser canopies and plants show poor calcium incorporation by the cell wall. Therefore, plants are susceptible to pathogen infections, especially fungi [8]. In turn, phosphorus is a nutrient playing a fundamental role in the early maize developmental stages, as well as grain formation and maturation [9, 10]. It stimulates root system development, indirectly increasing the plant resistance to periodic soil moisture deficiencies. Numerous literature reports indicated a large influence of soil temperature on phosphorus uptake by maize. The uptake of this component is limited at temperatures below 12°C. Then the plants exhibit clear symptoms of its deficiency in the form of red discoloration along the edges of the leaf blades and their subsequent dieback, especially in case of water deficiency, as well as marked inhibition of growth and development [11]. These symptoms occur especially in cool spring years, even when phosphorus content in soil is sufficient [12]. An underdeveloped root system prevents the uptake of phosphorus in quantities sufficient for plants. Therefore, the main objective of the conducted field study was to determine the effect of nitrogen and phosphorus (NP mineral fertilizer) on the nutritional status of maize plants at the BBCH 63 stage.

2. Methods

2.1. Experimental field

Field trial was carried out at the Department of Agronomy of Poznań University of Life Sciences, on the fields of the Agricultural Experimental Station Gorzyn, in the years 2015-2018. It was conducted for four years in the same random block design (split-split-plot) with 3 factors and 4 field replicates. The following variables were tested: A – 1st order factor – NP fertilizer sowing depth [A1 – 0 cm (broadcast), A2 – 5 cm (in rows), A3 – 10 cm (in rows), A4 – 15 cm (in rows)]; B – 2nd order factor – type of supplementary nitrogen fertilizer [B1 – ammonium nitrate, B2 – urea]; C – 3rd order factor – date of supplementary nitrogen fertilization [C1 – before sowing, C2 – top dressing in the BBCH 15/16 stage]. The same level of mineral fertilization (100 kg $N·ha^{-1}$, 70 kg $P_2O_5·ha^{-1}$ and 130 kg $K_2O·ha^{-1}$) was applied in all experimental objects. Fertilization was balanced against phosphorus, which was applied at the whole required dose in the form of ammonium phosphate (18% N, 46% P_2O_5), according to the experimental design under the 1st order factor. N and K fertilization was performed before maize sowing using urea (46% N) and potassium salt (60%). The fertilizer coulters (on objects with initial fertilization) were set 5 cm aside from the seeds. Application depth of NP fertilizer was according to the 1st order factor levels. Maize sowing was performed with a precision seeder, with a built-in granular fertilizer applicator (Monosem). Gross plot size: 24.5 m^2 (length – 8.75 m, width – 2.8 m). The abundance of soil before the assumption of the experiment in nutrients was at on average level.

2.2. Determination of N, P, K, Ca and Mg contents in plant dry matter at the tassel flowering stage (BBCH 63)

The analysis of mineral contents in plant dry matter was performed in the laboratory of the Agronomy Department of the Poznań University of Life Sciences. From each plot, 8 plants were randomly selected for chemical analysis.

DRIS - Diagnosis and Recommendation Integrated System

DRIS standards were calculated based on the methodology from the study of Łabuda and Beverly [13] and Beaufils [14].

$$I(N) = \frac{[f(N/P) + f(N/K) - f(Mg/N) - f(Ca/N)]}{4}$$

$$I(P) = \frac{[f(P/Mg) - f(N/P) - f(K/P) - f(Ca/P)]}{4}$$

$$I(K) = \frac{[f(K/P) - f(N/K) - f(Ca/K) - f(Mg/K)]}{4}$$

$$I(Ca) = \frac{[f(Ca/N) + f(Ca/P) + f(Ca/K) - f(Mg/Ca)]}{4}$$

$$I(Mg) = \frac{[f(Mg/N) + f(Mg/K) - f(P/Mg) + f(Mg/Ca)]}{4}$$

where: N, P, K, Ca, Mg – content (%).
when $N/P > n/p$ then $f(N/P) = [(N/P)/(n/p) - 1] \times (1000/CV)$,
=when $N/P < n/p$ then $f(N/P) = 1 - [(n/p)/(N/P)] \times (1000/CV)$,
where:
N/P – the ratio of N to P in the plant material,
n/p – the ratio of N to P in the DRIS standard (Tab. 1),
CV – coefficient of variation for the n/p ratio for the DRIS standard,
1000 – conversion factor.

