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THE INFLUENCE OF FERTILIZATION BY CONTROLLED AMMONIUM NUTRITION (CULTAN) ON MAIZE YIELD, N UPTAKE AND CONTENT OF NITRATES IN SOILS WITH A HIGH CONTENT OF MINERAL NITROGEN

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ABSTRACT

Nitrogen losses caused by leaching present one of the most significant risks of crops fertilization for the environment. The technology of fertilization is one of the most important factors, which can affect the nitrogen losses. The aim of the experiment was to assess the influence of nitrogenous fertilization by CULTAN method (Controlled Uptake Long Term Ammonium Nutrition) on the maize crop and content of nitrates in the soil after harvesting maize (*Zea mays* L.). The experiment took place in the Czech Republic, at three sites with various soil-climate characteristics, in the years 2010-2012. A conventional way of nitrogen fertilization by even application of Calcium Ammonium Nitrate on the soil surface was compared with local injection of a nitrogenous fertilizer by CULTAN method. By local application of ammonium ion, a satiated space with diffusion gradient, so called depot, is being created in the soil. The content of nitrate and total mineral nitrogen in the soil profile (0-30 cm and 30-60 cm) before setting up the experiment and at harvest time was determined in tincture 0.01mol.l^{-1} $CaCl_2$. Throughout the experiment, it was possible to observe a lower content of nitrate nitrogen in the soil after maize harvesting by CULTAN method, with the condition that the beginning of the growth was not accompanied by extreme weather.

Key words: leaching, ammonium, CULTAN depot, injection, maize.

INTRODUCTION

The level of nitrogen efficiency in mineral fertilizers rarely exceeds 50% (Rasmussen and Rhode, 1991). The most frequent nitrogen losses are caused by denitrification, volatility and leaching (Raun et al., 1999). The risk of leaching of nitrate nitrogen increases with a higher content of nitrates in the soil together with intensive soil washing (Troeh and Thompson, 2005).

Besides the doses of nitrogenous fertilizer, the fertilization timing, and the plant overlay, draining mineral nitrogen from the soil is one of the key factors determining the risk of nitrogen leaching (Di and Cameron, 2002).

The principle of CULTAN method (Controlled Uptake Long Term Ammonium Nutrition) consists in placing the nitrogenous fertilizer containing ammonium cation in the root area in such a way that the needed nitrogen is offered to the plant in an accessible, but little mobile in the soil form (Weimar and Walg, 2003; Kubešová et al., 2013). By local application of ammonium ion, a satiated space with diffusion gradient is created. The positively charged ammonium ion is bound to the negatively charged clay particles and organic matters (Kücke and Scherer, 2006). The most frequently used form of application is injection of a liquid ammonium fertilizer into the soil while making a so called depot (Boelcke, 2003).

The ammonium nitrogen is applied in the depot in an exactly determined dose (Scharpf and Weier, 1995). In the centre of the depot the concentration of ammonium nitrogen exceeds the absorbent abilities of the soil, whereas the edge of the depot shows these abilities further on (Sommer, 2005). Ammonium depots are stable towards nitrification processes in the

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soil thanks to toxic characteristics of ammonium (Menge Hartmann and Schittenhelm, 2008). But Pfab et al. (2012) and Sedlář et al. (2013) suggest that the toxicity of ammonium is not sufficient for a complete inhibition of microbial activity in the surrounding of the depots. Nitrate nitrogen gets out of the soil more easily than ammonium one. This is mainly due to the fact that both nitrate and ammonium nitrogen can be immobilized by microorganisms, but the nitrate one is also a subject to losses by denitrification and leaching (Malhi et al., 2001).

Ammonium ion as a nitrogenous source for plants differs in many ways from nitrate and urea, although it is used by fertilization as a concentrated depot into the soil (Sommer, 2005). By using CULTAN method, due to its phytotoxicity, ammonium can be received by plants only on marginal surface of the CULTAN depot, where it can be immediately implemented into the metabolism of nitrogenous compounds. To be able to receive ammonium into this metabolism, there must be a sufficient source of saccharides flowing into root tips from the aboveground part of the plants (Weimar and Sommer, 1990).

