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THE DYNAMICS OF NITROGEN VALORIFICATION IN WHEAT CROP UNDER THE INFLUENCE OF THE USED AGROFOUND

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ABSTRACT

The study assessed the efficiency of nitrogen use in winter wheat, cultivar 'Ciprian' through the combined application of nitrogen with phosphorus fertilizers, between 2016 and 2021. The research was organized within ARDS Lovrin, Timiş County, Romania, under the conditions of a chernozem soil type. The experimental factors considered were: experimental factor A - year of experimentation - six years 2016-2021; experimental factor B - mineral nitrogen fertilizers, with the following graduations: 0 kg N ha^{-1} (control), 30 kg N ha^{-1}, 60 kg N ha^{-1}, 90 kg N ha^{-1} and 120 kg N ha^{-1}; experimental factor C - mineral phosphorus fertilizers, with the following five graduations: 0 kg P ha^{-1} (control), 40 kg P ha^{-1}, 80 kg P ha^{-1}, 120 kg P ha^{-1} and 160 kg P ha^{-1}. Production has been taken into consideration for NEU evaluation (Y, kg ha^{-1}), the total nitrogen (N_{tot}) content (%) of the grains, N uptake (%) in relation to the experimental factors considered. Differences in NUEs had different significance compared to each experimental factor, and the interaction between A×B, A×C and B×C factors generated differences in statistically safe conditions ($p<0.05$ in A×C case, and $p<0.001$ in A×B and B×C case).

Keywords: fertilization, nitrogen uptake, nitrogen use efficiency, winter wheat, yield.

INTRODUCTION

Wheat is one of the most important crops in an economical point of view (Shiferaw et al., 2013; Grewal and Goel, 2015; Shewry and Hey, 2015), with a share of 90% of all cereals consumed worldwide (Ranum et al., 2014; Khokhar et al., 2017; Asseng et al., 2019; USDA, 2019). Romania, a top grain cultivator, ranks fourth among wheat producers in Europe, with a cultivated area of 2.1 million ha, annual production of 10.2 million tons and an average production of 4.7 per hectare (MADR). Obtaining high production, high quality, concomitant with preserving soil fertility and protecting the environment, is one of the desires of Romanian agricultural research.

Among the technological factors that contribute significantly to the increase in the production and quality of wheat, fertilization occupies an important place (Delogu et al., 1998; Lestingi et al., 2010), and amongst the fertilizers, nitrogen is distinguished with superiority. But it is precisely this chemical element that poses the most problems in terms of its effectiveness and destabilizing effects on the environment (Peoples et al., 2004; Syswerda et al., 2012; Lebender et al., 2014). Nitrogen (N) is commonly considered the most important mineral nutrient that limits the productivity of many agricultural crops around the world (Weih, 2014). Only a small part of the amount administered to crops is taken over by plants, the rest remains immobilized in the soil or is lost in the environment through volatilization or leaching.

Lately, there is a major concern for optimizing plant mineral nutrition, aiming at reducing nitrogen doses administered to crops and increasing its use efficiency (NUEs) (Neeteson and Carton, 2001; Burns, 2006; Agostini et al., 2010; Weih, 2014). The widely accepted conclusion is that NUE is the result of two main components: The

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ability of crops to extract nitrogen from the soil - N uptake efficiency (Rahn, 2002) and the ability of crops to use absorbed nitrogen to grow, develop, and generate production (Greenwood et al., 1989; Schenk, 2006).

The growth of NUEs involves a deep approach to this issue, which includes a correct assessment taking into account the culture, variety or hybrid, the pedo-climatic conditions of experimentation, and carefully planning the experimental devices. Regardless of the benefits of nitrogen associated with increasing and capitalizing on production, the amounts of chemical fertilizers administered to crops must be gradually reduced. Increasing the efficiency of nitrogen use is a long-term challenge. The causes of the variation of NUEs can be multiple, which is why several indices need to be determined to assess this aspect (Cassman et al., 2002). The most important indices used for understanding and superior quantification of crop response to fertilization (Dobermann, 2005) are: Nitrogen use efficiency (NUE), partial factor productivity (PFP), partial nutrient balance (PNB), nitrogen response efficiency (NRE) and nitrogen response recovery (RE).

