

RESPONSE OF AGROCHEMICAL CHARACTERISTICS OF MALTING BARLEY TO NITROGEN RATES

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Abstract. Nitrogen fertilization 0, 40, 80 and 120 kg N.ha⁻¹ was studied in malting barley at the experimental field of the Agricultural University of Plovdiv, Bulgaria during the period 2023-2025. Nitrogen was applied as ammonium nitrate in early spring in the tillering phase. The experiment was set up according to the block method with a plot size of 18 m² in four replications. It was established that that N₁₂₀ rate reduced grain harvest index in both experimental years. The accumulated amounts of nitrogen, phosphorus and potassium at maturity were higher in 2025 under the more favorable hydrothermal conditions during the vegetation and the higher productivity of barley. The grain contained an average of 85.7 - 99.8 kg N.ha⁻¹; 39.3 - 44.0 kg P₂O₅.ha⁻¹ and 21.8 - 26.5 kg K₂O.ha⁻¹. The highest removal of 162.0 kg N.ha⁻¹ and 142.5 kg K₂O.ha⁻¹ was established at application of N₁₂₀ in 2025. Barley fertilization by 120 kg N.ha⁻¹ reduced the total phosphorus uptake at maturity by 5.9 kg P₂O₅.ha⁻¹, compared to that at the rate N₈₀ under less favorable hydrothermal conditions (2024). The total uptake of nutrients changed from 211.7 kg NPK.ha⁻¹ (N₀ in 2024 to 387.8 kg NPK.ha⁻¹ (N₁₂₀ in 2025). More favorable conditions during the barley vegetation in 2025 increased the average NPK uptake by 14.1%, compared to the average uptake in 2024. Rates of N₈₀ and N₁₂₀ increased nitrogen expense for one ton grain formation by 15.6% and 32.5%, respectively, compared to N₀. The main agrochemical parameters uptake and expense of nitrogen, phosphorus and potassium of barley were positively related to the applied rates of 0, 40, 80 and 120 kg N.ha⁻¹. High values of the correlation coefficient were established.

Keywords: Nutrients uptake and expense, barley

INTRODUCTION

Nitrogen is the main nutrient for barley yield and quality in combination with optimal agrotechnical factors such as soil cultivation, fertilization, plant protection, etc. (BAZITOV ET AL., 2011;). The nutrients absorption by barley is directly related to the amount of dry mass formed and the concentration of nutrients in plant organs (KANT ET AL. 2011). Nitrogen is absorbed unevenly during the growing season and its maximum amount in individual plant organs occurs simultaneously with the course of their intensive formation (FAGERIA ET AL., 2010; MUURINEN ET AL. 2007). It takes up most intensively during the phases of tillering to heading, after which the rate of absorption decreases until full maturity. Phosphorus is absorbed in larger quantities during tillering and most intensively during heading. After these stages, it enters in very small quantities until milk maturity, when its absorption completely ceases (SYERS ET AL., 2008). Potassium comes exclusively from the soil solution (RENGEL, Z AND DAMON, P. M. 2008). According to ROGERS ET AL. (2024) assimilation of nitrogen and phosphorus of barley are the main cause of donor limitation during the grain filling period. At full maturity, more than 80% of the nitrogen and phosphorus are localized in the grain and less than 20% of the potassium. From 51% to 89% of the phosphorus in the grain comes from the flag leaf (SYLVESTER-BRADLEY AND KINDRED 2009). In phosphorus deficiency, the flag leaf dries out rapidly and stops photosynthesis when the grains have accumulated only 60% of their potential dry mass (GONZALEZ AND TREJO-TELLEZ, 2007). The effectiveness of each nutrient mainly depends on its efficiency of absorption and utilization (BARR ET AL., 2011). Absorption efficiency is connected with the relative uptake of a nutrient under given provision or supply.

Utilization efficiency is determined as total or main productivity relative to the nutrient uptake (DAS, R., AND HARIKRISHNAN, P. 2015).

