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Received: 2021-11-16; Accepted: 2021-12-10

THE JUVENILE PHASE OF MAIZE: NUTRIENT CONTENTS AS AN INDICATOR OF GRAIN YIELD

Summary

The study presents the results of a 4-year field study aimed at assessing nutrient content of two maize juvenile stages (BBCH 17/18 and BBCH 18/19) in relation to the depth of two-component (NP) mineral fertilizer placement in the soil layer (0, 5, 10, 15 cm), type of nitrogen fertilizer (ammonium nitrate, urea) and date of its application (before sowing, in the BBCH 15/16 stage). Maize showed a high capacity to compensate for growth in the early developmental stages, which resulted from the action of the component placed in deeper soil layers. The highest phosphorus content in maize plants was recorded at the 8-9-leaf stage for a depth of 10 cm. The effect of nitrogen dilution depended on the form and date of fertilizer application. Plants fertilized with ammonium nitrate at the 5-6-leaf stage showed the greatest decrease in N content from the 7-8-leaf stage to the 8-9-leaf stage. The content of phosphorus and nitrogen at the 7-8- and 8-9-leaf stages was significantly correlated with grain yield. Higher correlation coefficients were recorded for the 8-9-leaf stage.
Key words: *maize (Zea mays* L.*), initial fertilization, juvenile phase, correlation coefficient*

FAZA MŁODOCIANA KUKURYDZY: ZAWARTOŚĆ SKŁADNIKÓW POKARMOWYCH JAKO INDYKATOR PLONU ZIARNA

Streszczenie

W pracy przedstawiono wyniki 4-letnich badań polowych, których celem była ocena zawartości składników pokarmowych w dwóch fazach młodocianych kukurydzy (BBCH 17/18 i BBCH 18/19) w zależności od głębokości umieszczania nawozu dwuskładnikowego (NP) w warstwie gleby(0, 5, 10, 15 cm), rodzaju nawozu azotowego (saletra amonowa, mocznik) oraz terminu jego aplikacji (przed siewem, w fazie BBCH 15/16). Kukurydza wykazywała dużą zdolność kompensacji wzrostu we wczesnych stadiach rozwoju, który wynikał z działania składnika umieszczonego w głębszych warstwach gleby. Największą zawartość fosforu w roślinach kukurydzy odnotowano w stadium 8-9 liścia dla głębokości 10 cm. Efekt rozcieńczenia azotu zależał od formy i terminu stosowania nawozu. Rośliny nawożone saletrą amonową w stadium 5-6 liścia wykazały największy spadek zawartości N w okresie od stadium 7-8 liścia do stadium 8-9 liścia. Zawartość fosforu i azotu w stadium 7-8 liścia i 8-9 liścia była istotnie skorelowana z plonem ziarna. Większe współczynniki korelacji odnotowano dla stadium 8-9 liścia.
Słowa kluczowe: *kukurydza (Zea mays* L.*), nawożenie startowe, faza młodociana, współczynnik korelacji*

1. Introduction

Nutrients, including nitrogen, should be applied in such a way so that their uptake by maize follows the rhythm of its demand and growth in order to fully utilize maize yield-forming potential [1, 2]. Several phases can be distinguished in maize development, each of which plays a specific role in its life cycle. Maize builds up a potential yield structure in the 6-12-leaf stage, because this is when the cobs are set and the number of rows per cob is established [3]. This trait is genetically determined, nevertheless, the number of rows in the cob can be reduced as a result of environmental and agriculture stresses [4]. According to Subedi and Ma [5], plant nitrogen malnutrition before the 8-leaf stage leads to an irreversible reduction in the number of cobs and potential kernels even up to approx. 30%. Binder et al. [6] showed that the delay in nitrogen application to the 6-leaf stage reduced grain yield by 12%. Therefore, the aim of the field study was to determine the effect of nutrient content in maize plants collected at two juvenile developmental stages and their influence on grain yield.