The western part of the country is an agricultural representative area for Romania, and provides about 30% of the annual wheat production, with variable productivity. Nitrogen is frequently administered in two or even one round, significantly reducing the recovery coefficient of this fertilizer so important for plant growth and development.

The current study was based on experiments with fertilizers to increase the efficiency of nitrogen use by winter wheat crops, both by the combined application of nitrogen with phosphorus fertilizers and by application periods and rotation of crops in the soil, highlighted by data obtained in 53 years of long-term experiments with fertilizers. Given the significant number of data in the ARDS Lovrin archive, only experimental data from 2016-2021 were considered in this study.

MATERIAL AND METHODS

General considerations on the area of research. The research was carried out in the experimental field of ARDS Lovrin, in a long experience with fertilizers, established in 1967. In this study, the results obtained over six years, from 2016 to 2021, were considered and analysed.

Due to its geographical location, the area of the experimental field has favourable ecological conditions for the winter wheat crop. The experimental field was placed on soil of the chernozem type, with the main physico-chemical indicators presented in Table 1. The pH value indicates a weak acid reaction, the soil is rich in humus on the surface and low in humus in-depth, with normal content of total nitrogen (N_{tot}), low phosphorus and medium potassium.

Table 1. Agrochemical indices of the chernozem located at SCDA Lovrin, Timiş County, Romania

Agrochemical index	Value
pH in H_2O	6.7
Humus (%)	3.2
N total (%)	0.170
P (ppm)	61
K (ppm)	270

Note: The chemical analysis of soil was carried out at OSPA Timiș laboratories.

In this area, the average annual air temperature is about 10.9°C. The average temperature of the coldest month is -1.2°C and is recorded in January and the warmest month is represented by a temperature of 21.7°C and is recorded in July. The total active temperatures (ΣT>0°C) recorded between February and November is 2935°C, with variations between 2800-3100°C and the total actual temperatures (ΣT>10°C) recorded between April and October is 1543°C, with annual variations ranging from 1200-1800°C. Between the warmer and colder years there is a difference in the vegetation period of 600-700°C.

In the analyzed period, 2015-2020, from the data recorded at the Lovrin meteorological station, Figure 1, the temperature recorded significant variations from the normal period, the warmest year being 2017-2018, with a deviation of 2°C from the multiannual average. The agricultural year 2015-2016 recorded an average annual temperature of 11.7°C, with a deviation of 0.8°C from the normal area.

There has been a marked warming trend over the last decade, with the warmest months - spring and autumn months, negatively influencing the growth and development of autumn grain crops.