Main requirement in sustainable agriculture is the maintenance of a non-deficit nutrients balance in the soil (FIXEN, P. 2015). Nitrogen fertilization rates of barley are most often in the range of 60 to 150 kg N.ha⁻¹, depending on the region and the growing conditions (ALI, M. ET AL. 2022). The uptake of nutrients and their expense per one ton grain formation are basic agrochemical indicators directly related to mineral nutrition and fertilization of crops and are indispensable parameters of Best Management Practices (ANBESSA, Y. AND JUSKIW, P. 2012.). They are necessary scientific information for calculating fertilizer rates and optimizing the level of fertilization (GORBANOV, S. 2016). The nutrients uptake and expense characterize the response of varieties and hybrids to mineral nutrition in order to differentiate and precise fertilization (GÓRNY, A. G. 2009). These two parameters depend on many factors: weather conditions, soil moisture and reserves, nitrogen rates, the amount of formed dry biomass, and others (LADHA ET AL., 2005). The expense of nutrients for one ton grain of barley is usually 23–28 kg N.ha⁻¹, 11-15 kg P₂O₅.ha⁻¹, and 22-26 kg K₂O.ha⁻¹ for one vegetation period (KAUR, S. AND KAUR, R. 2022).

The aim of the present study was to determine the effect of the nitrogen fertilizing rates on the uptake and expense of nitrogen, phosphorus and potassium of winter barley in maturity.

MATERIAL AND METHODS

The field fertilizing trail was carried out on the experimental field of Agricultural University of Plovdiv, Bulgaria during the period 2023-2025. Nitrogen fertilization rates 0, 40, 80, and 120 kg N.ha⁻¹ were studied in Bulgarian winter two-row barley variety Emon. The experimental design consisted of a randomized, complete block design with four replications. The size of individual trial plots was 18 m². Nitrogen as ammonium nitrate (34% N) was applied as top dressing early in the spring in the tillering phase on the background P₅₀ pre-sowing fertilization as triple superphosphate. The precursor of the barley was a sunflower and standard farming practices for the region of Southern Bulgaria were applied during the vegetation period. The experiment was conducted on an alluvial-meadow soil type Mollic Fluvisols (FAO & IIASA, 2023) under non-irrigated conditions. The soil has a slightly alkaline reaction (pH water = 7.24), it is poorly supplied with mineral nitrogen, moderately supplied with mobile phosphates and very well supplied with absorbable potassium.

The average annual air temperature in the experimental field area was 12°C. The region was characterized by high temperatures in the summer months of July and August, mild winters with not very low average daily temperatures (the lowest average monthly temperature was in January - 0°C) and frequent warming. The average amount of annual precipitation in the region was less than the average for Bulgaria (512 mm) and it was unevenly distributed by month. Droughts were very common, starting from the beginning of summer and continuing until the end of October. The data from Table 1 indicate that the air temperature was higher than the average values for the region during both barley growing seasons. Higher average monthly air temperatures were recorded during the 2023/2024 growing season compared to those during the 2024/2025 growing season. Autumn was warm and dry, the plants germinated and emerged within the optimal agrotechnical period and they formed more than 3 brothers before falling into winter dormancy. The amount of precipitation was characterized by large variation and extremely uneven distribution during the barley growing season. In 2023/2024, there was a strong deviation from the norm in the average precipitation for the months of

October, February and June, which were many times lower than the multi-year values. The month of April was also characterized by less precipitation. The month of May was significantly wetter than the norm with precipitation of 82 mm, which exceeds the norm by 31 mm. During the 2024/2025 growing season, the precipitation in October was insignificant, but the average precipitation values in March, April and May exceeded the average values for the region, which characterizes the 2024/2025 growing season as more favorable for the development of barley.

