The impact of nitrogen fertilizer injection on kernel yield and yield formation of maize

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ABSTRACT

In field experiments over three vegetation periods (2010–2012) we studied impact of the CULTAN (controlled uptake long term ammonium nutrition) method on yield and yield parameters of kernel maize. The field experiments were conducted at three sites with different soil-climatic conditions. CULTAN treatments were fertilized once with the total amount of nitrogen using an injection machine (at the canopy height of 20 cm) and compared to conventional fertilization with calcium ammonium nitrate application at pre-sowing preparations. In all treatments the amount of nitrogen was the same, 140 kg N/ha. In 2010 at Humpolec site, CULTAN urea ammonium nitrate + inhibitor of nitrification treatment gave by 20.5% higher number of ears compared to CULTAN urea ammonium nitrate treatment. In 2011 at Ivanovice all CULTAN treatments reached statistically significantly higher number of kernels per ear. The higher 1000 kernel weight at CULTAN treatments was observed in 2012 at the Ivanovice site; a statistically significant difference between conventional and CULTAN urea ammonium nitrate + inhibitor of nitrification treatment was observed. Fertilization of maize with nitrogen using the CULTAN method under the conditions of the Czech Republic provides the same yield certainty as the conventional surface application and the CULTAN method of fertilization increases the yield certainty at delayed sowing. Harvest index was statistically significantly influenced by year, fertilization treatment and site.

Keywords: ammonium; number of ears per plant; number of kernels per ear; thousand weight kernel; harvest index

The impact of nitrogen fertilization on plants depends on soil conditions, climatic factors and agrotechnology, plant type and the method of fertilizer application (Blankenau et al. 2002). Balík (1986) states that plants under conditions of the Czech Republic, uptake less than 50% of fertilizer. Nitrogen fertilization in maize influences mostly the number of kernels per ear, ear length and 1000 kernel weight (Petr et al. 1988). The principle of the CULTAN (controlled uptake long term ammonium nutrition) method lies in single application of nitrogenous fertilizers containing the ammonium cation to the root space; essential nitrogen is thus provided to a plant in available form that is little mobile in soil (Sommer 2005). The most frequently used form of the CULTAN method is injection of liquid ammonium fertilizer into soil creating so-called 'depots' (Boelcke 2003, Kubešová et al. 2013a). Such ammonium depots are resistant to nitrification processes due to high concentration of ammonium in soil (Sommer 2005). Positively charged ammonium ion is bound in soil to negatively charged clay particles and organic compounds (Kücke and Scherer 2006). It is therefore possible to reduce nitrogen fertilization into one single dose at vegetation period (Boelcke 2003). At CULTAN method the symptoms of ammonium nitrogen toxicity on fertilized plants were not observed; Sommer (2005) explains that at the CULTAN method of fertilization only part of the roots participate in the uptake of ammonium nitrogen from the depots margins. The roots uptake

Table 1. Characteristics of experimental sites

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

nitrogen out of there only if they are sufficiently supplied with saccharides from the aboveground parts and plants can thus use nitrogen in metabolism of the nitrogenous compounds. The roots that participate in uptake of nitrogen and ammonium from depots become denser and branch due to saccharides produced in the aboveground part of plant and their distribution changes according to the plant growth stage; they usually grow from the free soil towards depots. Absorbed ammonia in roots is immediately bound to amino acids that may be translocated in roots and the lower part of straw directly towards the growth centres. However, the objective of our research was to compare various nitrogen (N) management strategies as the CULTAN method with the N fertilization in form of calcium ammonium nitrate on the kernel yield of maize.

MATERIAL AND METHODS

In small plot field trials at Hněvčeves, Humpolec and Ivanovice na Hané sites in 2010–2012 the impact of fertilization using the CULTAN method on yield and yield formation of maize was observed. Exact description of sites is given in Table 1. The experiment consisted of 4 treatments, each with 4 replications. Conventional treatment (CAN) was fertilized on surface prior to sowing. CULTAN fertilization was applied at the maize canopy height of 20 cm using the injection machine GFI 3A (Maschinen und Antriebstechnik GmbH Güstrow, Germany). The treatments and the N management are given in Table 2. Detailed methodology of the trial is stated by Kubešová et al. (2013b). Content of mineral nitrogen (mg/kg) in the soil profile before CULTAN application and after harvest is given in Tables 3 and 4. Evaluation of the results was done using the single-factorial analysis of variance ANOVA followed with the Scheffe's test at the probability level $P < 0.05$ in the programme Statistica 9.1 (StatSoft, Tulsa, USA). Values in columns and individual stages marked with the same letters are not statistically significantly different at the probability level above.

