THE EFFECT OF INJECTION APPLICATION OF AMMONIUM FERTILIZER ON THE YIELD OF MAIZE*

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The effect of plant nitrogen nutrition by CULTAN (Controlled Uptake Long Term Ammonium Nutrition) method on the yield of maize and the content of nitrogen in various evolution phases was being observed in a field experiment carried out in the years 2010–2011. The experiment took place at three stations with different soilclimatic conditions. CULTAN variants were fertilized with a one-off total dose of nitrogen (by the means of a injection machine, to the depth of 5 cm in the soil) and compared with conventional fertilization, when Calcium Ammonium Nitrate was spread in a blanket manner on the soil's surface. In one injection variant nitrogenous fertilizer containing sulphur (Urea Ammonium Sulphate) was observed. The same dose of nitrogen 140 kg $N.ha^{-1}$ was applied in all variants. In 2011 the biggest grain yield was achieved at Hněvčeves, where all CULTAN variants proved better yield than the conventional variant (15,03 $t.ha^{-1}$). Statistically significant bigger grain yield was observed by injection variant Urea Ammonium Nitrate + inhibitors of nitrification variant, in comparison with the conventional variant by 15,5%. In Hněvčeves there was a tendency to getting better straw yield by CULTAN variants in 2010.

ammonium; inhibitor of nitrification; injection; CULTAN depot; nitrogen content

INTRODUCTION

Maize can be an important farming product for Czech agriculture in the years to come. The main reason is its wide range of exploitation (e.g. fodder in the form of grain and silage, raw material for biogas production, food industry) (Zimolka, 2008). Characteristic features of conventional nitrogenous fertilization are split doses of nitrogen and the preference of nitrate forms of fertilization. Nitrate forms act quickly, but most crops require slow action of nutrients. Unfortunately, usage of nitrates raises the environmental risk by leaching.

The principle of CULTAN (Controlled Uptake Long Term Ammonium Nutrition) method lies in one-off localization of nitrogenous fertilizers containing ammonium cation in the area of roots in such a manner that the needed nitrogen is provided for the plant in an accessible, but in the soil environment also mobility restricted, form (Weimar, 2003). The most frequently used form of application of nitrogenous fertilizers through CULTAN method is injecting a liquid ammonium fertilizer into the soil while creating so called depot (Boelcke, 2000). Positive ammonium ion is bound to the negative clay particles and organic matter in the soil (Kücke, Scherer, 2006). Therefore, it is possible to reduce fertilization to one total dose of nitrogen per vegetation (Boelcke, 2003). Ammonium ion is not flooded out of this zone, and neither is it nitrified thanks to its high concentration of ammonia and a higher pH value. In order to eliminate phytotoxicity of ammonium due to an excessive ammonium nitrogen application, the application must be carried out partly outside the root system and roots must grow towards the source of nitrogen. Contrary to a proportional application of ammonium, when all roots receive nitrogen evenly, by CULTAN method nitrogen is received by only a part of the roots, which grow all the way to the edge of the newly created depot (Sommer, 2005). By CULTAN method, the intensity of nitrogen reception is controlled by the phytotoxicity of loose ammonium in cells (Sommer, Rossig, 1978). According to Schumacher (2009), by CULTAN point grouting fertilization the usability of nitrogen from the fertilizer makes up to 90%.

Plants receive nitrogen depending on the effectiveness of the synthesis of carbonic compounds, i.e. according to other factors of growth (daylight, temperature, water) (Weimar, 2003). Received ammonium ion is immediately built in into the organic compounds in the roots points (Balík et al., 2007). Sommer (2003) states that received ammonium nitrogen is transmitted directly to young leaves, thus

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Table 1. Characteristics of the experimental sites

Site	Hněvčeves	Humpolec	Ivanovice na Hané
Altitude (m a.s.l.)	265	525	225
Precipitation (mm)	597	667	548
Average annual temperature (°C)	8.1	6.5	9.2
Soil suborder	haplic luvisol	cambisol	chernozem
Soil type	clay loam	sandy loam	loam
pH ($CaCl_2$)	6.3	6.6	7.3
Ca (mg/kg), Mehlich III	2522	2217	4458
Mg (mg/kg), Mehlich III	185	183	287
K(mg/kg), Mehlich III	291	197	390
P (mg/kg), Mehlich III	89	120	142

Table 2. Fertilization system of the field trial

Variant	Application before sowing (kg N/ha)	CULTAN (application to 20 cm plants) (kg N/ha)
CAN	140	
CULTAN UAN		140
CULTAN UAS		140
CULTAN UAN + IN		140

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) + inhibitors of nitrification

there is no translocation from older leaves to young ones, as it is common when using nitrate nutrition. As the production of cytokinins in roots points increases, the number of auxins and gibberellins in sprouts is reduced (S o m m e r, S c h e r e r, 2007). Besides that, cytokinins influence the formation of cells in the endosperm of the grain, therefore they affect the grain size and the weight of thousands of seeds (H e r z o g, G e i s l e r, 1977), which fundamentally influences the yield of the main product of maize (P e t r et al., 1988). It can be said that when using nitrogenous fertilization by CULTAN method, the root system develops more progressively (S o m m e r, 2005). This effect is partially achieved by shifting the time of fertilization into the period of a latent lack of nitrogen, which causes a lower ratio between aboveground biomass and roots (H e j n á k et al., 2005). The reception of nutrients and resistance to drought improve with a better developed root system (S o m m e r, 2003).