2. Materials and Methods

2.1. Experimental field

Field trial was carried out at the Department of Agronomy of Poznan 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 $N \cdot ha^{-1}$, 70 kg $P_2O_5 \cdot ha^{-1}$ and 130 kg $K_2O \cdot ha^{-1}$) 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 net plot area for harvesting was 12.25 m^2. Thermal and humidity conditions in the maize growing seasons are presented in Tab. 1. 2018 was definitely the warmest and driest growing season. In turn, the largest sum of precipitation in the initial period of maize growth was recorded in 2016. The lowest average daily temperature at the level of 12.8°C was recorded in 2017. Soil abundance in basic macronutrients and pH is listed in Tab. 2.

Table 1. Average monthly air temperatures and monthly total precipitation for the growing season [7]
Tab. 1. Średnie miesięczne temperatury powietrza i miesięczne sumy opadów w sezonach wegetacyjnych kukurydzy [7]

Years	Temperature [°C]			
	April	May	June	Average
2015	9.3	13.9	16.9	13.4
2016	9.6	16.3	19.9	15.3
2017	7.3	13.7	17.4	12.8
2018	12.9	16.9	18.5	16.1
Years		Rainfall [mm]		Sum
2015	17.6	27.2	66.6	111.4
2016	47.3	47.3	123.8	218.4
2017	40.6	56.8	68.2	165.6
2018	36.2	17.4	25.6	79.2

Table 2. Nutrient contents and soil pH before establishing the experiment in maize growing seasons [7]
Tab. 2. Zawartość składników pokarmowych i pH gleby przed założeniem doświadczenia w sezonach wegetacyjnych kukurydzy [7]

Specification	Years			
	2015	2016	2017	2018
P [mg P kg^{-1} dm of soil]	40.0	104.0	73.0	49.0
K [mg K kg^{-1} dm of soil]	111.0	97.0	108.0	116.0
Mg [mg Mg kg^{-1} dm of soil]	29.0	44.0	53.0	53.0
pH [1 mol dm^{-3} KCl]	4.5	4.6	5.6	5.1

2.2. Plant material

A single plant sample consisted of 8 maize plants from each experimental plot at the discussed developmental stage. After drying, the content of minerals was determined.

2.2.1. Determination of N, P, K, Mg and Ca contents in plant dry matter at the 7-8-leaf stage (BBCH 17/18) and 8-9-leaf stage (BBCH 18/19)

The analysis of mineral contents in dry matter of plants was performed at the laboratory of the Agronomy Department of the Poznań University of Life Sciences, according to the methods described by Gawęcki [8].

2.2.2. Determination of micronutrient contents in plant dry matter at the 7-8-leaf stage (BBCH 17/18) and 8-9-leaf stage (BBCH 18/19)

Cu, Zn, Mn and Fe contents were determined at the Regional Chemical and Agricultural Station in Poznań, in accordance with the applicable methodology for this type of assays.

2.3. Statistical analysis of the results

Statistical analysis of the collected field results was performed using analysis of variance for dependent systems, i.e. for a complete randomized block design with split-split-plot units in 4 blocks. The significance of differences was tested at the level of 0.05. The interaction between grain yield and nutrient contents was determined using simple correlation analysis, using Excel 1997 spreadsheet and STATPAKU program.

3. Results

3.1. Changes in plant chemistry during the juvenile stage

3.1.1. 7-8-leaf stage (BBCH 17/18)

In the present study, none of the experimental factors significantly affected the content of phosphorus, magnesium, and calcium in the dry matter of maize plants at the 7-8-leaf stage (BBCH 17/18) – Tab. 3. For nitrogen, maize fertilized with nitrogen using top dressing was characterized by a significantly higher content of this component as compared to the pre-sowing application. A significantly higher potassium content was recorded for ammonium nitrate compared to urea (Tab. 3).