Table 1. Assessment of nutrient ratios in maize leaf [15]
Tab. 1. Ocena stosunków składników odżywczych w liściu kukurydzy [15]

Nutrient ratio	Number of observations	Mean	Standard deviation (SD)
n/p	1909	9.035	2.136
n/k	1908	1.463	0.426
p/k	1909	0.169	0.054
ca/n	1553	0.160	0.057
ca/p	1553	1.117	0.612
ca/k	1553	0.237	0.122
mg/n	1556	0.071	0.029
mg/p	1557	0.639	0.330
mg/k	1556	0.104	0.063
mg/ca	1554	0.465	0.182

2.3. Weather and soil conditions

The thermal and humidity conditions occurring in the growing seasons of maize have been presented in an earlier work by the author [16].

2.4. Statistical analysis

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

3. Results

3.1. Changes in ear leaf chemical composition at the tassel flowering stage (BBCH 63)

Nitrogen content significantly depended on the depth of NP fertilization and the date of nitrogen dose supplementation (Tab. 2). Significantly higher nitrogen content in dry matter of maize leaf blades was recorded for row fertilization at 10 cm depth, while the lowest for broadcast fertilization. Considering the date of nitrogen dose supplementation, it was found that maize plants were characterized by significantly higher nitrogen content in maize leaf blades as a result of pre-sowing application of this component at the discussed developmental stage compared to the post-harvest application of this component (Tab. 2). For potassium, its significantly higher content was recorded for nitrogen application before maize sowing, compared to top dressing nitrogen application.

Nitrogen content in maize leaf blades also significantly depended on the interaction of the type of nitrogen fertilizer and the date of supplementing the dose of this component (Tab. 3).

Table 2. Nutrient contents in maize leaves [g·kg^{-1}] (2015-2018)
Tab. 2. Zawartość składników pokarmowych w liściach kukurydzy [g·kg^{-1}] (2015-2018)

Experimental factor / Factor levels		N	P	K	Mg	Ca
NP fertilizer placement depth	0 cm (broadcast)	27.44	3.09	23.54	4.43	6.44
	5 cm	27.81	3.10	21.23	4.28	6.26
	10 cm	29.07	3.17	19.61	4.33	6.20
	15 cm	28.59	3.20	23.51	4.54	6.47
NIR $_{0.05}$		0.945	ns	ns	ns	ns
Nitrogen fertilizer type	ammonium sulfate	27.84	3.13	22.01	4.33	6.27
	urea	28.61	3.15	21.93	4.46	6.42
NIR $_{0.05}$		ns	ns	ns	ns	ns
Nitrogen supplementation date	before sowing	28.58	3.14	23.42	4.43	6.35
	5-6 leaf stage	27.87	3.14	20.53	4.36	6.34
NIR $_{0.05}$		0.599	ns	2.724	ns	ns
Mean		28.22	3.14	21.97	4.39	6.34

ns – not significant

Source: own study / Źródło: opracowanie własne

Table 3. Nitrogen content in maize leaf blades in relation to the interaction of nitrogen fertilizer type and nitrogen dose supplementation date [g·kg^{-1}] (2015-2018)
Tab. 3. Zawartość azotu w blaszkach liściowych kukurydzy w zależności od współdziałania rodzaju nawozu azotowego i terminu uzupełnienia dawki azotu [g·kg^{-1}] (2015-2018)

Nitrogen fertilizer type (B)	Nitrogen supplementation date (C)	
	before sowing	5-6 leaf stage
Ammonium sulfate	28.50	27.18
Urea	28.66	28.55
NIR $_{0.05}$	for the interaction of nitrogen fertilizer type (B) and nitrogen supplementation date (C) B/C = **0.848**; C/B = **1.073**	

Source: own study / Źródło: opracowanie własne

For urea, the application date of the supplemental nitrogen dose did not have a significant effect on the value of this trait. For ammonium nitrate, maize was characterized by a significantly higher nitrogen content in leaf blades as a result of pre-sowing nitrogen application compared to top dressing nitrogen fertilization In the present study, only zinc and manganese contents were significantly influenced by research factors (Tab. 4). Maize fertilized in rows had a significantly higher content of zinc in leaf blades compared to the broadcast application. Maize fertilized with urea contained significantly more manganese in leaf blades than ammonium nitrate.

