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Research Article

Influence of Nitrogen Fertilization on Biomass Accumulation of the Brewer's Spring Barley

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Abstract

The objective of this study was to analyses the nitrogen fertilization effect on biomass accumulation and grain quality of the brewer's barley. The study was conducted in randomized blocks with 4 replicates in Warsaw Agriculture University Experimental Field in Chylice. The experimental factors were: three cultivars of spring barley (Maresi, Poldek and Rasbet of chaffy grain) and nitrogen doses (0, 30, 60, 90 kg N/ha). The size of grain yield and protein content in the grain of brewer's spring barley is closely dependent on nitrogen fertilization. The highest nitrogen fertilization used in the experiment (90 kg/ha) increases the protein content in the grain above the allowed norm, making it incompetent raw material for the brewing industry. The condition to produce high dry matter by the plants of brewer's spring barley is constant and high relative growth rate since the beginning of the growing season, so the growing of barley should be focused on obtaining fast-growing form.

Keywords: Nitrogen Fertilization; Hordeum Vulgare; Grain Quality; Biomass Accumulation; Cgr; H

Introduction

Barley (*Hordeum vulgare L.*) is the most produced cereal of great economic importance. It is grown in a wide geographic range under different conditions [1, 2]. Barley was and still is very important feed grain, not only in Poland but also throughout Europe. However, in the structure of seeding, the share of spring barleys is small and its cultivation aims mainly to acquire raw material for barley malt production, required to produce beer. Taking into account the use of barley for feed, the main emphasis is placed on the cultivation of winter barley. It is commonly known that the potential of winter cultivars of this species exceeds that of spring form by at least 1 t/ha. However, in Poland, due to low winter hardiness of winter, spring forms dominate it the cultivation [3].

Nitrogen is one of the main factors modifying the growth, development and productivity of crops [4]. It affects the quality parameters of grain, hence the need to respect the principles of the proper allocation of the total dose of that component planned for barley. It is applied in proportion to the current food needs of crops, especially in the late stages of development [2]. It should be emphasized that the specific protein is associated not only with reduced nitrogen fertilization, but also with relatively large yields obtained under normal conditions of fertilization with phosphorus, potassium and magnesium. In the cultivation of malting barley, the ratio of N : P : K, should be 1 : 2 : 3. Determining the optimal dose of nitrogen is quite difficult and depends on the accurate determination of nitrogen in the soil. Incorrect determining the dose and increasing the amount of nitrogen can affect significantly the leaves size, their durability and, a large extent, processes determining biomass and yielding [5].

Furthermore, one observed the interaction of nitrogen with the properties of barley cultivars, which is related to certain morphological-physiological characteristics of cultivars (plants capacity of tillering, light requirements, utilization efficiency of nitrogen taken, rigidity, resiliency and elasticity of blades). A lower response to increasing nitrogen fertilization was observed for variants tillering stronger, with greater light requirements and more susceptible to lodging [6].

Therefore, nitrogen fertilization of cereal, in particular – brewer's barley, is the subject of numerous experimental works, aimed to determine the optimal dose size that allows for obtaining high grain yield without compromising its quality. Besides, establishing the optimum is especially important in the case of malting barley, because the overfertilization with nitrogen leads to exceeding limits of the nitrogen content in the grain, making it incompetent raw material for brewing industry [3, 6].

The objective of this study was to analyse the nitrogen fertilization effect on biomass accumulation and grain quality of the brewer's barley.

Material and Methods

Study region

The study was conducted in randomized blocks with 4 replicates in Warsaw Agriculture University Experimental Field in Chylice (40 km west of Warsaw) which was established on IIIb class soils of very good rye complex of average richness in potassium and high in phosphorus (table 1). Potatoes cultivated on farmyard manure were previous crop to barley. The area of each plot was 30 m^2.

Properties	Value
% of N total	0.09
P mg·kg-1 of soil	43.0
K mg·kg-1 of soil	117.0
pH KCl	6.6

Table 1. Soil properties before the experiment.

The experimental factors

The experimental factors were: three cultivars of spring barley (Maresi, Poldek and Rasbet of chaffy grain) and nitrogen doses (0, 30, 60, 90 kg N/ha). One sowed 350 germinating seeds of Maresi Poldek and Rasbet cultivars per m^2. Nitrogen fertilization in doses of 30 and 60 kg N/ha was applied before seeding in the form of ammonium nitrate and a dose of 90 kg N / ha was applied twice - 60 kg N / ha before seeding and 30 kg N/ha during the shooting phase. Moreover, during the process fertilization of phosphorus (granulated single superphosphate 18.5 % – 72 kg P_2O_5/ha) and potassium (KCl 60 % – 90 kg K_2O/ha) were added to the soil. The dates of emergence were noted 2 weeks after sowing. At the beginnings of vegetation, one sprayed dicotyledenous weeds with the herbicide Aminopielik D450 SLW (active substances 2.4-D and DICAMBA), while by the end of vegetation fungal diseases of barley were controlled.

