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INFLUENCE OF NITROGEN AND PHOSPHORUS FERTILIZATION ON WHEAT YIELD UNDER RAINFED CONDITIONS AT S.C.D.A. ȘIMNIC-CRAIOVA

Dunăreanu Claudia[1], Novac Mihaela[1], Radu Valeriu[1*], Piscanu Liliana[1], Islicaru Ileana[1], Popescu Loredana[1]
[1] Șimnic-Craiova Agricultural Research and Development Station (S.C.D.A. Șimnic-Craiova), 54 Șoseaua Bălcești, 200721 Craiova, Dolj, Romania
** Correspondence author. E-mail*: raduvaleriu17@yahoo.com

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ABSTRACT

This study evaluated the effect of nitrogen and phosphorus fertilization on wheat grain yield under rainfed conditions at S.C.D.A. Șimnic-Craiova during 2022-2026.The experiment was conducted as a two-factor 5 × 5 design with two replications and 25 fertilizer combinations. Phosphorus was applied at rates of 0-160 kg P_2O_5 ha^{-1}, while nitrogen rates ranged from 0 to 160 kg N ha^{-1}. Mean grain yield increased from 1.81 t ha^{-1} in the unfertilized control (P0N0) to 6.87 t ha^{-1} at P160N120. Both phosphorus and nitrogen had highly significant effects on wheat yield. However, the interaction between the two nutrients was not statistically significant. Nitrogen application increased yield from 3.26 t ha^{-1} at N0 to 5.92 t ha^{-1} at N160. The small and non-significant difference between N120 and N160 indicated a yield plateau at higher nitrogen doses. Although P160N120 produced the highest numerical yield, it did not differ significantly from P160N160.The results confirm the importance of balanced N and P fertilization, while showing that yield alone cannot establish the economic optimum fertilizer dose.

INTRODUCTION

Wheat productivity is determined by the availability of nutrients and water, as well as by soil properties and environmental conditions that control fertilizer-use efficiency (Aulakh & Malhi, 2005). Long-term experiments have shown that combined nitrogen and phosphorus application can support higher yields than separate application or omission of either nutrient (Hao et al., 2007; Takahashi & Anwar, 2007). At the same time, the relationship between applied N and P levels and wheat yield is often nonlinear, with yield increments decreasing as fertilization levels increase (Lollato et al., 2019; Yokamo et al., 2023).

In rainfed systems, nitrogen-use efficiency is closely dependent on soil water availability. The water regime, nitrogen rate, and method of application can influence both wheat yield and the efficiency of nitrogen use (Garabet et al., 1998; López-Bellido & López-Bellido, 2001; López-Bellido et al., 2005). In southwestern Romania, limited rainfall and the low fertility of sandy soils have also been identified as constraints to crop production in a study on cowpea (Matei et al., 2015). For phosphorus, crop response to fertilization depends to a large extent on the soil

nutrient-supply status and soil properties, which supports adapting P inputs to the agrochemical context of the study area (Buczko et al., 2018).

In southern and southwestern Romania, field studies have documented the positive effect of combined N-P fertilization on winter wheat yield (Mocanu et al., 2012) and fertilizer-dependent changes in the accumulation of major macroelements in soil and wheat plants, accompanied by differences in yield (Dodocioiu & Buzatu, 2024). Soil reaction, humus content, and nutrient-supply level are therefore key indicators for characterizing the agrochemical status of a site and establishing an appropriate fertilization regime (Dodocioiu et al., 2013). Although nutrient losses were not assessed in the present experiment, they should be considered when fertilization recommendations are extrapolated to sloping agricultural land, where runoff-related losses may occur (Dodocioiu et al., 2012). The present study focuses on grain yield; however, research on wheat in southwestern Romania has also addressed quality-related traits, including the phenolic content and antioxidant activity of whole-grain flour (Păunescu et al., 2016).

Previous assessments of the reddish preluvosol at S.C.D.A. Șimnic-Craiova highlighted its acidic reaction and relatively low level of natural fertility, characteristics relevant to crop nutrition and fertilizer response (Radu et al., 2019).

