THE EFFECT OF SOIL pH AND NITROGEN RATES ON SPRING BARLEY PRODUCTIVITY*

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The effect of soil pH and nitrogen fertilization (rates 0, 85, 170 and 255 mg N per pot, i.e. 30, 60 and 90 kg $N.ha^{-1}$) on the productivity of spring barley, cv. Jubilant, has been studied in small-plot field trials conducted in cylindrical pots without bottom, of area 0.029 m^2 and embedded into the soil profile. On extremely acid soil the studied parameters did not reach the values found on neutral soils at all levels of nitrogen nutrition and under the given conditions of cultivation (humus content 1.7 to 2.8%; N_{tot} = 0.20 to 0.29%; high to very high supply of available phosphorus, suitable to good supply of available potassium and low to suitable supply of available magnesium; microplots). All N rates were efficient on neutral soil and the yield was slightly increasing on extremely acid soil only at the rates up to 60 kg $N.ha^{-1}$. Correlation index (*r*) between nitrogen uptake by harvest and straw and grain yields was high – from 0.74 to 0.82 on neutral soil, while it was ranging from 0.48 to 0.56 on acid soil. Blockage of nitrogen supply from extremely acid soil medium became a limiting factor of yield formation. A year had a significant influence on the formation of yield parameters. Unfavourable weather conditions became a limiting factor of barley growth and yield on neutral soil. This limiting factor was low pH on extremely acid soil. Nitrogen content in grain of spring barley is fully question of a year. There was not statistically significant difference in nitrogen content between plants cultivated on neutral and extremely acid soil. Intensity of nitrogen fertilization had not affected significantly nitrogen content in grain and straw, but the uptake of nitrogen by harvest of spring barley was considerably affected by pH of soils, as their yields were much lower on extremely acid soil.

soil pH; nitrogen rates; spring barley productivity

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INTRODUCTION

Metabolic and growth processes of agricultural crops are affected by conditions of cultivation environment. It is a common situation that genetically coded yield potential is realized maximum up to 70%. Production capacity of plants stressed by some vegetation factors, e.g. low temperatures, drought, excessive moisture, anaerobiosis, soil acidity, nutrient deficit etc., is even lower.

In view of maintenance of soil fertility an equalized balance of nutrients, concretely mainly also of nitrogen, is substantial. It has been proved that nitrogen conversions are in close correlation with soil fertility. Fertilizers are an important active component of nitrogen balance. As reported by Růžek (1997), the meaning of nitrogen fertilization consists in the fact that it should equalize the disproportions between the supply of available nitrogen in soil and demands of cultivated crop for nitrogen fertilization in certain period. The use of nitrogen fertilizers results not only in balance of losses of a closed circulation of nutrients, but also in a marked stimulation of biomass production of plants. The share of fertilizers in the level of reached agricultural production amounts to approximately 30%, whereas an emphasis is paid particularly on nitrogen component. As reported by Kudějarov (1989) and Vostal (1990), fertilizers represent 50–60% of total inputs of nitrogen into environment, that is into soil. According to Vaněk et al. (1995), nowadays it is necessary to use fertilizers for renovation of soil fertility also due to the fact that numbers of cattle fell substantially in the Czech Republic. Therefore, there is a lower production of organic fertilizers as well as decreasing areas of clover crops.

Soil reaction is an important factor, which jointly decides upon soil fertility. The total area of a farmland with acid reaction takes about 10 million km^2 of the earth's surface. Now in the Czech Republic the share of arable land with unfavourable acid reaction is about 25%. The soil acidity in many regions of the Czech Republic seriously restricts the growth of plants. The situation may get even worse, if the present trend continues, when the annual consumption of calcium is estimated to be hardly 33.9 kg of CaO per 1 ha of farmland. Thus occurs also decrease of saturation of sorption complex by calcium and further, decrease of soil pH can be expected and consequently, soil fertility (Vaněk et al., 1995). Effectiveness of nitrogen fertilization in soils of different fertility belongs in recent years to most important tasks in mineral nutrition of plants. The aim of this study was to obtain new knowledge on the effect of selected factors of soil fertility and nitrogen fertilization on productivity of spring barley.