The times of measurements and corresponding developmental stages were determinsd according to Zadoks et al. [7]. The sowing was done on 28.03, the first sampling was taken on 8.05, and plants were at the developmental stages in 19-21 Zadoks (the most of plant was at the beginning of tillering), the second one – on 22.05 when the plants were in the tillering phase, the third one – 5.06 when the plants were in the shooting phase (34 Zadoks), the fourth – on 19.06 when the beginning of earing was observed, the next sampling on 3.07 was in 75 Zadoks (i.e. milky stage), the last one was on 17.07 when the majority of plants was in the dough stage (grain fill period) and some in full ripening.

During vegetation, monthly total rainfall [mm] and the average monthly temperature [°C] in Chylice amounted to: in April – 19.4 mm and 8.5 °C, in May – 34.1 mm and 11.4 °C, in June – 35.8 mm and 19 °C, in July – 55.2 mm and 18.4 °C, in August – 57.0 mm and 19.0 °C.

At the time of harvesting (late July), one determined grain yield, which was converted to a water content of 15% and reported in t/ha after weighing harvested grain per plot and determining the content of dry matter. The nitrogen content of the dry weight of the grain was determined with the Kjeldahl method and measured with the DK 6 VELP Scientifica.

Leaf area index (LAI) measurement

LAI measurements were performed at 14 day intervals using an optical tool LAI 2000 Plant Canopy Analyzer (LI-COR, Lincoln, NE). The camera also allowed for designating the average angles orientation of the leaves in the canopy. The study was performed according to the recommendations of the manufacturer and it depended on the completion of the two measurements over the canopy and six measurements in the canopy. Basing on these results, the tool calculated the average LAI in the canopy value.

Crop growth rate (CGR) measurement

Crop growth rate was calculated using the following formula:

$$CGR\ (g\ m^{-2}\ d^{-1}) = (W2 - W1)/(t2 - t1)$$

where: W1 and W2 are the first and second measurement of shoot biomass (g m^{-2}), respectively, and t1 and t2 symbolize the first and second time (d), respectively, of the measurement.

Harvest index (HI)

Harvest index was calculated using the following formula:

Harvest index = total grain weight (dry weight)/total aboveground biomass (dry weight)

The collection of dry matter

The collection of plants for dry matter from the field consisted in collecting a representative sample (their aerial parts) from each plot. At the next stage, the plants were divided into leaves, culm and spike and placed into appropriately labeled envelopes. The plants were dried in an oven at 105 °C for 2 h and then at 75 °C until complete evaporation of water.

Statistical analysis

All the collected results from the plots were subjected to a statistical multivariate analysis of variance at the significance level α = 0.05.

Results and Discussion

Nitrogen is a key component of many organic compounds [8], which is closely correlated with photosynthesis, dry matter production and grain yield [9, 10]. Overfertilization with nitrogen causes the plants and soil microorganisms not to be able to make full use of the supplied nitrogen which in turn results in large losses of this component and groundwater contamination. It is therefore important to determine the proper dosage of nitrogen needed for plant growth [11-13].

The influence of nitrogen fertilization on the size of the surface assimilation of whole plants was visible in all cultivars taken for the present study (table 2). The area was significantly increased across the range of doses studied and it obtained the highest values in the milky stage of grain. In the cultivar Rasbet, in the fertilization dose range of 0 to 60 kg N/ha, one observed an increase of green surface of plants. Moreover, the application of a dose of 90 kg N/ha caused a slight decrease in the assimilation surface plants. In turn, in the cultivar Poldek, the size of the assimilation surface was highest at 90 kg N/ha, while the lowest – in the control plots (table 2).

Nitrogen dose (kg/ha)	0	30	60	90
Cultivar	Maresi			
Dry matter (g/m^2):				
grains	118.9	154.3	179.6	174.8
culm	296.8	408.6	436.8	422.7
spike	528.1	735.7	672.3	667.7
Cultivar	Poldek			
Dry matter (g/m^2):				
grains	137.4	175.8	162.5	182.4
culm	301.6	383.7	337.2	387.7
spike	550.6	583.6	591.8	692.6
Cultivar	Rasbet			
Dry matter (g/m^2):				
grains	161.5	154.1	187.8	162.5
culm	421.2	408.9	464.8	402.9
spike	629.2	635.6	683.1	602.6

Table 2. Effect of nitrogen fertilization on the size of the assimilation surface of the brewer's spring barley.

