Impact of nitrogen fertilizer injection on grain yield and yield formation of spring barley (*Hordeum vulgare* L.)

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ABSTRACT

The experiment was carried out to observe the influence of the CULTAN method (controlled uptake long term ammonium nutrition) on grain yield and yield formation of spring barley cultivar Jersey. In four-year small-plot experiment under conditions of the Czech Republic, two methods of nitrogen fertilization were used: conventional surface fertilization and local fertilizer injection rich in ammonium into soil during vegetation at BBCH 29-30 stages. Furthermore, the impact of sulphur amendment in fertilizer and increased dose of fertilizer were observed. Basic dose of nitrogen was 80 kg N/ha, increased dose 130 kg N/ha. At CULTAN treatment, same or significantly higher grain yields were obtained compared to conventional nitrogen fertilization. Grain yield at CULTAN fertilization is formed mainly on the main stem because of reduced tillering; it has the impact on significantly higher percentage of grain retained on 2.5 mm sieve. A tendency to lower protein content in grain was recorded at local injection of fertilizer compared to conventional fertilization. CULTAN-treated plants showed a lesser dependency of qualitative parameters on fertilizer dose and sulphur amendment in fertilizer. A positive influence of the CULTAN method on yield and quality of grain was observed mainly at the less fertile site.

Keywords: ammonium; protein content; thousand grain weight; sulphur; CULTAN

At CULTAN (controlled uptake long term ammonium nutrition) treatment the plants may uptake ammonium in high concentrations from special depots near the roots of plants. Contact of phytotoxic ammonium with root systems of plants is thus very small. Phytotoxic ammonium is present outside of the roots (Marschner 1995, Sommer 2005). Plants uptake nitrogen from depots in dependence on the extent of saccharide synthesis, i.e. based on the availability of other growth factors (water, temperature, light, availability of other nutrients). The change of ammonium to nitrate occurs exclusively in marginal parts of depots; inside depots the concentration of ammonia is too high for the activity of nitrifying bacteria (Walter 2001). Injection of nitrogen fertilizers at concentrated lines decreases immobilization and more nitrogen of applied fertilizers is available to plants. Line injection also reduces nitrification and thus decreases the risk of nitrogen loss caused by leaching (Petersen et al. 2004). At even application, the concentration of ammonia in soil is not toxic and all roots of plants participate equally in nutrient uptake. At CULTAN treatment the uptake of ammonia is realized only by part of roots which reach the margin of the toxic depot. These roots are strongly branched and concentrate around the depots margins; during the growth the roots move from the outer margin of the depot towards the center (Balík et al. 2008). As soon as the uptake of nitrogen overcomes the ability of ammonium to assimilate into organic compounds, free ammonia may cause symptoms of local phytotoxicity in root cells and thus short-time interruption of nitrogen sorption. Formation of new root apices enables the sorption of ammonium to continue on condition that a sufficient amount of saccharides is available. This regulation of ammonium uptake

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results in its optimum usage by plants despite its high concentration in soil (Weimar 2001). Because of the ammonia phytotoxicity, above-ground plant parts must supply roots and stem bases with saccharides. Uptaken ammonium is immediately bound to organic nitrogen compounds in roots. The development of root systems and supply of stems base with assimilates is thus clearly supported compared to conventional fertilization. It suggests that CULTAN method ameliorates the uptake of nutrients and increases resistance to drought compared to conventional nitrogen fertilization in nitrate form or as urea (Sommer 2005). Differences in distribution of assimilates depend on the method of nitrogen fertilization, which influences synthesis of phytohormones and specific balance between phytohormones in plants; this influences growth and development of plants and yield formation (Sommer and Scherer 2009).

The aim of this trial was to compare conventional nitrogen fertilization of spring barley with CULTAN treatment, with respect to grain yield and its parameters.

MATERIAL AND METHODS

Small-plot trial was set up in 2007 at two sites in Humpolec and Ivanovice na Hané, in the Czech Republic. Detailed characteristics of these sites are given by Kozlovský et al. (2009). Three treatments using injection fertilization of all nitrogen in one dose (CULTAN system) were compared with three treatments using nitrogen surface broadcast fertilization (conventional treatment). Each treatment had four replications. Experimental scheme is given in Table 1.

Spring barley (*Hordeum vulgare* L.) cultivar Jersey was used in the trial, at the sowing density of 450 seeds per m^2. The size of a fertilized plot was 39 m^2 (3 × 13 m), of which 15 m^2 (1.25 × 12 m) was harvested. CULTAN fertilization was applied at the BBCH 29-30 growth stage (the end of tillering to the beginning of stem elongation stages) with the GFI 3 A injection machine (Maschinen und Antriebstechnik GmbH, Güstrow, Germany), with 12 injection wheels working at a width of 3 m. Each wheel disposes of 12 hollow-spikes that apply fertilizer to a depth of 5 cm.