The received ammonium is immediately bound in the roots into amino acids, which can be relocated in the roots and the bottom part of the stem directly towards the growing parts. Thus, a greater development of the root system is achieved. The production of cytokinins in the root tips increases, causing the decrease of auxins and gibberellins in the sprouts (Sommer and Scherer, 2009). This leads to better development of the root system by CULTAN plants. The aim of the trial was to assess the influence of injection fertilization by CULTAN method on the yield, nitrogen uptake and content of nitrate in soil after maize harvesting.

MATERIAL AND METHODS

Three sites with various soil-climate characteristics, Hněvčeves, Humpolec and Ivanovice na Hané, were the venue of a small plot field experiment with maize (*Zea mays* L.), hybrid Texxud, FAO 340, in the years 2010-2012. The individual characteristics of the experimental sites are stated in Table 1. A conventional way of nitrogenous nutrition by even application of fertilizer Calcium Ammonium Nitrate on the soil surface was compared with local injection of a nitrogenous fertilizer by CULTAN method.

The experiment’s scheme is illustrated in Table 2. 82,000 grains were sowed per hectare. The area of the fertilized plot was 45 m^2 (3 x 15 m), out of which 19.6 m^2 (1.4 x 14 m) was harvested.

Table 1. Characteristics of experimental sites

	Site		
	Hněvčeves	Humpolec	Ivanovice na Hané
Altitude (m above sea level)	265	525	225
Precipitation (mm)	597	667	548
Average temperature per year (°C)	8.1	6.5	9.2
Soil suborders	haplic luvisol	cambisol	chernozem
Soil type	clay loam	sandy loam	loam
pH ($CaCl_2$)	6.3	6.6	7.3
Ca (mg kg^{-1}), Mehlich 3	2 522	2 217	4 458
Mg(mg kg^{-1}), Mehlich 3	185	183	287
K (mg kg^{-1}), Mehlich 3	291	197	390
P (mg kg^{-1}), Mehlich 3	89	120	142

Table 2 .Fertilization system of the field trial

	Variant	Application before sowing	Application to 20 cm tall plants
1	CAN (conventional)	140 kg $N.ha^{-1}$	
2	CULTAN UAN		140 kg $N.ha^{-1}$
3	CULTAN UAS		140 kg $N.ha^{-1}$
4	CULTAN UAN + IN*		140 kg $N.ha^{-1}$

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) + nitrification inhibitor.

Crop management was in compliance with standard technologies of growing maize. When the plants were 20 cm tall, the application of the fertilizer by CULTAN method was done by injection machine GFI 3A (Maschinen und Antriebstechnik GmbH, Germany) into the depth of 5 cm in the root area (Table 2).

Besides the crop parameters, the content of nitrogen in the soil was also observed. The content of nitrate and total mineral nitrogen in the soil profile (0-30 cm and 30-60 cm) before setting up the experiment and at harvest time was determined in tincture 0,01 $mol.l^{-1}$ $CaCl_2$ (Houba et al., 1986) by segment flow analysis with colorimetric settings on SKALAR SAN plus SYSTEM device (Skalar Analytical, Netherlands).

The total amount of nitrogen in the plant material was determined by method based on Kjeldahl on VAPODEST 50s device (Gerhardt, Germany). The results evaluation was done by one-factor analysis of variance ANOVA, followed by Scheffé´s test on the level of significance at $P<0.05$ in Statistica 9.1 programme (StatSoft, Tulsa, USA). The figures shown in individual tables in individual rows labelled by same letters bear no statistical difference on the mentioned level of significance.

RESULTS AND DISCUSSION

Soil samples for determination of the mineral nitrogen content were taken at the time when optimal conditions for mineralization had been reached. Therefore, the content of nitrate as well as ammonium form of nitrogen is high (Table 3). In 2010 the content of mineral nitrogen in the soil was higher due to application of the fertilizer to the forecorp. Higher figures in 2011 at all sites were caused by above-average temperatures at the beginning of spring. Detailed results regarding grain yield are published by Kubešová et al. (2014).

