Influence of nitrogen fertilizer injection (CULTAN) on yield, yield components formation and quality of winter wheat grain

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ABSTRACT

The CULTAN (Controlled Uptake Long Term Ammonium Nutrition) system is based on one-time injection of the whole dose of nitrogen required for the vegetation period. The effect of this method on yield and grain quality of winter wheat was observed in a 2-year small-plot trial at 4 different experimental sites in the Czech Republic. The experiment comprised two treatments with the total amount of nitrogen applied during fertilization of 150 kg N/ha. At the CULTAN treatment the whole dose was applied all at once using the GFI 3A injection machine (Maschinen und Antriebstechnik GmbH Güstrow), whereas at the control treatment, the dose was divided into three applications. The average grain yield of winter wheat in 2007 was 9.56 t/ha (control) and 8.78 t/ha (CULTAN); in 2008 it was 9.91 t/ha (control) and 9.63 t/ha (CULTAN). The differences in 2008 were not statistically significant. The contents of nitrogen and gluten were significantly lower at CULTAN treatment in both years. The values of falling number, Zeleny test and bulk density were generally similar at both treatments.

Keywords: winter wheat; nitrogen; ammonium injection; quality of grain

Higher mobility of mineral forms of nitrogen in soil precludes one-time usage of high dose of N fertilizers at conventional fertilization of winter wheat; the dose must be divided into several applications. In contrast, the CULTAN method enables to apply nitrogen required by wheat plants in the vegetation period all at once (Sommer 2003). This method is based on injection of ammonium form of fertilizer to the depth of 6–10 cm into the ground, where it is retained in the spots with high concentration of ammonium, so-called depots (Boelcke 2000). In the depot, ammonium ions are bound to clay particles and organic mass and the toxicity of ammonium prevents microorganisms from nitrification of ammonium fertilizer and resulting shift of nitrates out of the reach of wheat plant root system (Sommer 2003). At the CULTAN method, wheat plants uptake most of nitrogen in the ammonium form and can thus adjust its amount themselves by spreading roots into the diffuse zones left after N was drawn from around of the depot surface (Kücke and Scherer 2006).

Based on the information on the CULTAN method there is a presumption of higher uptake of nitrogen by wheat plants than in conventional fertilization onto the soil surface (Sommer 2005); in the latter method, many authors report the average uptake of N from fertilizer in the range of 15–60%, depending on fertilizer type and year (Balík 1985, Delin et al. 2008). Still, when the ammonium solutions are injected to soil to the depth of 3 cm, the losses of nitrogen caused by ammonia volatilization are reduced by 30% compared to surface application (Nyord et al. 2008a).

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Table 1. Characteristics of experimental sites

Site	Altitude (m)	Annual average		Soil type	Soil characteristics	pH/$CaCl_2$
		precipitation (mm)	temperature (°C)			
Čáslav	240	555	8.9	greyic phaeozem	loam	6.6
Hněvčeves	265	597	8.1	haplic luvisol	clay loam	6.3
Humpolec	525	667	6.5	cambisol	sandy loam	6.6
Ivanovice na Hané	225	548	9.2	chernozem	loam	7.3

CULTAN fertilization is applied when the first symptoms of slight N deficiency occur at plants, in the case of winter wheat this period corresponds to the end of tillering, i.e. BBCH 29 stage. It results in the shift of the ratio of roots and aboveground mass in benefit of roots, which changes hormonal balance in wheat plants (Weimar 2003). Wheat plants grown using the CULTAN method thus perform a slower growth of aboveground mass in the first half of vegetation period, while they catch up in the second half of the vegetation (Sommer 2005). Fast initial increase of dry matter in cereals, mainly in the stages of tillering and stem elongation, never leads to high grain yields. To increase grain yield, it is more advantageous if dry matter is increased in the postfloral stage (after earing) (Petr et al. 1988). As stated by Schittenhelm and Menge-Hartmann (2006) the results proved that the cereals fertilized using injection of ammonium solutions with urea have more upright leaves, leaf blades are shorter and the colour of leaves is greener, while the stalk is shorter and firmer than at plants fertilized on soil surface. These phenological changes can positively influence grain yield due to higher absorption of light, photosynthesis and harvest index. According to Kücke and Scherer (2006) the crops grown using the CULTAN method achieve comparable yields and quality of the main product as in conventional growing.

