Dynamics of the nitrogen uptake by spring barley at injection application of nitrogen fertilizers

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ABSTRACT

Influence of CULTAN system (controlled uptake long term ammonium nutrition) on the nitrogen uptake by spring barley (*Hordeum vulgare* L.) was observed at 5-year small-plot field experiments under conditions of the Czech Republic (central Europe). Nitrogen uptake by CULTAN-fertilized plants was more even during vegetation period probably due to delayed term of fertilizer application. Nitrogen concentration in the aboveground biomass at BBCH 51 and in straw had no effect on grain yield. Post-heading nitrogen uptake as well as contribution of nitrogen translocation to total nitrogen in grain did not differ among both nitrogen fertilization treatments. Increase in grain size of spring barley by the CULTAN system can be explained by tendency to lower number of ears per area rather than by prolonged nitrogen uptake from soil. Lower protein content in grain of CULTAN-fertilized spring barley can be caused by increase in grain retained on a 2.5 mm sieve and also decrease in total nitrogen concentration in aboveground biomass at BBCH 51. No significant effect of CULTAN treatment on nitrogen use efficiency and nitrogen uptake efficiency was recorded. Significantly higher nitrogen utilization efficiency at CULTAN treatment could be explained by lower grain protein content compared to conventional treatment.

Keywords: depot; nitrification; nitrate; leaching and losses; nitrogen assimilation

The CULTAN (controlled uptake long term ammonium nutrition) system consists in injection of fertilizer with a significant ratio of nitrogen in ammonium form into the root space of plants; the place of fertilizer application in soil is called 'depot'. Positive charge of ammonium and high concentration of fertilizer in these depots result in higher stability of fertilizer in soil (Sommer and Scherer 2009), which may improve nitrogen use efficiency (NUE; defined as grain dry matter per unit of nitrogen available from the soil, fertilizer included) (Ladha et al. 2005).

Better nitrogen use efficiency is an important presupposition for increased profit of production (Beatty et al. 2010). Ladha et al. (2005) state that increase in NUE may be also achieved by reducing nitrogen losses from the applied fertilizer either by application of slow release fertilizer or by using nitrification inhibitors. As an alternative method of NUE increasing, nitrogen fertilizer can be placed in bands, sideways, or below the seeds. Band-placed nitrogen fertilizer leads to a reduced nitrogen immobilization by microorganisms (Ladha et al. 2005). Improving nitrogen use efficiency may also have environmental impacts through nitrate leaching by reducing the amount of fertilizer not used by the crop (Gaju et al. 2011).

Delay in nitrogen fertilization and higher stability of nitrogen fertilizer in soil at CULTAN treatment leads to prolonged soil nitrogen assimilation (Sommer and Scherer 2009). Increase in post-anthe-

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sis nitrogen uptake from soil is related to reduced rate of nitrogen remobilized from vegetative organs (Suprayogi et al. 2011), which, according to Užík and Žofajová (2012), results in delayed senescence. A delayed leaf senescence leads to prolongation of photosynthesis that increases grain yield and carbon filling into seeds (Pask et al. 2012).

The aim of this study was to investigate ability of nitrogen fertilizer injection to improve nitrogen use efficiency and to prolong nitrogen assimilation from soil resulting in increased grain yield, improved given qualitative parameters of grain and thus in environmental and economical benefits.

MATERIAL AND METHODS

Small-plot field experiments with spring barley (*Hordeum vulgare* L.) cv. Jersey were run during 2007–2011 at three sites with different soil-climatic conditions in the Czech Republic (central Europe). Conventional method of fertilization with calcium ammonium nitrate was compared with injection of urea ammonium nitrate applied at the BBCH 29–30 growth stages (the end of tillering to the beginning of stem elongation). Both treatments were evaluated at two amounts of nitrogen fertilizers: 80 kg N/ha and 130 kg N/ha (Table 1).

Detailed description of methodology is given by Sedlář et al. (2011).