In addition to nitrogen fertilization, weather is an important factor with can modify assimilation area crop. As noted by Liszewski et al. [14], optimum weather conditions in the barley shooting phase enable producing the maximum assimilation area, which makes it possible for plants to achieve high yields. In the study, present temperature and rainfall contributed to shortening the filling and ripening grain period and faster vegetation completion. Figure 1 shows the total yield of dry mass of the aboveground part of the examined plants. As presented in previous studies by Hay [15], total dry matter yield of cereal plants measured at harvest shows a positive correlation with grain yield obtained. The increase in grain yield with greater production of dry weight of plants results from the increase in the number of grains collected from 1 m2 [16]. In the field experiments, it was noted that the cultivar Poldek was characterized by the lowest dry matter yield of aerial parts, while Rasbet – by the highest yield, while the average grain yield was the lowest.

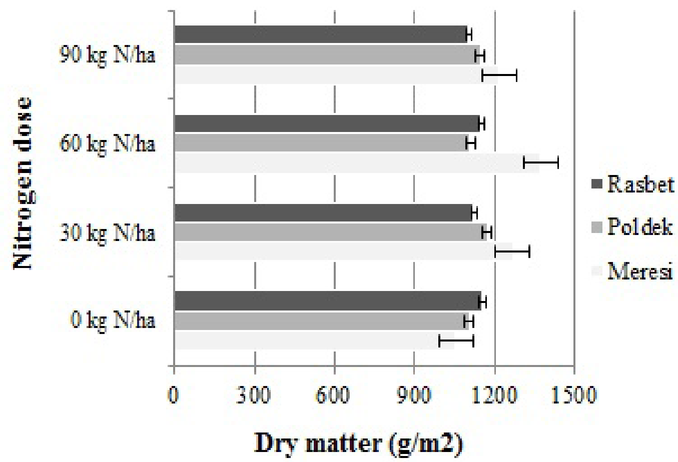

Figure 1. The influence of nitrogen fertilization on the growth of the dry weight of the aerial parts of plants of spring barley malting depending on the cultivar (Maresi, Poldek, Rasbet) (error bars represent the standard error).

In this study, there was a significant increase in dry matter at 60 kg N/ha, while with other doses of fertilizer (0, 30 and 90 kg N/ha), the level of accumulation of dry matter was at a similar level, on average approx. 1150 g m^{-2} (Figure. 1). The cultivar Poldek was characterized by the lowest yield of dry weight of the aboveground part of about 1133 g m^{-2}, while the highest Maresi – approx. 1200 g m^{-2} (Figure. 1). The statistical analysis (table 3) showed that the growth and development of the brewer's barley was significantly influenced by nitrogen fertilization used, date and cultivar of sampling plots.

The crop growth rate (CGR) as reported by Hatch [17], it is an increase in plant dry weight per land area unit occupied by the plant which usually equals to about 13-43 g m^{-2} d^{-1} for crops C3 plants. In the present study, one observed the influence of nitrogen on the growth rate of the crop. In the cultivar Maresi at 30, 60 and 90 kg N/ha, one obtained CGR of a similar average value for the entire growing season, approx. 15.5 g m^{-2} d^{-1} which was the highest value, while in the cultivars Rasbet and Poldek, the course of changes of CGR was characterized by significant differences and obtained an average value for the entire growing season, approx. 14.1 and 13.4 g m^{-2} d^{-1}, respectively (Figure. 2). The research study conducted by Mollah and Paul [18] shows that wheat and barley leaves play a significant role in the formation of grain yield.

Factors of analysis	Degree of freedom	The mean square
LAI		
A- Cultivar	3	0.025
B- dose N	4	0.442**
Error		
HI		
A- Cultivar	3	0.047**
B- dose N	4	0.044 **
Error		
CGR		
A- Cultivar	3	1.907
B- dose N	4	0.939
Error		
Dry matter		
A- Cultivar	3	1.28×10^7 **
B- dose N	4	2.91×10^5 **
C-Time	7	6.06×10^4
Error		3.18×10^4

** significance level at α = 0.05

Table 3. Analysis of variance for LAI, HI, CGR and dry weight of the aboveground parts.