Although the favorable effects of N and P fertilization on wheat are well documented, information on the shape of the yield response to graded combinations of the two nutrients under rainfed conditions and on the preluvosol at Șimnic is less developed. Characterizing this response is important because limited availability of one nutrient can restrict the utilization of the other, while at higher rates yield increases tend to diminish. The working hypothesis was that combined N-P fertilization produces higher yields than separate application of the two nutrients and that the yield response becomes curvilinear, with smaller marginal increases at higher fertilization levels.

The objective of this study was to evaluate the grain-yield response to five nitrogen fertilization levels and five phosphorus fertilization levels, applied separately and in combination during 2022-2026, and to characterize the shape of the N-P response and identify the zone of maximum observed yield under rainfed conditions at S.C.D.A. Șimnic-Craiova. The analysis is limited to the mean N–P yield response across the five seasons; treatment-specific interannual variability is outside the scope of this study.

MATERIAL AND METHODS

The experiment comprised five winter wheat growing seasons corresponding to the 2022-2026 harvest years, from the 2021-2022 to the 2025-2026 agricultural cycle, and was conducted at the Șimnic-Craiova Agricultural Research and Development Station under rainfed conditions. Winter wheat was grown after maize, and the biological material used was the Dropia cultivar.

The experiment was organized as a two-factor 5x5 design with two replications, with treatments laid out in the field according to the Latin rectangle method. Factor A was phosphorus fertilization, expressed as P_2O_5, at five levels: 0, 40, 80, 120, and 160 kg P_2O_5 ha^{-1} (P0-P160); factor B was nitrogen fertilization at five levels: 0, 40, 80, 120, and 160 kg N ha^{-1} (N0-N160. This resulted in 25 fertilization treatments and 50 experimental plots. Each plot measured 8x4 m (32 m^2), and P0N0 was the unfertilized control.

Mineral fertilization was differentiated according to the N and P levels

specified for each treatment. The following fertilizers were used: 20-20-0 compound fertilizer, ammonium nitrate containing 33.4% N, and 36% P_2O_5 concentrated superphosphate. Ammonium nitrate was used in treatments fertilized exclusively with nitrogen, while concentrated superphosphate was used in those fertilized exclusively with phosphorus. In treatments receiving combined fertilization, the requirements for the two nutrients were supplied using the compound fertilizer and, where necessary, supplemented with single-nutrient fertilizers. Phosphorus fertilizers and the 20-20-0 compound fertilizer were applied before sowing and incorporated during seedbed preparation, whereas ammonium nitrate was applied in spring during the growing season.

Land preparation included ploughing to depths ranging from 18 to 32 cm, followed by disking before sowing. Sowing was carried out in October of the year preceding harvest, and harvesting took place in July. Axial One (1 L ha^{-1}), Mustang (0.5 L ha^{-1}), Karate Zeon (0.15 L ha^{-1}), and Falcon Pro (0.8 L ha^{-1}) were used for weed, disease, and pest control.

At the beginning of the experiment, before the establishment of the fertilization treatments, the soil profile at the experimental site was characterized agrochemically. These determinations were performed in order to establish the initial soil conditions. Soil reaction (pH) was determined potentiometrically in an aqueous suspension at a soil: water ratio of 1:2.5 (SR 7184/13-2001). Humus content was determined by the Walkley-Black wet-oxidation method, as modified by Gogoașă (STAS 7184/21-82), and total nitrogen by the Kjeldahl method (STAS 7184/2-85). Available phosphorus and potassium were extracted in ammonium acetate-lactate solution according to the Egner-Riehm- Domingo method; phosphorus was determined by UV-Vis spectrophotometry and potassium by flame photometry. The degree of base saturation (V,%) was expressed according to determinations of the soil adsorption complex.