The aim of this experiment was to compare conventional fertilization of winter wheat and the CULTAN method with respect to yield parameters, grain yield and its qualitative indicators.

Table 2. Content of nutrients in soils at experimental sites (mg/kg), Mehlich III

Site	Ca	Mg	K	P
Čáslav	2763	193	276	173
Hněvčeves	2522	158	291	89
Humpolec	2217	183	197	120
Ivanovice na Hané	4458	287	390	142

MATERIALS AND METHODS

Small-plot trial was set up in 2006 on four sites in Čáslav, Hněvčeves, Humpolec and Ivanovice na Hané, Czech Republic. The characteristics of the sites are given in Tables 1 and 2. In the trial, the control variant fertilized with partial nitrogen doses was compared to CULTAN treatment, in which all the fertilizer was applied at one dose. Each treatment had 4 replications and the scheme of the trial is shown in Table 3.

Winter wheat (*Triticum aestivum* L.) cultivar Sulamit (E) 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 growth stage with the GFI 3A injection machine (Maschinen und Antriebstechnik GmbH Güstrow, Germany), with 12 injection wheels working at a width of 3 cm. Each wheel disposes of 12 hollow-spikes that apply fertilizer to a depth of 5 cm.

At the BBCH 31 stage, the number of plants per m^2 was determined. The number of spikes per m^2 was determined prior to harvest and the grains per spike were determined as average of a sheaf of 50 spikes before harvest. The harvest was done with a small plot combine harvester; yield was determined by weighing grains from individual plots and converting them into 14% moisture. The samples were taken of the harvested grains, they were sieved on the laboratory sifter Swing 160 (Mezos, Czech Republic) and afterwards the qualitative indicators were determined; bulk density with the laboratory cereal tester (MEOPTA, Czech Republic), type 1938 (ČSN ISO 7971-2), sedimentation index using the Zeleny test, and the gluten content in dry matter of grain with the NIR OmegAnalyzer G (Bruins Instrument,

Table 3. System of fertilization of field trial

No.	Treatment	Dosage of added N per ha (fertilizer form)			
		BBCH 22	BBCH 29	BBCH 33	BBCH 52
1	control	43 kg (AS)	–	87 kg (CAN)	20 kg (CAN)
2	CULTAN	–	150 kg (UAS)	–	–

AS – ammonium sulphate; CAN – calcium ammonium nitrate; UAS – urea ammonium sulphate

USA), falling number with the viscometer Falling number 1400 (Perten, Sweden) from grain ground in the laboratory hammer mill PSY MP40 (Mezos) with the sieve 0.8 mm (ČSN ISO 3093). The content of N-substances in grain was determined with the Kjeldahl method on the KJELTEC AUTO 1030 Analyzer (Tecator, Poland) and by multiplying the results with the coefficient 5.7 (ČSN 46 1011-18). To evaluate the results, one-factor ANOVA analysis was used followed with the Scheffe's test at the $P < 0.05$ level of significance. The computations were done using the Statistica 8.0 programme (StatSoft, USA).

RESULTS AND DISCUSSION

The grain yield is related to the number of spikes per m^2, number of grains per spike and 1000 grain weight (Petr et al. 1988). In the year 2007, we reported statistically significantly lower grain yield of winter wheat at CULTAN treatment at all sites (Table 4), which was caused by more than 1-month drought in all Czech Republic in the month of April. The monthly precipitatons in April 2007 were 3.1 mm in Čáslav (long-term average 36 mm), 1.8 mm in Hněvčeves (long-term average 28 mm), 1.8 mm in Humpolec (long-term average 45 mm), 2.4 mm in Ivanovice na Hané (long-term average 37 mm). A negative influence of drought was also observed by Walter (2001) in the year 2000, who reported lower yields at CULTAN treatments compared to multiple applications of fertilizer; he reported similar difference also in the content of N-substances and sedimentation index. However, in the years 1996 to 1999 he reached higher yields at CULTAN treatments. In 2008, the control and CULTAN treatments in our experiment gave similar results of grain yield; no statistically significant difference was obtained at either experimental site. The conditions of the year 2008 were very favourable for growing cereals, which is confirmed with significantly higher yields in Čáslav and Hněvčeves, compared to the year 2007; yield increase resulted from higher number of grains per spike and higher 1000 grain weight. In Humpolec, the trend was however opposite; we obtained an interannual decrease of average yield from 9.28 t/ha to 7.57 t/ha. This decrease was caused by lower number of grains per spike and significantly lower 1000 grain weight in the year 2008. Humpolec site is situated in less favourable locality with worse soil and climate conditions, which do not guarantee stability of yield and is thus less suitable for food wheat production. The average grain yield from all sites in 2007 was 9.56 t/ha at control treatment and 8.78 t/ha at CULTAN treatment; in 2008 the values were 9.91 t/ha and 9.63 t/ha, respectively. In the years 1987–1991, Sommer (1992) also obtained slightly lower grain yields of wheat using the UAS (Urea Ammonium Sulphate) CULTAN method compared to CAN (Calcium Ammonium Nitrate) conventional method; the results were however statistically significant only in the year 1990. Similar results were reported also by Boelcke (2000). Nyord et al. (2008b) explains lower yields of winter wheat fertilized with nitrogen injection as a result of too tough soil in