MATERIAL AND METHOD

On the experimental site at Sojovice near Lysá nad Labem in the years 1996 to 1998 micro-plot field trail with spring barley was established each year. Micro-plots were of area 0.029 m^2 and were composed of cylindrical pots without bottom of diameter 19 cm and embedded 30 cm into soil profile. Spring barley Jubilant was an experimental plant, 15 plants per pot were cultivated.

Soils used in the trials were sampled before spring of 1996 from two sites with Fluvisol and were stored at the experimental site. In the years 1996 to 1997 before filling of pots, samples from stored soils were taken to determine basic agrochemical characteristics. Soil pH/KCl, humus content after Tjurin and the content of available nutrients by the Mehlich II method were determined in dried at 40 °C and homogenised soil samples. In early spring of 1998 samples were taken from stored soils to determine nitrogen content. From freshly taken samples after their homogenisation mineral nitrogen (N_{min}) was determined in extraction of 1% K_2SO_4 by ion selective electrodes. In addition, samples were dried at 40 °C and further analyses were prepared from fine earth. The total nitrogen (organic + $N\text{–}NH_4^+$) was set by mineralization by concentrated sulphuric acid by the method after Kjeldahl, subsequent distillation and titration. Aerobic incubation method was used to determine mineralizable nitrogen. The soil mixed with sand in ratio 1 : 1 was incubated for 7 days at the moisture 60% of maximum water capacity and temperature of 30 °C. This was followed by determination of mineral nitrogen in extraction of 1% K_2SO_4 by ion selective electrodes. Mineral N is the content of mineral nitrogen before incubation and mineralizable N represents an increment of mineral N during incubation. Agrochemical characteristics of soils are presented in Table I.

According to geological and soil situation of the territory concerned the soil 1 had the character of medium heavy Fluvisol on fluvial deposits and favourable moisture conditions. It had high to very high supply of available phosphorus, convenient supply of available potassium and available magnesium, medium humus content and neutral reaction (pH > 6.5). The soil 2 was medium heavy Fluvisol on sands, more dependent on precipitation. It had high content of available phosphorus, suitable to good supply of available potassium, low to suitable supply of available magnesium, medium humus content and extremely acid reaction (pH < 4.5).

Mildly arid climate with average annual temperature of 8.6 °C, 14.8 °C during the vegetation period (April to September), with average annual sum of precipitation 542 mm, 353 mm of it during the vegetation, is typical for an experimental site.

I. Agrochemical characteristics of soils (samples taken for analysis in the given year before trial establishment)

Soil	Humus (%)		pH/KCl		Content of available nutrients (mg.kg^{-1})					
					P – Mehlich II		K – Mehlich II		Mg – Mehlich II	
	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
Neutral	2.85	2.17	6.9	6.7	161	123	168	153	127	123
Extremely acid	2.12	1.69	4.4	4.3	125	103	208	176	92	113

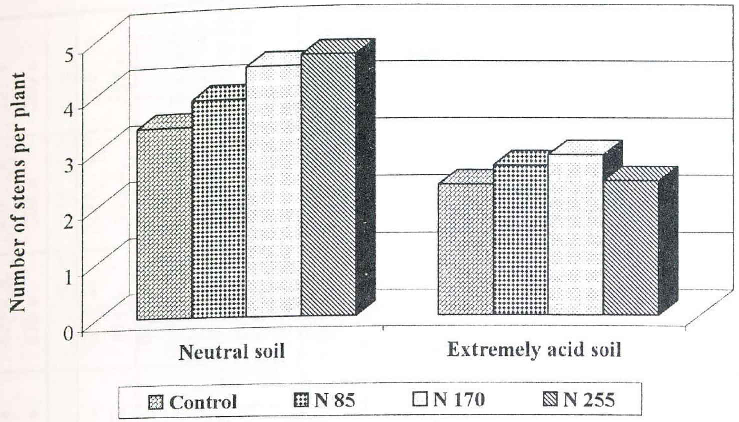
Soil	Total N (%)	N min. (mg.kg^{-1})	Mineralizable N (mg.kg^{-1})
Neutral	0.29	85	12
Extremely acid	0.20	102	–

The layout of the trial included four variants on each soil with five replications. Only phosphorus was used as a fertilizer on the control variant (255 mg per pot or 90 kg.ha^{-1}, respectively) and potassium (320 mg per pot or 110 kg.ha^{-1}, respectively) in the form of potassium dihydrogenphosphate. Except it in other three variants were applied graded nitrogen rates (85, 170 and 255 mg per pot or 30, 60, 90 kg.ha^{-1}, respectively). Ammonium sulphate was used as a nitrogen fertilizer. All fertilizers were applied in the form of solution by mixing with all the content of soil before filling of the pot. After the harvest the content of total nitrogen was found in plants by the Kjeldahl's method. The trial has been statistically evaluated by the computer program Statgraphics by multiple analysis of variance at α = 0.05 and regression analysis.

