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Research Article

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Effectiveness of Applied Nitrogen Rates in Barley

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ABSTRACT
The effectiveness of nitrogen rates 0, 40, 80 and 120 kg N.ha-1 on the productivity and the indexes Partial factor productivity and Agronomic efficiency of malting barley was studied in the experimental field of Agricultural University of Plovdiv, Bulgaria in the period of 2023-2025. The total nitrogen as NH4NO3 was applied as top dressing. The experimental design was a randomized, complete block design with four replications and a size of experimental plots of 18 m2 after a sunflower as a predecessor. A high effect of low N40 fertilization of barley variety Emon has been proven in terms of PFP-N and AE-N indicators. The productivity per unit of soil and fertilizer nitrogen (PFP-N) for grain, for grain + straw and for grain protein exceeds 3.17, 2.93 and 2.93 times, respectively, those at the N120 rate in 2024 and 2.7, 2.5 and 2.2 times, respectively, in 2025.

Keywords: Nitrogen, Fertilization, Effectiveness, Barley

Introduction

Nitrogen is the nutrient strongly limiting yield of the barley [1]. It is easily mobile in the agroecosystems and can cause environmental pollution in case of improper use [2,3]. According to Dobermann efficient nitrogen use are associated with higher yields, economically optimal nutrition and fertilization, minimal losses of soil nutrients and sustainable soil fertility [4]. The average nitrogen efficiency is comparatively low and varies between 20-50% [5,6]. The data for field crops cultivation are extremely inefficient, with nitrogen efficiency ranging from 14% to 59% [7]. Nitrogen use efficiency (NUE) indicators are modern methods for assessing the effectiveness of N fertilization on crop yields and its effect on soil fertility and they can be expressed by agronomical, physiological and economic indicators [8-10].

According to Snyder the indexes Partial factor productivity and Agronomic efficiency determine the productive efficiency, where income is the main output. Partial factor productivity PFP-N (units of crop yield per unit of nutrient input) is the simplest form of the yield efficiency [11,6]. Typical average values of PFP-N are 40 – 80 kg·kg-1; higher than 60 kg·kg-1 are in good practice systems, with low nitrogen rates or low soil nitrogen supply [12]. Usually the PFP-N changed from higher values at application of low N rates to lower values when N rates were increased [13,14].

The index Agronomic efficiency of nitrogen (increased yield per unit of N input) characterizes the ability of plants to increase yield in response to nitrogen fertilization [15]. It is most dependent on nitrogen fertilization and climatic conditions for cereals [16]. Agronomic efficiency of N is higher of25 kg·kg 1 in the best agricultural practice systems, with low nitrogen use rates or low soil nitrogen supply [13,12]. It is often used for economic evaluation of fertilization and usually its values decrease with increasing N rates [17,18].

The objective of the present study was to established the influence of the nitrogen rates on the productivity and main nitrogen indexes Partial factor productivity (PFP-N) and Agronomic efficiency (AE-N) in barley.

Materials and Methods

A field fertilizer trail was conducted to evaluate the effectiveness of nitrogen fertilization on the Bulgarian malting barley variety Emon. Variety Emon is a long-standing standard for winter two-row barley, created at the Institute of Agriculture – Karnobat, Bulgaria. It is characterized by high productivity, stable over the years (yield 5000-6000 kg.ha-1) and very good brewing and technological qualities. The study was carried out on the

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experimental field of Agricultural University of Plovdiv, Bulgaria during the period 2023-2025. The influence of nitrogen fertilization rates from 0 to 120 kg N.ha-1 was studied in the following variants: 1. Control N0; 2. N40; 3. N80; 4. N120. The experimental design consisted of a randomized, complete block design with four replications. The size of individual trial plots was 18 m2. Nitrogen as NH4NO3 form 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. Standard farming practices for the region of Southern Bulgaria were applied during the growing period of barley. The experiment was conducted on an alluvial-meadow soil type Mollic Fluvisols under non-irrigated conditions [19]. 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 air temperatures were higher than the average for the region during the two vegetation periods of the barley (Table 1). The autumn was warm and dry, the seedlings emerged in the optimal agrotechnical period and formed more than 3 tillers before winter rest. The total sum of rainfall varied a lot during vegetation. During 2023/2024 there is a huge deviation of the norm of the average rainfall for the months of October, February and June. They were times less than the norms from the years before. With less rain is the month of April as well. May was way more humid than the average with 82 litres per square meter, which is higher than average of 51 litres. During 2024/2025 the October rainfall was insignificant, but the average rainfall during the months of March, April and May are above the average for the region. This summarize 2024/2025 as more suitable for the barley vegetation.

