THE EFFECT OF SOIL pH ON UTILIZATION OF NITROGEN FERTILIZER BY SPRING BARLEY IN THE YEAR OF APPLICATION AND IN THE FOLLOWING YEAR*

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The effect of soil pH on utilization of fertilizer nitrogen and its balance in the system soil – plant were studied in small-plot field trials using the stable isotope of nitrogen ^{15}N in the year of application of ^{15}N and in the following year. The 15 spring barley plants, cv. Jubilant, were cultivated per cylindrical pot without bottom, of area 0.029 m^2 and embedded into the soil profile. Nitrogen fertilization was applied in the form of solution by mixing with the whole volume of soil before filling the pots, i.e. in rates 0, 85, 170 and 255 mg N per pot, i.e. in conversion 0, 30, 60 and 90 kg $N.ha^{-1}$. It follows from the results that the percentage of soil nitrogen in the total uptake by harvest ranged from 94 to 86% on neutral soil and from 95 to 82% on extremely acid soil and was practically identical on both soils. "The priming effect" represented increased uptake of soil nitrogen by about 25 to 35% on neutral soil. "The priming effect" was not manifested at all or only very weakly (up to 10%), on extremely acid soil. Uptake of fertilizer nitrogen by spring barley was higher and losses were lower on neutral soil than on the soil with low pH value. The total balance of nitrogen fertlizer with ^{15}N after two years from application of fertilizer shows that on the soil with neutral pH value, spring barley utilized 41–46% in the first year and in the successive year it took 3–4% of ^{15}N, and 15–18% of nitrogen remained in soil and losses amounted to 32–40%. On extremely acid soil spring barley took 33–37% in the first year and in the second year 1–2% of ^{15}N, after the second year of application 11–13% of ^{15}N stayed in soil and the losses reached 50-55%.

spring barley; small-plot field trials; soil pH; ^{15}N; balance of fertilizer nitrogen

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INTRODUCTION

Great attention in plant nutrition has been devoted to nitrogen which most of all nutrients affects the growth and yield of farm crops. It follows from numerous experimental studies that soil nitrogen participates most in yield formation. Its percentage share in the total uptake of nitrogen by the harvest is fluctuating from 70 to 90% on fertile sites, 50–70% on less fertile ones (Jefimov, Osipov, 1991; Khalil et al., 1997). Except the soil mineral nitrogen, also nitrogen of old soil power, i.e. nitrogen bound in organic compounds in soil, which is mineralizing during vegetation and becomes available and utilizable by plants, participates in plant nutrition (Vaněk et al., 1995, 1996; Petr et al., 1995). Amount of this mineralizable nitrogen is associated with soil fertility and climatic conditions and weather pattern during vegetation and out of vegetation play an important role in its efficiency by plants. It can be released 60–120 kg of $N.ha^{-1}$ per year by mineralization of soil organic matter on well-supplied soil. This nitrogen can be both utilized by plants and there is a danger that it will be washed out or denitrified, because it is released independently on the development of plant stand (Körschens, 1990; Balík et al., 1997). Cultivation and manure regime must be organized in such a way to allow utilization of vegetation as high as possible. The use of nitrogen fertilizers has to be oriented on optimum utilization of nitrogen.

The use of stable nitrogen isotope ^{15}N makes possible to distinguish fertilizer nitrogen and soil nitrogen and gives a possibility to study the processes of transformation and circulation of nitrogen in the system fertilizer – soil – plant – environment. One of the factors, that can principally affect the processes of transformations and circulation of nitrogen, is soil acidity. It is necessary to extend knowledge on the effect of soil acidity on utilization of fertilizer nitrogen and soil nitrogen by plants for more efficient application of nitrogen fertilizers and for better utilization of nutrient potential of soils. The aim of the trial was to answer the following questions:

- what is the effect of pH on utilization of fertilizer nitrogen in the year of application and in the following year;
- what is the balance of fertilizer nitrogen in the system soil – plant in the year of application of ^{15}N and in the following year at extremely acid and neutral soil reaction.