Table 4. Grain yield in t/ha (14% moisture)

Treatment	Čáslav		Hněvčeves		Humpolec		Ivanovice n. H.	
	2007	2008	2007	2008	2007	2008	2007	2008
control	7.46^{a}	9.51^{a}	11.69^{a}	12.87^{a}	9.41^{a}	7.61^{a}	9.70^{a}	9.64^{a}
CULTAN	7.09^{b}	9.11^{a}	10.09^{b}	12.47^{a}	9.15^{b}	7.53^{a}	8.80^{b}	9.41^{a}

his experiment; point injector thus was not able to penetrate it and inject all the fertilizer to the required depth, certain amount of fertilizer then rested on the soil surface where it volatilized. They further suggest the minimum depth for effective usage of the fertilizer as 5 cm. Contrary to previous authors, Weber et al. (2008) in a 2-year trial with winter wheat cultivar Enorm determined the yield of CULTAN-UAS treatment on average by 0.8 t/ha higher compared to the treatment with CAN fertilizer applied in several doses with addition of S at regeneration fertilization, the amount of N being at the level of 180 kg/ha. Yet, higher yield of CULTAN method was significant only in one experimental year. Structure of yield parameters at CULTAN treatment comprised the same number of spikes, higher number of grains per spike and statistically significantly lower 1000 grain weight, compared to respective conventional treatment. Sommer and Fischer (1993) and Boelcke (2003) in multi-year trials reported the same grain yield in CULTAN and conventional treatments; CULTAN yield was based on higher number of spikes per m^2, same number of grains and lower 1000 grain weight. Kücke (2003) even observed grain yield of winter wheat cultivar Ohrum higher by 26% at CULTAN treatment with the application dose of 150 kg N/ha as UAS, compared to the treatment fertilized with same dose N in form of urea divided into three applications; higher yield was due to significantly higher numbers of spikes and grains per spike and slightly higher 1000 grain weight.

Table 5 displays the content of N in grain and the uptake of N at harvest of grain converted to dry matter. The experiment showed higher content of nitrogen in grains of control treatment, in both experimental years and at all sites. The average N content in grain was 2.18% and 2.01% at control and CULTAN treatments, respectively. Yet, the average uptake of N at control was 183 kg N/ha, compared to 159 kg N/ha at CULTAN treatment. According to Petersen (2001), the uptake of nitrogen from fertilizer is mostly dependent on precipitation; in the case of local N application to the soil the uptake is higher, which was not confirmed in our trial. In 2008 we observed a slight decrease of N content in grains of both treatments in Čáslav; it may be explained by coincident increase of grain yield at this site, compared to the year 2007. Higher grain yield causes dilution of the N content in grain. The N uptake at Čáslav site was on average by 15 kg lower at CULTAN treatment in both experimental years. Interannually, the increase of N uptake by wheat increased circa by 25 kg N/ha. At Hněvčeves site, a similar interannual trend of grain yield was observed as in Čáslav, but as for the N content in grain, the trend is opposite; it can be explained with positive effect of pea used as forecrop in Hněvčeves for the year 2008. Pea residues ploughed under evolved enormous amount of nitrogen and the N uptake by grain reached the level of 268 kg N/ha at control and 230 kg N/ha at CULTAN treatment. The preceding year, the forecrop was rape and the N uptake was lower by 72 kg N/ha at control and by 82 kg N/ha at the CULTAN treatment. In Humpolec and Ivanovice na Hané, oilseed rape served as forecrop in both studied years. In Humpolec, we observed a significant decrease of N uptake as well as of grain yield in 2008. The content of N in grain was the same in both years. In Ivanovice, the content of N in grain and N uptake were interannually comparable.