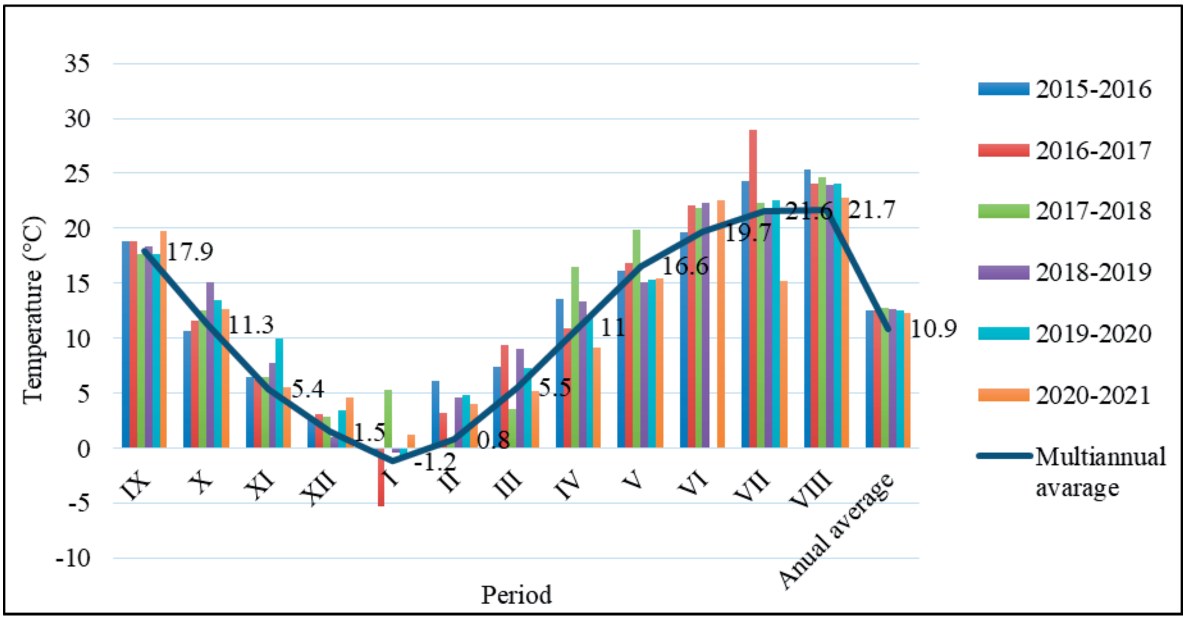

Figure 1. The evolution of temperatures between 2015-2021 recorded at the Lovrin meteorological station, compared to the multiannual average (MMA) over 70 years

As for precipitation, it displays a value of 506.2 mm annually (70-year multiannual average). The distribution of rainfall between the two seasons was uneven. Thus, it was observed that in the warm season due to the prevailing north-western circulation, there were about 60% of the total annual rainfall. The cold season was poorer in precipitation. Figure 2 shows the monthly and annual evolution of rainfall recorded in Lovrin. Analysing the sum of annual precipitation, the variation in the range of 450.5-913.3 mm was observed. This leads to the classification of the agricultural years in the study period in a satisfactory category in terms of the amount of rain falling (between 450-600 mm), except for the agricultural year 2015-2016 which was surplus, and when 913.3 mm were recorded. However, the atmospheric heat, accompanied by the pedological drought in the spring months, is unfavourable to the exploitation of technological inputs by the plants cultivated in the area, respectively the winter wheat crop in the case of this study.

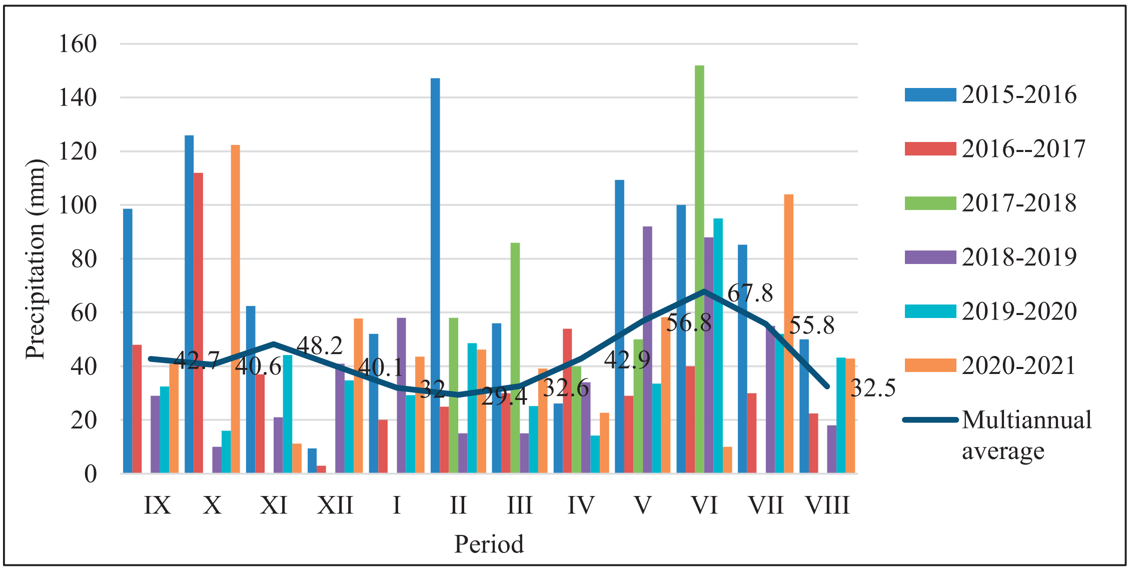

Figure 2. The evolution of precipitation between 2015-2021 recorded at the Lovrin meteorological Station, compared to the multiannual average (MMA) over 70 years

