Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 1, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

RESEARCH ON THE IMPACT OF NITROGEN AND PHOSPHORUS FERTILIZERS ON WINTER WHEAT YIELD AND QUALITY UNDER THE PEDOCLIMATIC CONDITIONS OF CENTRAL MOLDOVA

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Abstract

Winter wheat is a key agricultural crop that responds positively to fertilizers under the soil and climatic conditions of our country. However, factors influencing fertilizer efficiency and dosing challenges necessitate the implementation of long-term studies to investigate the complex interactions among plant, soil, fertilizer, and climate, as well as their impact on crop yield. This paper presents findings from a long-term study on the use of chemical fertilizers (NP) in winter wheat, carried out at the Agricultural Research and Development Station Secuieni, Romania (26°5` E; 46°5` N) during the period 2020-2023. The yields obtained from applying chemical fertilizers varied depending on the applied dose. On average, the studied factors had a considerable influence on wheat yield, resulting in significant variability in yield, ranging from 4886 kg ha^{-1} (unfertilized, N_0P_0) to 7117 kg ha^{-1} ($N_{80}P_{160}$ active substance). The interaction between phosphorus and nitrogen on wheat seed yield demonstrated a significant impact, contributing to increases of up to 21.7% and 16.1%, respectively, compared to the control.

Key words: *climate, nitrogen, phosphorus, plant, quality indicators, winter wheat, yield.*

INTRODUCTION

Straw cereals, especially wheat (*Triticum aestivum* L.), are the most widely cultivated plant in the world, grown in over 100 countries, and are a prime commercial source (Voinea & Ilie, 2023).

Winter wheat is one of the most important crops in the world of particular economic importance, with bread made from wheat flour being the essential food, also ensuring about 20% of total calories consumed (Chiriță et al., 2023). Wheat is an important source of energy and protein for humans all over the world. As wheat flours have the unique properties to form a strong and elastic dough, the majority of wheat is consumed in form of baked goods and a high baking quality is required (Rossmann et al., 2020).

Fertilization is a basic technological element of modern agriculture. The complex process of absorption of nutrients is dependent on a number of biotic and abiotic factors and the interaction between them (Șimon et al., 2022). Agrochemical optimization of the soil-plant system is the essential alternative to achieve high-quality, stable yields and is achieved through the rational and balanced application of fertilizers, differentiated and integrated, with sustainability according to crop requirements and effective soil input (Rusu, 2021).

It is well known that nitrogen significantly influences the growth and development of plants. Knowledge of the physiological mechanisms that contribute to the absorption and use of nitrogen is particularly important to increase the efficiency of the use of this chemical element (Agapie et al., 2021).

Wheat is a crop that efficiently uses chemical fertilizers with nitrogen and phosphorus, nitrogen being the chemical element that causes higher yield increases. The superiority of wheat yield achieved by using nitrogen is natural, considering that nitrogen represents the "pivot of fertilization", the decisive factor in increasing wheat yields, and phosphorus has a smaller effect (Ceclan et al., 2024).

During the vegetation period, the accumulation of nitrates in the soil does not occur at the same time as the plants' requirements, and for this reason, the application of chemical fertilizers is required to ensure the necessary nutrients for plant growth. Wheat needs nitrogen in the spring for the completion of germination and for vegetative growth, or during this time it often happens that the soil has a small amount of nitrogen (Dodocioiu & Buzatu, 2024).

Efficient utilisation of phosphorus (P) is paramount for crop production, resource sustainability, and food security. For responsible management of P fertilisers across varying fertilisers supply scenarios in wheat cultivation, it is imperative to systematically assess the impact of soil characteristics, crop varieties, and crop rotation practices on P efficiency (Yan et al., 2024).

The efficient capture and utilisation of fertiliser nitrogen (N) by cereals has implications for crop growth, grain yield, farm profits, the environment and human nutrition (Duncan et al., 2018).

Rapid innovation in modern agriculture has revealed that optimized P fertilizer placement allows to reduce P fertilizer input, thereby effectively increasing fertilizer use efficiency and crop yield (Du et al., 2020).