Uptake of nitrogen by the whole plant during the harvest time is shown in Table 4. On average, most nitrogen was consumed by the maize at site Hněvčeves. In 2010 the uptake was comparable in all variants. In the following year, the injection variant CULTAN UAN achieved statistically higher uptake by 17.3% against the conventional variant, which can be explained by the location of the fertilizer in an accessible and stable form for a longer period of vegetation (Sommer, 2005). In 2012 sowing at this site was delayed and the highest nitrogen uptake was achieved by variant CULTAN UAS, which supports the opinion of Vaněk et al. (2007) that Ammonium Sulphate is the most suitable fertilizer for maize. By variant CULTAN UAN it was possible to observe at harvest time a statistically lower uptake of nitrogen by the whole plant in comparison with the conventional variant. In 2012, although the sowing was slightly delayed, CULTAN variants, which were fertilized by the plant height of 20 cm, showed comparable or higher nitrogen uptake than conventional variants.

Generally the lowest nitrogen uptake was observed at site Humpolec. The differences in uptake were significantly influenced by the year. In 2010 and 2011, lower nitrogen uptake was caused by smaller growth activity in relation to the temperature of the outer environment. In 2012 the nitrogen uptake by the whole plant was higher but comparable among variants of fertilization.

At Ivanovice site in 2010 the same phenomenon as in Hněvčeves could be observed – the highest nitrogen uptake was achieved by variant CULTAN UAN. The nitrogen uptake by the whole plant determined at harvest time was statistically higher than in variant CAN. In 2011 there was a tendency of higher uptake by CULTAN variants, even though the summer months were below average as far as precipitation and temperatures are concerned.

Table 3. Content of mineral nitrogen (mg $.kg^{-1}$) in the soil profile before CULTAN application in maize (0.01 $mol.l^{-1}$ $CaCl_2$)

Site	Year	Soil profile (cm)					
		0 - 30			30 - 60		
		NO_3^-	NH_4^+	N_{min}	NO_3^-	NH_4^+	N_{min}
Hněvčeves	2010	55.7	35.7	91.4	14.1	4	18.1
	2011	47	18.1	65.1	14.1	3.9	18
	2012	64.1	1.2	65.3	19.5	1.5	21.0
Humpolec	2010	10.4	4.1	14.5	26.3	5	31.3
	2011	29	15.5	44.5	15.1	3.5	18.6
	2012	26.6	3.9	30.5	5.7	2.2	7.9
Ivanovice na Hané	2010	16.7	2.3	18.9	13.1	18.9	32.0
	2011	41.5	1.7	43.7	22.4	2	24.2
	2012	24.4	1.4	25.8	26.6	1.5	28.1

Table 4. Nitrogen uptake by the whole maize plant (kg $N.ha^{-1}$)

Variant	Hněvčeves			Humpolec			Ivanovice na Hané		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
1	327^a	364^a	334^a	163^a	159^a	208^a	310^a	234^a	200^a
2	314^a	427^b	296^b	138^b	154^a	198^a	332^b	248^{ab}	219^a
3	327^a	342^a	362^a	169^a	149^a	213a	304^a	275^b	226^a
4	322^a	359^a	353^a	161^a	143^a	196^a	302^a	243^{ab}	219^a

Values within the column marked with the same letter are not statistically different ($P<0.05$).

The injection variant with sulphur reached higher uptake by 17% compared with the variant when CAN was evenly spread before the sowing, which is in compliance with the view of Babiánek and Ryant (2007), who stated that adding sulphur to the fertilizer had a positive effect on the uptake of nitrogen. The lowest nitrogen uptake was observed at this site in 2012, which was caused by dry weather. Despite this fact, a tendency towards higher yield was observed by injection fertilized variants.