Zinc content in maize leaf blades also significantly depended on the interaction of the type of nitrogen fertilizer and the date of supplementing the dose of this component (Tab. 5). For urea, the application date of the supplemental nitrogen dose did not have a significant effect on the value of this trait. For ammonium nitrate, as a result of pre-sowing nitrogen application, maize was characterized by a significantly higher zinc content in leaf blades compared to top dressing nitrogen application (Tab. 5).

3.2. Diagnosis and Recommendation Integrated System (DRIS)

The sum of nutritional status absolute values (sum of indices) of maize plants in this study varied (Tab. 6). Considering the depth of NP fertilizer application, maize fertilized with NP fertilizer at a depth of 5 and 10 cm was characterized by significantly lower values of the sum of indices compared to broadcast and row fertilization performed at a depth of 15 cm (Tab. 6). Regarding nitrogen fertilizer type, maize fertilized with urea was characterized by a lower sum of nutritional status indices compared to ammonium nitrate fertilization. On the other hand, the application of the entire nitrogen dose before maize sowing resulted in a lower sum of the nutritional status indices of maize plants compared to nitrogen applied in split doses (Tab. 6). Nitrogen, regardless of the study factors, was the component most highly limiting grain yield.

Table 4. Micronutrient contents in maize leaves [g·kg^{-1}] (2015-2018)
Tab. 4. Zawartość mikroskładników w liściach kukurydzy [mg·kg^{-1}] (2015-2018)

Experimental factor / Factor levels		Cu	Zn	Mn	Fe
NP fertilizer placement depth	0 cm (broadcast)	7.79	68.14	132.44	196.15
	5 cm	6.90	81.05	145.59	201.91
	10 cm	6.64	74.46	161.91	195.85
	15 cm	5.88	73.94	169.35	206.17
NIR $_{0.05}$		**ns**	**4.818**	**ns**	**ns**
Nitrogen fertilizer type	ammonium sulfate	6.75	73.80	141.18	202.25
	urea	6.85	74.99	163.47	197.79
NIR $_{0.05}$		**ns**	**ns**	**18.700**	**ns**
Nitrogen supplementation date	before sowing	6.93	73.23	148.04	196.37
	5-6 leaf stage	6.67	75.56	156.60	203.68
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**
Mean		6.80	79.40	152.32	200.02

ns – not significant

Source: own study / Źródło: opracowanie własne

Table 5. Zn content in maize leaves [mg·kg^{-1}] in relation to the interaction of nitrogen fertilizer type and nitrogen dose supplementation

Tab. 5. Zawartość Zn w liściach kukurydzy [mg·kg^{-1}] zależności od współdziałania rodzaju nawozu azotowego i terminu uzupełnienia dawki azotu

Nitrogen fertilizer type (B)	Nitrogen supplementation date (C)	
	before sowing	5-6 leaf stage
Ammonium sulfate	76.99	70.62
Urea	75.85	74.14
NIR $_{0.05}$	for the interaction of nitrogen fertilizer type (B) and nitrogen supplementation date C) B/C = **5.033**; C/B = **5.797**	

Source: own study / Źródło: opracowanie własne

Table 6. DRIS index values (2015-2018)

