THE IMPACT OF CONTROLLED UPTAKE LONG TERM AMMONIUM NUTRITION ON WINTER WHEAT YIELD AND QUALITY OF GRAIN

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The effect of controlled uptake long term ammonium nutrition (CULTAN) on yield and grain quality of winter wheat was examined at three sites in a two-year small-plot field experiment. Two treatments using injection fertilization of all nitrogen in one dose (CULTAN system) were compared with two treatments using nitrogen surface broadcast fertilization in three doses. The effect of N-fertilizer containing sulphur was further examined in each fertilization system. The injection fertilization was applied at the end of winter wheat tillering in 2008 and at the beginning of spring vegetation in 2009. The grain yields of CULTAN treatments were lower in 2008; in the following year the grain yields of both fertilization systems were comparable. The differences were not generally statistically significant. Protein content, gluten content and sedimentation index were lower in CULTAN treatments in both years. Using the urea ammonium sulphate in CULTAN system instead of urea ammonium nitrate increased all measured characteristics in both years.

winter wheat; N-fertilizer injection; grain quality, nitrogen, sulphate

INTRODUCTION

The CULTAN "Controlled Uptake Long Term Ammonium Nutrition" method is based on injection of ammonium form of fertilizer into the ground, where it is retained in so-called depots (Boelcke, 2000). In the depot, ammonium is bound to soil and organic particles; moreover, its toxicity prevents nitrifying bacteria from transformation into more mobile nitrate form. For this reason, compared to the conventional fertilization with ammonium nitrate divided into three applications onto soil surface, CULTAN system enables to apply all nitrogen needed for vegetation at one dose without losses of nitrogen caused by wash-out and with no risk of underground water contamination (Kücke, Scherer, 2006). At CULTAN method, plants develop a dense root system at places with lower concentration of ammonium around the depots to regulate the amount on nitrogen taken by the plant by successive growth of roots towards the depot until the exhaustion of fertilizer. The uptake of nitrogen by wheat plants is thus higher than in conventional fertilization (Sommer, 2005). Balík (1985) and Delin et al. (2008) report the average uptake of N from fertilizer in the range of 15–60%, depending on fertilizer type and year, whereas Nyord et al. (2008) found that when 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.

Sommer (2005) recommends application of fertilizers to winter wheat with CULTAN method at BBCH 29 growth stage, not until the plants show symptoms of slight N-deficiency. In such plants, the root: shoot ratio is more favourable for roots. Furthermore, CULTAN plants take most of nitrogen in form of ammonium ions, which must be bound to organic substances directly in roots; the result of this process is creation of amino acids and it supports root growth (Sommer, 2003). The change of the root: shoot ratio is related to the change in phytohormonal regulation and increased production of cytokinins, which are important for yield-oriented growth in the second half of vegetation (Weimar, 2003). Schittenhelm and Menge-Hartmann (2006) report that crops fertilized with 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 changes can positively influence grain yield due to higher absorption of light and higher photosynthesis. At present, this method is being intensively tested in practical conditions in Germany. In our soil-climatic conditions, no complex observations have been performed, yet. The aim of this experiment was to compare conventional fertilization of winter wheat and the CULTAN method with respect to grain yield and its qualitative indicators.

MATERIAL AND METHODS

In 2007, a two-year small-plot trial was established in order to assess the influence of injection application of

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nitrogen fertilizers by so-called CULTAN method on yield and quality of winter wheat grain. The trial was carried out at three sites with different soil-climatic conditions, namely in Čáslav, Hněvčeves and Ivanovice na Hané (Tables 1, 2 and 3).