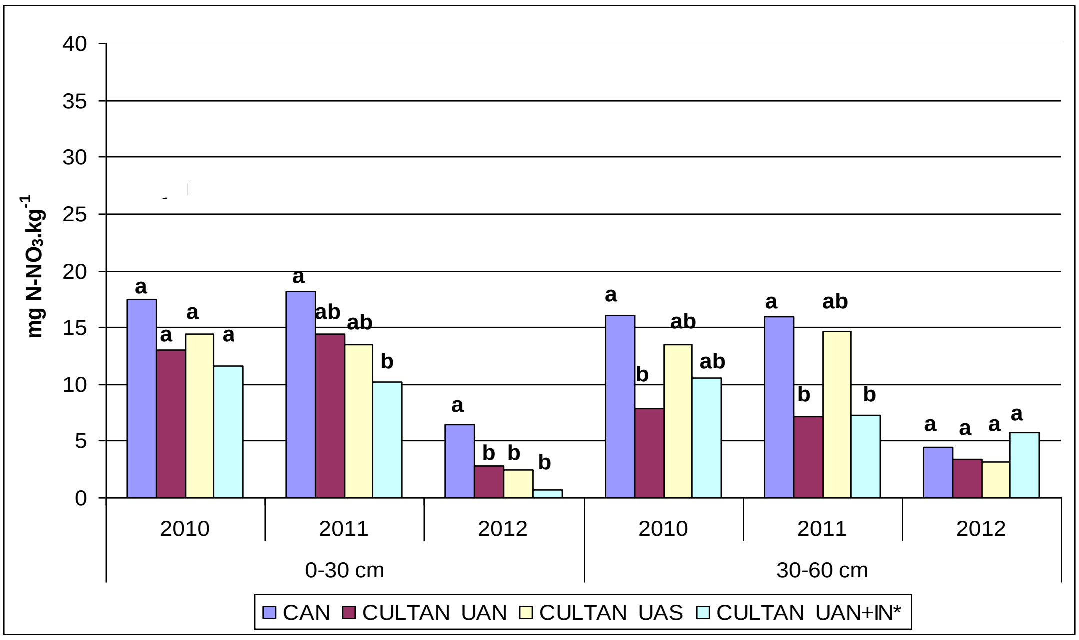
At all sites in all years of the experiment, more nitrogen was consumed than there had been applied by all variants. The superfluous nitrogen was probably released by mineralization of the organic matter in the soil. At site Hněvčeves, the content of mineral nitrogen in the soil layer 0-30 cm was in 2010-2012 after harvesting always lower by CULTAN variants in comparison with the conventional one. Differences among variants were caused by a higher content of the nitrate form by conventional variants.

The ammonium form was by all variants on a comparable level. The content of the nitrate and ammonium form was by all variants with the exception of CULTAN UAS higher in the layer 0-30 cm than in 30-60 cm, which can be explained by the findings of Vaněk (1973) that the ammonium ion from Ammonium Sulphate succumbs to nitrification most slowly.

In 2010 all applied nitrogen was consumed both by conventional and CULTAN methods and a slight shift of nitrogen into deeper soil layers was observed, despite the fact that in 2010 the end of the growth period was at site Hněvčeves below average with regard to precipitation. In 2010 there was a tendency towards a lower content of nitrate in topsoil by injection fertilized variants (Figure 1). However, in the layer 30-60 cm some differences could be observed. The lowest content of nitrate was by injection variant CULTAN UAN and the difference from the conventional variant was statistically significant.

In 2011 at the same site, there was a lower content of nitrate by variants CULTAN UAN and CULTAN UAN + IN, both in topsoil and subsoil, which is in compliance with the results of Kubešová (2010) at the same site in 2008-2009. By the variant with an inhibitor, in both layers of the soil profile, statistical significant differences were found in comparison with the conventional variant.

In 2012 the lowest content of nitrate of the three years was observed at this site. All CULTAN variants reached statistically lower content of nitrate in comparison with the conventional variant in the soil layer 0-30 cm; the lowest content of nitrates was found by variant CULTAN UAN + IN, which complies with the results of Schuster et al. (2011) that the use of an inhibitor decreases the mobility of nitrogen in the soil and thus reduces the risk of leaching nitrates.



Values within experimental years and individual soil profiles marked with the same letter are not statistically different (P<0.05).