Meteorological data for the five agricultural cycles corresponding to the 2022-2026 harvest years (2021-2022, 2022-2023, 2023-2024, 2024-2025, and 2025-2026) showed pronounced climatic variability under rainfed conditions. Total precipitation was 508.3, 775, 463, 438, and 781 mm, respectively, compared with the corresponding long-term means of 663.7, 658.7, 663.7, 661.8, and 639.7 mm. The respective precipitation deviations were -155.4, +116.3, -200.7, -223.8, and +141.3 mm. Mean temperatures were 12.7, 13.5, 15.5, 13.5, and 12.7 °C, with deviations from the corresponding long-term means of +0.3, +1.1, +3.1, +1.0, and 0.0 °C, respectively. These meteorological data characterize the rainfed conditions under which the mean response of wheat yield to N–P fertilization was evaluated.

Grain yield was determined annually during 2022-2026 and expressed in t ha^{-1}. A combined factorial analysis of variance was conducted on the annual means of the 25 N-P combinations to evaluate the average fertilization response across the five harvest years (2022-2026). Year was included as a blocking factor, whereas phosphorus fertilization (P), nitrogen fertilization (N), and the PxN interaction were treated as fixed effects. In this analysis, the residual term represented the variation in treatment response among years that was not partitioned into separate year x fertilization interaction components. The residual term had 96 degrees of freedom and was used as the error term for testing the mean effects across years. Least significant differences (LSD) for comparing means were calculated from the residual error mean square at the 5 %,1 %, and 0.1 % significance levels. For the main factors P and N, LSD values were calculated for comparisons among marginal means, while

the corresponding LSD for treatment-combination means was used for pairwise comparisons among the 25 N-P combinations.

To further characterize the shape of the yield response, the 25 means of the N-P combinations were analyzed using a second-order polynomial response-surface model: $Y = \beta_0 + \beta_1 xP + \beta_2 xN + \beta_{11} xP^2 + \beta_{22} xN^2 + \beta_{12} xPxN$, where xP and xN were coded as 0,1,2,3, and 4 for the nominal levels 0,40,80,120, and 160. The model was used descriptively to characterize the curvilinear response and the approach to a yield-plateau region.

RESULTS AND DISCUSSIONS

The soil in the experiment developed on fine-textured proluvial parent material deposited over sands and gravels. The groundwater table is at a depth greater than 10 m. In the A horizon (0-27 cm), the texture is loamy-clayey, with 31.9 % clay. The agrochemical characterization of the soil profile is presented in Table 1.

Table 1

Agrochemical characteristics of the soil profile at the experimental site

Horizon	Depth (cm)	pH (H_2O)	Humus (%)	Total N (%)	Available P_2O_5 (mg 100 g^{-1} soil)	Available K_2O (mg 100 g^{-1} soil)	V (%)
A	0–27	5.8	2.03	0.090	1.90	12.5	76.84
A/B	27–48	6.1	1.10	0.071	1.70	13.8	82.47
Bt_1	48–75	6.4	0.94	0.060	1.68	15.1	83.26
Bt_2	75–100	6.4	1.10	0.056	1.70	15.8	83.28
Bt_3	100–140	6.4	0.89	0.040	1.66	16.0	84.47
Bd	140–160	6.6	0.85	0.020	1.67	15.3	86.06

The data in Table 1 show changes in the main agrochemical indicators with depth. Soil reaction is slightly acidic in the surface horizon, with pH increasing from 5.8 in the A horizon (0-27 cm) to 6.6 in the Bd horizon (140-160 cm). Overall, humus content decreases from 2.03 % to 0.85 %, and total nitrogen from 0.090 % to 0.020 %, reflecting the decline in organic and nitrogen reserves down the profile.

Available P_2O_5 content varied within a narrow range, from 1.66 to 1.90 mg 100 g^{-1} soil, with the maximum value recorded in the surface horizon. Available K_2O ranged from 12.5 to 16.0 mg 100 g^{-1} soil, while base saturation increased from 76.84% in the A horizon to 86.06 % in the Bd horizon. For interpreting the crop response to fertilization, the A horizon is the most relevant, being characterized by a pH of 5.8, 2.03 % humus, 0.090 % total N, 1.90 mg available P_2O_5 100 g^{-1} soil, and 12.5 mg available K_2O 100 g^{-1} soil. These initial values characterize the agrochemical context in which the wheat response to N and P fertilization was evaluated. The results are consistent with the previous characterization of the reddish preluvosol at S.C.D.A. Șimnic reported by Radu et al. (2019), which also indicated an acidic soil reaction and a relatively low level of natural fertility.