Quality food wheat of the Sulamit cultivar was sown in right agricultural time limits. The forecrop were peas (2008) and winter rape (2009) in Čáslav; peas (2008) and maize (2009) in Hněvčeves; winter rape (2008) and peas (2009) in Ivanovice na Hané. The Nmin content were measured in early spring time at the level of 24 ppm (2008) and 15 ppm (2009) in Čáslav; 28 ppm (2008) and 17 ppm (2009) in Hněvčeves; 13 ppm (2008) and 25 ppm (2009) in Ivanovice na Hané. The trial consisted of two treatments fertilized onto soil surface (conventional) and two treatments fertilized with point injection (CULTAN) using the GFI 3A injection machine (f. Maschinen und Antriebstechnik GmbH Güstrow). At conventional treatments, nitrogen fertilizer was applied in three doses; the terms of application are specified in Table 4. At CULTAN treatments all nitrogen was applied in one dose at BBCH 29 growth stage in 2008 and at BBCH 22 in 2009. Each treatment had four replications, the size of individual plots being 39 m^2, out of which 15 m^2 was harvested.

Qualitative parameters were determined from samples of grain that had been sieved on the laboratory sifter Swing 160 (f. Mezos). Sedimentation index was measured with the Zeleny test, gluten content in dry matter of grain with the NIR OmegAnalyzer G (f. Bruins Instruments) and falling number with the viscometer Falling number 1400 (f. Perten) from grain ground in the laboratory hammer mill PSY MP40 (f. Mezos) with 0.8 mm sieve. The content of N-substances in grain was determined with the Kjeldahl method on the KJELTEC AUTO 1030 Analyzer (f. Tecator) and by multiplying the results with the coefficient 5.7. To evaluate the results, one-factor distribution analysis was at the $P < 0.05$ level of significance.

Table 1. Characteristics of experimental sites

Site	Soil type	Soil class	pH ($CaCl_2$)	Mehlich III ($mg.kg^{-1}$)			
				Ca	Mg	K	P
Čáslav	greyic phaeozem	loam	6.9	2461	120	126	60
Hněvčeves	haplic luvisol	clay loam	6.3	1979	125	181	82
Ivanovice na Hané	chernozem	loam	7.3	3792	230	411	162

Table 2. Amount of precipitation on the experimental sites (mm)

Site	Year / month	Vegetation period						Longterm annual average
		II	III	IV	V	VI	VII	
Čáslav	2008	17.2	46.8	40.6	44.4	89.1	56.1	555
	2009	77.6	66.1	23.7	64.8	74.6	100.2	
	normal	22.0	33.0	36.0	66.0	73.0	83.0	
Hněvčeves	2008	26.0	43.0	29.5	58.5	30.8	77.4	597
	2009	48.5	47.6	5.6	55.6	100.2	92.3	
	normal	25.0	32.8	28.1	55.5	61.5	74.9	
Ivanovice na Hané	2008	5.9	41.9	42.5	80.7	35.4	58.9	548
	2009	61.3	69.1	8.3	62.0	89.1	111.6	
	normal	21.5	33.5	37.0	61.0	70.1	70.0	

Table 3. Average temperature on the experimental sites (°C)

Site	Year / month	Vegetation period						Longterm annual average
		II	III	IV	V	VI	VII	
Čáslav	2008	3.3	4.2	8.9	14.6	18.6	19.0	8.9
	2009	0.3	4.6	13.3	14.4	15.7	19.3	
	normal	0.4	4.3	8.6	14.0	16.6	18.4	
Hněvčeves	2008	3.5	4.6	9.7	15.4	19.8	19.9	8.1
	2009	–0.4	4.3	13.3	14.3	15.7	18.9	
	normal	0.6	4.3	9.6	14.4	17.1	19.1	
Ivanovice na Hané	2008	2.7	4.2	9.6	14.8	18.9	19.8	9.2
	2009	0.1	4.6	13.3	14.9	16.9	20.3	
	normal	0.6	4.2	9.7	15.0	18.0	19.8	