MATERIAL AND METHOD

Small-plot field trial with spring barley has been established each year at experimental site at Sojovice near Lysá nad Labem in the years 1996 to 1998.

Small plots were of the area 0.029 m^2 and were formed by cylindrical pots without bottom of diameter 19 cm and embedded 30 cm into the soil profile. Spring barley Jubilant was an experimental crop, 15 plants were cultivated per pot.

Soils used in the trial were sampled from two sites from the area of fluvisols. In year 1997 before the establishment of trial soil samples were taken from stored soil to determine basic agrochemical characteristics. Soil pH/KCl value, humus content after Tjurin and the content of available nutrients by the method Mehlich II were determined in soil samples dried at 40 °C and homogenized. In year 1998 in early spring soil samples were taken to set the nitrogen content. Mineral nitrogen (N_{min}) was determined from freshly taken samples after their homogenization in extract of 1% K_2SO_4 by ion selective electrodes. Furthermore, samples were dried at 40 °C and further analyses were done from fine earth. The total nitrogen (organic + $N - NH_4^+$) was determined by mineralization by concentrated sulphuric acid by the method after Kjeldahl, subsequent distillation and titration. Aerobic incubation method was used to determine mineralizable nitrogen. Soil dissolved by sand in ratio 1 : 1 was incubated seven days at 60% moisture of maximum water capacity and temperature of 30 °C. Determination of mineral nitrogen in 1% K_2SO_4 by ion selective electrodes followed then. 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.

Soil 1 had the character of medium-heavy fluvisol on fluvial deposits and favourable moisture condition according to the map of geological and soil conditions of the territory concerned. It had high reserve of available phosphorus, suitable reserve of potassium and magnesium, medium content of humus and neutral reaction (pH > 6.5). Soil 2 was medium heavy fluvisol on

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

Soil	Humus (%)	pH/KCl	Content of available nutrients ($mg.kg^{-1}$)		
			P – Mehlich II	K – Mehlich II	Mg – Mehlich II
Neutral	2.17	6.7	123	153	123
Extremely acid	1.69	4.3	103	176	113
Soil	N total (%)	N min. ($mg.kg^{-1}$)	N mineralizable ($mg.kg^{-1}$)		
Neutral	0.29	85	12		
Extremely acid	0.20	102	–		

sands, more dependent on precipitation. It had a high reserve of available phosphorus, suitable reserve of potassium and magnesium, medium content of humus and extremely acid reaction (pH < 4.5).

Slightly arid climate with average annual temperature 8.6 °C, during vegetation (April–September) 14.8 °C, with average annual sum of precipitation 542 mm, out of it 353 during vegetation, is characteristic for the experimental site.

Diagram of the trial included four variants on each soil with five replicates. Only phosphorus (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 were applied in the control variant. Except it gradated nitrogen rates (85, 170 and 255 mg per pot or 30, 60 and 90 $kg.ha^{-1}$, respectively) were used in other three variants. Ammonium sulphate with 25% atomic enrichment by stable isotope ^{15}N was used as nitrogen fertilizer and traditional ammonium sulphate was used as fertilizer in 1998. The soil used in 1997 was stored at the experimental site and was used again in 1998 to fill the pots. All fertilizers were applied in the form of solution by mixing with amount of soil needed for filling of a pot. Soil moisture in pots was adjusted after emergence of plants and during vegetation it was kept by watering with distilled water on 60% of maximum water capacity. Plants were not chemically treated.

The content of total nitrogen in plants and in soil was determined after harvest in the Agricultural Regional Laboratory Mstětice by the method after Kjeldahl and its isotope composition was measured on emission spectrometer NOI-6 at the Saxon Institute for Agriculture. The trial was evaluated statistically by computer program Statgraphics by multiple analysis of variance at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The effect of the level of pH on utilization of fertilizer nitrogen by spring barley and its balance in the system soil – plant in the year of application of stable isotope ^{15}N, i.e. in 1997 and the following year 1998, was evaluated in this work.