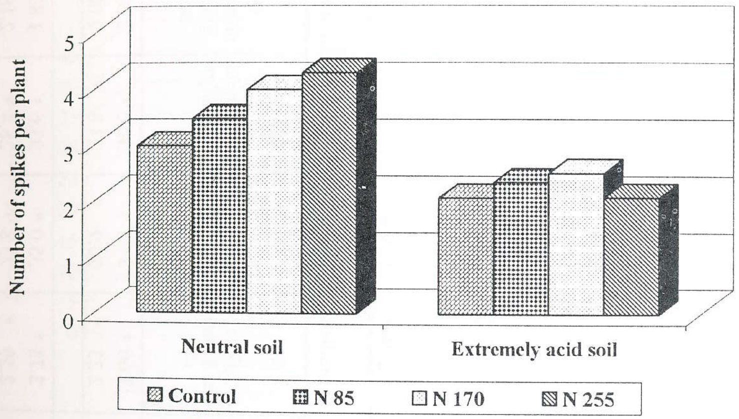
RESULTS AND DISCUSSION

The results obtained are in Figs. 1 to 9 and their statistical evaluation is presented in Tables II to IV.

The first studied parameters were the following: number of stems (Fig. 1) and number of spikes (Fig. 2) per plant. As given in Tab. III, pH value of soil had a significant influence on the formation of these yield parameters. On neutral soil on average for three years 4.05 stem and 3.66 spike was formed on one plant, that is statistically significantly more than 2.51 stem and 2.23 spike on one plant cultivated on extremely acid soil. Application of nitrogen fertilizer was increasing the number of stems and spikes in spring



1. Effects of soil reaction and nitrogen rates on formation of spring barley stems (average number per plant in the years 1996 to 1998)



2. Effects of soil reaction and nitrogen rates on formation of spring barley spikes (average number per plant in the years 1996 to 1998)

barley, particularly on soil with favourable pH, where all three rates were efficient. Higher number of stems and spikes was recorded on extremely acid soil only at the rates 30 and 60 kg of nitrogen (Table II).

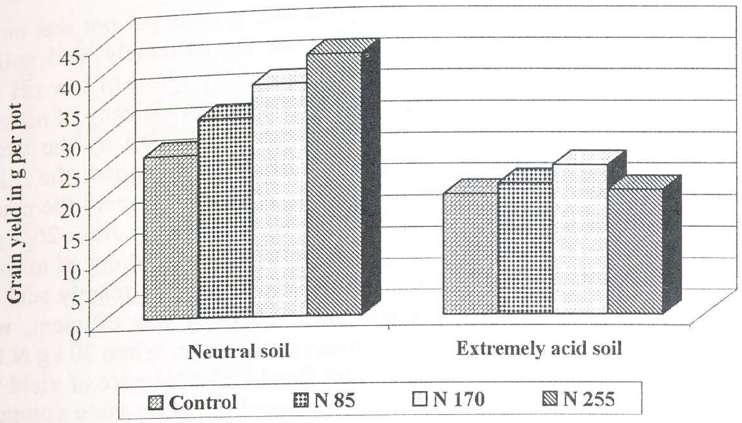
Variants with higher number of productive tillers, and thus with higher number of produced spikes, had also higher resulting productivity, as can be

II. Effects of soil reaction and nitrogen fertilization on the studied parameters – statistical evaluation by multiple analysis of variance at α = 0.05