Table 3. Macronutrient contents in maize plants at the 7-8-leaf stage [$g \cdot kg^{-1}$] (2015-2018)
Tab. 3. Zawartość makroskładników w roślinach kukurydzy w fazie 7-8 liścia [$g \cdot kg^{-1}$] (2015-2018)

Experimental factor Factor levels		N	P	K	Mg	Ca
NP fertilizer placement depth	0 cm (broadcast)	39.52	4.55	44.51	2.25	2.01
	5 cm	45.55	5.66	41.83	2.06	1.75
	10 cm	46.84	5.13	42.14	2.01	1.79
	15 cm	42.29	5.76	38.28	1.90	1.56
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**	**ns**
Nitrogen fertilizer type	ammonium sulfate	43.69	5.34	43.05	2.06	1.74
	urea	43.40	5.21	40.32	2.05	1.82
NIR $_{0.05}$		**ns**	**ns**	**2.435**	**ns**	**ns**
Nitrogen supplementation date	before sowing	42.01	5.27	41.00	2.03	1.74
	5-6 leaf stage	45.09	5.28	42.38	2.01	1.81
NIR $_{0.05}$		**1.468**	**ns**	**ns**	**ns**	**ns**
Mean		43.54	5.27	41.68	2.04	1.77

ns – not significant

Source: own study / Źródło: opracowanie własne

In the present study, none of the experimental factors significantly affected the micronutrient contents in the dry matter of maize plants at the 7-8-leaf stage (BBCH 17/18) – Tab. 4. Zinc content in the dry matter of maize plants in the present study was significantly dependent on the interaction of the type of nitrogen fertilizer and date of supplemental nitrogen application (Tab. 5). In case of ammonium nitrate, the date of nitrogen dose supplementation did not significantly differentiate the value of this trait. For urea, maize fully fertilized with nitrogen before sowing was characterized by a significantly higher Zn content in plant dry matter compared to top dressing nitrogen fertilization.

3.1.2. 8-9-leaf stage (BBCH 18/19)

In the present study, none of the experimental factors significantly affected the content of nitrogen, potassium, magnesium and calcium in the dry matter of maize plants at the 8-9-leaf stage (BBCH 18/19) – Tab. 6. As regards phosphorus, a significantly higher content of this component was recorded for row fertilization (irrespective of depth) as compared to broadcast fertilization.

Nitrogen content in plant dry matter at the 8-9-leaf stage (BBCH 18/19) significantly depended on the interaction of nitrogen fertilizer type and date of application of supplemental nitrogen dose (Tab. 7). It was found that the type of nitrogen fertilizer applied before sowing had no significant effect on nitrogen content of maize plant dry matter at the discussed developmental stage. In the 5-6-leaf stage (BBCH 15/16), significantly higher nitrogen content was recorded for urea compared to ammonium nitrate (Tab. 7)

In the current study, none of the experimental factors differentiated the content of copper, zinc and manganese. Iron content in plant dry matter at the 8-9-leaf stage (BBCH 18/19) was significantly dependent on the depth of NP fertilization application (Tab. 8). Significantly the lowest Fe content in maize dry matter was noted for the application of NP fertilizer at a depth of 15 cm compared to the other tested depths of multi-component fertilizer application.

Table 4. Micronutrient contents in maize plants at the 7-8-leaf stage [$mg \cdot kg^{-1}$] (2015-2018)
Tab. 4. Zawartość mikroskładników w roślinach kukurydzy w fazie 7-8 liścia [$mg \cdot kg^{-1}$] (2015-2018)

Experimental factor / Factor levels		Cu	Zn	Mn	Fe
NP fertilizer placement depth	0 cm (broadcast)	5.26	53.55	112.03	254.42
	5 cm	4.70	54.18	131.39	289.79
	10 cm	4.55	52.75	113.39	324.04
	15 cm	4.31	52.01	108.26	389.04
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**
Nitrogen fertilizer type	ammonium sulfate	4.93	54.99	115.04	312.17
	urea	4.48	51.25	117.50	316.48
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**
Nitrogen supplementation date	before sowing	4.67	53.73	121.70	328.95
	5-6 leaf stage	4.74	52.51	110.83	299.70
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**
Mean		4.70	53.12	116.26	314.32

ns – not significant

Source: own study / Źródło: opracowanie własne

Table 5. Zn content in maize plants at the 7-8-leaf stage [$mg \cdot kg^{-1}$] (2015-2018)
Tab. 5. Zawartość Zn w roślinach kukurydzy w fazie 7-8 liścia [$mg \cdot kg^{-1}$] (2015-2018)