Samples of aboveground biomass at BBCH 51 stage (heading, ¼ of complete stage) were taken from 0.25 m^2 area. Total nitrogen concentration in aboveground biomass was determined by the Kjeldahl method using the Vapodest 50s (Gerhardt, Königswinter, Germany). To express grain protein content, nitrogen concentration in grain was multiplied by the 6.25 coefficient (ČSN 46 1100-5).

Statistical analysis of data was carried out using the Statistica version 9.0 (StatSoft, Tulsa, USA). Data are presented in the results at four treatments of nitrogen fertilization across the three sites and five years. Standard analysis of variance (ANOVA) procedures with the Fisher *LSD* test were used to calculate significant differences between individual treatments of nitrogen fertilization.

Linear regression and the resulting correlation coefficients were calculated by compiling the data obtained using the all four nitrogen fertilization treatments. Agronomical traits and traits related to nitrogen uptake by plants were analysed two by two using all possible combinations. Coefficients of correlation (*r*) between assessed traits are presented in correlation matrix for both conventional and CULTAN treatments (Table 5).

Calculations:

Aboveground N content at maturity (AGNM):

$$AGNM = (GN \times GY) + (SN \times SY) \text{ (kg N/ha)}$$

Where: AGNM – aboveground N at maturity; GN – grain N concentration (%); GY – grain yield (t/ha); SN – straw N concentration (%) and SY – straw yield (t/ha).

Nitrogen at heading lost or gained (NLG, Bahrani et al. 2011 modified):

$$NLG = \frac{AGNM - AGNH}{AGNH} \times 100 \text{ (\%)}$$

Where: AGNH – aboveground N at heading (BBCH 51) (kg N/ha).

Post-heading (BBCH 51) nitrogen uptake (PHNU, Pask et al. 2012 modified):

$$PHNU = AGNM - AGNH \text{ (kg N/ha)}$$

Contribution of nitrogen translocation to total nitrogen in grain (NTRg, Užík and Žofajová 2012):

$$NTRg = \frac{AGNH - SN \times SY}{GY \times GN} \times 100 \text{ (\%)}$$

Nitrogen use efficiency (NUE, Gaju et al. 2011):

$$NUE = \frac{GY}{SAN + FN} \text{ (kg grain dry matter/kg available N from soil and fertilizer)}$$

Where: SAN – soil available N before sowing (kg N/ha) and FN – N applied in fertilizer, i.e. 80 kg N/ha and 130 kg N/ha, respectively.

Table 1. Fertilizer treatment, nitrogen amounts and timing

Treatment	Dosage of added N per ha (fertilizer form)			Total N dosage per ha (kg)
	before sowing	BBCH 28–29	BBCH 29–30	
Conventional 80	80 kg (CAN)	–	–	80
CULTAN 80	–	–	80 kg (UAN)	80
Conventional 130	80 kg (CAN)	50 kg (CAN)	–	130
CULTAN 130	–	–	130 kg (UAN)	130

CAN – calcium ammonium nitrate (27% N); UAN – urea ammonium nitrate (30% N)

Table 2. Nitrogen concentration in aboveground biomass at the BBCH 51 growth stage and in straw (%)

	Conventional 80	CULTAN 80	Conventional 130	CULTAN 130
N content at BBCH 51	1.86[a]	1.73[a]	2.09[b]	1.86[a]
Straw N content	0.64[a]	0.56[b]	0.73[c]	0.60[ab]

Values within the row marked with the same letter are not statistically different at $P < 0.05$

Nitrogen uptake efficiency (NUpE, Gaju et al. 2011):

$$NUpE = \frac{AGNM}{SAN + FN}$$ (kg N uptake at harvest/kg available N from soil and fertilizer)

Nitrogen utilization efficiency (NUtE, Černý et al. 2012):

$$NUtE = \frac{GY}{AGNM}$$ (kg grain DM/kg N uptake at harvest)

RESULTS AND DISCUSSION

Significantly higher total nitrogen concentration in aboveground biomass at the beginning of heading (BBCH 51) and in straw (Table 2) was observed at conventional fertilization compared to CULTAN treatment at application of 130 kg N/ha. This phenomenon could be explained by delayed term of CULTAN application, which is in accordance with the findings of Egle et al. (2008).

