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Nitrogen, Phosphorus and Year Effects on Grain Yield, Thousand Kernel Weight and Hectoliter Weight in Maize Crop

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ABSTRACT

Efficient nitrogen (N) and phosphorus (P) fertilization is essential for optimizing maize yield. A three-factorial field experiment was conducted at the Agricultural Research and Development Station (ARDS), Turda, Romania, during 2022 to 2024, using the maize hybrid *Zea mays* L. Turda 344. The experimental factors included year (2022, 2023, 2024), nitrogen fertilization (0-200 kg/ha N), and phosphorus fertilization (0-160 kg/ha P_2O_5), established in a randomized complete block design with six replications on clay-loam Chernozem soil. The results showed significant main effects of year and nitrogen on yield, with 2023 producing significantly higher yields compared with the other years. Grain yield increased from 5093 kg/ha under unfertilized conditional (N_0) to a maximum of 6666 kg/ha at an optimal nitrogen rate of 150 kg/ha N. Phosphorus application resulted in a modest yield increase, from 5,881 kg ha^{-1} (P0) to 6,146 kg ha^{-1} at the highest P rate. Thousand-kernel weight (TKW) showed a strong response to nitrogen, whereas hectoliter weight (HW) remained mostly unchanged. These findings indicate that nitrogen is the primary driver of yield improvements under the local agro-climatic conditions, with an optimal application rate of 150 kg/ha N recommended for sustainable maize production.

Keywords: nitrogen, phosphorus, yield, thousand kernel weight, hectoliter weight.

INTRODUCTION

Agriculture, as the main source of food, is significantly affected by climate change, such as temperature fluctuations and irregular rainfall (Markou et al., 2020). One of the strategies for increasing the yields of agricultural crops, to produce enough food for the world population, is to maintain soil fertility.

Fertilization is a widely used management practice that increases crop productivity and is found in almost all agricultural regions (Ju et al., 2009). This technological approach, along with the climate regime, meets the requirements of agricultural crops. To ensure food for people and achieve high yields it is necessary to apply mineral fertilizers, since they by their faster action will satisfy the nutritional requirements of crops faster than natural or organic fertilizers (Brodowska et al., 2022).

Maize (*Zea mays* L.) is an essential crop worldwide due to its use as food for humans, animals, and industry, being a significant source of starch (Gul et al., 2021). To achieve optimal yields, maize demands advanced crop technology, and its yield is significantly determined by effective fertilizer application (Cheverdin and Piskareva, 2020). However, it is important that fertilization applications be balanced; otherwise, excessive or irrational fertilization can reduce the efficiency of fertilizer use and cause various environmental problems (Zhao et al., 2014).

Fertilization is an effective method to increase soil fertility and crop yield (Zhang et al., 2025), but long-term fertilizer application and multi-annual fertilization lead to essential changes in soil fertility (Petcu and Petcu, 2006; Rusu et al., 2024b).

As regards the evolution of soil fertility under the impact of long-term fertilization, it is useful to focus attention on sustainability by achieving high yields while maintaining the balance of the soil-plant system and the favorable evolution of soil productivity and fertility (Chiper et al., 2024).

Among the nutrients needed for crop growth, nitrogen (N) as well as phosphorus

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(P) are considered the most important elements for the successful cultivation of maize (Ibrahim et al., 2021; Nefziger and Rapp, 2021).

Nitrogen is one of the most important nutrients for agricultural production, especially for maize yields (Fathi, 2022; Laskari et al., 2022), but it is often better valued when fertilization is supplemented with phosphorus.

In this context, the present paper aims to bring new information on the effect of long-term fertilization with NP-type mineral fertilizers on the development of the crop, as well as the identification of sustainable variants of fertilization of maize.

MATERIAL AND METHODS

A poly-factorial field experiment was conducted over three years (2022-2024) at the Agricultural Research and Development Station (ARDS) Turda to evaluate the effect of long-term fertilization on maize yield, Thousand Kernel Weight (TKW) and Hectoliter Weight (HW). The experiment was realized according to the method of randomized blocks with six repetitions and 65,000 plants/ha. The soil on which the experiment was located was a clay-illuvial chernozem with medium fertility, weak acid-neutral pH and moderate content of phosphorus and mobile potassium.