Mean wheat yield during 2022-2026 generally increased with increasing nitrogen and phosphorus fertilization levels, with a more pronounced response at the first fertilization increments (Table 2). The P0N0 control yielded 1.81 t ha^{-1}. In the absence of phosphorus, increasing the nitrogen level from N0 to N160 was associated with an increase in yield from 1.81 to 4.08 t ha^{-1}, while in the absence of nitrogen, increasing phosphorus from P0 to P160 was associated with an increase

in yield from 1.81 to 4.40 t ha $^{-1}$. The combined ANOVA confirmed highly significant effects for both P ($F=138.81$; $p < 0.001$) and N ($F=109.54$; $p < 0.001$).

The highest numerical yield values were obtained in treatments in which both nutrients were applied at medium and high levels. However, the PxN interaction was not significant in the combined analysis ($F=0.77$; $p=0.720$), showing that, across years, the response can be explained mainly by the individual effects of the two factors, without evidence of an additional statistical interaction between them.

Table 2

Mean grain yield during 2022-2026 according to the N-P combination (t ha^{-1})

P / N	N0	N40	N80	N120	N160	Mean of P levels
P0	1.81	2.84	3.26	3.61	4.08	3.12
P40	2.50	4.12	5.03	5.35	5.59	4.52
P80	3.65	4.99	5.71	6.33	6.48	5.43
P120	3.94	5.54	6.10	6.43	6.62	5.73
P160	4.40	6.06	6.60	6.87	6.82	6.15
Mean of N levels	3.26	4.71	5.34	5.72	5.92	-

Combined ANOVA 2022-2026 (year as block; error df = 96): Year: $F=98.48$; $p < 0.001$; P: $F=138.81$; $p< 0.001$; N: $F =109.54$; $p < 0.001$; P×N: $F=0.77$; $p = 0.720$.

LSD values from the combined ANOVA (t ha^{-1}): P: $LSD_5\% =0.287$; $LSD_1\%=0.380$; $LSD_{0.1}\% =0.491$; N: $LSD_5\% =0.287$; $LSD_1\% =0.380$; $LSD_{0.1}\%= 0.491$; P×N: $LSD_5\% =0.642$; $LSD_1\% =0.850$; $LSD_{0.1}\% =1.098$.

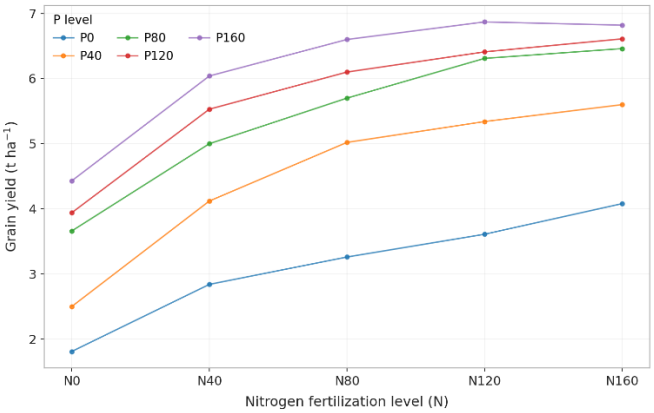


Figure 1. Response of mean wheat yield to N level at each P level during 2022-2026 (t ha^{-1})

The highest numerical value of mean yield was recorded at P160N120, with 6.87 t ha^{-1}, representing an absolute increase of 5.06 t ha^{-1} over P0N0 and a relative increase of approximately 279.6 %. The P160N160 treatment yielded 6.82 t ha^{-1}, only 0.05 t ha^{-1} below P160N120. The difference between the two treatments was far below $LSD_5\%=0.642$ t ha^{-1} for comparisons among factorial combinations; therefore, P160N120 cannot be considered statistically superior to P160N160. The result

supports the existence of a yield-plateau region at high nitrogen fertilization levels.