The experimental device. The study was conducted in a long-term experience, founded in Lovrin in 1967. The experience was organized in the field according to the method of subdivided plots, in four repetitions and a three-year landing: soy-wheat-corn. The experimental factors are represented by the year of experimentation and chemical fertilizers with nitrogen and phosphorus: experimental factor A - the year of experimentation - six years 2016-2021; experimental factor B is represented by mineral nitrogen fertilizers and the following five graduations: 0 kg N ha^{-1} (control), 30 kg N ha^{-1}, 60 kg N ha^{-1}, 90 kg N ha^{-1} and 120 kg N ha^{-1}; experimental factor C - mineral phosphorus fertilizers - comprises the following five grades: 0 kg P ha^{-1} (control), 40 kg P ha^{-1}, 80 kg P ha^{-1}, 120 kg P ha^{-1} and 160 kg P ha^{-1}. The area of an experimental variant was 36 m^2 and the area of the harvestable 14 m^2. Phosphorus fertilizers, in the form of triple superphosphate, were administered in the autumn and incorporated under the basic ploughing. Nitrogen fertilizers were applied fractionated: 40% of the dose at "spring comings", and 60% in the bellows phase. The winter wheat (*Triticum aestivum* L.) cultivar that was experimented on was the 'Ciprian', created and certified at ARDS Lovrin.

Determining the yield and quality of winter wheat crop. The crop was harvested with the help of the experimental harvester at a humidity of about 14% and the results obtained were calculated in kg ha^{-1} and reported to STAS humidity - 14%. The protein content analysis was done at the ARDS Lovrin wheat improvement Laboratory using the Perten inframatic 9200 apparatus. The nitrogen content in the soil and winter wheat grains was determined by the Kjeldahl (1983) method.

Determination of nitrogen recovery ratio. Several indicators are described in the literature and used to highlight the crop response to fertilization as accurately as possible (Cassman et al., 2002). Studies conducted over time have highlighted the quantitative and qualitative level of yields in relation to the amount of nitrogen absorbed, and on the basis of these values various indices on the efficiency of nitrogen use have been calculated (Dobermann, 2005).

Concerning the objectives of this study, the nitrogen use efficiency (NUE) equation (1) was evaluated. For this purpose, plant N Uptake were determined, equation (2), total nitrogen (N_{tot}) in report to grain production and protein content.

For their calculation the formulas suggested by Dobermann, Moll and Hiremath will be used.

Nitrogen use efficiency (NUE) was

calculated with the formula suggested by Moll, equation (1). For N uptake the formula suggested by Hiremath, equation (2) was used.

$$NUE(\%) = (Nf - Nc)/Nsupply \quad (1)$$

in which:

Nf - total nitrogen of fertilized crop;

Nc - total nitrogen of control variant (unfertilized);

Nsupply - rate of N fertilizer applied.

$$\text{Plant N uptake (kg N ha}^{-1}\text{)} = N_{tot}\text{ (kg N kg}^{-1}\text{ yield) x GY (kg ha}^{-1}\text{)/100} \quad (2)$$

in which:

Nt - N_{tot} (kg N ha^{-1});

GY - wheat grain yield (kg ha^{-1}).

Statistical analysis. The results were statistically interpreted using the program Statistica, version 10; the t-test, the F-test, and the multiple correlations were used. The results were considered statistically significant at a $p \leq 0.05$ value.

RESULTS AND DISCUSSION

Contribution of experimental factors to production in 2016-2021. The recorded production levels highlighted the differentiated response of wheat crop, 'Ciprian' cultivar, to fertilization with N, range 0-120 kg ha^{-1}, on the five fertilization levels with P (range 0-160 kg ha^{-1}). There was also a variation in production during the experimental period, under the conditions of the 25 fertilizing variants achieved. The production data obtained during the study period (2016 to 2021) in the experimental variants are presented in Table 2.