The experiment had nitrogen and phosphorus fertilization as experimental factors, as follows: nitrogen (N) doses: 0, 50, 100, 150, 200 kg N (active substance - a.s.) ha, was applied in the form of ammonium nitrate, entirely at sowing; phosphorus doses (P): 0, 40, 80, 120, 160 kg P_2O_5 (active substance - a.s.) ha, were fully applied in autumn, in the form of superphosphate, with incorporation under the plough. The third experimental factor is the year of study (A): 2022, 2023, and 2024.

The biological material used was the maize hybrid Turda 344, created at ARDS Turda. This is a hybrid with a medium vegetation period (FAO 380), adapted to the conditions of the Transylvanian culture area, characterized by good yield stability and moderate tolerance to water stress.

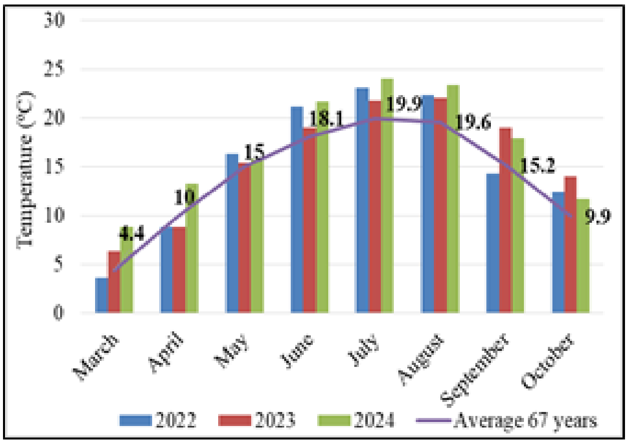
For weed control specific herbicides were used in pre-emergence and post-emergence.

The obtained results were processed statistically by the variance analysis method and establishing the least significant difference - LSD - (5%, 1% and 0.1%) (ANOVA, 2015).

The climate of the area is continental-moderate, with average multiannual temperature (67 years) of 9.3°C and an annual rainfall amount of 532.2 mm, distributed unevenly during the year.

Data on average temperature (Figure 1) show that in Turda, monthly temperatures are generally higher than the multi-annual average, with some exceptions (months April and September), suggesting that in the Transylvanian Plateau, the process of heating the weather is present. These temperatures negatively impacted the maize crop; those in spring caused a delayed emergence, while summer temperatures affected the formation and filling of maize grain cobs.

The rainfall regime (Figure 1) was variable, during the vegetation period from one month to another and from one year to another. The drought prevailing in most spring and summer months, except for 2023 when starting in June, the amount of rainfall accumulated until the end of the vegetation period was above the normal period, which is reflected in the maize yield.



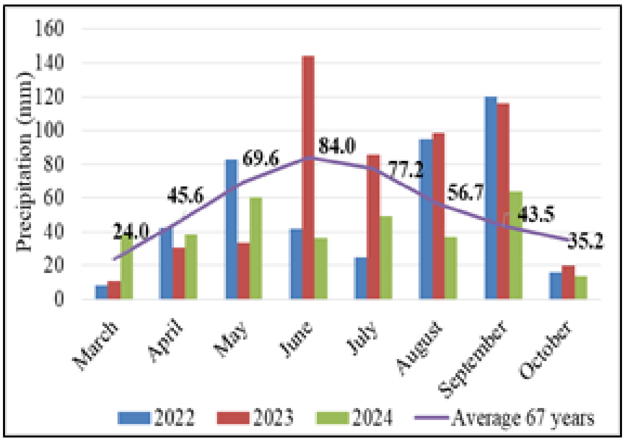


Figure 1. Average air temperature and the sum of precipitation recorded during the maize growing season

RESULTS AND DISCUSSION

Analysis of variance showed very significant effects for year (A) and nitrogen (N) on grain yield. Phosphorus (P) had a modest but significant effect on $p < 0.05$. The interactions of A×N and A×P were also significant, indicating the variation in fertilization response according to annual conditions (Table 1).

The results obtained by Barşon et al. (2021) also showed that fertilization had a significant influence on the yield and mass of 1000 grains (TKW). However, large and excessive doses of N, applied disproportionately to P, can lead to acidifying effects on soils (Rusu et al., 2024a).