The total nitrogen concentration of barley grain in maturity was analyzed by Kjeldahl method after wet digestion by H2SO4 and H2O2 as a catalyst [20]. The grain protein concentration was calculated as a percentage of total nitrogen in the grain multiplied by a coefficient of 5.7. The grain protein yield was determined as grain yield (kg.ha-1) multiplied by the concentration of protein in the grain (%), and divided by 100. The main nitrogen use efficiency indicators of Partial factor productivity and Agronomic efficiency were calculated on dry weight basis using the following formulas : PFP-N = Y/F (kg.kg−1); and AE-N = (Y-Y0)/F (kg.kg−1); where Y and Y0 were grain or grain protein yields from fertilized treatments and unfertilized control, respectively, and F – applied N rate (kg N.ha−1) [21].

The data were statistically analyzed with the ANOVA procedure and Duncan's multiple range test at level of significance p ≤ 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.

Table 1: Average Temperatures and Precipitation

	October	November	December	January	February	March	April	May	June
Temperature (oC)									
2023/ 2024	16.2	9.4	4.6	3.3	9.2	10.6	16.4	17.1	26.5
2024/ 2025	13.7	6	5.6	3.3	1.7	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 ($L.m^{-2}$)									
2023/ 2024	2.75	67.25	54.5	75.25	5.25	44.25	31.25	82.25	1.25
2024/ 2025	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

Results and Discussions

The average yield of grain of Emon variety is 3973 kg/ha-1 during 2024 (Table 2). 2025 was more favorable in comparison of rainfall during the spring period, the average yield of grain was higher with 4776 kg/ha^{-1}. The researched norms of nitrogen fertilization 40, 80 and 120 kg N/ha^{-1} have positive effect over the yield of grain during the two experimental period. The effect of fertilization with N80 is higher during 2024 which leads to higher yield with 32% in comparison with the control. The higher nitrogen fertilization norm N120, provenly lowers the yield of grain with 438 kg/ha^{-1} in comparison with N80 norm. In 2025, a proven effect of nitrogen rate N120 was established, with a yield increase of 28.3% over control plants. The application of rates N40 and N80 leads to similar grain yields of 4765 - 4928 $kg.ha^{-1}$ in 2025.

Table 2: Grain yield of barley depending on nitrogen fertilization, $kg.ha^{-1}$

Rates	2024 year	% to N0	2025 year	% to N0
N0	3335 d	100	4123 c	100
N40	4188 b	125.6	4765 b	115.6
N80	4403 a	132.0	4927 b	119.5
N120	3965 c	118.9	5290 a	128.3
Average	3973		4776	

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

The results in Table 3 indicate a similar trend in terms of the total grain+straw yield obtained for barley. The average amount of grain+straw in 2025 exceeds the average grain+straw yield obtained in 2024 by 1750 kg.ha-1. Nitrogen fertilization increased grain+straw yield by 19.9 – 29.5% in the first experimental year, with the differences between N80 and N120 rates not being significant. In 2025, the effect of the studied nitrogen rates was proven, compared to the unfertilized control. The highest total grain+straw yield was established when fertilizing with 120 kg N.ha-1, which exceeded the control variant by 34.1%.

Table 3: Grain+Straw yield of barley depending on nitrogen fertilization, kg.ha^{-1}

Rates	2024 year	% to N0	2025 year	% to N0
N0	8299 c	100	9887 d	100.0
N40	9947 b	119.9	11107 c	112.3
N80	10744 a	129.5	11930 b	120.7
N120	10194 ab	122.8	13258 a	134.1
Average	9796		11546	

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

Grain protein yield in barley depends on the conditions of the year and the nitrogen rate (Table 4). The average grain protein yield in the wetter year 2025 is higher by 79.9 kg.ha-1, compared to the average protein yield obtained in 2024. The highest crude protein yield of 550.4 kg.ha-1 was proven to be obtained at the N80 rate in 2024, with no differences in this indicator at the N40 and N120 rates. The grain protein yield of the Emon variety has been proven to increase in parallel with the amount of nitrogen applied in the experimental year 2025. The highest yield of 714.2 kg.ha-1 was found when fertilizing with N120, which exceeded by 61.9% that of the plants from the control variant.