Table 1

Air temperature and c precipitation during barley vegetation period									
	October	November	December	January	February	Mart	April	May	June
Temperature (°C)									
2023/24	16.2	9.4	4.6	3.3	9.2	10.6	16.4	17.1	26.5
2024/25	13.7	6	5.6	3.3	1.9	10.3	12.5	17.5	24.8
Long-term norm	12.7	7	1.4	-0.2	1.7	5.7	11.4	16.7	20.7
Precipitation (mm.m ⁻¹)									
2023/24	2.75	67.25	54.5	75.25	5.25	44.25	31.25	82.25	1.25
2024/25	0.3	15.1	143	26	20	49	78	64	28
Long-term norm	43.5	51	59	46.4	37.5	36.5	46.6	51.1	65.7

The grain and straw yields were determined in full maturity. Samples of these plant parts were dried, weighed, ground and mineralized with concentrated sulfuric acid under hydrogen peroxide catalyst to determine the concentration of the macronutrients nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O). On this basis, main agrochemical indicators were determined: uptake of nitrogen, phosphorus and potassium in maturity; nutrient exence for 1 t of grain formation; harvest indices of nitrogen, phosphorus and potassium. The nutrient uptake was calculated by multiplying the concentration of the element (%) in the grain or in the straw and their dry mass. The expense of nitrogen, phosphorus and potassium for obtaining 1 t of grain was calculated from the total uptake of each nutrient divided by the grain yield. The harvest indices of nitrogen, phosphorus and potassium were defined as the ratio of the grain nutrient to the content of total grain+straw nutrient.

The data were statistically analyzed with the ANOVA procedure and Duncan's multiple range test at level of significance $p \leq 0.05$ was used to find significant differences among means. The regression analysis was done for assessment of the effect of nitrogen fertilization rates on the studied parameters.

RESULTS AND DISCUSSIONS

The average grain and straw yields of the studied nitrogen rates were higher in the more favorable hydro-thermal year 2025 (Table 2). The increase was by 803 kg.ha⁻¹ for grain yield and by 946 kg.ha⁻¹ for straw yield, compared to their yields obtained in 2024. The N₈₀ rate was highly effective for barley productivity in 2024, exceeding the control variant N₀ by 32.0% for grain yield and by 27.0% for straw yield. The high N₁₂₀ rate had been shown to reduce grain yield by 438 kg.ha⁻¹ compared to the variant fertilized with the moderate N₈₀ level. A similar trend was observed with respect to the amount of straw obtained from barley in

2024. A proven positive effect of the nitrogen rate on barley productivity in 2025 was established. High grain and straw yields were obtained at the application of 120 kg N.ha⁻¹, which exceeded the control variant by 28.3% and 34.1%, respectively. The grain harvest index of barley variety Emon changed within relatively narrow limits from 0.389 (N₁₂₀ in 2024) to 0.429 (N₄₀ in 2025). The high rate N₁₂₀ was proven to reduce the GHI values in both experimental years.

Table 2

Rate	Grain		Straw		GHI	
	2024 year	2025 year	2024 year	2025 year	2024 year	2025 year
N ₀	3335 d	4123 c	4965 c	5764 d	0.402 b	0.417 a
N ₄₀	4188 b	4765 b	5759 b	6342 c	0.421 a	0.429 a
N ₈₀	4403 a	4927 b	6341 a	7003 b	0.410 ab	0.413 a
N ₁₂₀	3965 c	5290 a	6229 a	7968 a	0.389 c	0.399 b
Average	3973	4776	5823	6769	0.406	0.415

*Values with identical letters within each column are not significantly different at p<0.05 according to Duncan's multiple range test

Table 3

Uptake of nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) in barley grain in dependence of nitrogen fertilization

Rate	kg N.ha ⁻¹		kg P ₂ O ₅ .ha ⁻¹		kg K ₂ O.ha ⁻¹	
	2024 year	2025 year	2024 year	2025 year	2024 year	2025 year
Grain						
N ₀	67.4 c	77.4 c	29.8 c	36.2 c	15.7 d	20.2 d
N ₄₀	88.4 b	92.8 b	41.3 b	43.2 b	21.8 c	24.3 c
N ₈₀	96.4 a	103.7 b	45.1 a	46.0 ab	24.2 b	28.1 b
N ₁₂₀	90.8 ab	125.3 a	40.9 b	50.6 a	25.4 a	33.3 a
Average	85.7	99.8	39.3	44.0	21.8	26.5
Straw						
N ₀	19.4 c	17.9 d	17.4 d	19.6 c	62.1 c	69.7 d
N ₄₀	23.0 b	20.9 c	21.9 c	22.2 b	77.2 b	81.2 c
N ₈₀	29.2 a	28.0 b	26.0 a	27.3 a	85.6 a	93.8 b
N ₁₂₀	28.0 a	36.7 a	24.3 b	32.7 a	86.0 a	109.2 a
Average	24.9	25.9	22.4	25.4	77.7	88.5
Grain+Straw						
N ₀	86.8 c	95.3 d	47.2 c	55.8 c	77.7 c	89.9 d
N ₄₀	111.4 b	113.7 c	63.1 b	65.4 bc	98.9 b	105.5 c
N ₈₀	125.6 a	131.7 b	71.1 a	73.3 b	109.8 a	121.9 b
N ₁₂₀	118.8 ab	162.0 a	65.2 b	83.3 a	111.3 a	142.5 a
Average	110.7	125.7	61.6	69.5	99.5	115.0