Table 2. Treatments of the field experiments

Treatment	Before sowing (kg N/ha)	CULTAN (plant height 20 cm) (kg N/ha)
CAN-conventional	140	–
CULTAN UAN	–	140
CULTAN UAS	–	140
CULTAN UAN + IN	–	140

CULTAN – controlled uptake long term ammonium nutrition; CAN – calcium ammonium nitrate, 27% N; UAN – urea ammonium nitrate, 30% N; UAS – urea ammonium sulphate, 24% N, 6% S; UAN + IN – urea ammonium nitrate, 30% N + inhibitor of nitrification (DCD)

Table 3. Content of mineral nitrogen (N_{min}, mg/kg) in the top soil (0–30 cm) before CULTAN (controlled uptake long term ammonium nutrition) application (0.01 mol/L $CaCl_2$)

Site	Year	N_{min}
Hněvčeves	2010	91.4
	2011	65.1
	2012	65.3
Humpolec	2010	14.5
	2011	44.5
	2012	30.5
Ivanovice na Hané	2010	18.9
	2011	43.7
	2012	25.8

Table 4. Content of mineral nitrogen (N_{min}, mg/kg) in the top soil (0–30 cm) after harvest (0.01 mol/L $CaCl_2$)

Treatment	Hněvčeves			Humpolec			Ivanovice na Hané		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
CAN	19.7	20.5	10.2	12.3	21.5	20.7	14.6	17.9	9.4
UAN	16.4	14.9	5.7	6.4	8.3	13.0	16.6	11.6	13.5
UAS	16.4	15.2	5.2	7.8	15.9	15.1	22.9	24.2	15.2
UAN + IN	13.5	10.8	3.7	6.4	9.8	15.5	17.0	13.6	10.4

CAN – calcium ammonium nitrate, 27% N; UAN – urea ammonium nitrate, 30% N; UAS – urea ammonium sulphate, 24% N, 6% S; UAN + IN – urea ammonium nitrate, 30% N + inhibitor of nitrification (DCD)

RESULTS AND DISCUSSION

At none of the sites during the three years of trial a decrease of plants related to the CULTAN-applied fertilization was observed. In 2010 the lowest number of ears was observed at Hněvčeves (Table 5), whereas the highest at Ivanovice, where the conventional treatment and CULTAN UAS treatment reached statistically significantly higher number of ears than the CULTAN UAN + IN treatment. The influence of inhibitor on ear number may be observed in the same year at Humpolec site, where the 4th treatment reached by 20.5% higher number of ears compared to CULTAN UAN. In 2011, significantly higher number of ears per plant was detected related to the fertilization treatment in Hněvčeves site where the CULTAN UAS treatment reached ear number higher by 12.4% in comparison with conventional treatment. In the same year at Ivanovice site CULTAN treatment gave lower number of ears per plant; it was however compensated by statistically significantly longer ears and higher number of kernels in ear and also by higher thousand weight kernel (TKW), which confirms a positive impact of injection methods of fertilization CULTAN on principle yield parameters in maize. The reason may be a longer period of assimilate storage at CULTAN-fertilized plants (Sommer 2005). In 2012, statistically significantly higher number of ears was obtained at all treatments at Hněvčeves. Yet, no statistically significant treatment-related differences in number of ears per plant were observed at either of sites in 2012. In 2010 the impact of fertilization on ear length at Hněvčeves and Ivanovice sites was not statistically significant,

