INFLUENCE OF INJECTION NITROGEN APPLICATION ON SPRING BARLEY (*HORDEUM VULGARE* L.) LODGING*

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The experiment was carried out to observe the influence of the CULTAN method (Controlled Uptake Long Term Ammonium Nutrition) on lodging of spring barley cultivar Jersey under conditions of the Czech Republic. In a four-year small-plot field trial, two methods of nitrogen fertilization were compared: conventional surface fertilization and injection of liquid fertilizer into soil during vegetation at the DC 29-30 growth stages (CULTAN method). Furthermore, the impact of sulphur amendment in fertilizer and increased dose of fertilizer were observed. Basic dose of nitrogen was 80 kg N ha^{-1}, the increased one was 130 kg N ha^{-1}. CULTAN-treated plants tended to lower number of spikes per square metre, shorter stalk, higher dry matter content in aboveground biomass at heading, and lower nitrogen concentration in aboveground biomass at the DC 28 and 45 growth stages compared to conventionally treated plants. This tendency was more apparent at experimental site at higher altitude. Compared to conventional fertilization, CULTAN treatment tended to lesser lodging, at higher-situated sites these differences were significant. Neither the impact of the dose of nitrogen nor the influence of the sulphur-amended nitrogen fertilizer on the observed parameters was recorded.

ammonium; CULTAN; dry matter content; length of stalk; sulphur

INTRODUCTION

Nitrogen fertilization increases grain yield of barley, however high supply of nitrogen can lead to grain yield reduction due to increased risk of lodging (Zebarth, Sheard, 1991). Furthermore, starch content and bulk weight lower with increasing nitrogen rate as well (Oscarsson et al., 1998). Resistance of plants to diseases and lodging is the most important factor affecting grain yield of malting barley under conditions of the Czech Republic (Špunar et al., 2002). Direct losses of yield caused by lodging achieve up to about 40% but they can be multiplied by losses arising during harvesting. Simultaneously, negative consequence of lodging is yield reduction due to lower productivity of harvesting machinery (Zimolka et al., 2006). Resistance of plants to lodging can be improved by breeding as well as agrotechnology (Berry et al., 2004). Berry et al. (2000) state that preventive measures against lodging are soils with lower nitrogen concentration, delayed sowing date, delayed nitrogen fertilization date, and lower nitrogen supply resulting in decreased stand density. The consequence of lodging is the decreased number of grains per spike (Acreche, Slafer, 2011) and further deterioration of malting quality such as higher incidence of brown grain apexes, mycotoxins, mildew, and pre-harvest sprouting (Zimolka et al., 2006).

The CULTAN method consists in the 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'. Plants take up nitrogen from the depots in dependence on the extent of saccharide synthesis, i.e. based on the availability of other growth factors. This uptake and distribution of assimilates in plants different from conventional treatment leads to altered growth habit (Sommer, 2005).

The aim of the present study was to compare spring barley development at conventional nitrogen fertilization with CULTAN treatment, with respect to the possibility of reducing lodging due to CULTAN fertilization.

MATERIAL AND METHODS

Small-plot trials were set up in 2007 at two sites (Humpolec and Ivanovice, Czech Republic). The characteristics of these sites are given in Table 1. Three treatments using injection fertilization (CULTAN system) were compared with three treatments using

* Supported by the Ministry of Education, Youth and Sports of the Czech Republic, S grant.

doi: 10.7160/sab.2013.440402

Table 1. Characteristics of experimental sites

Site	Altitude (m)	Annual average		Soil type	Soil texture	$pH/CaCl_2$
		precipitation (mm)	temperature (°C)			
Humpolec	525	667	6.5	Cambisol	sandy loam	6.6
Ivanovice	225	548	9.2	Chernozem	loam	7.3

Table 2. System of fertilization of field trial

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

nitrogen surface broadcast fertilization (conventional treatment). Two levels of nitrogen dose (80 and 130 kg N ha^{-1}) were studied. The effect of N-fertilizer containing sulphur was further examined in each fertilization system: ammonium sulphate instead of calcium ammonium nitrate was applied at conventional treatment and urea ammonium sulphate was injected instead of urea ammonium nitrate at CULTAN treatment. Each treatment had four replications (Table 2).