Optimum plant density of winter wheat in spring period according to Petr et al. (1988) varied between 350 and 500 plants per m^2. In our experiment, wheat was in the density between 331–426 plants per m^2 at a sowing rate of 450 seeds per m^2 (Table 6). At Čáslav site in 2007, plant density was low; furthermore, in both experimental years, the number of plants per m^2 was statistically significantly lower at CULTAN method than at control. In all other cases the optimum plant density was achieved and no significant differences were observed between the two treatments.

Based on the values obtained at other localities, it may be presumed that the CULTAN fertilization

Table 5. Uptake and content of N in grain

Parameter	Treatment	Čáslav		Hněvčeves		Humpolec		Ivanovice n. H.	
		2007	2008	2007	2008	2007	2008	2007	2008
Uptake of N in grain (kg N/ha)	control	144[a]	169[a]	196[a]	268[a]	167[a]	138[a]	192[a]	191[a]
	CULTAN	125[b]	156[a]	148[b]	230[b]	148[b]	117[b]	162[b]	169[a]
Content of N in grain (%)	control	2.24[a]	2.07[a]	1.95[a]	2.42[a]	2.07[a]	2.11[a]	2.31[a]	2.30[a]
	CULTAN	2.10[a]	1.99[a]	1.71[b]	2.14[b]	1.89[b]	1.80[b]	2.14[b]	2.09[a]

Table 6. Yield components of crop

Parameter	Treatment	Čáslav		Hněvčeves		Humpolec		Ivanovice n. H.	
		2007	2008	2007	2008	2007	2008	2007	2008
Number of plants per m^2 (pcs) in BBCH 31	control	344^a	377^a	407^a	416^a	420^a	418^a	386^a	387^a
	CULTAN	331^b	364^b	396^a	426^a	418^a	418^a	384^a	378^a
Number of spikes per m^2 (pcs)	control	484^a	589^a	621^a	457^a	615^a	630^a	559^a	728^a
	CULTAN	450^b	589^a	599^a	436^a	585^b	696^b	473^a	726^a
Number of grains per spike (pcs)	control	36^a	50^a	39^a	51^a	44^a	41^a	43^a	44^a
	CULTAN	36^a	49^a	38^a	49^a	42^b	38^b	38^b	44^a
1000 grain weight (g)	control	43.4^a	47.4^a	51.1^a	53.1^a	44.2^a	36.4^a	40.5^a	46.8^a
	CULTAN	42.8^a	46.5^b	51.3^a	52.9^a	43.1^b	37.0^b	42.5^b	47.2^a

technique does not cause significant mechanical or chemical damage to the crop. However, Nyord et al. (2008b) stated that injection of ammonium solutions results in a significant mechanical damage of roots and leaves of plants. Petersen et al. (2004) using ^{15}N found that such damage of roots caused during fertilization leads to a 2 to 3-day delay in the uptake of applied fertilizer and the maximum uptake of N is reduced by 2.6 kg/ha per day.

The number of spikes per m^2 is related to the number of plants per m^2 and their productive tillering (Petr et al. 1988). To obtain the maximum number of productive stems, it is necessary to avoid a nitrogen deficiency (Martinek et al. 2009). The experiments carried out with different cultivars in the Central Institute for Supervising and Testing in Agriculture give the value of 598 spikes per m^2 for the Sulamit cultivar (Horáková et al. 2006). The values obtained from all sites of our trial give the average number of plants per m^2 as 585 at control and 569 at CULTAN treatment. In the year 2007, CULTAN treatment at all sites reached lower number of spikes per m^2 than control; however, the differences were statistically significant only at Čáslav and Humpolec sites (Table 6). In the year 2008, the number of plants per m^2 was significantly higher at CULTAN treatment at Humpolec site; at other sites, both treatments reached comparable values. Karpensteinmachan and Heyn (1992) reported that higher density of spikes shows better adaptability to climate conditions and is supported by a higher uptake of nitrogen and more effective utilisation of N-fertilizer from spring application. Lower number of spikes per m^2 obtained in our trial in 2007 is probably caused by drought lasting for more than 1 month following the injection of fertilizer. According to Sommer (2005) CULTAN fertilization should be performed only at the moment when wheat plants show clear symptoms of N-deficiency, which is usually at the end of tillering stage and at the beginning of stem elongation. At this stage, the plants of the control treatment were well supplied with nitrogen obtained from regeneration fertilization and their development was slightly advanced compared to CULTAN treatment. The CULTAN method manifests excessive growth in the second half of vegetation and the plants then catch up with or even gain upon those fertilized on ground surface with nitrate form of N (Sommer 2003). Extreme drought in 2007 however prevented CULTAN treatments from catching up with the control plants in their development.