The combinations containing mineral N showed a significant improvement in yield stability in which N + P and N + K are almost identical. In all fertilisation variants, the additional supply of manure stabilised the wheat yields. The mineral supply of N + P + K with additional manure provided the best yield stability and lowest agronomic risk for yield failure (Macholdt et al., 2018).

In the modern agriculture, the importance of using chemical fertilizers is undeniable. In the structure of chemical fertilizers, those with nitrogen occupy the main place due to their contribution in determining the yield increase, as well as due to the weight with which they participate in the applied fertilization formulas (Dumitraşcu et al., 2003; Mihăilă et al., 1996; Petcu et al., 2003).

MATERIALS AND METHODS

The experience was placed from 2020 to 2023 at the Agricultural Research and Development Station Secuieni (A.R.D.S. Secuieni) on a typical cambic faeoziom (chernozem) soil with medium texture. The experience was conducted on a typical cambic chernozem soil type, middle texture, acid: pH_{H2O} - 5.98, characterized as: supplied in phosphorus (77.6 ppm P_{AL}), Ca (13.6 mEq/100 g soil Ca) and Mg (1.8 mEq/100 g soil Mg), middle supplied in active humus (1.88%) and nitrogen (16.2 ppm $N\text{-}NO_3$) and poorly supplied in potassium (124.6 ppm K_2O) (Pochişcanu et al., 2017).

The experience was established using a subdivided plot design. The main plots were assigned to different phosphorus doses (0, 40, 80, 120, and 160 kg active substance P_2O_5/ha), while the subplots were allocated to varying nitrogen doses (0, 40, 80, 120, and 160 kg active substance N/ha). Fertilization was carried out using ammonium nitrate and superphosphate, with the amount of fertilizer applied corresponding to the designated phosphorus and nitrogen doses in each treatment. In the field, in this case, the cultivation technology specific to the conditions in Central of Moldavia was used, and the data obtained was interpreted statistically according to the method of variance analysis (Leonte & Simioniuc, 2018). The experimental setup followed a three-year crop rotation system comprising wheat, corn, and beans.

The analysis of temperature and precipitation trends during the winter wheat vegetation period in the Secuieni area indicates a shift towards increasingly hot and dry conditions. These meteorological extremes have the potential to cause significant agricultural losses.

The temperatures recorded in the three agricultural years, compared to the multiannual average, indicate clear warming in most months of the year, except April and May, where the temperatures were lower than the multiannual average by 0.4°C and 0.2°C, respectively.

This warming trend is more pronounced in the winter and early spring months, but summers are also becoming progressively warmer (Table 1). Between October and July, the average temperature was 9.1°C, which is 1.9°C higher than the multiannual average of 7.3°C over the past 60 years.

Table 1. Temperature registrated at A.R.D.S. Secuieni during winter wheat vegetation period

Month	2020/ 2021	2021/ 2022	2022/ 2023	Monthly average	Multiannual average 60 years	Dev.
October	10.8	8	11.5	10.1	9.2	0.9
November	7.8	5.6	5	6.1	3.6	2.5
December	1.8	-0.2	0.8	0.8	-1.5	2.3
January	-0.6	-0.1	2.4	0.6	-3.7	4.3
February	3.4	2.6	1	2.3	-1.9	4.2
March	6.2	2.7	6	5.0	2.8	2.2
April	10	9.5	8.1	9.2	9.6	-0.4
May	13.9	16.3	15.4	15.2	15.4	-0.2
June	20	20.7	19.9	20.2	18.9	1.3
July	20.9	22.2	22.6	21.9	20.4	1.5
Monthly average	9.4	8.7	9.3	9.1	7.3	1.9

In terms of precipitation over the entire growing season of the wheat crop, deviations from the multiannual average were varied, with their distribution being extremely uneven across the plant's growth and development phases. The smallest deviations, compared to the multi-year average for the same periods, were 4 mm in December, while the largest deviations were recorded in July, with 33.1 mm (Table 2). From the sowing of the winter wheat to harvest, the crop experienced a significant precipitation deficit of 179.5 mm, compared to the multiannual average for the same period.