RESULTS AND DISCUSSION

The results presented in Table 5 suggest that CULTAN treatments in 2009 gave higher grain yields than conventional treatments with nitrogen application divided into several doses. In 2008, when the injection of fertilizers was applied at BBCH 29 growth stage, CULTAN treatments gave lower grain yields. Yet, in both years a positive effect of nitrogen fertilizer with sulphur was observed; it led to an increase in yield of winter wheat grain in both systems of fertilization. In 2009, the highest yields at all sites were obtained at CULTAN II treatment, where UAS was applied. On the contrary, in 2008, the highest yields at all sites were gained at conventional treatment II with ammonium sulphate for regeneration fertilization. The obtained results indicate that to reach the maximum yields of wheat grain using CULTAN method, it is necessary to apply the injection of fertilizers early enough (at the time of regeneration fertilization), and not to wait until BBCH 29 growth stage of wheat as recommended by Sommer (2005). This growth stage corresponds to the period in which intensive droughts have been reported in recent years in the Czech Republic; drought significantly worsens the uptake of fertilizer. The development of conventionally fertilized crops at this period is more advanced and the drought disables CULTAN plants to catch up, which results in lower yields of wheat grain at application at BBCH 29 stage (Kozlovský et al., 2007). Still, in the case of favourable distribution of precipitation, CULTAN treatments may reach higher grain yields, even at fertilization at BBCH 29 stage, which is confirmed by the results of many authors from Germany (Walter, 2001; Weimar, 2003; Weber et al., 2008).

In the experimental year 2008, the content of N-substances in grain was lower at CULTAN treatments compared to conventional fertilization; the differences were mostly statistically significant (Table 6). In 2009, the content of N-substances in grain at CULTAN treatment was lower only at Čáslav site; at Hněvčeves and Ivanovice na Hané sites the values of N-substances at CULTAN treatments were equal or higher, but the differences were never statistically significant. Using ammonium sulphate for regeneration fertilization had no effect on the change of N-substances values; however, application of UAS instead of UAN in CULTAN method led to an increase of N-substances in grain. Minimal value of 11.5% required by the Czech national standard 46 1100-2 (ČSN, 2006) for food wheat was not reached only by three CULTAN treatments in 2008 (Table 6). The solution for lower content of N-substances in wheat grain at CULTAN treatments is use of qualitative fertilization; the condition of this treatment is however sufficient precipitation at the time of applica-

Table 4. Experimental scheme (kg N.ha^{-1} and type of fertilizer)

Treatment	Term of fertilization				Total kg N. ha^{-1}
	BBCH 22	BBCH 22, 29	BBCH 33	BBCH 52	
Conventional I	43 kg (CAN)		87 kg (CAN)	20 kg (CAN)	150
CULTAN I		150 kg (UAN 390)			150
Conventional II	43 kg (AS)		87 kg (CAN)	20 kg (CAN)	150
CULTAN II		150 kg (UAS 240)			150

CAN – Calcium Ammonium Nitrate; UAN 390 – Urea Ammonium Nitrate; AS – Ammonium Sulphate (20.5% S); UAS 240 – Urea Ammonium Sulphate (6% S)

Table 5. Grain yield at 14% moisture (t.ha^{-1})

Treatment	Čáslav		Hněvčeves		Ivanovice na Hané	
	I	II	I	II	I	II
Conventional I	9.44^{bc}	7.15^{a}	12.59^{ab}	10.33^{a}	9.43^{a}	8.95^{a}
CULTAN I	8.58^{a}	7.05^{a}	12.10^{a}	10.54^{ab}	9.25^{a}	9.04^{a}
Conventional II	9.51^{c}	7.45^{ab}	12.87^{b}	10.64^{b}	9.64^{a}	9.00^{a}
CULTAN II	9.11^{b}	7.97^{b}	12.47^{ab}	10.72^{b}	9.41^{a}	9.12^{a}

I – harvest year 2008, II – harvest year 2009; values within the column marked with the same letter are not statistically different ($P < 0.05$)

Table 6. Content of N in grain (%)

Treatment	Čáslav		Hněvčeves		Ivanovice na Hané	
	I	II	I	II	I	II
Conventional I	11.8^{b}	12.2^{a}	13.3^{c}	12.6^{a}	13.3^{c}	13.8^{a}
CULTAN I	10.7^{a}	11.5^{a}	11.6^{a}	12.7^{a}	10.1^{a}	13.8^{a}
Conventional II	11.8^{b}	12.4^{a}	13.8^{c}	12.6^{a}	13.1^{bc}	13.4^{a}
CULTAN II	11.4^{ab}	12.0^{a}	12.2^{b}	13.3^{a}	12.3^{b}	13.5^{a}

I – harvest year 2008, II – harvest year 2009; values within the column marked with the same letter are not statistically different ($P < 0.05$)

tion so that the fertilizer may be uptaken by the plant. Possibility of this combination is recommended by S o m m e r (2005).