Number of spikes per m^2 was determined prior to harvest and grains per spike were determined as average of sheaf of 50 spikes before harvest. The harvest was done with a small plot combine harvester; grain yield was determined by weighing grains from individual plots and converting them into 14% moisture values, thousand grain weight was further determined. The samples were taken of the harvested grain and sieved with the laboratory sifter Swing 160 (Mezos, Hradec Králové, Czech Republic) with the 2.5 × 20 mm mesh. Protein content in grain was determined with the Kjeldahl method on the Vapodest 50s (Gerhardt, Königswinter, Germany) and by multiplying the results with the 6.25 coefficient (ČSN 46 1100-5).

To evaluate the results, one-factor ANOVA analysis was used followed with the Scheffé's test at the $P < 0.05$ level of significance. The computations were done using the Statistica 9.0 programme (StatSoft, Tulsa, USA).

In the year 2007 the beginning and the end of vegetation were extraordinary dry and warm. Therefore harvest was done at an earlier date. In 2008 there was an extraordinary dry and warm June. There was extraordinary warm April in 2009, in Ivanovice accompanied by a strong drought. Harvest date in the year 2010 was markedly delayed especially in Ivanovice due to a wet end of vegetation period. No significant damage to vegetation

Table 1. System of fertilization of field trial

Treatment	Dosage of added N per ha (fertilizer form)			Total N dosage (kg) per ha
	before sowing	BBCH 28-29	BBCH 29-30	
Conventional 1	80 kg (CAN)	–	–	80
CULTAN 1	–	–	80 kg (UAN)	80
Conventional 2	80 kg (CAN)	50 kg (CAN)	–	130
CULTAN 2	–	–	130 kg (UAN)	130
Conventional + S	23 kg (AS) + 57 kg (CAN)	–	–	80
CULTAN + S	–	–	80 kg (UAS)	80

CAN – calcium ammonium nitrate (27% N); UAN – urea ammonium nitrate (30% N); AS – ammonium sulphate (20.5% N, 24% S); UAS – urea ammonium sulphate (19% N, 5% S)

Table 2. Number of spikes per m^2 (pcs)

Treatment	Humpolec				Ivanovice na Hané			
	2007	2008	2009	2010	2007	2008	2009	2010
Conventional 1	970[a]	1 074[c]	1 334[bc]	1 032[b]	994[a]	931[a]	497[a]	864[b]
CULTAN 1	942[a]	876[a]	1 070[a]	938[a]	1 041[a]	1 189[b]	463[a]	739[a]
Conventional 2	1 027[b]	1 020[bc]	1 400[c]	1 162[c]	998[a]	1 038[a]	463[a]	958[c]
CULTAN 2	1 049[b]	879[a]	1 244[b]	1 032[b]	975[a]	981[a]	524[a]	888[bc]
Conventional + S	1 063[b]	855[a]	1 346[bc]	1 032[b]	966[a]	1 059[a]	472[a]	938[bc]
CULTAN + S	1 046[b]	980[bc]	1 238[b]	982[a]	1 052[a]	1 165[b]	459[a]	960[c]

Values within the column marked with the same letter are not statistically different (P < 0.05)

from both undesirable organisms and weather conditions occurred during all experimental years.

RESULTS AND DISCUSSION

Number of plants per square unit did not differ between conventional and CULTAN treatments, which was also observed in the experiments with winter wheat by Kozlovský et al. (2009). Higher number of spikes per square unit (Table 2) was observed at Humpolec site at conventional nitrogen fertilization with 80 kg N/ha and 130 kg N/ha from 2008 to 2010, since the CULTAN-treated plants suffer from latent deficiency of nitrogen at the tillering stage, which results in reduced tiller formation (Petr et al. 1988). Sulphur amendment in fertilizer led to increased number of spikes per m^2 only at CULTAN treatment applying 80 kg N/ha. More intense tillering may be caused by higher production of ethylene, as a consequence of production of methionine by sulphur amendment in fertilizer (Dugardeyn and Van Der Straeten 2008). At Ivanovice na Hané site the number of spikes per square unit did not differ among the methods of fertilization, which can be explained by soil-climatic conditions at this site resulting in more intense mineralization of organic compounds (Tesař et al. 1992). CULTAN-fertilized plants thus do not suffer from nitrogen deficiency in the time of fertilization, and the change in proportion of above-ground parts to roots is not observed (Sommer 2005).