Table 2. Precipitation registrated at A.R.D.S. Secuieni during winter wheat vegetation period

Month	2020/ 2021	2021/ 2022	2022/ 2023	Monthly average	Multiannual average 60 years	Dev.
October	33	3	19.8	18.6	36.9	-18.3
November	14.6	10.8	41.7	22.4	27.7	-5.3
December	6.2	39	19	21.4	25.4	-4.0
January	2	5.4	13.2	6.9	19.6	-12.7
February	16	4.6	12.6	11.1	19.2	-8.1
March	10.2	0.8	7.6	6.2	26.3	-20.1
April	1.2	38.4	38.4	26.0	44.9	-18.9
May	69.6	20.8	21	37.1	64.3	-27.2
June	72.6	56.6	29.8	53.0	84.7	-31.7
July	39	35.2	68.2	47.5	80.6	-33.1
Monthly average	264.4	214.6	271.3	250.1	429.6	-179.5

RESULTS AND DISCUSSIONS

Climatic conditions during the growing season are the main factor that determines crop yield, especially in areas where the only source of water is from rainfall and groundwater and even the extreme temperatures can significantly reduce crop yield.

Phosphorus fertilizer application (after the averages of five graduations of nitrogen fertilizers) resulted in yields ranging from 7145-8647 kg·ha^{-1} in 2020-2021, 4460-6326 kg·ha^{-1} in 2021-2022, and 4940-5285 kg·ha^{-1} in 2022-2023. On average, the influence of phosphorus on yields ranged from 5515 kg·ha^{-1} in the variant unfertilized, to a maximum of 6714 kg·ha^{-1} in the variant where the phosphorus dose applied was 160 kg of active substance.

Yield increases from phosphorus fertilizer application (2020-2023 average) from 550 kg·ha^{-1} (10%) at the P_{40} dose to 1199 kg·ha^{-1} (22%) at the P_{160} dose (Table 3). The yields obtained, compared to the control variant, were superior and were statistically confirmed and interpreted as highly significant.

Table 3. The influence of phosphorus fertilizers on winter wheat yield

Nitrogen dose (kg/ha)	Yield kg· ha^{-1}				Relative yield (%)	Dif.	Sem.
	2020/ 2021	2021/ 2022	2022/ 2023	Average yield			
P_0	7145	4460	4940	5515	100	Mt.	Ct.
P_{40}	7636	5448	5112	6065	110	550	***
P_{80}	7801	5766	5151	6239	113	724	***
P_{120}	8647	5983	5285	6638	120	1123	***
P_{160}	8539	6326	5276	6714	122	1199	***
LD 5%	46	87	99	77			
LD 1%	61	120	140	107			
LD 0.1%	79	166	166	145			

Nitrogen fertilizer application (after the averages of five graduations of phosphorus fertilizers) resulted in yields ranging from 6827-8668 kg·ha^{-1} in 2020-2021, 5337-6119 kg·ha^{-1} in 2021-2022, and 4604-5418 kg·ha^{-1} in 2022-2023. On average, the influence of nitrogen on yields ranged from 5589 kg·ha^{-1} in the variant with no fertilizer application, to a maximum of 6715kg·ha^{-1} in the variant where the nitrogen dose applied was 120 kg of active substance. Yield increases from nitrogen fertilizer application (2020-2023 average) were 417 kg·ha^{-1} (7%) at the N_{40} dose and 1126 kg·ha^{-1} (20%) at the N_{120} dose (Table 4). The yields obtained, by applying different doses of nitrogen, compared to the control variant, were superior and were statistically confirmed and interpreted as highly significant.