Table 5. Number of ears per plant and ear length

Treatment	Hněvčeves			Humpolec			Ivanovice na Hané		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Number of ears per plant									
CAN	1.09^{a}	1.05^{a}	1.22^{a}	1.35^{ab}	1.15^{a}	1.03^{a}	1.90^{b}	1.58^{a}	1.02^{a}
UAN	1.03^{a}	1.15^{ab}	1.16^{a}	1.22^{a}	1.22^{a}	1.02^{a}	1.85^{ab}	1.37^{b}	1.00^{a}
UAS	1.07^{a}	1.18^{b}	1.22^{a}	1.35^{ab}	1.20^{a}	1.00^{a}	1.92^{b}	1.33^{b}	1.00^{a}
UAN + IN	0.99^{a}	1.16^{ab}	1.31^{a}	1.47^{b}	1.15^{a}	1.00^{a}	1.80^{a}	1.35^{b}	1.00^{a}
Ear length (cm)									
CAN	19.4^{a}	19.0^{a}	20.0^{ab}	19.6^{ab}	19.8^{a}	20.7^{a}	17.7^{a}	18.0^{a}	18.4^{b}
UAN	19.3^{a}	19.2^{a}	20.0^{ab}	20.5^{b}	19.8^{a}	21.0^{a}	18.0^{a}	18.6^{a}	18.5^{b}
UAS	19.0^{a}	18.9^{a}	20.1^{b}	19.2^{a}	19.6^{a}	21.0^{a}	18.0^{a}	18.9^{a}	18.1^{a}
UAN + IN	19.6^{a}	19.4^{a}	19.9^{a}	19.8^{ab}	19.6^{a}	21.1^{a}	18.3^{a}	18.5^{a}	18.5^{b}

CAN – calcium ammonium nitrate, 27% N; UAN – urea ammonium nitrate, 30% N; UAS – urea ammonium sulphate, 24% N, 6% S; UAN + IN – urea ammonium nitrate, 30% N + inhibitor of nitrification (DCD) where at Humpolec the ears longer by 4.2% were observed at 2nd treatment compared to conventional treatment and by 6.7% longer than at 3rd treatment, which is statistically significant (Table 5). In 2011 no statistically evident differences in the ear length in relation to treatments were found at any station. In 2012 statistically evident shorter ears were observed at injection treatment with sulphur at Ivanovice in comparison with other treatments. The lowest number of kernels per ear was obtained at Hněvčeves in 2010 and 2011 (Table 6), probably due to below-average precipitations in July and August, which is supported by the results of Zinselmeier et al. (1999), who reported a water deficit 5 days before earing stage to be critical and to strongly affect the number of kernels per ear. However, at 2nd and 4th treatments, a tendency to higher number of kernels per ear was observed, which is confirmed by Sommer (2005) who states that CULTAN-fertilized plants are more resistant to drought. In 2011 at Ivanovice all CULTAN treatments reached statistically significantly higher number of kernels per ear, even though the yield in this year was influenced by several stress factors (May ground frosts, strong precipitation deficit in May, July and August). Bertin and Gallais (2000) state that the nitrogen-deficiency stress has a 32% share on reduction of number of kernels in ear. The trial has not confirmed a negative impact of CULTAN-fertilization, which causes a nitrogen deficiency in plants at the beginning of the vegetation period, on the number of kernels per ear compared to the conventional treatment.

Total weight of kernels obtained in maize (*Zea mays* L.) is strongly genetically influenced (Reddy and Daynard 1983). However, stress conditions, such as drought (Brooks et al. 1982), assimilates availability (Blum 1998) and temperature (Wardlaw and Wrigley 1994) significantly affect the final values of TKW. Influence of the above-mentioned stressors on TKW was observed in 2010; at all sites the lowest values were obtained due to cold and rainy weather at the grain filling stage which negatively affected kernel weight. At Hněvčeves in 2011 higher TKW was obtained in CULTAN UAS treatment (Table 6), which confirms synergic effect of nitrogen and sulphur on yield formation (Malhi et al. 2007). Tendency to higher TKW at CULTAN treatments was observed in 2012 at Ivanovice, where the statistically significant difference between conventional and CULTAN UAN + IN treatments was observed. It may be supposed that in this year with spring frosts at the time of maize emergence and an extreme lack of precipitation at the time of grain filling a positive impact of sink/source effect occurred at CULTAN treatments (Sommer and Scherer 2007); it is in compliance with the statement by Borrás and Otegui (2001) who reported that an increase of TKW is related to changes in the sink-source ratio during post-anthesis.