Nitrogen fertilizer type (B)	Nitrogen supplementation date (C)	
	before sowing	5-6 leaf stage
Ammonium sulfate	53.89	56.09
Urea	53.56	48.94
NIR $_{0.05}$	for the interaction of nitrogen fertilizer type (B) and nitrogen supplementation date C) B/C = 3.554; C/B = 6.981	

Source: own study / Źródło: opracowanie własne

Table 6. Macronutrient contents in maize plants at the 8-9-leaf stage [$g \cdot kg^{-1}$] (2015-2018)
Tab. 6. Zawartość makroskładników w roślinach kukurydzy w fazie 8-9 liścia [$g \cdot kg^{-1}$] (2015-2018)

Experimental factor / Factor levels		N	P	K	Mg	Ca
NP fertilizer placement depth	0 cm (broadcast)	37.78	3.52	50.94	2.37	1.95
	5 cm	41.32	4.30	48.39	2.62	1.67
	10 cm	43.74	4.90	49.58	2.35	1.65
	15 cm	41.89	4.75	50.98	2.38	1.72
NIR $_{0.05}$		**ns**	**0.444**	**ns**	**ns**	**ns**
Nitrogen fertilizer type	ammonium sulfate	40.26	4.41	50.79	2.52	1.78
	urea	42.10	4.32	49.16	2.34	1.72
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**	**ns**
Nitrogen supplementation date	before sowing	41.08	4.35	51.05	2.45	1.80
	5-6 leaf stage	41.29	4.38	48.90	2.41	1.69
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**	**ns**
Mean		41.18	4.36	49.97	2.43	1.74

ns – not significant

Source: own study / Źródło: opracowanie własne

Table 7. N content in maize plants at the 8-9-leaf stage [g·kg^{-1}] (2015-2018)
Tab. 7. Zawartość N w roślinach kukurydzy w fazie 8-9 liścia [g·kg^{-1}] (2015-2018)

Nitrogen fertilizer type (B)	Nitrogen supplementation date (C)	
	before sowing	5-6 leaf stage
Ammonium sulfate	40.72	39.80
Urea	41.43	42.77
NIR $_{0.05}$	for the interaction of nitrogen fertilizer type (B) and nitrogen supplementation date C) B/C = **1.275**; C/B = **2.614**	

Source: own study / Źródło: opracowanie własne

Table 8. Micronutrient contents in maize plants at the 8-9-leaf stage [mg·kg^{-1}] (2015-2018)
Tab. 8. Zawartość mikroskładników w roślinach kukurydzy w fazie 8-9 liścia [mg·kg^{-1}] (2015-2018)

Experimental factor Factor levels		Cu	Zn	Mn	Fe
NP fertilizer placement depth	0 cm (broadcast)	5.13	62.29	102.37	201.71
	5 cm	5.05	55.83	125.80	208.81
	10 cm	4.53	54.92	119.70	190.56
	15 cm	4.78	54.16	116.16	163.32
NIR $_{0.05}$		**ns**	**ns**	**ns**	**22.101**
Nitrogen fertilizer type	ammonium sulfate	4.74	56.80	112.15	186.50
	urea	5.01	56.81	119.86	195.68
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**
Nitrogen supplementation date	before sowing	4.79	55.95	116.45	179.52
	5-6 leaf stage	4.96	57.66	115.56	202.67
NIR $_{0.05}$		**ns**	**ns**	**ns**	**ns**
Mean		4.87	56.80	116.00	191.09