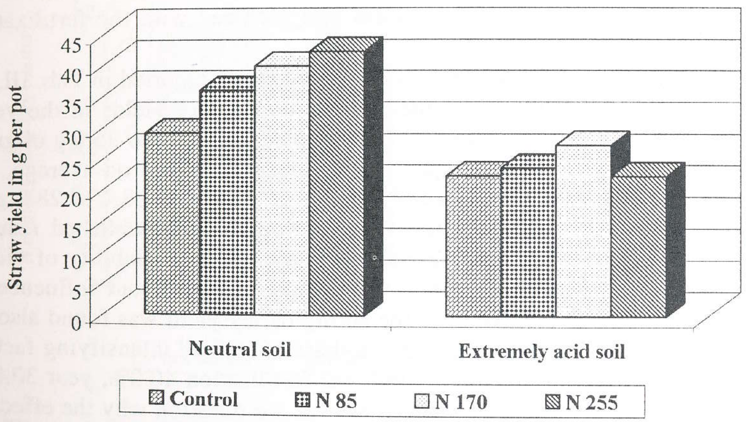
Soil	Variant of trial	Stems per 1 plant	Spikes per 1 plant	Grain yield per pot (g)	Straw yield per pot (g)	% of nitrogen in grain dry matter	% of nitrogen in straw dry matter	Uptake of nitrogen during harvest by aboveground biomass per pot (mg)	Uptake of nitrogen by grain per pot (mg)	Uptake of nitrogen by straw per pot (mg)
Neutral	control	3.37 *	2.96 *	26.2 *	29.0 *	2.09 *	1.02 *	693 *	453 *	240 *
	N 85	3.84 *	3.45 *	32.0 *	35.8 *	2.06 *	1.09 *	990 *	598 *	392 *
	N 170	4.40 *	3.96 *	37.2 *	39.7 *	2.11 *	1.07 *	1009 *	625 *	380 *
	N 255	4.59 *	4.26 *	41.7 *	40.0 *	1.83 *	0.83 *	965 *	652 *	313 *
Extremely acid	control	2.28 *	2.05 *	19.1 *	22.3 *	2.35 *	1.08 *	554 *	354 *	200 *
	N 85	2.61 *	2.33 *	20.8 *	23.5 *	1.78 *	1.06 *	577 *	325 *	252 *
	N 170	2.79 *	2.49 *	23.7 *	27.1 *	1.97 *	1.08 *	688 *	402 *	286 *
	N 255	2.34 *	2.06 *	19.8 *	22.2 *	1.90 *	1.04 *	510 *	304 *	206 *

III. Effects of soil and year on the studied parameters – statistical evaluation by multiple analysis of variance at α = 0.05

Soil	Stems per 1 plant	Spikes per 1 plant	Grain yield per pot (g)	Straw yield per pot (g)	% of nitrogen in grain dry matter	% of nitrogen in straw dry matter	Uptake of nitrogen during harvest by aboveground biomass per pot (mg)	Uptake of nitrogen by grain per pot (mg)	Uptake of nitrogen by straw per pot (mg)
Neutral	4.05 *	3.66 *	34.3 *	36.6 *	2.02 *	1.00 *	914 *	642 *	284 *
Extremely acid	2.51 *	2.23 *	20.9 *	23.8 *	2.00 *	1.07 *	582 *	544 *	168 *
Year									
1996	4.19 *	3.73 *	35.0 *	33.6 *	1.83 *	1.15 *	939 *	709 *	200 *
1997	2.96 *	2.59 *	23.8 *	28.4 *	2.18 *	1.13 *	770 * *	478 *	251 *
1998	2.69 *	2.51 *	23.8 *	28.6 *	2.02 * *	0.82 *	535 *	–	–



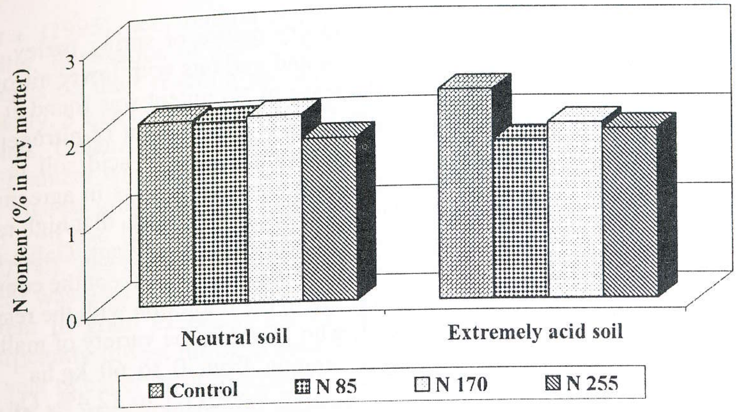
3. Effects of soil pH and nitrogen rates on grain yield of spring barley (average over the years 1996 to 1998 in g per pot)