Table 1. Analysis of variance table results

Anova	DF	Yield			TKW			HW		
		S	s^2	F	S	s^2	F	S	s^2	F
Year (A)	2	264284400	132142200***	789.507***	9048***	4524	25.31***	755	377.45	134.665***
Phosphorus (P)	4	3415804	853951**	4.845**	2117**	529	3.10**	34	8.46	12.157***
AP	8	9439185	1179898	6.695	3994**	499	2.92	7	0.88	1.262
Nitrogen (N)	4	143009000	35752260***	164.464***	19448	4862	34.28**	9	2.20	3.329**
AN	8	17270960	2158871	9.931	5924	740	5.22	25	3.18	4.794
PN	16	6469281	404330	1.860	1626	102	0.72	12	0.77	1.157
APN	32	8185511	255797	1.177	7613	238	1.68	27	0.85	1.283
Error A	10	1673730	167373		1788	179		28	2.80	
Error P	60	10574170	176236		10257	171		42	0.70	
Error N	300	65216170	217387		42544	142		199	0.66	
T o t a l	444	529538211			104359			1138		

The need for food for the needs of the growing population is growing, and the scarcity of water resources is becoming increasingly serious (Shi et al., 2023), being an important factor contributing to the decrease in production.

The lack of rainfall during the maize growing season has significantly impacted the maize crop, resulting in a yield that did not exceed 8000 kg/ha. In comparison to the average yield of 6039 kg/ha (Control), the year 2023 recorded the highest yield at 7,107 kg/ha, with a difference of 1068 kg/ha, which is statistically confirmed as very significant. In contrast, the yields in 2022 and 2024 were below the average, at 5345 kg/ha and 5666 kg/ha, respectively.

The Thousand Kernel Weight (TKW) values were higher in 2023, averaging 272 g, while they were lower in 2024 at 262 g. The Hectoliter Weight (HW) values showed some variation; in 2024, the highest HW of 70.6 g was recorded, compared to 67.5 g in 2022 and 69.2 g in 2023 (Table 2).

Table 2. Year effects on grain yield, thousand kernel weight and hectoliter weight in maize crop

Year	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average	6039	Control	267	Control	69.1	Control
2022	5345	-695^{000}	266	-1	67.5	-1.64^{000}
2023	7107	1068***	272	5**	69.2	0.11
2024	5666	-373^{000}	262	-5^{00}	70.6	1.53***
LSD (p 5%)	105		3		0.4	
LSD (p 1%)	150		5		0.6	
LSD (p 0.1%)	217		7		0.9	

Nitrogen fertilization of maize is one of the most important management practices affecting crop growth and yield (Binder et al., 2000).

Many maize growers apply mineral fertilizers without prior agrochemical analysis and without considering the needs of the crop, so only a part of the applied quantity is used properly by the plants, the rest being retained in the soil or transferred to the water by leaching or washing. Some researchers state that the uptake or use of nitrogen in plants is increased by 60% in the case of ammonium nitrate (AN) fertilization source (da Silva et al., 2020).

Data from differentiated nitrogen application show that yield increased steadily with the nitrogen dose up to 627 kg/ha at the maximum nitrogen dose. The application of nitrogen fertilizers led to an increase in yield ranging between 1478 and 2806 kg/ha, compared to the unfertilized control as observed by Șimon et al. (2022). TKW, compared to the experiment average, had negative differences of 5 g at N_{50} and 11 g at N_0, with significant and very significant differences. At high nitrogen doses (N_{150}) there was an increase of up to 6 g, but after this threshold a slight decrease (5 g) was observed when applying N_{200}, both values having statistically assured significance compared to N_0. HW compared to average (69.1) varied slightly, with statistically significantly negative assured difference at N_0 for the other nitrogen doses the differences did not register statistical assurance (Table 3).

Table 3. Nitrogen application effects on grain yield, thousand kernel weight and hectoliter weight in maize crop

N	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average	6039	Control	267	Control	69.1	Control
0	5093	-946^{000}	256	-11^{000}	68.9	-0.20^{0}
50	5765	-274^{000}	262	-5^{0}	69.4	0.15
100	6179	140*	270	3	69.1	0.05
150	6493	454***	273	6***	69.2	0.13
200	6666	627***	272	5**	69.0	-0.13
LSD (p 5%)	137		4		0.2	
LSD (p 1%)	180		5		0.3	
LSD (p 0.1%)	231		6		0.4	

The data presented in Table 4 shows that compared to the average (6039 kg/ha) the yield did not vary excessive, the values being quite close. The application of a 40 kg/ha dose of P_2O_5 increases maize yield by 171 kg/ha compared to when phosphorus was not applied. Moreover, all P doses have yield increases compared to level 0, the differences reach up to 265 kg/ha. This is also the case with TKW, where although there is an increase in values when applying the first dose of phosphorus, there are no statistically assured differences, it is well known that there is a direct relationship between production and TKW. In the case of HW there was an increase only in the variant applied to 120 kg/ha P, the difference being significant compared to the average, but the costs of applying phosphorus do not justify this increase.