*Values with identical letters within each column and plant part are not significantly different at p<0.05 according to Duncan's multiple range test.

The accumulated amounts of nitrogen, phosphorus and potassium in the barley grain and straw at maturity were higher in 2025 under the more favorable hydrothermal conditions during the vegetation and the higher productivity of barley (Table 3). The average nutrient content of grain yield was as follows: 85.7 - 99.8 kg N.ha⁻¹; 39.3 - 44.0 kg P₂O₅.ha⁻¹ and 21.8 - 26.5 kg K₂O.ha⁻¹. Nitrogen showed the highest grain+straw uptake, which was reached to 125.7 kg N.ha⁻¹ an average in 2025. The smallest amount of phosphorus (61.6 kg P₂O₅.ha⁻¹ an average) was established in the aboveground dry mass of barley in 2024 harvest year. The total uptake of potassium in 2025 (115.0 kg K₂O.ha⁻¹ on average) was higher than that of nitrogen in

the drier year 2024 (110.7 kg N.ha⁻¹ on average). The influence of the studied rates 40, 80 and 120 kg N.ha⁻¹ on the amount of accumulated nitrogen, phosphorus and potassium in the grain and straw of barley had been proven during both growing seasons. The lowest uptake of the nutrients was established in the control variant. Barley grain grown without fertilization contained 67.4 - 77.4 kg N.ha⁻¹; 29.8 - 36.2 kg P₂O₅.ha⁻¹ and 15.7 - 20.2 kg K₂O.ha⁻¹. No significant differences of nitrogen and potassium uptake of barley were found between studied rates N₁₂₀ and N₈₀ in 2024. The nutrient uptake was in the range of 125.6 - 118.8 kg N.ha⁻¹ and 109.8 - 111.3 kg K₂O.ha⁻¹. Barley fertilization with 120 kg N.ha⁻¹ reduced the total phosphorus uptake at maturity by 5.9 kg P₂O₅.ha⁻¹, compared to that at the rate N₈₀ under less favorable hydrothermal conditions (2024).

Table 4

Harvest index of nitrogen, phosphorus and potassium in barley in dependence of nitrogen fertilization

Rate	NHI		PHI		KHI	
	2024 year	2025 year	2024 year	2025 year	2024 year	2025 year
N ₀	0.776 ns	0.812 a	0.632 b	0.649 ns	0.202 b	0.225 ns
N ₄₀	0.794	0.816 a	0.653 a	0.661	0.220 a	0.230
N ₈₀	0.768	0.787 ab	0.634 b	0.628	0.221 a	0.231
N ₁₂₀	0.764	0.773 b	0.628 b	0.607	0.228 a	0.234
Average	0.776	0.797	0.637	0.636	0.218	0.230

*Values with identical letters within each column are not significantly different at p<0.05 according to Duncan's multiple range test

The harvest index of nitrogen, phosphorus and potassium characterizes the amount of the nutrient in the grain from the total absorbed nutrient in maturity. Our results indicated that the values of this indicator varied within relatively narrow limits for the Emon variety grown at rates N₀ – N₁₂₀ (Table 4). In maturity, the largest amount of absorbed nitrogen was distributed into the grain, followed by absorbed phosphorus. Potassium harvest index was characterized by the lowest values 0.218 - 0.230 on average. The average share of grain nitrogen was 0.764 - 0.773 parts of the total absorbed nitrogen in maturity. The distributed phosphorus into the barley grain was on average 0.628 - 0.607 parts of the total phosphorus at maturity. Nitrogen fertilization did not significantly affect the NHI in the harvest year 2024. The increased N₁₂₀ rate proven reduced NHI compared to the N₀ control in 2025. Nitrogen fertilization slightly affected the distributed amounts of phosphorus and potassium into the grain in 2025. A positive effect of N₄₀ rate on the phosphorus harvest index was found in 2024.