Uptake of fertilizer nitrogen and soil nitrogen by harvest of spring barley is documented in Table II, statistical evaluation is in Table III. Nitrogen uptake from fertilizer with ^{15}N by spring barley was dependent on soil properties and fertilizing rate. When ammonium sulphate was applied in the amount containing gradated rates 85, 170 and 255 mg of N, uptake in the year of application (1997) on neutral soil reached the values 39 – 70 – 107 mg of N. This corresponds to the values found by the authors in previous trials on similar type of soils (Hejnák et al., 1996). On the contrary, uptake on extremely acid soil was distinctly lower (26 – 59 – 83 mg of N per pot). In the year following the application of ^{15}N we found only relatively low amounts of this nitrogen in harvest of spring barley, on average 15 times less than in the first year on neutral soil and 20 to 25 times less than in the first

II. Uptake of fertilizer nitrogen and soil nitrogen by harvest of spring barley ($mg.pot^{-1}$)

Soil	Variant of trial	Average annual total uptake of N	N uptake from fertilizer			N uptake from old soil reserve	Percentage of N from soil reserve	"Priming effect"
			in year of application	*in following year*	in total			
Neutral	control	559	–	–	–	559	100	–
	N 85	760	*39*	*3.05*	42	718	94	159
	N 170	820	*70*	*5.40*	75	745	91	186
	N 255	827	*107*	*8.15*	115	712	86	153
Extremely acid	control	536	—	—	–	536	100	–
	N 85	603	*26*	*1.76*	28	575	95	39
	N 170	647	*59*	*2.72*	62	585	90	49
	N 255	472	*83*	*3.37*	87	385	82	–

III. Statistical evaluation of nitrogen uptake by harvest of spring barley

	Neutral soil		Extremely acid soil		
	number	average	homogenous groups	number	average
Total N uptake by plants	32	741.000	* *	564.125	32
N uptake from fertilizer in the year of application	12	72.028	* *	56.800	12
N uptake from fertilizer in the following year	12	5.533	* *	2.616	12
N uptake from old soil reserve	32	683.500	* *	520.250	32
"Priming effect"	12	166.000	* *	29.300	12

year on extremely acid soil. It ranged from 3.05 to 8.15 mg of N on soil with neutral reaction under gradated nitrogen rates and from 1.76 to 3.37 mg of N on soil with low pH value. Differences among soils were statistically significant.

The experiment indicated the main role of soil fertility and non-fungible function of soil nitrogen in yield formation of agricultural crops. As it follows from many scientific studies (e.g. Jefimov, Osipov, 1991; Khalil et al., 1997), particularly on soil with high fertility, the plants utilize 70–90% of nitrogen from soil and the rest only from fertilizers. The percentage of soil nitrogen in total uptake of nitrogen by harvest reaches 50 to 70% on less fertile soils. It follows from the results presented in Table II that the percentage of soil nitrogen in the total uptake by harvest ranged from 94 to 86% on neutral soil and from 95 to 82% on extremely acid soil in this small-plot field trial and was practical the same on both the studied soils. The percentage of soil nitrogen was falling with growing rates of nitrogen fertilizer. These values correspond with ours, earlier obtained data (Hejnák et al., 1996).

The importance of nitrogen fertilization consists in the fact, as reported Růžek (1997), that it should equalize disproportions between reserve of available nitrogen in soil and requirements of cultivated crop for nitrogen nutrition in certain period. Except it, nitrogen fertilization has a direct impact on circulation of nitrogen in soil. It activates processes of mineralization of soil organic mass. This leads to increased uptake of soil nitrogen by plants, especially on soils with higher fertility. Despite this the so-called "priming effect" N fertilization can affect significantly nutritive condition of plant as well as the total yield of agriculturally utilizable production, as it was showed by detected yields of grain and straw. Increased nitrogen uptake from soil was recorded in soil with favourable reaction, which reached the values 153–186 mg of N per pot. "Priming effect" was not manifested at all or only weakly on extremely acid soil (up to 49 mg of N). It can be caused by low microbial activity, or by lower reserve of mineralizable nitrogen in this extremely acid soil.