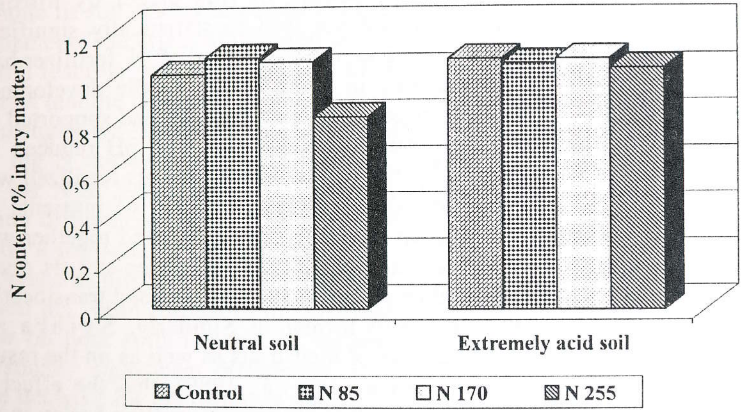
4. Effects of soil pH and nitrogen rates on straw yield in spring barley (average over the years 1996 to 1998 in g per pot)

seen in Figs. 3 and 4, where are summarised the yields of grain and straw into average values over three years of the trial. On the neutral soil in the control variant, the grain yield was 26.2 g per pot compared with the mare 19.1 g on the soil with low pH value. When you look at Table III, you can see that when we do the average of all variants, the differences between yields are even greater on both soils. Average yield 34.3 g grain per pot was on the soil with neutral reaction and only 20.9 g on the extremely acid soil. It follows from it, and Fig. 3 confirms it, that depressive effect of low pH was not eliminated by supply of nitrogen fertilizer. The low efficiency of nitrogen fertilization on extremely acid soil was apparently affected by the use of physiologically acid ammonium sulphate. When it was applied, the differences in yields on the studied soils were even greater, because on the neutral soil all rates are efficient and the yield is growing gradually from 26.2 g in the control through 32.0 g and 37.2 g at the rates 85 and 170 mg of nitrogen to 41.7 g at the nitrogen rate 255 mg. On the contrary, on extremely acid soil merely the rate 170 mg of N per pot (60 kg $N.ha^{-1}$) was efficient, what increased the yield to 23.7 g per pot in three-year average. When 30 kg $N.ha^{-1}$ were applied, only statistically insignificant trend to the increase of yield was recorded and the rate 90 kg $N.ha^{-1}$ even decreased the grain yield compared with the variants with lower nitrogen fertilization. Similar results like in grain were also recorded in the straw yield. Also K u b i n e c (1998) found in field trials on Chernozem on loess statistically significant increase of the yield in two studied spring barley varieties (Jubilant and Garant) as early as at the rate 30 kg $N.ha^{-1}$ and the highest yield was obtained with the fertilization rate 55–70 $kg.ha^{-1}$.

The formation of yield parameters was affected, as reported in Tab. III, by weather conditions. It is documented by the total lower yields in the years 1997 and 1998 compared with 1996. For example, in this year 35.0 g of grain per pot and 33.6 g of straw of spring barley were collected on average, but in the years 1997 to 1998 it was only 23.8 g of grain and 28.4 to 28.6 g of straw. As could be seen from this contribution from unpublished results, inter-year differences were above all caused by greater variability of yields on the soil with more favourable soil reaction. A significant influence of weather conditions in formation of the spring barley yield was found also by K u l í k (1995) in his study, who set the share of studied intensifying factors and year on the yield increment as follows: fertilization 40.0%, year 30.8%, forecrop 14.8% and variety 14.4%. To answer the question why the effect of weather conditions and hence also the effect of changed soil conditions, connected with it, was manifested more on the neutral soil than on acid soil, we are of the following opinion. The limiting factor, that is the most deviated from the optimum level needed for yield formation, is very low pH value on extremely acid soil, therefore worse weather conditions cannot so markedly reduce the level of low yield-forming level, which is low anyway. On the soil with favourable reaction, on the contrary, the limiting factor may be just e.g. worse weather. The fact, that low pH affects significantly the yield formation on extremely acid soil is confirmed, that the effect of nitrogen fertilization



5. Effects of soil pH and nitrogen rates on nitrogen content (% in dry matter) in spring barley grain (average over the years 1996 to 1998)