Table 4. The influence of nitrogen fertilizers on winter wheat yield

Phosphor dose (kg/ha)	Yield kg·ha^{-1}				Relative yield (%)	Dif.	Sem.
	2020/ 2021	2021/ 2022	2022/ 2023	Average yield			
N_0	6827	5337	4604	5589	100	Mt.	Ct.
N_{40}	7524	5389	5105	6006	107	417	***
N_{80}	8142	5679	5302	6374	114	785	***
N_{120}	8607	6119	5418	6715	120	1126	***
N_{160}	8668	5459	5335	6487	116	898	***
DL 5%	75	102	46	77			
DL 1%	99	135	61	107			
DL 0.1%	128	174	79	145			

In the first year of experimentation, 2020-2021, yields varied significantly, ranging from 6133 kg·ha^{-1} in the control variant (unfertilized) to a maximum of 9429 kg·ha^{-1} in the variant with an $N_{120}P_{120}$ fertilizer dose, indicating a high efficiency of nitrogen and phosphorus fertilization. In the variants where phosphorus was not applied, increasing the nitrogen dose from N_0 to N_{160} led to a 28.6% yield increase on winter wheat, from 6133 kg·ha^{-1} to 7887 kg·ha^{-1}.

In the second year of testing, yields ranged from 3993 kg·ha^{-1} (unfertilized) to a maximum of 6822 kg·ha^{-1}, achieved in the variant where the applied fertilizer dose was $N_{80}P_{160}$.

Regardless of the nitrogen and phosphorus doses applied to winter wheat, all fertilized variants recorded higher yields compared to the control variant, which received no fertilization. This emphasizes the positive impact of fertilization on plant growth and development compared to the unfertilized variant.

The lowest yield in the final year of testing was recorded in the control variant (4531 kg · ha^{-1}), while the highest yield (5601 kg · ha^{-1}) was achieved in the variant where the applied fertilizer dose was $N_{120}P_{120}$.

During the period 2020-2023, winter wheat yields showed variations due to the combination of fertilizers used, the dosage applied, and weather conditions. Thus, over the three years of testing on winter wheat, yields for the unfertilized variant (N_0P_0) ranged from 3993 to 6133 kg · ha^{-1}, with an average of 4886 kg · ha^{-1}. Compared to this, the average yield increases on winter wheat, resulting from fertilizer application ranged between 4% and 46%, representing 207 to 2231 kg·ha^{-1}.

It was observed that nitrogen fertilizers resulted in higher yield increases in all the years studied. Thus, on the P_0 agrofund, nitrogen fertilizers applied at doses of N_{40}-N_{160} led to yield increases on winter wheat of 4-22%, representing 207-1082 kg·ha^{-1}; on the P_{40} agrofund, increases ranged from 25% to 30%, representing 1206 - 1467 kg·ha^{-1}; on the P_{80} agrofund, increases of 25-26% were recorded, representing 1229-1293 kg·ha^{-1}; on the P_{120} agrofund, increases ranged from 32% to 43%, representing 1541-2114 kg·ha^{-1}; and on the P_{160} agrofund, increases of 35-42% were observed, representing 1690-2052 kg·ha^{-1} (Table 5).

Compared to the control variant (no fertilizer), regardless of the fertilizer dose applied, the yields on winter wheat were higher and were interpreted as highly significant.

Table 5. The influence of nitrogen and phosphorus fertilizers on winter wheat yield during the period 2020-2023

Applied dose	Yield kg·ha^{-1}				Relative yield	Dif.	Semnif.
	2020/ 2021	2021/ 2022	2022/ 2023	Average yield			
N_0P_0	6133	3993	4531	4886	100		***
$N_{40}P_0$	6593	4003	4682	5093	104	207	***
$N_{80}P_0$	7339	4233	5077	5550	114	664	***
$N_{120}P_0$	7772	5348	5113	6078	124	1192	***
$N_{160}P_0$	7887	4720	5296	5968	122	1082	***
N_0P_{40}	6540	4659	4598	5266	108	380	***
$N_{40}P_{40}$	7252	6014	5009	6092	125	1206	***
$N_{80}P_{40}$	7551	5362	5160	6024	123	1138	***
$N_{120}P_{40}$	8322	6156	5300	6593	135	1707	***
$N_{160}P_{40}$	8515	5050	5494	6353	130	1467	***
N_0P_{80}	6604	6229	4659	5831	119	945	***
$N_{40}P_{80}$	7522	5673	5149	6115	125	1229	***
$N_{80}P_{80}$	7944	5932	5314	6397	131	1511	***
$N_{120}P_{80}$	8470	5978	5586	6678	137	1792	***
$N_{160}P_{80}$	8464	5020	5054	6179	126	1293	***
N_0P_{120}	7318	5375	4730	5808	119	922	***
$N_{40}P_{120}$	8154	5849	5278	6427	132	1541	***
$N_{80}P_{120}$	8919	6045	5397	6787	139	1901	***
$N_{120}P_{120}$	9429	6299	5601	7110	146	2224	***
$N_{160}P_{120}$	9416	6168	5417	7000	143	2114	***
N_0P_{160}	7539	6428	4500	6156	126	1270	***
$N_{40}P_{160}$	9096	5225	5406	6576	135	1690	***
$N_{80}P_{160}$	8958	6822	5570	7117	146	2231	***
$N_{120}P_{160}$	9039	6816	5490	7115	146	2229	***
$N_{160}P_{160}$	9061	6339	5415	6938	142	2052	***
5%	103	201	180	161			
1%	137	267	241	215			
0,1%	176	304	317	266			