This trend is consistent with long-term experiments showing nonlinear wheat responses to mineral fertilization and diminishing additional yield increases at high levels of nutrient supply (Hao et al.,2007; Takahashi & Anwar, 2007; Lollato et al., 2019). The higher yields obtained under combined N-P fertilization are also consistent with results reported for winter wheat in other experiments, including those in southern Romania (Mocanu et al., 2012; Dodocioiu & Buzatu, 2024).

The marginal means for the N factor, obtained by averaging across the five P levels and the five years, were 3.26, 4.71, 5.34, 5.72, and 5.92 t ha^{-1} for N0, N40, N80, N120, and N160, respectively. Successive increases were 1.45, 0.63, 0.38, and 0.20 t ha$^{-1.}$ The first three increases exceeded $LSD_5\%$ = 0.287 t ha^{-1}, whereas the N120-N160 difference of 0.20 t ha^{-1} was below the significance threshold. Thus, the combined analysis confirms the diminishing response to nitrogen and the absence of a significant yield increase when moving from N120 to N160.

For the P factor, the marginal means calculated across all nitrogen levels and the five years were 3.12, 4.52, 5.43, 5.73, and 6.15 t ha^{-1} for P0, P40, P80, P120, and P160, respectively. The increases between successive levels were 1.40, 0.91, 0.30, and 0.42 t ha^{-1}. All these differences were at least slightly greater than $LSD_5\%$ = 0.287 t ha^{-1}, indicating that a significant response to phosphorus was maintained up to P160, although the magnitude of the increases was much smaller at the higher levels. The plot of marginal means (Figure 2) shows a curvilinear response for both factors, with a more distinct plateau developing for nitrogen.

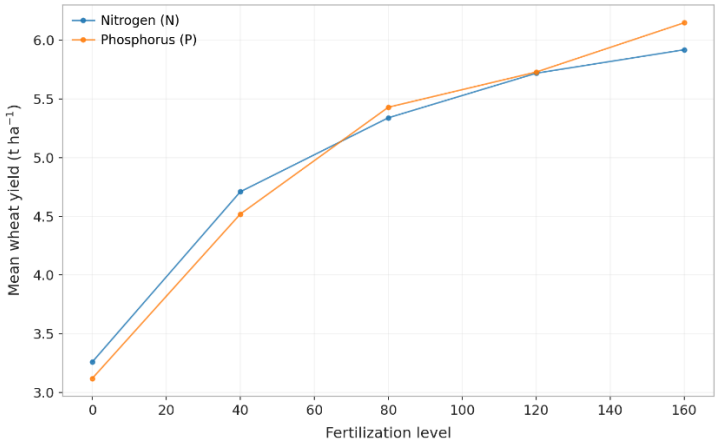


Figure 2. Marginal response of mean wheat yield to increasing nitrogen and phosphorus fertilization levels during 2022–2026 (t ha^{-1})

To describe the shape of the yield response to combined fertilization, a quadratic response-surface model was fitted to the 25 treatment means. In the model, xP and xN represent the coded levels of phosphorus and nitrogen fertilization (0,1,2,3, and 4), corresponding successively to levels P0-P160 and N0-N160, while Y represents mean grain yield (t ha^{-1}). The estimated equation was:

$$Y = 1.492 + 1.470xP + 1.428xN - 0.183xP^2 - 0.197xN^2 - 0.005xPxN.$$

The model explained 97.9% of the variation among the 25 treatment means (R^2=0.979; RMSE=0.21 t ha^{-1}). The negative coefficients of the quadratic terms

describe the progressive reduction in yield response at the higher levels of both factors. Within the experimental domain, the estimated surface indicates an approach to a plateau region at high P levels and within the N120-N160 interval, in agreement with the observed maximum values. The model is used to describe the mean response trend, complementing the annual analysis of variance.

The results confirm the important contribution of both nutrients to wheat yield formation. The main effects of P and N were highly significant in the combined ANOVA, while the PxN interaction was not significant. Therefore, the high yields of treatments fertilized with both nutrients should be interpreted primarily as the result of the cumulative effects of P and N supply, without claiming the existence of statistical synergy between the factors. This interpretation is consistent with the role of major-nutrient availability in their efficient use by the crop and with results reported in other wheat fertilization experiments (Aulakh & Malhi, 2005; Lollato et al., 2019). The curvilinear nature of the response indicates diminishing incremental yield gains at the highest fertilization levels.