In 2011 smaller length of plants was observed at CULTAN treatments at all experimental sites,

Table 6. Number of kernels per ear and 1000 kernel weight

Treatment	Hněvčeves			Humpolec			Ivanovice na Hané		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Number of kernels per ear									
CAN	437^a	430^a	482^a	540^b	470^a	466^a	466^a	494^a	484^a
UAN	416^a	443^a	492^a	545^b	486^a	468^a	468^a	544^b	504^a
UAS	392^a	426^a	512^a	474^a	480^a	477^a	477^a	542^b	486^a
UAN + IN	429^a	452^a	519^a	531^b	440^b	474^a	474^a	537^b	477^a
1000 kernel weight (thousand weight kernel (g))									
CAN	211^a	382^{ab}	319^a	138^b	242^{ab}	308^a	294^a	295^a	333^a
UAN	212^a	370^a	314^a	120^a	246^b	312^a	293^a	294^a	338^{ab}
UAS	201^a	392^b	332^a	123^a	234^a	312^a	290^a	296^{ab}	334^{ab}
UAN + IN	198^a	380^{ab}	327^a	118^a	238^{ab}	316^a	294^a	300^b	340^b

CAN – calcium ammonium nitrate, 27% N; UAN – urea ammonium nitrate, 30% N; UAS – urea ammonium sulphate, 24% N, 6% S; UAN + IN – urea ammonium nitrate, 30% N + inhibitor of nitrification (DCD)

Table 7. Kernel yield (%; conventional treatment (CAN) = 100%) and average kernel yield over periods 2010–2012 (14% moisture, t/ha)

Treatment	Hněvčeves			Humpolec			Ivanovice na Hané		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Kernel yield									
CAN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
UAN	94.4	111.3	113.6	88.7	105.6	96.3	98.1	100.0	107.1
UAS	92.7	110.6	103.4	87.1	100.0	101.9	100.0	103.3	102.0
UAN + IN	93.0	115.3	109.1	88.7	96.2	100.0	95.6	100.6	102.0
Average kernel yield over periods 2010–2012									
CAN		15.0^a			7.4^a			13.6^a	
UAN		16.1^a			7.1^a			13.8^a	
UAS		15.3^a			7.2^a			13.9^a	
UAN + IN		15.7^a			7.1^a			13.5^a	

CAN – calcium ammonium nitrate, 27% N; UAN – urea ammonium nitrate, 30% N; UAS – urea ammonium sulphate, 24% N, 6% S; UAN + IN – urea ammonium nitrate, 30% N + inhibitor of nitrification (DCD)

which is explained by Sommer (2005) as a consequence of change in the ratio of the aboveground parts and roots due to N deficiency at the beginning of vegetation. The same tendency was reported by Sedlář et al. (2011) at CULTAN-fertilized spring barley.

In 2010 at all sites a clear tendency to lower yields at CULTAN treatments was observed (Table 7). The lowest yield in this year was obtained at Hněvčeves at surface CAN application. The possible explanation is that the basic fertilization at conventional treatment combined with colder summer months accelerated initial growth compared to the CULTAN treatments. On the contrary, at Ivanovice all CULTAN treatments had similar yields as conventional treatment, which may be caused by faster mineralisation at this site and faster initial growth of maize plants at CULTAN treatments; nitrogen deficiency caused by basic fertilization was fixed with fast mineralization. In 2011 higher yields were obtained at CULTAN treatments compared to conventional treatment at Hněvčeves and Ivanovice sites. At Hněvčeves site, statistically significantly higher yield by 15.3% at 4th treatment over the conventional one. Higher yield of CULTAN fertilization according to Sommer (2005) is explained by longer time of assimilate storage in ears. Blaylock and Cruse (1990) in his trials with maize also observed a statistically significant increase in yield and better utilization of nitrogen from injection-applied UAN fertilizer compared to surface application. At this site, higher yield was formed by higher number of kernels at CULTAN treatments, which was caused by favourable weather conditions during grain filling stage. At Ivanovice site, higher yields at CULTAN treatments were given by higher number of kernels and higher TKW. Slightly warmer months in 2011 and 2012 at Humpolec had a significant impact on smaller differences in kernel yield in dependence on the fertilization treatment. The highest kernel yield in 2011 was recorded at CULTAN UAN treatment, the difference over conventional treatment being 5.6%. In 2012 at Ivanovice the absolute values showed lower yields at all treatments compared to the previous year, which was caused by late spring frosts. Yet, the tendency to higher yields in CULTAN treatments was observed, which is in compliance with the statement of Sommer (2005) that the CULTAN-fertilized plants are more resistant to stress. Distinctive differences in maize kernel yields were observed in 2012 at the Hněvčeves site, where all injection-fertilized treatments reached higher yields compared to conventional treatment. At CULTAN UAN treatment a yield higher by 13.6% was recorded compared to conventional treatment. Even though the absolute values show very high yields at all treatments and sowing was slightly delayed because of the weather conditions, it may be stated that the CULTAN fertilization of