The number of grains per spike in our experiment was on average by 2 pieces lower at CULTAN treatment than at control. In the year 2007 the average number of grains per spike obtained from all sites was 43.5 and 41.6 pieces at control and CULTAN treatments, respectively; in 2008, the values were even higher, i.e. 46.5 and 44.8 pieces, respectively. At Ivanovice na Hané site, the difference between the two treatments in 2007 was statistically significant; in Humpolec, the difference was statistically significant in both experimental years. Number of grains per spike at Čáslav and Hněvčeves sites was significantly lower in 2007 than in 2008, whereas the opposite trend was observed in Humpolec (Table 6).

As for the 1000 grain weight in our trial, the same value, i.e. 45.4 g, was obtained at both treatments as the average of all sites and both years. In Humpolec in 2007, however, 1000 grain weight was significantly lower at CULTAN treatment. At all the studied yield components, the year 2007 had a strong negative influence on CULTAN treatment at this site compared to control. In Čáslav a significantly lower value of 1000 grain weight was obtained at CULTAN treatment in 2008, although the number of spikes per m^2 and the number of grains in spike were the same at both treatments. In cases where the number of grains in spike was significantly lower, 1000 grain weight was significantly higher, which is attributed to the autoregulation ability of wheat.

Major qualitative indicators of winter wheat grain comprise the content of N-substances, gluten content, sedimentation index, falling number and bulk density. All these parameters were observed in our trial and are summarised in Table 7. Nitrogen fertilization has the most positive impact on the level of proteins and wet gluten in dry matter of grain. Content of N-substances in grain was higher at control in both years and at all sites. At Hněvčeves and Humpolec sites, statistically significant differences were recorded in both years. Average values of N content were 12.4% (control) and 11.5% (CULTAN); both treatments thus exceeded the minimum content of N-substances (11.5%) required for food wheat according to the standard ČSN 46 1100-2. Similar results were reported by Weber et al. (2008), who reported a significantly lower N content in wheat grain at CULTAN treatment (UAS) compared to respective conventional method, the difference reached up to 2.5%. Contrary to our results, Sommer and Fischer (1993) as well as Kücke (2003) reported comparable content of N-substance in grain at CULTAN and conventional treatments.

At interannual comparison of the content of N-substances in grain at Čáslav site, significantly lower contents were determined in the year 2008 than in 2007; it might have been caused by higher yield in 2008. It complies with the results published by Kučerová (2005), who found a very strong negative correlation between the grain yield and content of N-substances in grain. In our trial no interannual change of N content in grain was observed at Humpolec and Ivanovice na Hané sites.

The content of nitrogen substances is closely related to the gluten content in grain; in both study years and at all sites, it was higher at control treatment. With the only exception being the Čáslav site, the differences were statistically conclusive, which contradicts the results of Weimar (1997), who determined higher content of N-substances in grain, gluten content and sedimentation index in winter wheat cultivar Flair treated with CULTAN method using 160 kg N/ha in form of UAS.

Sedimentation index measured by the Zeleny test determines quantity and quality of gluten proteins. According to Grausgruber et al. (2000), Zeleny test focuses, to a larger degree, quality of storage proteins rather than their quantity, and is mainly affected by genetic and environmental factors. In our experiment, the content of gluten as well as the results of the Zeleny test were higher at control treatments compared to the CULTAN plants; the differences were mostly statistically conclusive (Table 7). At Čáslav, Hněvčeves and Ivanovice na Hané sites, no significant interannual differences in sedimentation index were recorded. The Central Institute for Supervising and Testing in Agriculture at testing wheat cultivars obtained the value of 55 ml in Zeleny test for the Sulamit cultivar (Horáková et al. 2006); our results are slightly lower, on average it was 50 ml at control treatment and 44 ml at CULTAN treatment. Except for the results from Hněvčeves in 2007, the values of sedimentation index were sufficient to meet the limits for food wheat; the Czech standard ČSN 46 1100-2 prescribes the minimum value of Zeleny