Regarding the protein content in winter wheat, it ranged from 9% in the unfertilized variant to a maximum of 14.8% in the variant where the applied dose was $N_{160}P_{80}$. The gluten content varied within a wide range, from 16.9% in the unfertilized (control) variant to a maximum of 30.3% in the variant with the applied dose of $N_{160}P_{80}$ (Figure 1).

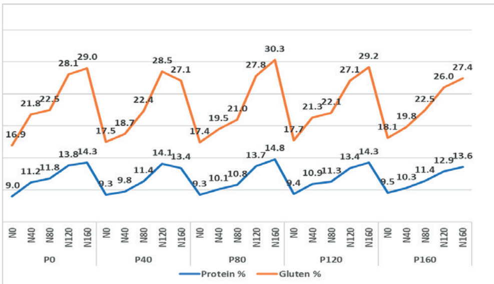

Figure 1. Protein content (%) and gluten content (%) according to the fertilizer dose applied

The starch content on winter wheat reached a maximum value of 71.6% in the control variant, but the application of fertilizers resulted in a progressive decrease in starch content as the applied dose increased, with a minimum of 67.4% observed at the $N_{160}P_{80}$ dose. Regarding kernel hardness, the lowest values, 19.8%, were observed in the control variant. However, as the fertilizer doses increased, a significant increase in kernel hardness was noted, reaching a maximum of 64.3% at the $N_{160}P_{80}$ dose (Figure 2).

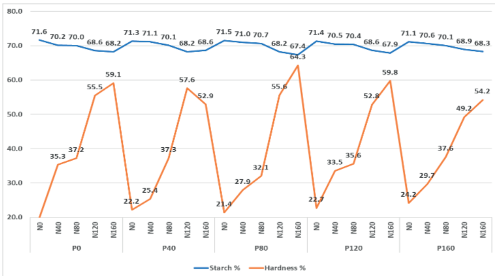

Figure 2. Starch content (%) and wheat kernel hardness (%) according to the fertilizer dose applied

CONCLUSIONS

These results highlight the significant impact of different fertilization levels on winter wheat yield, demonstrating that a higher phosphorus dose contributes to substantial yield increases.
On the P_0 agrofoundation, applying different nitrogen doses (40-160 active substances) led to 4-22% yield increases, equivalent to 207-1082 $kg \cdot ha^{-1}$. On the P_{40} agrofoundation, the increase ranged from 25% to 30%, totaling 1206-1467 $kg \cdot ha^{-1}$. For the P_{80} agrofoundation, yields rose by 25-26%, corresponding to 1229-1293 $kg \cdot ha^{-1}$. The P_{120} agrofoundation recorded increases of 32-43%, amounting to 1541-2114 $kg \cdot ha^{-1}$. Finally, on the P_{160} agrofoundation, 35% to 42% increases were recorded, equivalent to 1690-2052 $kg \cdot ha^{-1}$.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Ministry of Agriculture and Rural Development through the ADER 2023-2026 program from Project no. 18.1.1/27.07.2023 Development of solutions for soil health restoration while maintaining environmental sustainability by harnessing the fertilizing potential of organic fertilizers.

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