Table 2. Production data on experimental variants and study period, wheat crop

Trial	Fertilizers (kg ha^{-1} a.s.)		Yield (kg ha^{-1})						
	N	P	2016	2017	2018	2019	2020	2021	Mean 2016-2021
V1	0	0	3743.00	4856.00	4319.50	4091.00	4200.00	5622.22	4471.95
V2	30	0	4471.00	5101.00	4650.50	4365.00	4364.30	6244.44	4866.04
V3	60	0	5200.00	5516.00	5067.50	4585.00	4719.00	7127.78	5369.21
V4	90	0	5763.00	5857.00	5338.80	4713.00	4483.25	6755.56	5485.10
V5	120	0	5798.00	5960.00	5443.50	4773.00	4257.75	7122.22	5559.08
V6	0	40	4070.00	5178.00	4458.50	4083.00	3762.00	6338.89	4648.40
V7	30	40	4450.00	5641.00	4840.50	4160.00	4152.50	6456.10	4950.02
V8	60	40	5356.00	5936.00	5517.50	4488.00	4462.50	6650.00	5401.67
V9	90	40	5805.00	5945.00	5608.75	4440.00	4509.75	6700.00	5501.42
V10	120	40	5796.00	5985.00	5098.50	4590.00	4116.00	6819.44	5400.82
V11	0	80	4220.00	5434.00	4794.25	3973.00	4129.00	6780.56	4888.47
V12	30	80	4500.00	5798.00	5006.30	4820.00	4405.00	6500.00	5171.55
V13	60	80	5367.00	6300.00	5604.00	4685.00	4888.50	6700.00	5590.75
V14	90	80	5896.00	6674.00	5626.25	4813.00	4745.25	6802.80	5759.55
V15	120	80	5932.00	6355.00	5556.50	4840.00	4140.75	7200.00	5670.71
V16	0	120	4370.00	5434.00	5216.00	4583.00	4252.50	6594.44	5074.99
V17	30	120	4627.00	5702.00	5425.80	4860.00	4792.75	6600.00	5334.59
V18	60	120	5398.00	6616.00	5791.50	5203.00	4602.50	7197.22	5801.37
V19	90	120	5891.00	6616.00	5815.00	4968.00	4407.75	6852.78	5758.42
V20	120	120	6068.00	6563.00	5715.75	5105.00	3786.00	6750.00	5664.63
V21	0	160	4698.00	6100.00	5400.00	4315.00	3762.00	6500.00	5129.17
V22	30	160	4700.00	6000.00	5220.00	4800.00	4573.75	6512.00	5300.96
V23	60	160	5200.00	6700.00	5812.00	4835.00	4495.50	7202.78	5707.55
V24	90	160	5760.00	6900.00	6000.00	5020.00	4761.75	6955.56	5899.55
V25	120	160	6236.00	6292.00	6200.00	4695.00	4200.00	6480.56	5683.93
SE			±144.74	±108.67	±94.93	±65.39	±63.27	±70.51	±75.88

a.s. - active substance; SE - standard error.

Table 3. The effect of the interaction of experimental factors on the production of autumn wheat

Experimental factor	Factor graduation	Production (kg ha^{-1})
Experimental factor A - Year	2016	5203 d
	2017	6032 b
	2018	5425 c
	2019	4642 e
	2020	4359 f
	2021	6687 a
Experimental factor B - Dose of nitrogen administered to the crop (kg ha^{-1})	0	4851 c
	30	5224 b
	60	5602 a
	90	5683 a
	120	5597 a
Experimental factor C - Dose of phosphorus administered to the crop (kg ha^{-1})	0	5151 c
	40	5171 c
	80	5459 b
	120	5538 ab
	160	5639 a
A × B interaction		***
A × C interaction		***
B × C interaction		ns
A × B × C interaction		ns

From the analysis of production data, compared to the study period, it was found that the best year was the agricultural year 2021, followed by the year 2017. From the statistical analysis of the experimental data for wheat production, the factors considered (year, N-doses, P-doses) were obtained the values and levels of significance, presented in Table 3. The production differences showed different significance compared to each experimental factor considered, and the interaction between A×B and A×C factors led to differences that presented statistical safety.

Contribution of experimental factors to the total N content in wheat grains, range 2016-2021. The values for the total nitrogen (N_{tot}) content recorded in wheat grains during the study period and the N and P fertilization variants are shown in Table 4. The variation in N content was found in relation to the N and P doses administered, but also in relation to the experimental period. From the analysis of experimental data on the variation of N_{tot} content in wheat grains, the 'Ciprian' cultivar, and the factors considered (year, N doses, P doses) were obtained the values and statistical significance given in Table 5. Differences in N_{tot} content values showed different levels of significance relative to each experimental factor (year, N-doses, P-doses). The interaction between A×B and A×C has led to significant, statistically safe differences in N_{tot} content in wheat grains.