Table 5

Expenditure of nitrogen, phosphorus and potassium (kg) for the formation of 1 t of grain depending on nitrogen fertilization

Rate	Kg N		Kg P ₂ O ₅		Kg K ₂ O	
	2024 year	2025 year	2024 year	2025 year	2024 year	2025 year
N ₀	26.0 b	23.1 c	14.1 b	13.5 b	23.3 c	21.8 c
N ₄₀	26.6 b	23.9 c	15.1 ab	13.7 b	23.6 c	22.1 c
N ₈₀	28.5 ab	26.7 b	16.1 a	14.9 ab	24.9 b	24.7 b
N ₁₂₀	30.0 a	30.6 a	16.5 a	15.7 a	28.1 a	26.9 a
Average	27.8	26.1	15.5	14.5	25.0	23.9

*Values with identical letters within each column are not significantly different at p<0.05 according to Duncan's multiple range test

The average nitrogen expence for one ton grain formation of barley was 27.8 kg N in 2024 and 26.1 kg N in 2025 (Table 5). Within the two-year study period, it varied within the limits of 23.1 kg N (N₀ in 2024) to 30.6 (N₁₂₀ in 2024). Applied of 40 kg N.ha⁻¹ had a slight effect on the nitrogen expence compared to that of the control plants in the two experimental years. The nitrogen consumption for the formation of 1 t of main production was proven increased at the rate of N₁₂₀, compared to the control N₀ and the variant N₄₀ in 2024. In 2025, rates N₈₀ and N₁₂₀ demonstrated higher nitrogen expence for one ton grain formation by 15.6% and 32.5%, respectively, compared to N₀. The data showed a tendency to higher phosphorus and potassium expence for one ton grain formation of barley with increasing of nitrogen fertilization. This was more regularly expressed in terms of potassium expence and application of higher rates (N₈₀ and N₁₂₀). The potassium expence of barley grown at N₁₂₀ exceeded the control plants by 20.6% - 23.4%.

Table 6

Total uptake and total expence of nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) in barley in dependence of nitrogen fertilization

Rate	Uptake of NPK, kg.ha ⁻¹		Expence of NPK for 1 t grain	
	2024 year	2025 year	2024 year	2025 year
N ₀	211.7	241.0	63.4	58.5
N ₄₀	273.4	284.6	65.3	59.7
N ₈₀	306.5	326.9	69.5	66.3
N ₁₂₀	295.3	387.8	74.6	73.3
Average	271.7	310.1	68.2	64.5

The total uptake of main macronutrients (N+P₂O₅+K₂O) changed from 211.7 kg NPK.ha⁻¹ in the control variant N₀ in 2024 to 387.8 kg NPK.ha⁻¹ in the 120 kg N.ha⁻¹ variant in 2025 (Table 6). More favorable conditions during the barley vegetation in 2025 increased the average NPK uptake by 14.1%, compared to the average uptake in 2024. At the same time, the total NPK expence for one ton grain formation of barley was lower by 5.4% in 2025 experimental year. Nitrogen fertilization at rates of 40, 80 and 120 kg N.ha⁻¹ had a result higher uptake and expence of NPK throughout the experimental period. The highest values of the two main agrochemical indicators were found when fertilizing barley with N₁₂₀. They exceeded the control plants by 60.9% in total NPK uptake and by 25.3% in total NPK expence.