No significant differences in nitrogen lost or gained at heading (NLG) between conventional and CULTAN treatment were found (Table 3). Slight increase in NLG values at CULTAN-treated plants compared to conventionally treated ones could be explained according to Bahrani et al. (2011), who reported that the higher is the content of nitrogen accumulated in plant biomass before anthesis (Table 2), the higher is the probability of decrease in nitrogen content in aboveground biomass during grain filling period.

Post-heading nitrogen uptake (PHNU) as well as contribution of nitrogen translocation to total nitrogen in grain (NTRg) did not differ among both nitrogen fertilization systems. Contrary to the findings of Mickelson et al. (2003), no significant correlations between grain yield and nitrogen concentration in aboveground biomass at the BBCH 51 growth stage and in straw in our experiments were recorded (Table 5). It can be assumed that total nitrogen concentration in grain was insufficient for significant grain yield increase. Because of no significant correlations between nitrogen concentration in aboveground biomass at the BBCH 51 growth stage as well as straw nitrogen concentration between PHNU and NTRg values at both nitrogen fertilization systems, no significant correlations between grain yield and PHNU as well as NTRg were recorded.

Long-term plant nutrition intended by CULTAN system was not confirmed, which is in accordance with the findings of Flisch et al. (2013), who assume that nitrate developed through nitrification under CULTAN fertilization is continuously taken up by plants.

To improve nitrogen use efficiency, Beatty et al. (2010) state, that it is necessary to increase both nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE). By using the CULTAN system, significant improvement of NUtE compared to conventional treatment was achieved (Table 4), whereas no significant influence of CULTAN treatment on NUpE values was observed. Higher

Table 3. Nitrogen at heading lost or gained (NLG; %), post-heading nitrogen uptake from soil (PHNU; kg N/ha), contribution of nitrogen translocation to total nitrogen in grain (NTRg; %)

	Conventional 80	CULTAN 80	Conventional 130	CULTAN 130
NLG	100.9[ab]	116.7[a]	71.9[b]	106.2[ab]
PHNU	50.2[a]	52.5[a]	42.9[a]	51.6[a]
NTRg	51.2[a]	45.1[a]	59.6[a]	49.1[a]

Values within the row marked with the same letter are not statistically different at $P < 0.05$

Table 4. Nitrogen use efficiency (NUE; kg grain dry matter/kg N available), nitrogen uptake efficiency (NUpE; kg N/kg N available) and nitrogen utilization efficiency (NUtE; kg grain dry matter/kg N uptake at harvest)

	Conventional 80	CULTAN 80	Conventional 130	CULTAN 130
NUE	36.9^{a}	36.6^{a}	27.3^{b}	27.9^{b}
NUpE	0.82^{a}	0.75^{a}	0.48^{b}	0.44^{b}
NUtE	44.8^{a}	48.8^{b}	41.1^{c}	47.0^{ab}

Values within the row marked with the same letter are not statistically different at $P < 0.05$

NUtE values could be explained by Montemurro et al. (2006) as a result of increased post-anthesis nitrogen uptake from soil. However, regression coefficients between NUtE and PHNU were very low (Table 5). Because of lower protein content in grain observed by Sedlář et al. (2011) and Kozlovský et al. (2009) at CULTAN-treated spring barley and winter wheat, respectively, the significantly higher NUtE recorded at CULTAN treatment could be explained by lower grain protein content compared