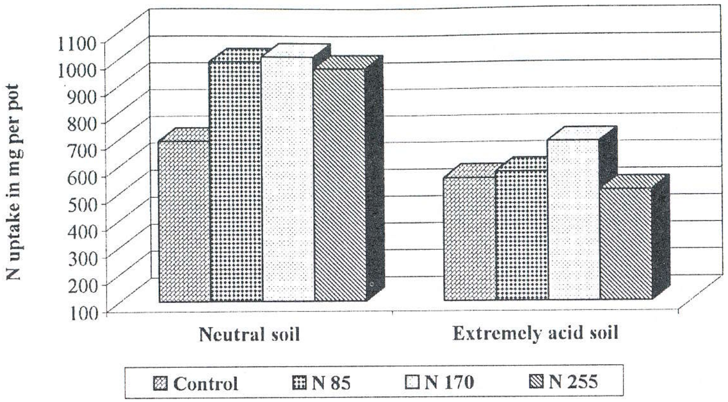
6. Effects of soil reaction and nitrogen rates on nitrogen content (% in dry matter) in spring barley straw (average over the years 1996 to 1998)

as an improving factor on this soil is considerably limited. To support this argument, we present, that while high correlation index between grain and straw yields and N fertilization 0.70 to 0.74 on neutral soil was found, this index was merely ranging from 0.24 to 0.26 on extremely acid soil.

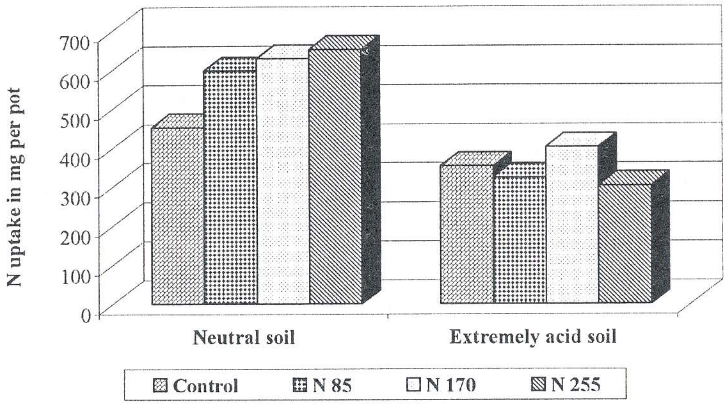
Figs. 5 and 6 record the contents of nitrogen in percentage in grain and straw dry matter. Graded rates of nitrogen fertilization were not manifested by the growth of nitrogen content in grain dry matter of spring barley. No difference was reported between the control and variants with lower nitrogen rates and even statistically significant decrease of N content was found at the rate of 90 kg N.ha^{-1}. Statistically significantly higher content of nitrogen in grain dry matter was recorded in the control on extremely acid soil in the evaluated years compared with the remaining variants. This is in agreement with the conclusions made by K a n d e r a (1995), who reports that high rates of nitrogen fertilization to spring barley of the varieties Jubilant, Galan and Novum worsen mechanical and chemical qualities of grain, except the content of nitrogen in grain. On the contrary, they are in contradiction with the results of W r ó b e l and B u d z y n s k i (1999) who found in the variety of malting barley Maresi at graded nitrogen rates ranging from 0 to 60 kg.ha^{-1} the growth of the content of crude protein in grain from 11.1 to 12.4%. On the soil with favourable pH value the effect of dilution of nutrients in dry matter of plants during ontogenesis was supported by nitrogen fertilization that improved the growth of plants and increased considerably the grain yield compared with the control variant. Deepening of this effect by nitrogen fertilization on extremely acid soil did not lead to statistically significant increase of the yield, except the variant with 60 kg of N fertilizer.ha^{-1}. Evidently it is given by the fact that in initial stages of the development nitrogen fertilization improved nitrogen uptake on this soil and supported the growth of barley, but in further course of vegetation low pH reduced the uptake of nitrogen by spring barley and plants on the variants fertilized with nitrogen starved more in this period. There was a deficit of nutrients for formation of upper leaves, drying up of lower leaves occurred together with increased re-transport of nitrogen into newly forming leaves and its reutilization. This deficit of nutrients then reflected in the decreased translocation of nitrogen into generative organs in its formation. Similarly, Š v i h r a and T a l a p k a (1995) assume on the basis of their trials as well as on the results of other authors (Z e n i š č e v a, Š p u n a r o v á, 1989), that the effect of factors of environmental induces qualitative changes in malting barley in the formation and use of assimilates mainly in the time after anthesis. The trials did not confirm our previous hypothesis that translocation of nitrogen in unfavourable conditions of acid soil reaction will tend to reproduction organs predominantly. No statistically significant difference has been found in the content of nitrogen in grain and straw of spring barley, as documented by the values in Table III, between the plants from neutral and extremely acid soil. Average content of nitrogen of all variants and replications on neutral soil was 2.02% in grain and 1.00% in straw, while the N content on extremely acid soil was 2.00 % in grain and 1.07% in straw. The values from Table III also indicate that the nitrogen content is strongly affected by the year. K a n d e r a (1995), too, reports that a year is the limiting factor of the grain quality. Realisation of genetic potential of cultivated spring barley varieties depends on their reaction on environmental conditions and their adaptation capacity. Š v i h r a and T a l a p k a (1995) found, that of comparing varieties (Bonus, Galan, Jubilant, Novum, Sladko, Svit) the greatest adaptability to environment was manifested by the variety Jubilant, which reached the second highest grain yield in three climate-different vegetation periods. Along with it, it had the best malting value at the lowest content of crude protein (11.77%). The authors found the lowest N content in grain in 1996 (1.83%), where was also obtained the highest yield. In the following years nitrogen content in grain exceeded 2% (2.18 or 2.02%, respectively). Statistically significantly lowest nitrogen content in dry matter of straw was found in the last year of experiment (0.82%). The differences among other years (1.15 and 1.13 % N) were statistically insignificant.