Moreover, as shown by Mollah and Paul [19], the nitrogen fertilization is important for obtaining an optimal status of nutrition at plants with nitrogen to maintain a maximum relative growth rate and thus high yielding crop.

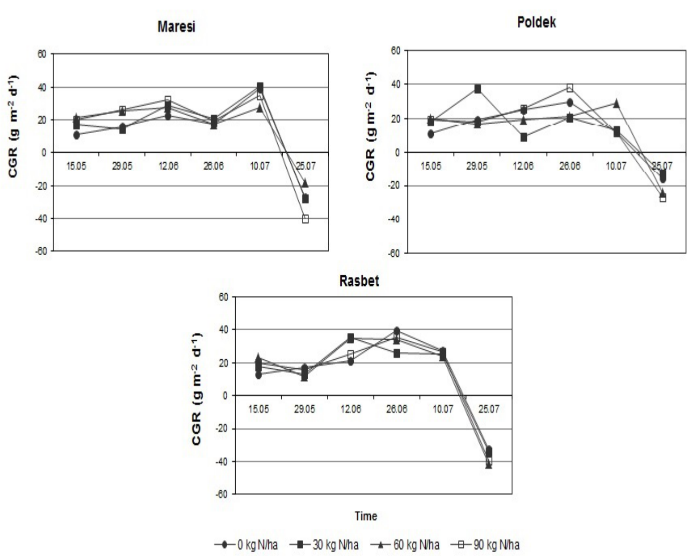

Figure 2. Crop growth rate of spring brewer's barley depending on nitrogen fertilization and cultivar (Maresi, Poldek, Rasbet).

According to Zheng and Moskal [20], the leaf area index (LAI) is used to monitor crop growth and development, to classify crop vitality and yield production, as well as to detect early crop stress. As suggested by Kross et al. [21], LAI is a good indicator of crop development and health, which is used as an input variable for crop growth and yield. During the growing season, in a cultivar Rasbet, LAI value peaked on average at 2.8, while the lowest – at about 2.5 for Meresi. In the case of the applied fertilizer, the highest statistically significantly average value of LAI was observed in plants growing at 90 kg N/ha – 3.0, while the lowest was observed at 0 and 30 kg N/ha, at the level of about 2.2 (Figure. 3, table 3). This is confirmed by the results of research conducted by Gillett et al. [22] and Nieróbca and Faber [23], which stated that nitrogen deficiency reduces LAI by limiting the growth of leaves and the acceleration of senescence.

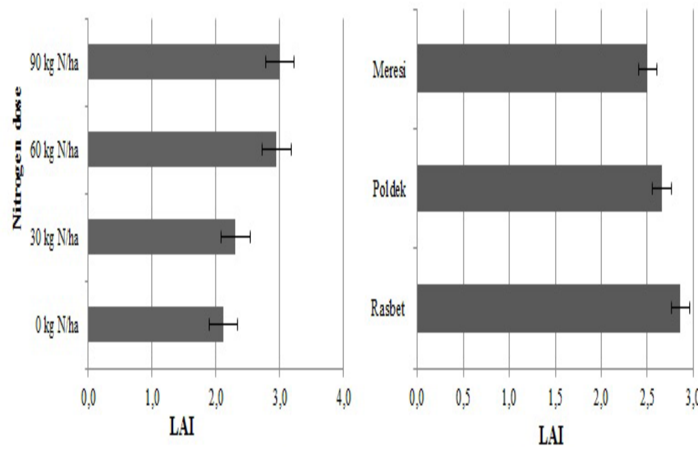

Figure 3. LAI size depending on the cultivar and nitrogen fertilization (Maresi, Poldek, Rasbet) (error bars represent the standard error)

In the field research conducted the value of the harvest index (HI) of the brewer's barley was in the range from 0.38 to 0.49, so it was in the range given by Hay [24], obtained for the latest cereal cultivars (0.4 to 0.6). The HI values were the highest for plants growing at 60 and 90 kg N/ha, while the lowest occurred at a dose of 30 kg N/ha (on average approx. 0.37). The cultivars Maresi and Poldek had a higher rate of agricultural yield (0.40 and 0.44 respectively), while the cultivar Rasbet was characterized by the lowest coefficient of agricultural yields (0.37) (Figure. 4). Similar harvest index values to those obtained for barley were also reported by Rozbicki [25] for winter triticale.