Table 5. Trait correlation

Trait	GY	Grain 2.5	NLG	PHNU	NTRg	NUE	NUpE	NUtE	N 51
Conventional treatments									
Grain 2.5	**0.55**	–	–	–	–	–	–	–	–
NLG	0.07	0.10	–	–	–	–	–	–	–
PHNU	0.19	0.26	**0.79**	–	–	–	–	–	–
NTRg	–0.05	–0.20	**–0.80**	**–0.97**	–	–	–	–	–
NUE	**0.61**	**0.65**	0.17	0.32	–0.28	–	–	–	–
NUpE	0.43	0.44	0.12	0.25	–0.18	**0.85**	–	–	–
NUtE	0.48	**0.57**	0.30	0.24	–0.28	**0.66**	0.28	–	–
N 51	–0.22	–0.24	–0.48	–0.39	0.44	–0.28	–0.13	**–0.55**	–
SN	–0.47	**–0.75**	–0.14	–0.10	0.08	–0.41	–0.17	**–0.75**	**0.56**
CULTAN treatments									
Grain 2.5	0.43	–	–	–	–	–	–	–	–
NLG	–0.07	0.05	–	–	–	–	–	–	–
PHNU	0.10	0.09	**0.68**	–	–	–	–	–	–
NTRg	–0.01	–0.10	**–0.54**	**–0.61**	–	–	–	–	–
NUE	0.45	**0.56**	–0.04	0.11	–0.10	–	–	–	–
NUpE	0.30	0.23	–0.18	0.09	0.03	**0.83**	–	–	–
NUtE	0.24	**0.61**	0.45	0.09	–0.27	0.40	–0.06	–	–
N 51	–0.14	–0.27	**–0.50**	–0.34	0.26	–0.08	0.09	–0.49	–
SN	–0.40	**–0.59**	–0.15	0.02	0.10	–0.31	0.04	**–0.74**	0.41

GY – grain yield, grain 2.5% of grain retained on a 2.5 mm sieve; NLG – nitrogen lost or gained at heading; PHNU – post-heading nitrogen uptake from soil; NTRg – contribution of nitrogen translocation to total nitrogen in grain; NUE – nitrogen use efficiency; NUpE – nitrogen uptake efficiency; NUtE – nitrogen utilization efficiency; N 51 – total nitrogen concentration at the BBCH 51 growth stage; SN – total nitrogen concentration in straw. The highest coefficients of correlation (r) indicated in bold were significant at $P < 0.05$

to conventional treatment which is in accordance with the findings of Albrizio et al. (2010).

Trčková et al. (2006) reported that nitrogen use efficiency was usually negatively correlated with nitrogen concentration in wheat biomass. Regression coefficients between NUE and nitrogen concentration in aboveground biomass were in our experiments (Table 5) slightly higher at conventional treatment compared to CULTAN treatment, which could be explained by tendency to decrease in total nitrogen concentration at CULTAN-treated spring barley.

A percentage of grain retained on a 2.5 mm sieve only slightly positively correlated with post-heading nitrogen uptake from soil (Table 5). Thus, the increase in grain size of spring barley by the CULTAN method recorded by Sedlář et al. (2011) can be explained by tendency to lower number of ears per area rather than by prolonged nitrogen uptake from soil.

Sedlář et al. (2011) reported a slight tendency to higher grain yield of CULTAN-treated spring barley compared to conventionally treated plants under conditions of the Czech Republic. Unlike the conventional treatments, no significant correlation between grain yield and percentage of grain retained on a 2.5 mm sieve at CULTAN treatments were recorded (Table 5) which can be explained by tendency to higher percentage of grain retained on a 2.5 mm sieve at CULTAN treatments (Sedlář et al. 2011).

Lower protein content in grain of CULTAN-fertilized spring barley reported by Sedlář et al. (2011) could be caused by tendency to lower total nitrogen concentration in aboveground biomass at the BBCH 51 growth stage (Table 2), which is in agreement with the results of Příkopa et al. (2005), and higher grain retained on a 2.5 mm sieve, which complies with the findings of Qi et al. (2006). Because of no significant differences in NTRg and PHNU values among all nitrogen fertilization treatments, lower grain protein content at the CULTAN treatment cannot be sufficiently explained by prolonged nitrogen uptake from soil.

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