Although in our study the results on the application of phosphorus are not impressive, as some authors say, the application of phosphorus fertilizers can increase the yield of crops such as maize, up to 65% in soil conditions with low phosphorus content (Amanullah et al., 2010).

Table 4. Phosphorus application effects on grain yield, thousand kernel weight and hectoliter weight in maize crop

P_2O_5	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average	6039	Control	267	Control	69.1	Control
0	5881	-158^{0}	263	-4^{0}	68.6	-0.50^{000}
40	6052	13	270	3	69.1	0.04
80	6078	39	267	0	69.1	-0.04
120	6039	-	266	-1	69.4	0.28*
160	6146	107	267	0	69.3	0.22
LSD (p 5%)	125		4		0.3	
LSD (p 1%)	166		5		0.3	
LSD (p 0.1%)	217		7		0.4	

To fully harness the potential of nitrogen, it is essential to maintain ideal environmental conditions. When the soil is parched and the air is frosty, the effectiveness of nitrogen diminishes significantly, hampering its ability to nourish plants and enhance growth.

Nitrogen efficiency was strongly conditioned by climate variables. In 2022, when temperatures were much higher than normal, associated with a poor rainfall regime, yields were lower than in the same year. However, by applying nitrogen at the maximum dose, an increase in yield of 1255 kg/ha compared to the N_0 variant was obtained. In 2023, climate conditions were more favorable for maize crops, and yield increased along with higher nitrogen (N) doses, with the most significant differences observed at elevated N levels. In 2024, the efficiency of higher nitrogen doses was not utilized as effectively as in the previous two years, although the difference from the unfertilized control was 1228 kg/ha. In the case of TKW, the interaction between climatic conditions and nitrogen doses did not have a very large influence; the differences obtained in this case were not statistically significant. In 2022, HW was recorded as lower than the average for the analyzed years, while in 2024, it was found to be higher than this average. The observed differences were statistically significant for each nitrogen dose applied. However, in 2023, the differences noted did not reach statistical significance when compared to the average of the three years, as detailed in Table 5.

The observed nitrogen trend was also confirmed for phosphorus; in 2022 and 2024, the yields were lower, regardless of the applied dose. In 2022 and 2023, the highest yields were obtained at average phosphorus doses, but in 2024, they increased at the same time as phosphorus doses. TKW values were linear in the case of the interaction of climatic factors with phosphorus, with small exceptions for 2023, where slight increases were recorded. As with nitrogen, HW was higher for 2024 and lower for 2022, with very significant statistical differences, confirming the potential for maximum recovery in favorable years and the role of phosphorus in improving quality even under more restrictive conditions (Table 6).

Table 5. Year effects and nitrogen doses on grain yield, thousand kernel weight and hectoliter weight in maize crop

Year	N	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average		5093	Control	256	Control	68.9	Control
2022	0	4682	-411^{000}	263	7*	66.7	-2.23^{000}
2023		5657	564***	260	4	69.3	0.41
2024		4940	-153	245	-11^{000}	70.7	1.82***
Average		5765	Control	262	Control	69.2	Control
2022	50	5076	-689^{000}	256	-6^{0}	67.6	-1.66^{000}
2023		6773	1008***	272	10**	69.4	0.12
2024		5446	-319^{00}	259	-3	70.8	1.54***
Average		6180	Control	270	Control	69.1	Control
2022	100	5376	-803^{000}	270	0	67.7	-1.48^{000}
2023		7374	1194***	272	2	69.0	-0.11
2024		5789	-391^{00}	268	-2	70.7	1.59***
Average		6493	Control	273	Control	69.2	Control
2022	150	5652	-841^{000}	270	-3	67.8	-1.39^{000}
2023		7839	1346***	279	6*	69.4	0.19
2024		5988	-505^{000}	270	-3	70.4	1.21***
Average		6666	Control	272	Control	69.0	Control
2022	200	5937	-729^{000}	272	0	67.5	-1.43^{000}
2023		7893	1227***	280	8*	68.9	-0.05
2024		6168	-498^{000}	265	-7^{0}	70.4	1.48***
LSD (p 5%)		237		6		0.6	
LSD (p 1%)		316		9		0.8	
LSD (p 0.1%)		414		11		1.1	