Exact data on balance of fertilizer nitrogen in soil and plant can be obtained only when stable isotope ^{15}N was used in fertilizer trials. It follows from experimental works of many authors that utilization of nitrogen from mineral fertilizers does not exceed 35–55%, 20–35% of applied nitrogen is bound in soil, predominantly in soil organic matter, and 20–35% represent the losses by mainly denitrification, volatilization of ammonium, to a less extent by washing out of nitrates, erosion and surface denudation (Matzel, Lippold, 1990; Lippold, Mouchová, 1995; Hejnák et al., 1996; Glendining et al., 1997; Tlustoš et al., 1997). Balance of fertilizer nitrogen with ^{15}N in the year of its application in soils with different pH is

IV. Balance of fertilizer nitrogen in the year of its application in cultivation of spring barley on soils of different pH (in % of supplied nitrogen)

Soil	Variant	Intake by plant			Rest in soil	Not found
		grain	*straw*	in total		
Neutral	N 85	*28*	*18*	46	26	28
	N 170	*27*	*14*	41	26	33
	N 255	*28*	*14*	42	24	34
Extremely acid	N 85	*14*	*17*	31	16	53
	N 170	*18*	*17*	35	16	49
	N 255	*16*	*17*	33	14	53

V. Balance of fertilizer nitrogen in following year after application in cultivation of spring barley in soils of different pH (in % from the rest of ^{15}N from the previous year)

Soil	Variant of trial	Total intake by plant	Rest in soil	Not found
Neutral	N 85	14	68	18
	N 170	12	61	27
	N 255	13	61	26
Extremely acid	N 85	13	78	9
	N 170	10	81	9
	N 255	10	83	7

in Table IV. We found 42–46% of N fertilizer in grain and straw, 24–26% of N stayed in soil and 28–34% of N from fertilizer was not found on neutral soil. We suppose that it is nitrogen lost for plants, not utilizable in further years. The utilization of nitrogen fertlizer by plants was significantly lower on extremely acid soil, only 31–35%, and solely 14–16% remained in soil. On the contrary, losses of nitrogen or not detectable nitrogen, respectively, amounted to 49–53%. The values obtained confirm the earlier published results of the balance of fertilizer nitrogen on this extremely acid soil (Hejnák, Lippold, 1998). However, these values cannot be compared with other literary sources, because other data on the balance of fertilizer nitrogen in the system soil – plant, where pH should be the main investigated characteristic, practically do not exist.

The utilization of fertilizer nitrogen with ^{15}N by plants in the following year after application was another subject of study. Results in Table V docu-

VI. Total balance of direct and subsequent action of fertilizer nitrogen in cultivation of spring barley in soils of different pH (in % of supplied nitrogen)

Soil	Variant of trial	Intake by plant			Rest in soil after harvest in the following year	Not found
		in the year of application	*in the following year*	in total		
Neutral	N 85	*46*	*4*	50	18	32
	N 170	*41*	*3*	44	16	40
	N 255	*42*	*3*	45	15	40
Extremely acid	N 85	*31*	2	33	13	54
	N 170	*35*	2	37	13	50
	N 255	*33*	*1*	34	11	55

VII. Statistical evaluation of the balance of fertilizer nitrogen

	Neutral soil			Extremely acid soil	
	number	average	homogenous groups	number	average
Uptake by grain in the year of application	12	27.897	* *	16.636	12
Uptake by straw in the year of application	12	15.123	* *	17.193	12
Rest in soil in the year of application	12	24.915	* *	14.711	12
Intake by plant in the following year	12	13.776	* *	11.100	12
Rest in soil in the following year	12	62.898	* *	80.990	12
Intake by plant in the following year	12	3.255	* *	1.539	12
Rest in soil after two years	12	16.433	* *	12.782	12

ment that 12–14% of the rest of ^{15}N from the previous year was used on neutral soil by plants, 61–68% remained in soil not utilized at all and 18–27% were evidently lost, because we did not succeed to detect this part ^{15}N. On

the soil with low pH plants took only 10–13% of ^{15}N from the rest in soil from the previous year, 78–83% was found in soil and solely 7–9% was not detected at all. High remainder, lower utilization and low losses on extremely acid soil in the following year is apparently connected with low microbial activity and weak mineralizing ability of this soil.