Gluten content is closely related to the content of N-substances in grain. Therefore, the values of CULTAN treatments were, with only one exception, always lower than conventional fertilization (Table 7). Using of ammonium sulphate for regeneration fertilization had no effect on gluten content; however, replacing ammonium nitrate with ammonium sulphate at CULTAN treatments led to an increase of gluten content in grain. This increase of values was statistically significant almost at all cases.

Sedimentation index is measured using the Zeleny test and determines the quality of gluten proteins (G r a u s g r u b e r et al., 2000). Table 8 summarizes the values of sedimentation index, indicating that both CULTAN treatments in 2008 reached lower values than conventional fertilization. In 2009 the slightly lower values were obtained only at CULTAN I treatment; values at CULTAN II treatment were comparable with conventional treatments at all experimental sites. Minimal value of 30 ml required by the Czech national standard 46 1100-2 (ČSN, 2006) for food wheat was obtained at all treatments.

Falling number is used to reveal damages of reserve substances of starchy endosperm of wheat grain by hydrolytic enzymes, synthesized in grain as a result of grain germination in spike initiated by excessive moisture (Z i m o l k a et al., 2005). As shown in Table 9, falling number is influenced by site conditions and year. At Ivanovice na Hané site, the values of falling number slightly decreased in both experimental years; on the contrary, at Hněvčeves site, CULTAN treatments gave slightly higher values of falling number, though not statistically significant. At Čáslav site, the falling number values at CULTAN treatment were higher in 2008 but lower in 2009. According to S o m m e r (2005) wheat plants cultivated with the CULTAN method have a shorter vegetation period than plants fertilized conventionally with ammonium nitrate, and thus falling number depends on the right term of harvest and weather during harvest. Yet, in 2009 the amount of precipitation at harvest was much higher than in 2008. The greatest interannual difference was observed in Ivanovice na Hané; the total amount of precipitation in the month of July was 59 mm and 112 mm in 2008 and 2009, respectively.

The results for the year 2009 indicate that at timely injection of fertilizers CULTAN treatments may reach yields and grain quality comparable to conventional fertilization. Moreover, qualitative parameters at all variants exceeded significantly minimal values required by the

Table 7. Gluten content (%)

Treatment	Čáslav		Hněvčeves		Ivanovice na Hané	
	I	II	I	II	I	II
Conventional I	28.2^{b}	27.6^{a}	33.1^{c}	28.1^{a}	32.3^{b}	29.2^{bc}
CULTAN I	24.4^{a}	26.0^{a}	27.6^{a}	27.4^{a}	24.0^{a}	27.5^{a}
Conventional II	28.1^{b}	27.3^{a}	35.0^{d}	28.0^{a}	31.7^{b}	29.8^{c}
CULTAN II	26.2^{ab}	26.1^{a}	29.6^{b}	30.0^{b}	28.5^{b}	28.2^{ab}

I – harvest year 2008, II – harvest year 2009; values within the column marked with the same letter are not statistically different ($P < 0.05$)

Table 8. Sedimentation index – Zeleny test (ml)

Treatment	Čáslav		Hněvčeves		Ivanovice na Hané	
	I	II	I	II	I	II
Conventional I	51^{b}	62^{a}	50^{b}	64^{a}	52^{b}	64^{b}
CULTAN I	43^{a}	57^{a}	42^{a}	63^{a}	36^{a}	60^{a}
Conventional II	51^{b}	61^{a}	53^{b}	64^{a}	51^{b}	64^{b}
CULTAN II	49^{b}	60^{a}	45^{a}	65^{a}	46^{b}	63^{b}