Spring barley (*Hordeum vulgare* L.) cultivar Jersey was used in the trial, at the sowing density of 450 seeds per m^2. The area of a fertilized plot was 39 m^2 (3 × 13 m), out of which 15 m^2 (1.25 × 12 m) was harvested. CULTAN fertilization was applied at the DC 29–30 growth stage (end of tillering–onset of stem elongation stages) with the GFI 3A injection machine (Maschinen und Antriebstechnik GmbH, Güstrow, Germany) to a depth of 5 cm.

Number of spikes per m^2, length of stalk and lodging were determined prior to harvest. Samples of aboveground biomass at growth stages of DC 28 (the end of tillering) and DC 51 (heading ¼ complete) were taken from the area of 0.25 m^2. 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. Nitrogen concentration in aboveground biomass was determined by the Kjeldahl method using Vapodest 50s (Gerhardt, Brackley, UK) system. Potassium concentration in aboveground biomass was measured by the flame atomic absorption spectrometry (F-AAS) on the SpectrAA280FS (Varian Vista Pro,Mulgrave, Australia). To evaluate the results, one-factor ANOVA analysis was used followed by the Fisher test at the $P < 0.05$ level of significance. The computations were done using the STATISTICA software (Version 9.0, 2010).

Weather conditions in experimental years: April 2007 was extraordinarily warm and dry. May and June 2007 were significantly above-average in precipitation amount – stand lodging occurred due to storm and strong wind on June 6, 2007. Torrential rains and strong wind were observed in June 2008 and torrential rains in July 2009 at Humpolec site. July 2009 was above-average in precipitation amount. Harvest date in the year 2010 was markedly delayed due to a wet end of vegetation period at Ivanovice site.

RESULTS

According to Berry et al. (2004) and Wiersma et al. (2011), lodging is significantly influenced by the stalk length. A tendency to shorter stalk was recorded at local injection of fertilizer compared to conventional fertilization. These differences were significant when higher dose of nitrogen was applied (Table 3). This tendency was more apparent at Humpolec than at Ivanovice site. No significant influence of sulphur-amended nitrogen fertilizer on the length of stalk was recorded.

Dry matter content in aboveground biomass at growth stage of DC 51 (Table 3) was higher in CULTAN-treated plants compared to conventionally fertilized plants. At Humpolec site these differences were statistically significant whereas at Ivanovice site only statistically insignificant tendency was observed. Neither the impact of the dose of nitrogen nor the influence of the sulphur-amended nitrogen fertilizer

Table 3. Length of stalk, nitrogen concentration in aboveground biomass at DC 28 and DC 45 growth stages and dry matter content in aboveground biomass at DC 51 growth stage

Treatment	Length of stalk before harvest (cm)	Dry matter content in aboveground biomass at DC 51 (%)	Nitrogen concentration in aboveground biomass at DC 28 (%)	Nitrogen concentration in aboveground biomass at DC 45 (%)
Conventional 80	$82.8^{a–c}$	20.0^{bc}	3.51^{ab}	2.13^{ab}
CULTAN 80	80.6^{a}	20.9^{c}	3.32^{a}	1.90^{a}
Conventional 130	84.7^{c}	19.0^{a}	3.84^{b}	2.21^{b}
CULTAN 130	$81.4^{a–c}$	20.3^{bc}	3.45^{a}	2.00^{ab}
Conventional S	83.2^{bc}	19.8^{ab}	3.68^{ab}	2.07^{ab}
CULTAN S	$81.7^{a–c}$	20.0^{bc}	3.62^{ab}	2.18^{b}
SD	2.5	1.0	0.39	0.24

$^{a–c}$values within the column marked with the same letter are not statistically different ($P < 0.05$), SD = standard deviation