At Ivanovice na Hané site neither the impact of the CULTAN method nor the influence of the nitrogen fertilizer dose on the number of grains per spike were observed. There was no influence of CULTAN system on number of grain per spike observed applying 80 kg N/ha at Humpolec site despite the lower number of spikes in CULTAN-treated variants. Tendency to higher number of grain per spike was recorded at conventional treatment when sulphur was supplied. Compensation ability of plants recorded by Baethgen et al. (1995) was not confirmed under trial conditions.

At CULTAN treatments, higher thousand grain weight was recorded (Table 3) compared to conventional methods of nitrogen fertilization at both experimental sites. According to Koutná et al. (2003) thousand grain weight is influenced geneti-

Table 3. Thousand grain weight (g)

Treatment	Humpolec				Ivanovice na Hané			
	2007	2008	2009	2010	2007	2008	2009	2010
Conventional 1	43.3[a]	44.9[a]	35.7[b]	49.3[c]	41.8[b]	37.8[b]	47.4[b]	42.7[bc]
CULTAN 1	44.8[b]	46.3[c]	37.3[c]	46.7[ab]	42.0[b]	43.3[e]	46.4[ab]	44.9[d]
Conventional 2	45.3[c]	44.8[a]	32.4[a]	46.5[a]	39.7[a]	36.0[a]	46.4[ab]	41.6[a]
CULTAN 2	44.8[b]	45.4[b]	37.2[c]	47.0[a]	41.9[b]	42.8[e]	45.6[a]	43.5[c]
Conventional + S	45.3[c]	44.9[a]	35.8[b]	48.1[bc]	41.8[b]	39.9[c]	46.5[ab]	42.0[ab]
CULTAN + S	47.3[d]	47.2[d]	35.1[b]	49.1[c]	41.9[b]	41.1[d]	46.4[ab]	41.4[a]

Values within the column marked with the same letter are not statistically different (P < 0.05)

Table 4. Ratio of grain above the 2.5 mm sieve (%)

Treatment	Humpolec				Ivanovice na Hané			
	2007	2008	2009	2010	2007	2008	2009	2010
Conventional 1	78.6[a]	89.7[d]	57.4[b]	87.1[c]	74.4[bc]	72.9[a]	95.6[d]	94.5[c]
CULTAN 1	79.0[ab]	87.9[bc]	78.3[d]	93.4[d]	75.5[c]	86.1[d]	92.8[bc]	95.9[d]
Conventional 2	79.5[b]	87.2[ab]	50.3[a]	80.1[a]	60.0[a]	74.4[ab]	92.3[abc]	91.6[b]
CULTAN 2	80.7[c]	87.0[a]	58.5[c]	86.6[c]	75.8[c]	84.9[c]	91.0[ab]	94.5[c]
Conventional + S	81.2[c]	88.3[c]	49.4[a]	83.9[b]	70.8[b]	76.0[b]	94.5[cd]	94.3[c]
CULTAN + S	87.2[d]	90.1[d]	59.3[c]	86.6[c]	74.7[bc]	84.0[c]	90.4[a]	89.6[a]

Values within the column marked with the same letter are not statistically different ($P < 0.05$)

cally only at 20.5%; therefore rather a significant influence of agrotechnology on this parameter can be expected. Higher thousand grain weight may be explained as in Sommer (2005), who states that reducing reutilization of nitrogen of older parts of plants in younger parts at CULTAN method slows down ageing of basis, and thus prolongs the time of assimilates storage in spikes. It complies with the results by Petr et al. (1988), who observed a lower thousand grain weight at smaller leaf area and shorter vegetation period. The least influence of the CULTAN method on thousand grain weight was recorded at sulphur-amended nitrogen fertilization, as the amendment of sulphur in the fertilizer led to increased thousand grain weight at conventional treatments; they thus reached the values obtained at CULTAN treatments. This corresponds to the findings by Griffiths et al. (1995) that sulphur fertilization leads to a delay of flag leaf aging. At CULTAN treatments lower dependence of thousand grain weight on the fertilizer dose and sulphur amendment was observed compared to conventional fertilization.

Higher percentage of grain retained on a 2.5 mm sieve (Table 4) was observed at CULTAN treatments than at conventional nitrogen treatments at all fertilization intensities. The percentage of grain retained on a 2.5 mm sieve positively correlated with a thousand grain weight. This relationships expressed by a linear function showing 82% and 49% dependence at the sites Humpolec and Ivanovice na Hané, respectively. CULTAN-treated plants achieved a higher percentage of grain retained on a 2.5 mm sieve compared to conventional fertilization despite the increased dose of nitrogen. This can be explained by a lower intensity of tillering of CULTAN-treated plants (Table 2).