MATERIAL AND METHODS

The experiment with maize was set up at Hněvčeves, Humpolec, and Ivanovice na Hané sites within the years 2010–2011 (for soil-climatic characterization of the stations see Table 1). In the experiment hybrid Texxud (FAO 340) was used, at the sowing density of 82 000 seeds per ha. It is a type of hybrid suitable for growing for grain. The experiment consisted of 4 versions, each repeated four times. The area of the fertilized plot was 45 m^2 (3 × 15 m), out of which 19.6 m^2 (1.4 × 14 m) was harvested. Fertilization by CULTAN method was carried out by injection machine GFI 3A (Maschinen und Antriebstechnik GmbH, Güstrow, Germany) on 20 cm maize sprouts. Nitrogen at the total amount of 140 kg/ha was applied at one go. Each application wheel consists of 12 spikes, which inject the liquid fertilizer into the depth of 5 cm (Table 2). Agrotechnical measures were in accordance with the standard technology used for growing maize. Essential supervised parameters of the experiment were the grain yield and straw yield (calculated based on 15 average plants harvested by hand) and the observation of the dynamics of nitrogen reception in various development phases (BBCH 14, BBCH 20, complete plant at harvest time). The total amount of nitrogen was determined by Kjeldahl's method on the Vapodest machine (Gerhardt, Königswinter, Germany). Results were evaluated using One-Factor Analysis of Variance (ANOVA), followed by Scheffé's test (STATISTICA software package, StatSoft Inc., Version 8, 2007 (level of significance $P < 0.05$). The figures in individual columns and phases marked by the same letters show no significant differences on the given level of significance.

RESULTS AND DISCUSSION

The range of annual maize grain yields at the individual sites was wide (Table 3). The 2010 best

Table 3. Grain yield (14% moisture, t/ha)

Variant	Hněvčeves		Humpolec		Ivanovice	
	2010	2011	2010	2011	2010	2011
CAN	12.42	15.03	6.28	5.39	16.27	15.00
CULTAN UAN	11.74	16.78	5.53	5.60	15.89	15.67
CULTAN UAS	11.56	16.65	5.44	5.32	16.27	15.56
CULTAN UAN+IN	10.92	17.36	5.53	5.17	15.59	15.42
F-test	0.21	2.92	1.74	0.89	0.91	0.93
D_{min}	4.13	1.80	0.91	0.58	1.07	0.93

D_{min} (minimal significant difference P = 0.05)

Table 4. Straw yield (100% dry mass, (t/ha)

Variant	Hněvčeves		Humpolec		Ivanovice	
	2010	2011	2010	2011	2010	2011
CAN	16.87	21.75	7.12	9.88	11.59	12.40
CULTAN UAN	16.94	24.85	6.45	9.33	14.07	14.12
CULTAN UAS	17.21	17.09	7.37	9.10	11.05	13.44
CULTAN UAN + IN	17.42	20.53	6.71	9.20	11.52	12.08
F-test	0.65	9.83	1.44	1.56	5.21	3.11
D_{min}	0.97	3.16	1.06	0.86	1.84	1.65

D_{min} (minimal significant difference P = 0.05)

yield was reached at Ivanovice. Interestingly, there were no statistically significant differences between variants at this site. In 2011, the best grain yield was achieved at Hněvčeves, where all CULTAN variants exhibited a better yield than the conventional variant (15.03 t/ha. Between the conventional variant and CULTAN UAN + IN a statistically significant difference of 15.5% in favour of CULTAN was observed. The better yield through CULTAN fertilization could be explained by a longer-lasting assimilates deposition into corncobs (Sommer, 2005; Sedlář et al., 2011). Also experimenting with maize, Blaylock, Cruse (1990) observed statistically significant yield increase and a better absorption of nitrogen from applied DAM fertilizer using point grouting, contrary to aboveground application.

A tendency towards a better grain yield by CULTAN variants was observed also in 2011 at Ivanovice na Hané, however, there were no statistically provable differences between variants. In both harvest years, the worst yield was achieved at Humpolec site, because of its unsuitability for growing maize (Zimolka et al., 2008). In 2010, the best yield at this site was produced by aboveground application of the fertilizer. Neither the application of a fertilizer containing sulphur, nor the inhibitor of nitrification had any serious effect on the yield of maize grain. The obtained results on the yield of grain correspond with the opinion of Walter (2003) that fertilization of maize by nitrogen through CULTAN system shows the same yield certainty as conventional aboveground application.