Table 7. Qualitative indicators of winter wheat

Indicator	Treatment	Čáslav		Hněvčeves		Humpolec		Ivanovice n. H.	
		2007	2008	2007	2008	2007	2008	2007	2008
Content of N-substances (%)	control	12.8[a]	11.8[a]	11.1[a]	13.8[a]	11.8[a]	12.0[a]	13.2[a]	13.1[a]
	CULTAN	12.0[a]	11.4[a]	9.7[b]	12.2[b]	10.8[b]	10.7[b]	12.6[b]	12.3[a]
Gluten content (%)	control	28.8[a]	28.1[a]	24.2[a]	35.0[a]	24.6[a]	27.9[a]	31.9[a]	31.7[a]
	CULTAN	26.1[a]	26.2[a]	20.3[a]	29.6[b]	21.0[b]	22.3[b]	28.0[b]	28.5[b]
Zeleny test (ml)	control	54[a]	51[a]	34[a]	53[a]	51[a]	54[a]	50[a]	51[a]
	CULTAN	50[b]	49[a]	24[b]	45[b]	44[b]	46[b]	46[a]	46[b]
Falling number (s)	control	389[a]	283[a]	369[a]	304[a]	392[a]	320[a]	322[a]	382[a]
	CULTAN	377[a]	305[a]	346[a]	310[a]	385[a]	323[a]	318[a]	361[a]
Bulk density (kg/hl)	control	78.6[a]	79.8[a]	80.9[a]	82.8[a]	78.1[a]	77.6[a]	79.0[a]	79.2[a]
	CULTAN	78.0[a]	79.7[a]	79.9[a]	82.8[a]	78.2[a]	77.9[a]	78.8[a]	79.5[a]

test as 30 ml. Weber et al. (2008) obtained slightly lower sedimentation index at CULTAN treatment fertilized with Urea Ammonium Sulphate. Weimar (1996) however determined the same value of sedimentation index at winter wheat (Ibis) fertilized with 172 kg N/ha both at CULTAN and conventional methods. In the year 1995 at application of 162 kg N/ha the sedimentation index of Batis cultivar was even higher at CULTAN treatment.

Falling number indicates the rate of alpha amylase activity in grain; it is an enzyme active in starch hydrolysis and is activated at the beginning of grain germination. The Central Institute for Supervising and Testing in Agriculture obtained the falling number of 358 s in trials with winter wheat cultivar Sulamit (Horáková et al. 2006). In our experiment, the values of falling number ranged between 283 and 389 s; average values were 345 and 340 at control and CULTAN treatments, respectively. No statistically significant differences in falling number values between the two treatments were observed in either site or year. The falling number value is mostly influenced by genetic and environmental factors, especially weather conditions at maturation stage (Grausruber et al. 2000). Falling number during maturation increases up to its maximum value at full maturity. At the beginning of grain germination, the falling number rapidly decreases (Piikki et al. 2008). At Čáslav, Hněvčeves and Humpolec sites the values obtained in 2008 were lower than in 2007. Still, the limit of minimal falling number of 220 s required by the standard ČSN 46 1100-2 for food wheat was reached at all treatments. Falling number may vary in dependence on the site conditions and year, while no dependence was observed on the content of N-substances in grain. Nevertheless, Wang et al. (2008) demonstrated positive correlation of falling number and N-substances in grain of winter wheat.

Bulk density is an indicator of flour extraction at mill production. In our experiment, the identical results of bulk density were obtained in both treatments. The lowest values, around 77.6 kg/hl were recorded at Humpolec site in 2008 which is the least suitable for growing of wheat for food production. The best location, based on the bulk density as well as other parameters, is then Hněvčeves. Bulk density reached here 82.8 kg/hl. According to the standard ČSN 46 1100-2, the limit of bulk density for food wheat is 76.0 kg/hl.

CULTAN treatments achieved lower values in many parameters; the differences were albeit statistically non-significant. We can thus conclude that the CULTAN method is a suitable alternative for nutrition of winter wheat. The results also show that further detailed examination of the CULTAN method is necessary before it can be recommended for usage in common agricultural practice.

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