Utilization of fertilizer nitrogen in the following year after application is ranging between 0.8 and 2.4% of applied amount, as reported in literary data (Bradbury et al., 1993). The values found (Table VI) correspond to these data on extremely acid soil (1–2%). On neutral soil in the following year higher amount (3-4%) was detected in grain and straw of spring barley. After two years in neutral soil remained 15–18% and in extremely acid soil 11–13% of supplied ^{15}N. It can be presupposed that this nitrogen is bound predominantly in organic soil mass. As reported by Timmons and Cruse (1991) in their field trials one year after application of 16–27% ^{15}N stayed bound in organic soil pool and only 1% was found in soil in inorganic form (NH_4^+, NO_2^- and NO_3^-). After four years 13–24% was found in soil organic mass and less than 0.5% represented inorganic nitrogen. Further data in Table VI show unambiguously total better utilization of fertilizer nitrogen in two years after application under favourable soil pH (44–50%) than under extremely acid reaction (33–37%). Losses of fertilizer nitrogen are lower on neutral soil (32–40%) than on extremely acid soil (50–55%). It follows from statistical evaluation of fertilizer nitrogen balance in Table VII that differences among soils were statistically significant.

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Vliv pH půdy na využití dusíku hnojiva jarním ječmenem v roce aplikace a v roce následném.

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V mikroparcelkových pokusech byl s pomocí stabilního izotopu dusíku ^{15}N sledován vliv pH půdy na využití dusíku hnojiva a jeho bilanci v systému půda – rostlina v roce aplikace ^{15}N a v roce následném. Jarní ječmen odrůdy Jubilant byl pěstován po 15 rostlinách v cylindrických nádobách bez dna o ploše 0,029 m^2 a zapuštěných do půdního profilu. Agrochemická charakteristika použitých zemin je uvedena v tab. I. Hnojení dusíkem bylo aplikováno ve formě roztoku promísením s celým objemem zeminy před naplněním nádob v dávkách 0, 85, 170 a 255 mg N na nádobu, tj. v přepočtu 0, 30, 60 a 90 kg N.ha^{-1}.

Odběr dusíku hnojiva a půdního dusíku sklizní jarního ječmene je znázorněn v tab. II a statisticky vyhodnocen v tab. III. Z výsledků vyplývá, že podíl půdního dusíku na celkovém odběru sklizní se pohyboval od 94 do 86 % na neutrální a od 95 do 82 % na kyselé zemině a byl na obou sledovaných zeminách prakticky stejný. „Priming effect“ představoval na neutrální zemině zvýšený odběr půdního dusíku o cca 25 až 35 %. Na kyselé zemině se „priming effect“ neprojevil nebo jen velice slabě (do 10 %).

Dalším předmětem sledování byla bilance dusíku hnojiva s ^{15}N v roce aplikace (tab. IV.) a v následném roce po aplikaci (tab. V) a dále celková bilance přímého a následného působení dusíku hnojiva (tab. VI) při pěstování jarního ječmene na zeminách s různým pH. Odběr dusíku z hnojiva jarním ječmenem byl vyšší a ztráty byly nižší na neutrální zemině než na zemině kyselé. Celková bilance dusíku hnojiva s ^{15}N po dvou letech od aplikace ukazuje, že na zemině s neutrálním pH využil jarní ječmen v prvním roce 41–46 % a ve druhém roce odebral 3–4 % ^{15}N, v zemině zůstalo 15–18 % dusíku hnojiva a ztráty činily 32–40 %. Na kyselé zemině jarní ječmen odebral v prvním roce 33–37 % a ve druhém roce 1–2 % ^{15}N, po druhém roce aplikace zůstalo v zemině 11–13 % a ztráty dosáhly 50–55 %. Rozdíly mezi zeminami byly statisticky průkazné (tab. VII).

jarní ječmen; mikroparcelkové pokusy; pH zeminy; ^{15}N; bilance dusíku hnojiva

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