Table 4. Data on the total nitrogen (N_{tot}) content in wheat grains by experimental variants and study period

Trial	Fertilizers (kg ha^{-1} a.s.)		N_{tot} (%)						
	N	P	2016	2017	2018	2019	2020	2021	Mean 2016-2021
V1	0	0	2.12	2.23	1.82	1.96	1.68	1.58	1.90
V2	30	0	2.23	2.39	2.21	2.14	2.00	1.82	2.13
V3	60	0	2.35	2.47	2.58	2.40	2.25	1.93	2.33
V4	90	0	2.53	2.65	2.81	2.53	2.46	2.14	2.52
V5	120	0	2.65	2.77	2.88	2.58	2.60	2.28	2.63
V6	0	40	2.14	2.21	1.96	2.00	1.72	1.63	1.94
V7	30	40	2.26	2.40	2.39	2.25	2.05	1.82	2.20
V8	60	40	2.39	2.56	2.56	2.40	2.30	2.12	2.39
V9	90	40	2.53	2.63	2.75	2.58	2.54	2.35	2.56
V10	120	40	2.63	2.84	2.82	2.61	2.56	2.49	2.66
V11	0	80	2.23	2.32	1.95	1.98	1.74	1.66	1.98
V12	30	80	2.35	2.42	2.25	2.28	2.18	1.82	2.22
V13	60	80	2.42	2.60	2.54	2.40	2.32	2.19	2.41
V14	90	80	2.60	2.74	2.77	2.54	2.54	2.44	2.61
V15	120	80	2.67	2.79	2.81	2.61	2.60	2.61	2.68
V16	0	120	2.21	2.37	1.82	1.91	1.65	1.72	1.95
V17	30	120	2.30	2.47	2.00	2.23	2.09	1.84	2.15
V18	60	120	2.44	2.56	2.58	2.42	2.40	2.37	2.46
V19	90	120	2.60	2.72	2.75	2.51	2.54	2.56	2.61
V20	120	120	2.63	2.81	2.86	2.56	2.70	2.63	2.70
V21	0	160	2.23	2.39	2.02	1.88	1.68	1.70	1.98
V22	30	160	2.28	2.37	2.05	2.25	2.14	1.88	2.16
V23	60	160	2.44	2.46	2.54	2.39	2.35	2.30	2.41
V24	90	160	2.49	2.63	2.54	2.51	2.56	2.63	2.56
V25	120	160	2.67	2.86	2.75	2.60	2.68	2.74	2.72
SE			±0.035	±0.038	±0.072	±0.048	±0.069	±0.073	±0.054

a.s. - active substance; SE - standard error.

Table 5. The effect of the interaction of experimental factors on the total nitrogen (N_{tot}) content in wheat grains

Experimental factor	Factor graduation	Production (kg ha^{-1})
Year	2016	2.440 c
	2017	2.570 a
	2018	2.470 b
	2019	2.370 d
	2020	2.260 e
	2021	2.230 f
Dose of nitrogen administered to the crop (kg ha^{-1})	0	1.950 e
	30	2.230 d
	60	2.440 c
	90	2.610 b
	120	2.690 a
Dose of phosphorus administered to the crop (kg ha^{-1})	0	2.330 d
	40	2.370 c
	80	2.400 b
	120	2.390 bc
	160	2.430 a
A × B interaction		***
A × C interaction		***
B × C interaction		ns
A × B × C interaction		ns

Table 6. Data on total N uptake during the study period and experimental variants, wheat crop