The protein content in grain (Table 5) was most affected by year, which is in agreement with the findings of Váňová et al. (2006). CULTAN fertilization led to the same or lower protein content in grain which is in agreement with the findings of Zimolka et al. (2006) and Ma et al. (1992), who report increased protein content in grain at shorter vegetation period. Sommer (2005) explains the prolongation of time of assimilates storage into spikes due to slowed down aging of halm basis. When sulphur-amended fertilizer was applied differences in protein content between the two methods of fertilization were not observed, which is in agreement with conclusions of

Table 5. Protein content (N × 6.25) (%)

Treatment	Humpolec				Ivanovice na Hané			
	2007	2008	2009	2010	2007	2008	2009	2010
Conventional 1	11.2[a]	11.0[ab]	10.6[b]	9.8[c]	12.7[bc]	11.0[bc]	9.8[ab]	8.5[ab]
CULTAN 1	11.6[ab]	11.1[ab]	10.9[b]	8.3[a]	10.6[a]	10.0[a]	9.7[a]	8.6[ab]
Conventional 2	11.7[b]	12.5[c]	10.9[b]	10.2[c]	13.6[c]	11.6[c]	10.3[b]	9.5[b]
CULTAN 2	12.6[c]	11.9[bc]	11.0[b]	8.9[ab]	13.5[c]	9.9[a]	9.9[ab]	9.0[b]
Conventional + S	11.7[b]	10.8[a]	9.8[a]	9.7[bc]	12.0[b]	11.3[bc]	9.9[ab]	8.2[a]
CULTAN + S	11.7[b]	11.0[ab]	10.2[ab]	9.6[b]	12.5[bc]	10.6[ab]	10.3[b]	9.2[b]

Values within the column marked with the same letter are not statistically different ($P < 0.05$)

Table 6. Grain yield (14% moisture) (t/ha)

Treatment	Humpolec				Ivanovice na Hané			
	2007	2008	2009	2010	2007	2008	2009	2010
Conventional 1	5.88^{a}	6.18^{b}	4.99^{b}	8.04^{bc}	7.05^{ab}	8.40^{bc}	7.86^{ab}	7.58^{b}
CULTAN 1	6.05^{ab}	6.25^{bc}	5.66^{c}	7.35^{a}	7.44^{ab}	8.83^{c}	7.94^{ab}	6.50^{a}
Conventional 2	5.92^{ab}	5.72^{a}	4.38^{a}	7.75^{b}	6.94^{a}	6.86^{a}	8.59^{c}	7.48^{b}
CULTAN 2	6.00^{ab}	6.41^{bc}	5.15^{b}	7.74^{b}	7.81^{b}	7.90^{b}	8.19^{b}	6.91^{ab}
Conventional + S	5.84^{a}	6.55^{c}	5.04^{b}	8.11^{c}	7.42^{ab}	8.37^{bc}	7.76^{a}	6.89^{ab}
CULTAN + S	6.20^{b}	6.51^{c}	5.13^{b}	8.09^{c}	7.29^{ab}	8.53^{bc}	8.16^{b}	6.30^{a}

Values within the column marked with the same letter are not statistically different ($P < 0.05$)

Griffiths et al. (1995), who report delayed flag leaf ageing using sulphur-containing fertilizers.

At CULTAN fertilization the same or higher grain yields were obtained (Table 6) compared to conventional nitrogen fertilization. The results of Schittenhelm and Menge-Hartmann (2006) explaining increased grain yield of plants injected with ammonium by higher number of spikes and higher number of grain per spike compared to conventional fertilization, were not confirmed under the conditions of Czech Republic. Conventional treatments gave increased grain yields at sulphur amendments compared to treatment with 130 kg N/ha. It can be expected that conventionally fertilized plants thus suffer from the lack of sulphur at higher nitrogen dose, which was confirmed in Eriksen et al. (2001) who state that the need of sulphur for spike development highly overcomes the amount of sulphur supplied through leaves, which is important for yield formation especially at high doses of nitrogen (Eriksen and Mortensen 2002, Grzebisz and Przygocka-Cyna 2007). Conventional treatments therefore bring about higher sensitivity to sulphur deficiency in soil. Yields at CULTAN treatments showed lower dependence of grain yield on the dose of fertilizer and sulphur amendment.

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