Table 6. Year effects and phosphorus doses on grain yield, thousand kernel weight and hectoliter weight in maize crop

Year	P_2O_5	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average		5881	Control	263	Control	68.6	Control
2022	0	5141	-741^{000}	268	4.62	67.1	-1.54^{000}
2023		7097	1215***	270	7.25*	68.8	0.19
2024		5407	-474^{000}	251	-11.87^{00}	69.9	1.35***
Average		6052	Control	270	Control	69.1	Control
2022	40	5363	-689^{000}	271	1.14	67.5	-1.67^{000}
2023		7256	1204***	273	3.48	69.3	0.16
2024		5538	-515^{000}	265	-4.63	70.6	1.51***
Average		6078	Control	267	Control	69.1	Control
2022	80	5568	-510^{000}	264	-3.44	67.1	-1.91^{000}
2023		7141	1063***	271	4.25	69.2	0.14
2024		5525	-553^{000}	266	-0.81	70.8	1.77***
Average		6039	Control	266	Control	69.4	Control
2022	120	5382	-657^{000}	263	-3.26	67.8	-1.61^{000}
2023		6897	858***	272	6.01	69.4	0.04
2024		5837	-202	264	-2.75	70.9	1.57***
Average		6146	Control	267	Control	69.3	Control
2022	160	5270	-876^{000}	265	-2.28	67.8	-1.47^{000}
2023		7144	998***	275	7.93*	69.3	0.03
2024		6024	-122	262	-5.65	70.8	1.45***
LSD (p 5%)		220		7		0.6	
LSD (p 1%)		297		9		0.8	
LSD (p 0.1%)		397		13		1.1	

The effect of applying nitrogen doses on phosphorus doses revealed cumulative effects. The application of phosphorus did not compensate for the lack of nitrogen, so regardless of the phosphorus dose, both the yield, TKW and HW remained modest, but at medium and high nitrogen doses (N_{150}-N_{200}), phosphorus fertilization caused very significant yield increases. In the $N_{200} \times P_{160}$ variant, the yields exceeded 7000 kg ha, with high values but not significant for TKW and no differences for HW (Table 7).

Previous studies have clearly shown the beneficial effect of nitrogen and phosphorus fertilizations on the growth, development, and yield of maize (Szulc et al., 2020), but the unilateral or phosphorus-only application of maize does not produce very good results.

Table 7. Nitrogen doses effect on phosphorus doses on grain yield, thousand kernel weight, and hectoliter weight in maize crop

N	P_2O_5	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average		5881	Control	263	Control	68.6	Control
0	0	5128	-753^{00}	255	-8^{0}	68.7	0.06
50		5686	-196	260	-3	69.1	0.55*
100		5959	77	265	2	68.4	-0.20
150		6391	509**	267	4	68.5	-0.07
200		6244	363*	267	4	68.3	-0.34
Average		6052	Control	270	Control	69.1	Control
0	40	4997	-1056^{000}	258	-12^{00}	68.7	-0.41
50		5809	-243	264	-6	69.4	0.29
100		6055	3	274	4	69.2	0.10
150		6607	555***	277	7	69.3	0.16
200		6794	742***	275	5	69.0	-0.15
Average		6078	Control	267	Control	69.1	Control
0	80	5077	-1001^{000}	253	-14^{000}	68.9	-0.11
50		5770	-308^{0}	262	-5	69.0	-0.05
100		6349	271	269	2	69.2	0.16
150		6571	493**	276	9*	69.3	0.21
200		6622	544***	277	10**	68.8	-0.22
Average		6039	Control	266	Control	69.4	Control
0	120	5139	-900^{000}	258	-8^{0}	69.0	-0.35
50		5638	-400^{0}	263	-3	69.3	-0.07
100		6260	221	268	2	69.6	0.21
150		6522	483**	273	7	69.5	0.17
200		6635	596***	269	3	69.4	0.04
Average		6146	Control	267	Control	69.3	Control
0	160	5124	-1021^{000}	256	-11^{00}	69.1	-0.18
50		5922	-224	261	-4	69.4	0.05
100		6274	126	274	7	69.3	-0.03
150		6374	228	273	6	69.5	0.15
200		7035	889***	274	7	69.3	0.01
LSD (p 5%)		306		8		0.5	
LSD (p 1%)		402		10		0.7	
LSD (p 0.1%)		516		13		0.9	