In 2010, the best straw yield of maize was achieved at Hněvčeves site. A tendency towards a better yield by CULTAN variants was observable although there were no statistically significant differences between variants. Similarly, the best straw yield of 2011 was observed also at Hněvčeves, by the conventional as well as CULTAN UAN variants (Table 4). A statistically lower yield (by 21.45%) was achieved by CULTAN UAS than by the conventional variant. At Ivanovice site a statistically comparable straw yield was observed in 2010. The following year at the same site, no favourable effect of the inhibitor of nitrification on the straw yield of maize was registered. In both harvest years, as concerns the grain and the straw yield of maize, the worst yield was achieved at Humpolec. However, in 2010 it was observed that added sulphur has a favourable effect on the yield at this station, which is in accordance with the findings (McGrath, Zhao, 1996) that sulphur plays a crucial role in plant metabolism and its deficit is reflected in the yield; and the reception of sulphur correlates with the reception of nitrogen (Malhi et al., 2007). At Humpolec there is a lower content of available sulphur in the soil, while at other stations sulphur is not a limitary nutrient (Kulhánek et al., 2011).

Table 5 shows total amounts of nitrogen in the aboveground biomass in development phases BBCH 14, BBCH 20, and in the complete plant at harvest time. In BBCH 14 phase, a higher content was mostly observed by CULTAN variants. In 2011, at Hněvčeves, the fourth variant showed a statistically provable higher

Table 5. Nitrogen content (%)

Vegetal phase	Variant.	Hněvčeves		Humpolec		Ivanovice	
		2010	2011	2010	2011	2010	2011
BBCH 14	1	4.06^{a}	4.20^{a}	3.43^{ab}	3.50^{a}	4.12^{a}	4.83^{a}
	2	3.84^{a}	4.24^{a}	3.36^{a}	3.49^{a}	4.12^{a}	4.82^{a}
	3	4.05^{a}	4.37^{a}	3.55^{ab}	3.55^{a}	4.07^{a}	4.89^{a}
	4	3.84^{a}	4.42^{b}	3.58^{b}	3.46^{a}	4.03^{a}	4.83^{a}
BBCH 20	1	3.47^{a}	3.93^{a}	2.95^{ab}	3.01^{a}	3.42^{a}	4.23^{a}
	2	3.39^{a}	3.78^{a}	3.00^{ab}	2.87^{a}	3.67^{b}	4.30^{a}
	3	3.66^{b}	3.90^{a}	3.26^{b}	2.98^{ab}	3.74^{b}	4.36^{a}
	4	3.40^{a}	3.87^{a}	3.26^{b}	2.76^{b}	3.55^{a}	4.34^{a}
Complete plant at harvest	1	1.18^{a}	1.05^{a}	1.30^{a}	1.10^{a}	1.21^{a}	0.92^{a}
	2	1.16^{a}	1.11^{a}	1.24^{a}	1.07^{a}	1.19^{a}	0.91^{a}
	3	1.20^{a}	1.10^{a}	1.41^{b}	1.09^{a}	1.20^{a}	1.02^{a}
	4	1.20^{a}	1.02^{a}	1.38^{b}	1.05^{a}	1.18^{a}	0.95^{a}

$^{a,\,b}$the same superscripts show insignificant differences on the given level of significance ($P < 0.05$)

content of nitrogen than the conventional variant and a similar situation was at Humpolec in 2010. At the other stations there were minimal diversions in the content of nitrogen in this phase within both years. At Hněvčeves, in BBCH 20 phase the CULTAN UAS variant reached in 2010 statistically provable better results than the conventional one.

At Humpolec site in 2010, the third and the fourth variant achieved a higher content of nitrogen than the conventional variant. At Ivanovice, the same year, a statistically provable higher content of nitrogen was observed by CULTAN UAN and CULTAN UAS variants, which is in accordance with the statement of Peterson (2001) that the reception of nitrogen is higher by local application into the soil. However, this trend was not confirmed at harvest, when complete plants of maize showed a comparable content of nitrogen and no statistically provable difference in relation to the fertilization variant was discovered, except for Humpolec station in 2010, when the third and the fourth variant reached a higher content of nitrogen.

CONCLUSION

In our experiment we compared the aboveground application of CAN before sowing maize and the application of a liquid fertilizer by grouting in the soil to the depth of 5 cm when the maize plants measured 20 cm. Fertilization of maize with nitrogen through CULTAN system shows the same yield certainty as the conventional aboveground application. The effect of the individual fertilization variants on individual maize parameters seems to be less prominent than the influence of the station. On the basis of the experiments with fertilization of maize by CULTAN method carried out in 2010 and 2011, it is possible to regard the CULTAN method as a comparable alternative of nitrogenous fertilization of maize in Czech conditions.

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