Table 7

Correltion of nitrogen fertilization rates with main agrochrmlcal parameters of barley

Year	N uptake	P uptake	K uptake	NPK uptake	N expence	P expence	K expence	NPK expence
2024	0.841	0.784	0.930	0.866	0.983*	0.984*	0.923*	0.982*
2025	0.991**	0.999**	0.998**	0.996**	0.964*	0.97*	0.963*	0.967*

**Correlation is significant at the 0.01 level

*Correlation is significant at the 0.05 level

The main agrochemical parameters uptake and expence of nitrogen, phosphorus and potassium of barley were positively related to the applied rates of 0, 40, 80 and 120 kg N.ha⁻¹ (Table 7). High values of the correlation coefficient were established. The correlation between nitrogen fertilization and the uptake of the nutrients individually, as well as the total NPK uptake in 2025, was proven at a significance level of 0.05 and values of the correlation coefficient above 0.990.

Table 8

Regression dependences of nutrients expense (y) of malting barley on nitrogen fertilization		
Nutrient	Regression model	R ²
2024 year		
N expense	$y = 25.91 + 0.0179x + 0.0001x^2$	0.985
P expense	$y = 14.07 + 0.0317x + 0.00005x^2$	0.994
K expense	$y = 23.34 + 0.0151x + 0.0005x^2$	0.997
NPK expense	$y = 63.33 + 0.0345x + 0.0005x^2$	0.998
2025 year		
N expense	$y = 23.05 + 0.0051x + 0.0005x^2$	0.984
P expense	$y = 13.43 + 0.0082x + 0.00005x^2$	0.969
K expense	$y = 21.66 + 0.0091x + 0.0003x^2$	0.978
NPK expense	$y = 58.15 + 0.0225x + 0.0009x^2$	0.991

The regression dependences of the parameter nutrients expense (y) of barley on the studied nitrogen rates (x) were not linear during the two experimental years (Table 8). The modelled dependences were represented by second-degree equations with high values of the determination coefficient $R^2 \geq 0.967$. The regression model indicated that the rise of nitrogen, phosphorus and potassium expense for 1 t grain formation depending on the fertilization increased with increasing the nitrogen rate. Within the framework of this study the expected additional expense for each kilogram of applied nitrogen was: 0.0051 - 0.0179 kg N; 0.0082 - 0.0317 kg P₂O₅; 0.0091 - 0.0151 kg K₂O. The higher expected additional expense for each kilogram of applied fertilizer nitrogen was obtained in 2024.

CONCLUSIONS

The average grain and straw yields were higher in 2025. The increase was by 803 kg.ha⁻¹ for grain yield and by 946 kg.ha⁻¹ for straw yield, compared to their yields in 2024. The high rate N₁₂₀ was proven to reduce the GHI values in both experimental years. The accumulated amounts of nitrogen, phosphorus and potassium in the barley grain and straw at maturity were higher in 2025 under the more favorable hydrothermal conditions during the vegetation and the higher productivity of barley. The average nutrient content of grain yield was as follows: 85.7 - 99.8 kg N.ha⁻¹; 39.3 - 44.0 kg P₂O₅.ha⁻¹ and 21.8 - 26.5 kg K₂O.ha⁻¹ with higher values in 2025. The highest uptake of nitrogen 162.0 kg N.ha⁻¹ and potassium 142.5 kg K₂O.ha⁻¹ in grain+straw was established at application of N₁₂₀ in 2025. Barley fertilization by 120 kg N.ha⁻¹ reduced the total phosphorus uptake at maturity by 5.9 kg P₂O₅.ha⁻¹, compared to that at the rate N₈₀ under less favorable hydrothermal conditions (2024). The total uptake of nutrients changed from 211.7 kg NPK.ha⁻¹ (N₀ in 2024 to 387.8 kg NPK.ha⁻¹ (N₁₂₀ in 2025). More favorable conditions during the barley vegetation in 2025 increased the average NPK uptake by 14.1%, compared to the average uptake in 2024. Applied of 40 kg N.ha⁻¹ had a slight effect on the nitrogen expense compared to that of the control plants in the two experimental years. Rates of N₈₀ and N₁₂₀ increased nitrogen expense for one ton grain formation by 15.6% and 32.5%, respectively, compared to N₀. The main agrochemical parameters uptake and expense of nitrogen, phosphorus and potassium of barley were positively related to the applied rates of 0, 40, 80 and 120 kg N.ha⁻¹. High values of the correlation coefficient were established.

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