Other investigated parameters were as follows: the total uptake of nitrogen by aboveground biomass of spring barley during the harvest (Fig. 7), uptake of nitrogen by grain (Fig. 8) and nitrogen uptake by straw (Fig. 9). According to Table III soil acidity has statistically significantly restrictive effect on these parameters. The effect of nitrogen fertilization was significant on the soil with neutral reaction, less significant on the extremely acid soil (Table II). It is of interest that the effect of the year was strongly manifested on the total uptake of nitrogen by harvest. The values were of ascending trend from average 939 mg N uptake by harvest per pot in 1996, over 770 mg N in 1997 to 535 mg N in 1998 (Table III). As referred to the results unpublished here, greater differences between years were recorded in cultivation of spring barley on a soil with favourable reaction.

Uptake of nitrogen by grain and straw had a different level in dependence on soil pH. With respect to the fact that the content of nitrogen in grain and straw on both soils in most of variants was on the same level, or without statistically significant differences, respectively, the grain and straw yields were decisive for the different uptake of nitrogen by spring barley on neutral and acid soils. Significantly higher uptake of nitrogen by grain and straw in 1996 than in the following years was affected mainly by higher yields in the former year. Differences between the years 1997 and 1998 were given predominantly by different N content per dry matter unit. Closeness or freeness of relationships between studied factors confirms the correlation dependencies in Table IV. Highly significant positive indexes of correlation are on neutral soil between nitrogen uptake by harvest and the yields of grain (r = 0.82), straw (r = 0.74) as well as between nitrogen content in straw (r = 0.81) of spring barley. No relationship was found between N uptake and N content in grain (r = 0.09). No significant correlation coefficients were recorded on

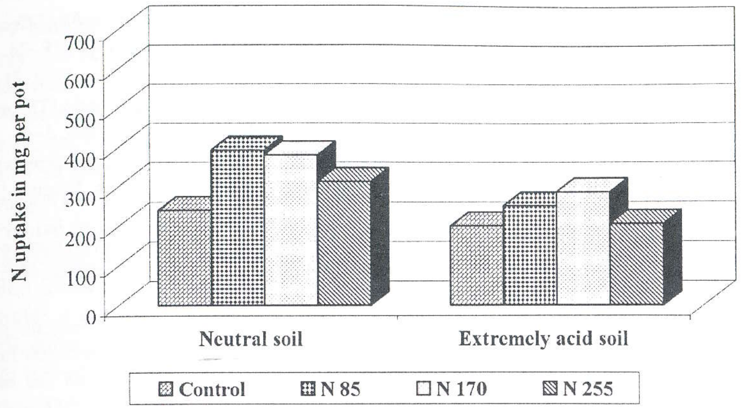


7. Effects of soil pH and nitrogen rates on nitrogen uptake by harvest of spring barley (average over the years 1996 to 1998 in mg per pot)