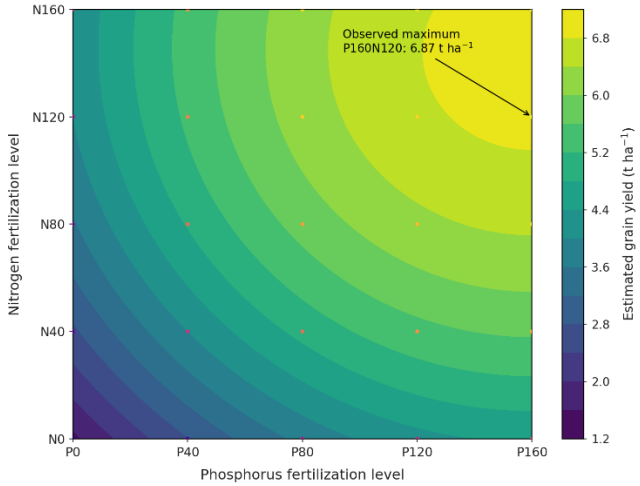


Figure 3. Estimated response surface of mean wheat yield as a function of nitrogen and phosphorus fertilization levels, based on the descriptive quadratic model fitted to the 25 treatment means

Note: xP and xN were coded on five levels (0-4), corresponding to treatments P0-P160 and N0-N160; the surface represents the estimated mean trend within the analyzed experimental domain.

Under rainfed conditions, the mean response to fertilization should be interpreted in the context of water availability, because nitrogen-use efficiency depends on the water regime (Garabet et al., 1998; López-Bellido & López-Bellido, 2001; López-Bellido et al., 2005). Water-deficit studies in wheat have also reported changes in chlorophyll and osmolyte status (Babeanu et al., 2019), supporting a cautious interpretation of fertilizer responses under variable water supply. The present analysis addresses the average response of the N–P treatments across the five growing seasons and does not attribute the observed response pattern to individual annual climatic conditions.

Overall, the combined ANOVA and response-surface modeling provide complementary information on the behavior of the fertilization treatments. Analysis of variance demonstrates the highly significant effects of P and N and the absence of a significant PxN interaction over the analyzed period, while the quadratic model describes the progressive reduction in response at higher rates. The convergence of these results supports the existence of a yield-plateau region, more evident for nitrogen, without equating the observed biological maximum with an economic optimum.

CONCLUSIONS

Under the rainfed conditions at S.C.D.A. Șimnic-Craiova, phosphorus and nitrogen fertilization had highly significant effects on mean wheat yield during 2022-2026. The combined ANOVA showed highly significant effects for P ($F=138.81$; $p< 0.001$) and N ($F=109.54$; $p<0.001$), while the PxN interaction was not significant ($F=0.77$; $p=0.720$).

Mean yield increased from 1.81 t ha^{-1} in the P0N0 control to a numerical maximum of 6.87 t ha^{-1} at P160N120. The highest yields were recorded for combinations with medium and high levels of both nutrients, but the absence of a significant PxN interaction indicates that the multi-year response was determined predominantly by the main effects of P and N.

The marginal response to nitrogen declined markedly as the fertilization level increased. The difference between N120 and N160 was only 0.20 t ha^{-1}, below $LSD_5\%=0.287$ t ha^{-1}, statistically confirming that the N response was approaching a plateau. For phosphorus, successive increases remained above $LSD_5\%$, although their magnitude declined at the higher levels. The descriptive quadratic model explained 97.9% of the variation among the 25 treatment combinations and supported the curvilinear shape of the response.

P160N120 was the combination with the highest observed numerical value, but its difference from P160N160 was only 0.05 t ha^{-1}, far below $LSD_5\%=0.642$ t ha^{-1} for comparisons among factorial combinations; the two treatments do not differ statistically at the 5% level. Consequently, the results support the existence of a high-yield and plateau region at the higher N levels rather than the identification of a single optimal treatment. Determining an economic optimum requires integrating fertilizer costs and the value of production.

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