Table 8. Harvest index

Treatment	Hněvčeves			Humpolec			Ivanovice na Hané		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
CAN	0.39^{a}	0.41^{ab}	0.48^{a}	0.43^{a}	0.31^{a}	0.51^{a}	0.57^{b}	0.51^{a}	0.50^{a}
UAN	0.37^{a}	0.37^{a}	0.53^{b}	0.42^{a}	0.34^{a}	0.49^{a}	0.49^{a}	0.48^{a}	0.50^{a}
UAS	0.36^{a}	0.44^{b}	0.52^{ab}	0.42^{a}	0.33^{a}	0.50^{a}	0.56^{b}	0.50^{a}	0.52^{a}
UAN + IN	0.35^{a}	0.42^{b}	0.53^{b}	0.41^{a}	0.32^{a}	0.51^{a}	0.54^{b}	0.52^{a}	0.47^{a}

CAN – calcium ammonium nitrate, 27% N; UAN – urea ammonium nitrate, 30% N; UAS – urea ammonium sulphate, 24% N, 6% S; UAN + IN – urea ammonium nitrate, 30% N + inhibitor of nitrification (DCD)

maize decreases the impact of delayed sowing on kernel yield. Statistically significant positive direct impact of sulphur in fertilizer on maize plants was not observed at either of the sites. Based on the results of the three-year experiment (Table 7), it is possible to agree with the statement of Walter (2003) that the nitrogen fertilization of maize using the CULTAN method in Germany shows the same yield certainty as conventional surface application, which was confirmed under the conditions of the Czech Republic, and that the CULTAN method of fertilization increases the yield certainty at delayed sowing.

Harvest index (HI) is the ratio of the kernel yield (t/ha) and the total kernel and straw yield (t/ha) expressed as 100% dry matter. Harvest index was statistically significantly affected by year, fertilization treatment and site. At Hněvčeves site, harvest index in 2012 was statistically significantly different from 2010 and 2011 (Table 8). Lower HI in 2010 at Hněvčeves was caused by lower kernel yield related to lower TKW; the latter was influenced by stress conditions at the time of grain filling. In 2012 all injected treatments gave higher harvest index compared to the conventional treatment, which may be explained by higher number of ears per spike at CULTAN treatments due to better resistance of dry CULTAN fertilization of plants at the heading stage, which is in agreement with Mori and Inagaki (2012) that higher harvest index is a critical factor for producing greater kernel yield under water deficit stress. At Humpolec site statistically significant difference in HI values was observed between the experimental years. No statistically significant difference in HI values related to the treatment was observed, which is in compliance with the findings of Sigunga et al. (2002) who did not observe an effect of fertilizer with different forms of nitrogen (ammonium nitrate vs. ammonium sulphate) on harvest index under normal conditions. In all experimental years no statistically significant influence of year on HI value was observed at Ivanovice. Lower HI values were obtained at CULTAN UAN treatment in all years; in 2010 it was statistically significant in comparison with conventional treatment. It may be supposed that these plants have the fastest uptake of nutrients that are effectively used in the assimilate formation without storage; they grow faster till the beginning of the generative phase and thus achieve the highest biomass yield. In 2011 and 2012 no statistically significant differences in the HI values related to the fertilization treatment were obtained. The above-mentioned harvest index values suggest that at Ivanovice site the HI values are the most stable despite the weather oscillations.

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Received on March 27, 2013
Accepted on December 19, 2013

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