ns – not significant

Source: own study / Źródło: opracowanie własne

4. Discussion

The above considerations concerning the initial growth and development of maize plant were discussed in the studies of [9, 10]. The aim of the study [9] was to evaluate the effect of soil supplementation with different forms of nitrogen fertilization and magnesium on the dynamics of dry matter accumulation by two types of maize hybrids in their initial growth period. This study showed that the stay-green maize variety had a higher dry matter accumulation rate at the 5-6-leaf stage and a higher daily dry matter gain (AGR) compared to the conventional hybrid. Moreover, it was found that the "stay-green" variety ES Paroli was characterized by a significantly higher accumulation of N, K and Mg compared to the traditional variety ES Palazzo. It was shown that maize grain yield was significantly associated with the plant nutritional status at the 5-6-leaf stage, regardless of the type of maize hybrid. The work of [10] showed that the "stay-green" hybrid during maize growing season had a greater increase in dry matter of a single plant than the classic variety. The values of the absolute growth rate (AGR), expressed by the dry matter of a single plant, its leaf blades and grain, were higher for the "stay-green" variety compared to the conventional variety. Differences in dry weight gain of a single plant increased with generative development of the varieties. This result has confirmed previous literature reports [11]. According to the latter author, the second critical period of maize nitrogen demand occurs at the beginning of flowering. The nitrogen accumulation rate of maize doubles in the period from the heading stage (BBCH 55-59) to the full ear flowering stage (BBCH 65). However, the increased maize nitrogen demand is brief and decreases to the baseline value in the milk maturity stage, i.e. the rate of nitrogen accumulation before full flowering. According to this author, nitrogen uptake is consistent with dry matter accumulation by maize. The rate decrease is slower and ends in the early soft dough stage of kernels, i.e. at approx. 45% dry matter content. Thus, it should be concluded that in addition to proper nutrition of maize plants, maize variety (its type) also has a decisive role in the size of grain yield (Fig. 1).

The increase in grain yield due to row fertilization (different depths) should be attributed to the higher phosphorus content in the dry matter of maize plants during early development. In the present study, phosphorus content at the 7-8-leaf stage for broadcast fertilization was 4.55 g·kg^{-1}, while it was 5.51 g·kg^{-1} for row fertilization, irrespective of component depth. This content at the 8-leaf stage was 3.52 g·kg^{-1} for broadcast fertilization and 4.65 g·kg^{-1} for row fertilization, respectively. Our result was confirmed by Barry & Miller [13], who found that high phosphorus concentration in the dry matter of maize plants before the 6-leaf stage significantly increased grain yield. These authors further showed that obtaining higher grain yield of row-fertilized plants, as a result of better nutrition, increased grain number per cob. This was also confirmed by Miller et al. [14], who argued that proper plant nutrition in the juvenile stages had a decisive effect on the final maize yield. The statement mentioned above was also confirmed in the present study by the simple correlation coefficients between nutrient content at the juvenile stage and grain yield (Tab. 9, Tab. 10). It was demonstrated that maize grain yield was significantly correlated with nitrogen and phosphorus content in the dry matter of maize plants at the 7-8-leaf stage. In turn, at the 8-9-leaf stage, in addition to the positive effect of nitrogen and phosphorus contents on grain yield, the value of this trait was significantly positively correlated with manganese content, while negatively correlated with the content of calcium and zinc (Tab. 10).