Table 4: Grain protein yield of barley depending on nitrogen fertilization, kg.ha^{-1}

Rates	2024 year	% to N0	2025 year	% to N0
N0	383.5 c	100	441.2 d	100
N40	502.0 b	130.9	528.9 c	119.9
N80	550.4 a	143.5	591.2 b	134.0
N120	519.4 b	135.4	714.2 a	161.9
Average	489.0		568.9	

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

The partial factor productivity of nitrogen in barley is determined by the amount of nitrogen applied and the hydrothermal conditions during the vegetation period (Table 5). Higher values of the Partial factor productivity of nitrogen index were found for barley in the more favorable precipitation year 2025 compared to those obtained for 2024. In 2025, the average yield of grain, grain+straw and grain protein per unit of nitrogen from all sources exceeds by 10.6, 23.1 and 1.0 kg the average PFP-N values for grain, grain+straw and grain protein in 2024. The productivity per unit of nitrogen from soil and fertilizers to produce 1 kg of grain, grain+straw and grain protein in barley decreases in parallel with the amount of nitrogen applied: 40, 80 and 120 kg N.ha^{-1}. The resulting PFP-N values for grain, grain+straw and protein at the low N40 rate exceed 3.17, 2.93 and 2.93 times, respectively, those at the N120 rate in 2024 and 2.7, 2.5 and 2.2 times, respectively, in 2025. The average Agronomic Efficiency of Nitrogen for grain, grain+straw and grain protein were similar in both experimental years and ranged from 11.9 - 13.3 kg.kg^{-1} (AE-N grain), 28.0 - 29.2 kg.kg^{-1} (AE-N grain+straw) and 2.06 -2.12 kg.kg^{-1} (AE-N protein) (Table 5). The values of this indicator were highest at the low rate of N40 and decreased in parallel with the amount of nitrogen applied N80 and N120. An exception to this pattern was found only with respect to AE-N protein in 2025, where the highest yield of grain protein per kilogram of nitrogen absorbed from fertilizers of 2.28 kg.kg^{-1} was obtained at a rate of N120. Hydrothermal conditions during the barley growing season have a stronger effect on the AE-N indicator in combination with the high rate of 120 kg N.ha^{-1}. At this rate, 4.4 kg grain, 12.3 kg grain+straw and 1.15 kg grain protein more are obtained for each kilogram of fertilizer nitrogen in the more favorable year 2025, compared to those obtained in 2024.

Table 5: Partial factor productivity of nitrogen (PFP-N) and Agronomic efficiency of nitrogen (AE-N) for grain, grain+straw and grain protein yield depending on nitrogen fertilization, kg.kg^{-1}

Rates	2024 year	2025 year	2024 year	2025 year
	PFP-N grain		**AE-N grain**	
N_{40}	104.7 a	119.1 a	21.3 a	16.1 a
N_{80}	55.0 b	61.6 b	13.4 b	10.1 b
N_{120}	33.0 c	44.1 c	5.3 c	9.7 b
Average	64.3	74.9	13.3	11.9
	PFP-N grain+straw		**AE-N grain+straw**	
N40	248.7 a	277.7 a	41.2 a	30.5 a
N80	134.3 b	149.1 b	30.6 b	25.5 b
N120	85.0 c	110.5 c	15.8 c	28.1 ab
Average	156.0	179.1	29.2	28.0
	PFP-N protein		**AE-N protein**	
N40	12.6 a	13.2 a	2.96 a	2.20 a
N80	6.9 b	7.4 b	2.08 ab	1.88 b
N120	4.3 c	6.0 b	1.13 b	2.28 a
Average	7.9	8.9	2.06	2.12

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

Conclusions

A high effect of low-rate N40 fertilization of barley variety Emon has been proven in terms of PFP-N and AE-N indicators. Productivity per unit of soil and fertilizer nitrogen (PFP-N) for grain, for grain+straw and for grain protein exceeds 3.17, 2.93 and 2.93 times, respectively, those at the N120 rate in 2024 and 2.7, 2.5 and 2.2 times, respectively, in 2025. High AE-N was found for grain (16.1 - 21.3), grain+straw (30.5 - 41.2) and grain protein (2.20 - 2.96) when fertilizing with N40. Hydrothermal conditions during the barley growing season have a stronger effect on the AE-N index in combination with the high rate of 120 kg N. ha-1, resulting in 4.4 kg of grain, 12.3 kg of grain+straw and 1.15 kg of grain protein more for each kilogram of fertilizer nitrogen in the more favorable year 2025, compared to 2024. A negative linear regression of the efficiency indicators PFP-N and AE-N from nitrogen fertilization was found with high coefficients of determination R2 ≥ 0.797.

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