The accumulation rate and the amount of dry matter decide on grain yield and quality. Holopainen et al. [26] states that in the period after heading, sunny and warm weather creates conditions for intensive photosynthesis and good grain filling. In contrast, the corresponding nitrogen fertilization can further mitigate the effects of weather as occurs during the growing season. Table 4 shows grain yield and its components depending on nitrogen. The cultivar Maresi (4.92 t/ha) fertilized with 60 kg N/ha reached the highest grain yield, while the variation Poldek without fertilization (4.23 t/ha) – the lowest. The applied fertilization also modified the grain yield and the highest grain yield was at 30 and 60 kg N/ha (about 490 g m^{-2}), while

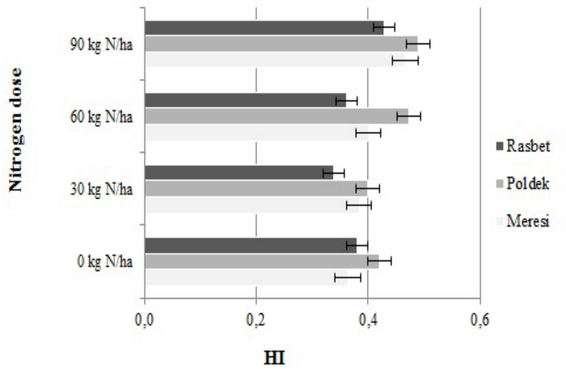

Figure 4. Harvest index (HI) for malting barley growing under four nitrogen levels (error bars represent the standard error)

the lowest yield was 440 g m-2 at a dose of 0 kg N/ha. The weight of 1000 grain in the studied cultivars ranged from 38.0 g of the cultivar Maresi without nitrogen to 47.1 g in Poldek at 60 kg N/ha. The nitrogen content in the grain of the examined cultivars ranged from about 1.8% N in Poldek with fertilization 0 kg N/ha to about 2.09 % in Maresi with fertilization of 90 kg N/ha. The cultivar Rasbet gained less than 2% of the nitrogen in the grain used for all combinations of fertilizer (table 4). With increasing nitrogen fertilization, the protein content in the dry matter increases, but simultaneously the grain uniformity reduces [27].

Conclusion

1. Based on the research study, it was found that the differentiated nitrogen fertilization doses had a statistically significant effect on the dry matter yield and quality of grain obtained.

2. The size of grain yield and protein content in the grain of brewer's spring barley is closely dependent on nitrogen fertilization. The highest nitrogen fertilization used in the experiment (90 kg/ha) increases the protein content in the grain above the allowed norm, making it incompetent raw material for the brewing industry.

3. Grain yield depends mainly on produced dry matter yield, and – to a lesser extent – on the coefficient of agricultural yield.

4. The condition to produce high dry matter by the plants of brewer's spring barley is constant and high relative growth rate since the beginning of the growing season, so the growing of barley should be focused on obtaining fast-growing form.

5. Increased nitrogen fertilization of spring barley positively influenced the leaf area index (LAI).

Cultivar	Nitrogen dose [kg/ha]	Grain yield [t/ha]	Weight of 1000 grains [g]	Nitrogen content * [%]			Malt extractivity by Bishop
				grains	leaves	culm	
Maresi	0	4.38	38.00	1,96	1.43	0.65	86.83
	30	4.86	38.2	1.90	1.25	0.66	86.89
	60	4.92	40.6	1.89	1.39	0.56	87.14
	90	4.61	36.5	2.09	1.47	0.67	86.58
Poldek	0	4.23	44.7	1.80	1.53	0.61	87.62
	30	4.58	43.2	1.90	1.62	0.66	87.39
	60	4.60	47.1	1.99	1.46	0.71	87.71
	90	4.49	42.8	2.02	1.69	0.69	87.26
Rasbet	0	4.37	36.9	1.87	1.47	0.62	86.78
	30	4.38	40.00	1.87	1.43	0.70	87.09
	60	4.47	45	1.97	1.51	0.70	87.52
	90	4.50	39.1	1.92	1.49	0.69	86.97

* nitrogen content at harvest

Table 4. Grain yield and its components in the cultivars depending on nitrogen dose.

Malt extract is perhaps the most important quality parameter for maltsters and brewers while selecting or purchasing malting barley [28]. Based on the weight of 1000 grain and protein content in the grain, one calculated theoretical malt extractivity according to the Bishop's formula. It was shown that the increase in the protein content in grain, can cause a decrease of the malt extractivity and deterioration of beer quality. As shown Błażewicz et al. [29], extractivity is the parameter which determines the final assessment of the brewing grain value. In our study, the best theoretical malt extractivity was observed at the dose of N 60 kg N/ha (table 4).

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