It is worth noting that the average maize yield ranged from 5093 kg/ha (N_0) to 7035 kg/ha ($N_{200}P_{160}$), but in phosphorus doses the biggest differences were only 369 kg/ha ($P_{160}N_{200}$). The lack of phosphorus at high doses of N generated significant decreases (422 kg/ha), highlighting the need for balanced intake of P for nitrogen recovery. TKW oscillated between 253 g and 277 g, depending on the level of nitrogen and phosphorus applied. The HW was relatively stable (68.3-69.6 kg/hl), but in this case the lack of phosphorus resulted in decreases of up to 0.74 kg/hl (N100) (Table 8).

Overall, the results demonstrate that medium-large doses of P (80-160 kg/ha a.s.) associated with N (100-200 kg/ha a.s.) ensure high yields, but according to Gudžić et al. (2019), long-term mineral fertilization can lead to increased soil acidity it is therefore important to use appropriate doses of fertilizers that ensure stable yields and keep the soil in optimal condition.

Table 8. Phosphorus doses effect on nitrogen doses on grain yield, thousand kernel weight and hectoliter weight in maize crop

P_2O_5	N	Yield (kg/ha)	Difference/ Significance	TKW (g)	Difference/ Significance	HW (kg/hl)	Difference/ Significance
Average		5093	Control	256	Control	68.9	Control
0	0	5128	35	255	-1	68.7	-0.24
40		4997	-96	258	2	68.7	-0.18
80		5077	-16	253	-3	68.9	0.05
120		5139	46	258	2	69.0	0.13
160		5124	31	256	0	69.1	0.24
Average		5765	Control	262	Control	69.2	Control
0	50	5686	-79	260	-2	69.1	-0.10
40		5809	44	264	2	69.4	0.17
80		5770	6	262	0	69.0	-0.24
120		5638	-126	263	1	69.3	0.05
160		5922	157	261	-1	69.4	0.12
Average		6180	Control	270	Control	69.1	Control
0	100	5959	-221	265	-5	68.4	-0.74^{00}
40		6055	-124	274	4	69.2	0.09
80		6349	169	269	-1	69.2	0.08
120		6260	81	268	-2	69.6	0.44
160		6274	95	274	4	69.3	0.14
Average		6493	Control	273	Control	69.2	Control
0	150	6391	-102	267	-6	68.5	-0.69^{0}
40		6607	114	277	4	69.3	0.07
80		6571	78	276	3	69.3	0.05
120		6522	29	273	0	69.5	0.32
160		6374	-119	273	0	69.5	0.25
Average		6666	Control	272	Control	69.0	Control
0	200	6244	-422^{000}	267	-5	68.3	-0.71^{0}
40		6794	128	275	3	69.0	0.02
80		6622	-44	277	5	68.8	-0.12
120		6635	-31	269	-3	69.4	0.45
160		7035	369*	274	2	69.3	0.36
LSD (p 5%)		301		8		0.5	
LSD (p 1%)		397		11		0.7	
LSD (p 0.1%)		510		14		0.9	

CONCLUSIONS

Grain yield of maize exhibited a positive response to increasing nitrogen application, increasing from 5,093 kg ha^{-1} in the unfertilized control (N_0) to a maximum of 7,035 kg ha^{-1} under the $N_{200}P_{160}$ treatment. Phosphorus fertilization significantly enhanced nitrogen use efficiency at higher N rates, whereas the omission of phosphorus at elevated nitrogen levels ($N_{200}P_0$) resulted in marked yield penalties, highlighting the strong synergistic interaction between nitrogen and phosphorus in maize nutrition.

Thousand-kernel weight varied between 253 and 277 g and was positively influenced by moderate phosphorus rates (40-80 kg ha^{-1}), while severe reductions were observed under phosphorus deficiency. Hectoliter mass remained relatively stable across fertilization treatments (68.3-69.6 kg hL^{-1}); however, the absence of phosphorus, particularly in combination with high nitrogen rates, led to statistically significant decreases, indicating impaired grain quality under nutrient imbalance.

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