I – harvest year 2008, II – harvest year 2009; values within the column marked with the same letter are not statistically different ($P < 0.05$)

Table 9. Falling number (s)

Treatment	Čáslav		Hněvčeves		Ivanovice na Hané	
	I	II	I	II	I	II
Conventional I	261^{a}	362^{b}	306^{a}	335^{a}	392^{a}	301^{b}
CULTAN I	283^{a}	313^{a}	313^{a}	336^{a}	363^{a}	276^{ab}
Conventional II	283^{a}	356^{b}	304^{a}	332^{a}	382^{a}	290^{ab}
CULTAN II	305^{a}	353^{b}	310^{a}	352^{a}	361^{a}	264^{a}

I – harvest year 2008, II – harvest year 2009; values within the column marked with the same letter are not statistically different ($P < 0.05$)

Czech national standard ČSN 46 1100-2 (ČSN, 2006) for food wheat. Year 2008 showed that in conditions of the Czech Republic injection of fertilizers as late as at BBCH 29 stage results in lower yields and worse quality of grain at CULTAN treatment compared to conventional fertilization. Yet, the literature referring to the grain quality of wheat treated with CULTAN method is not consistent. Similar results as those obtained in our study were reported by Weber et al. (2008); they reached significantly higher grain yield at using CULTAN system of fertilization, while the values of falling number, sedimentation index and content of N-substances were lower compared to conventional treatments. K ü c k e (2003), on the other side, obtained significantly higher yields of wheat grain at CULTAN treatment as well as higher values of falling number and contents of N and gluten in grain.

CONCLUSION

The obtained results show that the CULTAN method can be an equal alternative in winter wheat nutrition; it gave comparable yields and comparable grain quality. The differences were not generally statistically significant. Using of nitrogen fertilizer with sulphur amendment led to an increase in wheat grain yield at both fertilization systems. However, sulphur application improved qualitative parameters only at CULTAN treatment. With respect to the fact that it is a new method with highly different fertilization technology it is necessary to thoroughly verify the results in a further set of trials before its introduction as a widespread agricultural practice.

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Vliv dlouhodobé výživy amoniakem s kontrolovaným příjmem na výnos a kvalitu zrna ozimé pšenice.

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Vliv dlouhodobé výživy amoniakem s kontrolovaným příjmem (CULTAN metoda) na výnos a kvalitu zrna pšenice ozimé byl zkoušen ve dvouletém maloparcelkovém pokusu ve třech rozdílných půdně-klimatických podmínkách. Dvě varianty hnojené jednorázově celkovou dávkou dusíku pomocí injektážního stroje byly porovnávány se dvěma variantami hnojenými ve třech dávkách dusíku plošně na povrch půdy. V každém systému byl dále sledován vliv použití dusíkatého hnojiva obsahujícího síru. U každé varianty se aplikovalo 150 kg $N.ha^{-1}$. Injektážní aplikace hnojiva byla provedena ve fázi konce odnožování v roce 2008 a na začátku jarní vegetace v roce 2009. V roce 2008 byly u CULTAN variant nižší výnosy zrna na všech stanovištích, v následujícím roce byly výnosy zrna u obou systému výživy srovnatelné. Rozdíly ve výnosu mezi jednotlivými systémy hnojení byly většinou statisticky neprůkazné. Hodnoty obsahu dusíkatých látek, obsahu lepku a sedimentačního indexu byly v obou letech nižší u CULTAN variant, avšak větší rozdíly mezi systémy byly pozorovány v roce 2008. Použití síranu amonného s močovinou místo dusičnanu amonného s močovinou CULTAN metodou zvýšilo v obou letech hodnoty všech sledovaných charakteristik. Použití síranu amonného na regenerační hnojení zvýšilo výnos zrna, ale kvalitativní ukazatele nebyly ovlivněny.

pšenice ozimá; injektáž N-hnojiva; kvalitativní parametry zrna; dusík; síra

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