8. Effects of soil pH and nitrogen rates on nitrogen uptake by spring barley grain during the harvest (average over the years 1996 to 1998 in mg per pot)

acid soil, despite it, closer relationship was found between N uptake and yields (r = 0.48 and 0.56) compared with N uptake and contents of nitrogen in dry matter (r = 0.25 and 0.26). Efficiency of accepted nitrogen derived from the total grain and straw yield from one pot and uptake of nitrogen by this yield and calculated as a ratio of these characteristics expressed in mg ranged on soil with higher pH in the values from 69 to 87 mg of produced



9. Effects of soil pH and nitrogen rates on nitrogen uptake by spring barley straw during the harvest (average over the years 1996 to 1998 in mg per pot)

IV. Dependence between uptake of nitrogen by harvest of spring barley and selected factors – correlation index (r) and determinance (R^2)

	Soil	Grain yield		Straw yield		N content in grain		N content in straw		N rates of fertilizer	
		r	R^2	r	R^2	r	R^2	r	R^2	r	R^2
Uptake of nitrogen by harvest	neutral	0.82	67.5	0.74	54.7	0.09	0.79	0.81	66.4	0.42	17.4
	extremely acid	0.48	23.2	0.56	36.7	0.25	6.13	0.26	6.52	0.12	1.4

dry matter per 1 mg of accepted nitrogen and from 74 to 82 mg on the soil with low pH value. Not so great differences show that the plants of spring barley could use accepted nitrogen economically even on acid soil, but blocking of nitrogen intake from acid soil medium became a limiting factor of the yield.

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Vliv pH půdy a dávek dusíku na produktivitu jarního ječmene.

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V tříletých mikroparcelkových pokusech v cylindrických nádobách bez dna o ploše 0,029 m^2 a zapuštěných do půdního profilu byl sledován vliv pH půdy a dusíkatého hnojení (dávky 0, 85, 170 a 255 mg N na nádobu, tj. 0, 30, 60 a 90 kg $N.ha^{-1}$) na produktivitu jarního ječmene odrůdy Jubilant. Agrochemická charakteristika zemin je uvedena v tab. I. Výsledky jsou znázorněny na obr. 1 až 9 a jejich statistické vyhodnocení je uvedeno v tab. II až IV. Za daných podmínek pěstování (obsah humusu 1,7–2,8 %; N_{tot} = 0,20–0,29 %; vysoká až velmi vysoká zásoba přijatelného fosforu, vyhovující až dobrá zásoba přijatelného draslíku a nízká až vyhovující zásoba přijatelného hořčíku; mikroparcelky) při nižším pH nedosahovaly sledované parametry hodnot zjištěných na neutrálních půdách, a to při všech úrovních dusíkaté výživy. Na zemině neutrální byly efektivní všechny dávky N a na extrémně kyselé mírně rostl výnos pouze při dávkách do 60 kg $N.ha^{-1}$. Index korelace (*r*) mezi odběrem dusíku sklizní a výnosy slámy a zrna byl na neutrální zemině vysoký – 0,74 až 0,82, zatímco na kyselé zemině pouze 0,48 až 0,56. Limitujícím faktorem tvorby výnosu se stala blokace příjmu dusíku z extrémně kyselého půdního prostředí. Významný vliv na tvorbu výnosových ukazatelů měl ročník. Na neutrální zemině se nepříznivé povětrnostní podmínky staly limitujícím faktorem růstu a výnosu ječmene. Na extrémně kyselé zemině bylo tímto faktorem nízké pH. Obsah dusíku v zrnu jarního ječmene je výrazně ročníkovou záležitostí. Mezi rostlinami pěstovanými na neutrální a extrémně kyselé zemině nebyl v tomto ukazateli statisticky průkazný rozdíl. Intenzita hnojení dusíkem výrazně neovlivnila jeho obsah v zrnu a slámě, ale odběr byl výrazně ovlivněn pH zeminy, protože na extrémně kyselé půdě byly jejich výnosy podstatně nižší.

pH půdy; dávky dusíku; produktivita jarního ječmene

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