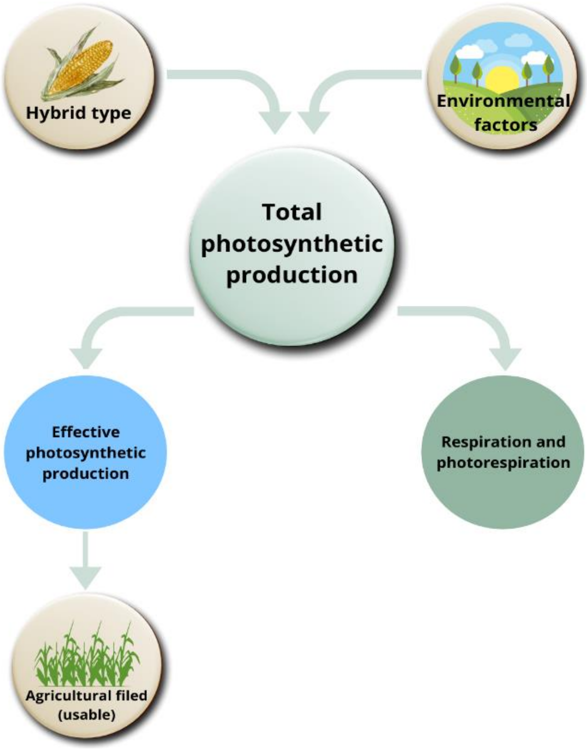

Fig. 1. List of factors determining the size and production of maize agricultural yield [12]
Rys. 1. Wykaz czynników decydujących o wielkości i produkcji plonu rolniczego kukurydzy [12]

Table 9. Correlation coefficients between nutrient contents in the dry matter of maize plants at the 7-8-leaf stage and grain yield
Tab. 9. Współczynniki korelacji pomiędzy zawartością składników pokarmowych zawartych w suchej masie roślin kukurydzy w fazie 7-8 liścia a plonem ziarna

Trait	N	P	K	Mg	Ca	Cu	Zn	Mn	Fe
P	0.265								
K	0.022	- 0.314							
Mg	0.039	- 0.497*	0.378**						
Ca	0.111	- 0.657**	0.467*	0.874**					
Cu	- 0.363	- 0.167	0.626**	0.235	- 0.28				
Zn	- 0.281	0.129	0.295	- 0.227	- 0.263	0.610*			
Mn	0.170	0.392	0.201	0.152	0.108	- 0.001	0.291		
Fe	- 0.086	0.372	- 0.800**	- 0.838**	- 0686**	- 0.329	0.006	- 0.319	
Grain yield	0.543*	0.523*	- 0.410	- 0.450	- 0.343	- 0.387	0.053	0.246	0.400

Source: own study / Źródło: opracowanie własne

Table 10. Correlation coefficients between nutrient contents in the dry matter of maize plants at the 8-9-leaf stage and grain yield
Tab. 10. Współczynniki korelacji pomiędzy zawartością składników pokarmowych zawartych w suchej masie roślin kukurydzy w fazie 8-9 liścia a plonem ziarna

Trait	N	P	K	Mg	Ca	Cu	Zn	Mn	Fe
P	0.738**								
K	- 0.61	- 0.083							
Mg	- 0.078	0.048	0.047						
Ca	- 0.820**	- 0.707**	0.504*	- 0.032					
Cu	- 0.175	- 0.574*	- 0.238	- 0.407	0.079				
Zn	- 0.568*	- 0.805**	0.027	- 0.213	0.555*	0.632**			
Mn	0.681**	0.548*	- 0.540*	0.110	- 0662**	- 0.081	- 0.536		
Fe	- 0.092	- 0.344	- 0.479	0.246	- 0.192	0.313	0.463	- 0.024	
Grain yield	0.722**	0.719**	- 0.258	0.321	- 0.719**	- 0.297	- 0.762**	0.734**	- 0.092

Source: own study / Źródło: opracowanie własne

5. Conclusions

1. Maize has a high capacity to compensate for growth in the early developmental stages, which results from the action of the component placed in deeper soil layers. Compensation of maize dynamics was probably caused by a significant increase in phosphorus content, which was already observed at the 7-8-leaf stage and confirmed at the 8-9-leaf stage.
2. The highest phosphorus content in plants was recorded at the 8-9-leaf stage for a depth of 10 cm. This value can be treated as optimal for agricultural practice.
3. A "mineral dilution effect" was observed in the period from the 7-8-leaf stage to the 8-9-leaf stage. This effect was pronounced for nitrogen, phosphorus and iron.
4. The effect of nitrogen dilution depended on the form and date of application of the fertilizer. Maize plants fertilized with ammonium nitrate at the 5-6-leaf stage showed the greatest decrease in N content in the period from the 7-8-leaf stage to the 8-9 leaf stage.
5. The content of phosphorus and nitrogen at the 7-8-leaf stage and the 8-9-leaf stage was significantly correlated with grain yield. Higher correlation coefficients were recorded for the 8-9-leaf stage.

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