Table 4. Stand lodging (9 – undetected, 1 – all-out occurrence) before harvest

Treatment	Humpolec site				Ivanovice site			
	2007	2008	2009	2010	2007	2008	2009	2010
Conventional 80	9^{a}	8^{bc}	6^{b}	7^{b}	3^{a}	4^{a}	8^{b}	9^{b}
CULTAN 80	9^{a}	9^{c}	9^{d}	9^{d}	3^{a}	8^{d}	8^{b}	9^{b}
Conventional 130	9^{a}	6^{a}	4^{a}	6^{a}	3^{a}	4^{a}	7^{a}	9^{b}
CULTAN 130	9^{a}	9^{c}	7^{c}	8^{c}	3^{a}	8^{d}	7^{a}	9^{b}
Conventional S	9^{a}	7^{ab}	4^{a}	7^{b}	3^{a}	6^{b}	8^{b}	9^{b}
CULTAN S	9^{a}	9^{c}	6^{b}	7^{b}	3^{a}	7^{c}	7^{a}	8^{a}
SD	0	1.6	1.9	1.2	0	1.7	0.5	0.5

$^{a–c}$values within the column marked with the same letter are not statistically different ($P < 0.05$), SD = standard deviation

on the dry matter content in aboveground biomass at growth stage of DC 51 was recorded.

Lower nitrogen concentration in aboveground biomass at the DC 28 growth stage (Table 3) was observed at CULTAN compared to conventional treatment. At Humpolec site these differences were statistically significant. Neither the impact of the dose of nitrogen nor the influence of the sulphur-amended nitrogen fertilizer on the nitrogen concentration in aboveground biomass at the DC 28 growth stage was recorded.

A tendency to lower nitrogen concentration in aboveground biomass at the DC 45 growth stage occurred at CULTAN-treated barley compared to conventionally treated one (Table 3). A significant difference was recorded only at Hněvčeves site when 130 kg N ha^{-1} was applied.

No significant influence of CULTAN fertilization on potassium concentration in aboveground biomass was recorded (data not shown). It is therefore concluded that the differences in lodging between CULTAN-treated plants and conventionally fertilized plants are not caused by the potassium concentration in aboveground biomass.

Lower lodging (Table 4) was observed at CULTAN treatment in comparison to conventional treatment. At Humpolec site these differences were statistically significant. An increase of the nitrogen dose from 80 to 130 kg N ha^{-1} resulted in significantly increased lodging only in rare cases mainly in conventionally treated plants.

Furthermore, at Humpolec site, 79.2% of the variability in lodging could be explained by the length of stalk and 74.8% by the number of spikes per square metre. At Ivanovice site, 51.0% of variability in lodging could be explained by the dry matter content in aboveground biomass at the DC 51 growth stage.

The different variables (length of stalk before harvest, dry matter content in aboveground biomass at the DC 51 growth stage, nitrogen concentration in aboveground biomass at the DC 28 growth stage, nitrogen concentration in aboveground biomass at the DC 45 growth stage, stand lodging) were also evaluated with ANOVA in order to study and confirm the effects of treatment and experimental site (Table 5). All variables were significantly influenced by the treatment. Experimental site also significantly influenced all variables except for length of stalk. Site × treatment interaction had significant influence on dry matter content in aboveground biomass at the DC 51 growth stage and nitrogen concentration in aboveground biomass at the DC 28 growth stage.

Table 5. Analysis of Variance

Source of variation	Length of stalk		Dry matter content in aboveground biomass at DC 51 stage		Nitrogen concentration in aboveground biomass at DC 28 stage		Nitrogen concentration in aboveground biomass at the DC 45		Stand lodging	
	F-ratio	*P*	*F*-ratio	*P*	*F*-ratio	*P*	*F*-ratio	*P*	*F*-ratio	*P*
Treatment	2.69	0.02	3.91	< 0.01	2.87	0.02	2.3	0.04	4.07	< 0.01
Site	0.07	ns	58.89	< 0.01	124.23	< 0.01	39.21	< 0.01	16.34	< 0.01
Treatment × site	0.67	ns	2.65	0.02	3.43	< 0.01	1.49	ns	0.94	ns

ns = nonsignificant

DISCUSSION

According to Neuberg et al. (2011), in ammonium-fed plants of *Festulolium* inhibited shoot growth was recorded. Tendency to a shorter stalk at CULTAN treatment is in accordance with higher harvest index observed by Sedlář et al. (2011b) in CULTAN-treated plants. Foulkes et al. (2011) recorded higher harvest index in plants less susceptible to lodging. Madani et al. (2010) showed that nitrogen available during anthesis had no effect on total aboveground biomass production but it increased the portion of grain in total aboveground biomass. This is in accordance with the results of Sommer (2005) and Sedlář et al. (2012) who stated that at CULTAN treatment, due to its higher stability in depots, nitrogen is available during later growth stages.