Trial	Fertilizers (kg ha^{-1} a.s.)		N uptake (%)						
	N	P	2016	2017	2018	2019	2020	2021	Mean 2016-2021
V1	0	0	79.46	108.20	78.81	80.38	70.74	89.02	84.43
V2	30	0	99.62	121.71	102.80	93.43	87.29	113.66	103.08
V3	60	0	122.25	136.45	130.69	110.20	107.00	137.55	124.02
V4	90	0	145.59	155.16	149.86	119.07	110.11	144.59	137.40
V5	120	0	153.60	165.21	156.62	123.09	110.55	162.44	145.25
V6	0	40	87.11	114.46	87.61	81.66	64.68	103.15	89.78
V7	30	40	100.71	135.58	115.49	93.42	85.24	117.80	108.04
V8	60	40	127.79	152.04	141.33	107.87	102.56	140.88	128.74
V9	90	40	146.65	156.45	154.49	114.51	114.72	157.51	140.72
V10	120	40	152.53	170.10	144.01	119.98	105.43	169.89	143.66
V11	0	80	94.02	125.84	93.36	78.76	71.71	112.41	96.02
V12	30	80	105.79	140.37	112.42	109.93	95.83	118.60	113.82
V13	60	80	129.94	163.58	142.56	112.60	113.21	146.93	134.80
V14	90	80	153.09	182.66	155.96	122.44	120.71	165.89	150.12
V15	120	80	158.19	177.27	155.97	126.52	107.51	187.58	152.17
V16	0	120	96.60	128.70	95.17	87.64	70.13	113.67	98.65
V17	30	120	106.34	141.05	108.52	108.28	100.06	121.58	114.30
V18	60	120	131.64	169.46	149.36	125.97	110.62	170.46	142.92
V19	90	120	152.96	179.91	160.17	124.64	112.13	175.53	150.89
V20	120	120	159.68	184.22	163.45	130.76	102.29	177.34	152.96
V21	0	160	104.67	145.54	108.95	81.00	63.36	110.61	102.36
V22	30	160	107.03	142.11	107.15	107.79	97.89	122.24	114.03
V23	60	160	126.81	164.56	147.85	115.36	105.68	165.54	137.63
V24	90	160	143.49	181.58	152.63	125.94	121.97	183.04	151.44
V25	120	160	166.29	179.93	170.77	121.91	112.74	177.65	154.88
SE			±5.23	±4.57	±5.48	±3.33	±3.56	±5.84	±4.49

a.s. - active substance; SE - standard error.

The contribution of experimental factors to N uptake in the range 2016-2021. N uptake data recorded during the study period, in relation to the N and P fertilization variants of wheat crop, the 'Ciprian' cultivar, are shown in Table 6.

From the statistical analysis of the experimental data on N uptake, the factors considered (year, N doses, P doses) were obtained in the values and statistical significance presented in Table 7. The differences between the N uptake values showed different meaning compared to each experimental factor considered. The interaction between A×B and A×C factors led to differences in static safety ($p<0.001$).

Table 7. N uptake values recorded in wheat and significance in relation to factors considered

Experimental factor	Factor graduation	N uptake (kg N ha^{-1})
Year	2016	127.9 d
	2017	155.7 a
	2018	135.0 c
	2019	109.3 e
	2020	98.66 f
	2021	149.8 b
Dose of nitrogen administered to the crop (kg ha^{-1})	0	94.67 d
	30	116.4 c
	60	136.5 b
	90	148.6 a
	120	150.8 a
Dose of phosphorus administered to the crop (kg ha^{-1})	0	121.0 c
	40	122.8 c
	80	131.9 b
	120	133.2 b
	160	138.1 a
A × B interaction		***
A × C interaction		***
B × C interaction		**ns**
A × B × C interaction		**ns**

Contribution of experimental factors to NUEs in the period 2016-2021. The calculated values for the NUE, concerning the study period and the N and P fertilization variants for the wheat crop, the 'Ciprian' cultivar, are shown in Table 8. The variation of NUE values was found in relation to the study period, but also to the experimental variants.

From the statistical analysis of the experimental data on calculated NUEs, the factors considered (year, N doses, P doses) were obtained in the values and statistical significance given in Table 9. Differences in NUEs had different significance compared to each experimental factor, and interaction between A×B, A×C and B×C factors generated statistically safe differences ($p<0.05$ in the case of A×C, and $p<0.001$ in the case of A×B and B×C). From the overall analysis of the NUE presented in Table 8, it was found that the lowest NUE were recorded in 2019 and the highest NUE were recorded in 2021.

Figure 8. Values for NUE during the study period and experimental variants, wheat crop