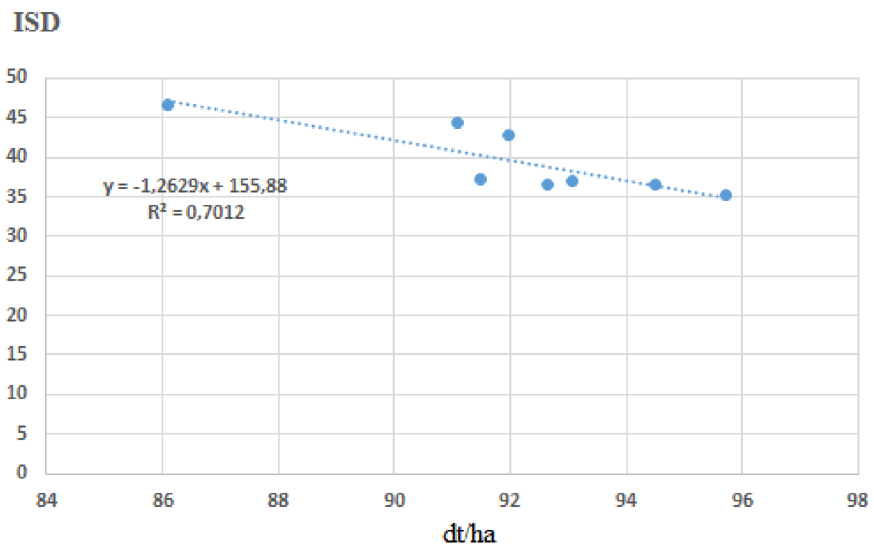
Tab. 6. Wartość indeksów DRIS (2015-2018)

Experimental factor Factor levels		Nutrient					Limiting component	Sum of indices
		N	P	K	Ca	Mg		
NP fertilizer placement depth	0 cm	- 17.97	- 5.34	5.15	0.27	17.89	N>P>Ca>K>Mg	46.61
	5 cm	- 13.83	- 3.19	- 0.60	0.20	17.42	N>P>K>Ca>Mg	35.25
	10 cm	- 9.80	- 2.83	- 5.11	- 0.60	18.34	N>K>P>Ca>Mg	36.67
	15 cm	- 15.96	- 4.54	3.37	- 0.96	18.10	N>P>Ca>K>Mg	42.92
Nitrogen fertilizer type	ammonium sulfate	- 14.82	- 3.36	1.22	- 0.48	17.44	N>P>Ca>K>Mg	37.32
	urea	- 13.85	- 4.07	- 0.31	- 0.05	18.29	N>K>P>Ca>Mg	36.57
Nitrogen supplementation date	before sowing	- 12.08	- 4.82	- 1.66	0.43	18.13	N>P>K>Ca>Mg	37.13
	5-6 leaf stage	- 16.65	- 4.60	4.51	- 0.96	17.70	N>P>Ca>K>Mg	44.42

Source: own study / Źródło: opracowanie własne

4. Discussion

Plant growth analysis can provide much needed information about the agriculture system, especially about the content and ratios of elements in plants, which can serve as the basis for the development of fertilization recommendations [13]. Diagnosis and Recommendation Integrated System (DRIS), developed by Beaufils [14], is one of the methods that uses element contents and ratios in a plant to assess the nutrient supply. This method allows to arrange nutrients in terms of their impact on yield reduction. Therefore, DRIS indices are a relative measure of nutrient deficiency or excess, as well as plant nutritional balance [17]. The current study showed that individual levels of experimental factors determined the nutritional status of maize plants. A tendency could be noticed that the lower the nutritional status index, the higher the maize grain yield (Fig. 1). The result obtained in this study confirmed previous literature reports [18]. According to these authors, the ear leaf was a useful part of the plant for the design of both nutritional status indices and grain yield prediction. A better nutritional balance in the juvenile maize phase also determines the greater dynamics of dry matter accumulation by this plant, which in turn is positively correlated with grain yield [19]. The result obtained in this study confirmed previous literature reports of the author [20], according to whom good initial maize vigor, expressed in dry matter of a single plant and dry matter yield, as well as proper plant nutrition in the juvenile stage, determines the size of grain yield and guarantees the utilization of the yield-generating potential of maize hybrids.



Source: own study / Źródło: opracowanie własne

Fig. 1. Relationship of grain yield and the sum of nutritional status indices (NSI)

Rys. 1. Zależność plonu ziarna od sumy indeksów stanu odżywienia (ISD)

5. Conclusions

1. Initial phosphorus application increased nitrogen content in the ear leaf with the increase in mineral fertilizer placing depth in soil, while zinc to the depth of 5 cm.

2. DRIS analysis confirmed the significant impact of the depth of phosphorus fertilizer placement on the plants' nitrogen balance. Initial fertilization with phosphorus improved the plant nutritional status, indicating N as the main nutrient deficient in the BBCH 63 stage.

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