Our results did not confirm the results of Del Moral et al. (1999) and Hussain, Leitch (2007) about regulating effect of sulphur on length of stalk. The results of Vaněk et al. (2008) and Kulhánek et al. (2011) indicate no sulphur deficiency at experimental sites Humpolec and Ivanovice.

According to Sedlář et al. (2011a), tendency to lower stand density was observed at CULTAN compared to conventional treatment. This tendency was more apparent at Humpolec than at Ivanovice site. Lower extent of tillering of CULTAN-treated plants can be explained by the lack of nitrogen during tillering (Longnecker et al., 1993; Koutná et al., 2003). The number of tillers positively correlates with lodging (Tripathi et al., 2003). Linear regression explains lodging due to the number of spikes per square metre ($r = 0.56$ at Humpolec site and $r = 0.13$ at Ivanovice site).

Nitrogen fertilization leads to thinner cell wall (Berry et al., 2000). However, at CULTAN treatment, the osmotic pressure of a cell is decreased due to lesser nitrate concentration in the cell. As a result, the cell wall becomes thicker at CULTAN treatment (Sommer, 2005), which could explain the higher dry matter content in CULTAN-treated plants compared to conventionally fertilized plants. This is in accordance with the results of Skobeleva et al. (2011) who state that lower osmotic pressure of ammonium-fed plant cells leads to a reduced elongation growth. Higher ratio of younger tissues to the old ones usually occurs because of high nitrogen supply, which results in higher susceptibility of plants to fungal diseases (Marschner, 1995).

The lower nitrogen concentration in aboveground biomass observed at CULTAN treatment compared to conventional treatment is in agreement with the conclusions of Sommer (2005), who states that because of the ammonia phytotoxicity, the nitrogen uptake of CULTAN-treated plants is controlled. This controlled ammonium uptake prevents the accumulation of nitrogen in plant tissues. According to Zimolka et al. (2006), increased nitrogen concentration in plant tissues during tillering can indicate risk to lodging.

No significant influence of CULTAN fertilization on potassium concentration in aboveground biomass was recorded. Potassium concentration in aboveground biomass was significantly affected by year, which is in agreement with the findings of Madaras, Lipavský (2009). Because of potassium deficiency, lignification of vascular bundles is impaired (Mengel, Kirkby, 1979), which can lead to higher susceptibility of plants to lodging (Marschner, 1995). According to Mengel, Kirkby (1979) and Balík et al. (2008), the uptake of inorganic cations such as calcium, magnesium, and potassium is reduced when ammonium is placed evenly in soil. However, at CULTAN treatment, only roots in depot zone are involved in ammonium uptake (Sommer, 2005).

More advantageous influence of CULTAN treatment on lodging at Humpolec compared to Ivanovice site can be explained by wetter climate conditions at Humpolec site which, according to findings of Mengel, Kirkby (1979), increase the risk of lodging. At CULTAN treatment, the organic nitrogen compounds are transported from the roots directly to the youngest developing leaves, and thus remobilization of nitrogen from older tissues to younger ones is reduced. This fact results in delayed senescence of stalk base, which leads to higher resistance to its damage (Sommer, 2005).

Increased lodging because of high nitrogen supply was observed at conventional treatment which is in agreement with the findings of O'Donovan et al. (2011) and Penckowski et al. (2009).

CONCLUSION

Grain yield of spring barley and its qualitative parameters at CULTAN treatment under conditions of the Czech Republic were recorded by Sedlář et al. (2011a). Grain yield was not significantly influenced by lodging: 32.9 and 4.6% of the variability in grain yield at Humpolec and Ivanovice site, respectively, could be explained by lodging. At Humpolec site, a thousand grain weight ($r = 0.56$) and a ratio of grain above the 2.5 mm sieve ($r = 0.69$) were significantly negatively influenced by lodging. Similarly, at Ivanovice site, a thousand grain weight ($r = 0.51$) and a ratio of grain above the 2.5 mm sieve ($r = 0.91$) were also significantly negatively influenced by lodging.

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Received for publication on November 29, 2012
Accepted for publication on September 02, 2013

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