Trial	Fertilizers (kg ha^{-1} a.s.)		NUE						
	N	P	2016	2017	2018	2019	2020	2021	Mean 2016-2021
V1	0	0							
V2	30	0	67.20	45.04	79.96	43.47	55.16	82.14	62.16
V3	60	0	71.31	47.09	86.46	49.69	60.44	80.89	65.98
V4	90	0	73.48	52.18	78.94	42.98	43.75	61.75	58.85
V5	120	0	61.78	47.51	64.84	35.59	33.18	61.18	50.68
V6	0	40							
V7	30	40	70.85	91.29	122.27	43.44	48.33	95.92	78.68
V8	60	40	80.56	73.08	104.19	45.81	53.04	86.43	73.85
V9	90	40	74.66	53.61	84.08	37.91	48.87	76.10	62.54
V10	120	40	60.89	51.59	54.33	33.00	28.91	67.39	49.35
V11	0	80							
V12	30	80	87.78	107.26	112.03	98.48	83.64	98.59	97.96
V13	60	80	84.14	92.31	106.24	53.70	70.78	96.52	83.95
V14	90	80	81.81	82.74	85.72	46.72	55.53	85.42	72.99
V15	120	80	65.61	57.56	64.30	38.45	30.65	82.13	56.45
V16	0	120							
V17	30	120	89.61	109.51	99.01	93.00	97.74	108.53	99.57
V18	60	120	86.96	102.11	117.58	75.97	66.47	135.74	97.47
V19	90	120	81.67	79.68	90.40	49.17	45.99	96.12	73.84
V20	120	120	66.86	63.36	70.53	41.98	26.29	73.60	57.10
V21	0	160							
V22	30	160	91.90	113.03	94.45	91.35	90.52	110.75	98.67
V23	60	160	78.92	93.94	115.06	58.29	58.24	127.53	88.67
V24	90	160	71.15	81.54	82.02	50.62	56.92	104.47	74.45
V25	120	160	72.36	59.78	76.63	34.60	35.00	73.86	58.71
SE			±2.08	±5.15	±4.27	±4.50	±4.47	±4.52	±3.71

a.s. - active substance; SE - standard error.

Table 9. The values of the NUE recorded in wheat and the significance in relation to the factors taken into account

Experimental factor	Factor graduation	NUE (kg ha^{-1})
Year	2016	70.90 c
	2017	100.00 b
	2018	106.80 a
	2019	63.48 d
	2020	56.65 e
	2021	106.9 a
Dose of nitrogen administered to the crop (kg ha^{-1})	0	control
	30	114.50 a
	60	90.77 b
	90	73.96 c
	120	57.32 d
Dose of phosphorus administered to the crop (kg ha^{-1})	0	66.87 c
	40	71.78 c
	80	89.62 b
	120	91.04 b
	160	101.30 a
A × B interaction	***	
A × C interaction	**	
B × C interaction	***	
A × B × C interaction	ns	

The variation of NUE values, based on N and P fertilization, was greatly influenced by the climatic conditions specific to the experimental years.

If an analysis of NUE values is made against phosphorus (P) fertilization levels, it was found that NUE values increased with P levels under the same nitrogen (N) assurance doses. This confirmed the interrelationship between N and P in the formation of agricultural production, in the better capitalization of N associated with phosphorus (P) doses.

Results regarding the optimization of the mineral fertilization in wheat, as the relationship between nitrogen and phosphorus, in the conditions of culture from SDE Timisoara, were communicated by Sala et al. (2015, 2016).

Duan et al. (2014), reported significant increases in wheat grain production (54.5% up to 93.8%) under the conditions of using nitrogen with phosphorus than under the conditions of using single nitrogen, and this led to better values for NUE.

Similar results have been obtained and communicated in other studies, regarding the variation of NUE in relation to mineral (phosphorus and potassium) and organic fertilizers, wheat crops or other cereal crops, under different pedoclimatic conditions and cultivated genotypes (Kabato et al., 2022; Rawal et al., 2022).

CONCLUSIONS

The results showed the interaction between the factors considered (year, nitrogen fertilizers, phosphorus fertilizers) in the values of NUE in wheat crops, directly correlated with production (Y), total nitrogen (N_{tot}) content in wheat grains and nitrogen taken (N uptake).

In relation to the year factor (experimental factor A), it can be estimated that by irrigation, as a method of supplementing the climatic factor given by precipitation, one can direct the recovery of nitrogen to wheat culture, with favourable effects in the efficiency of this nutrient element (NUE).

In relation to the nitrogen fertilizer factor (experimental factor B), the calculation of optimal doses is a method of increasing the efficiency of the fertilization of agricultural crops, in this case, wheat, in order to achieve better yields, Increase NUE and reduce N losses with environmental implications.

In relation to the phosphorus fertilizer factor (experimental factor C), it can be assessed on the basis of the data obtained that it is necessary to optimize the mineral fertilization of wheat, taking into account that with increasing doses of N it appears necessary to supplement phosphorus (P) in order to efficiently use the doses of N applied.

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