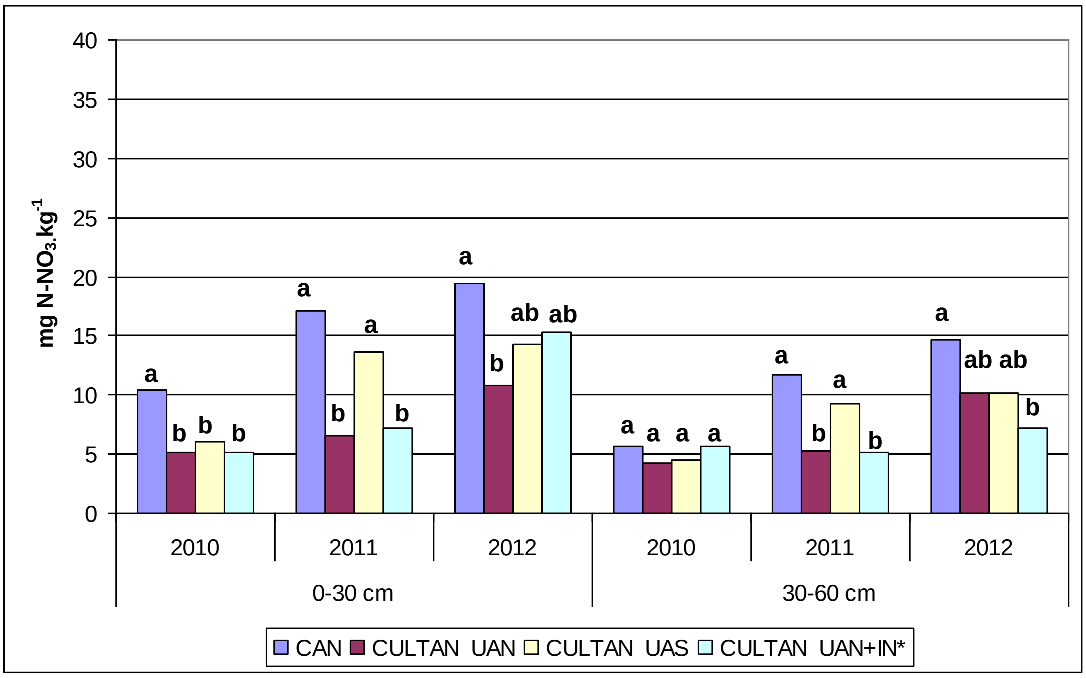
Figure 1. Content of nitrates in soil profile (0-30 cm; 30-60cm) after harvesting ($mg.kg^{-1}$), Hněvčeves

At site Humpolec the conventional variant proved a higher content of mineral nitrogen in both monitored layers of the soil profile in 2010-2011. The content of ammonium nitrogen at this site was comparable among all fertilization types in all years, and significantly differed only in layer 0-30 cm in 2010 when there was statistically lower content of ammonium by variant CULTAN UAN + IN in comparison with the conventional variant. The content of nitrate (Figure 2) was in 2010 at this site in layer

0-30 cm statistically lower by all injection fertilized variants by method CULTAN in comparison with the surface application CAN before sowing, which complies with the statement of Sommer (2005) that by CULTAN fertilization there is a lower content of nitrate in the soil. The content of nitrate under the top soil at site Humpolec was by all variants comparable. By CULTAN variants there was a negligible leakage of nitrate from the topsoil downwards, even though August and September were above average as regards precipitation. By the conventional variant, above average precipitation caused in sand-clay soils of Humpolec site a significant shift of nitrate to subsoil, which is in compliance with the statement of Sogbedji at al. (2000).

In 2011 the content of nitrate was in the whole soil profile lower by injection fertilized variants in comparison with the surface application CAN before sowing, statistically significant by variants CULTAN UAN and CULTAN UAN + IN.

In 2012 there was a lower content of nitrate in layer 0-30 cm by variant CULTAN UAN; in subsoil the lowest content of nitrate was achieved by the injection variant with an inhibitor.



Values within experimental years and individual soil profiles marked with the same letter are not statistically different (P<0.05).

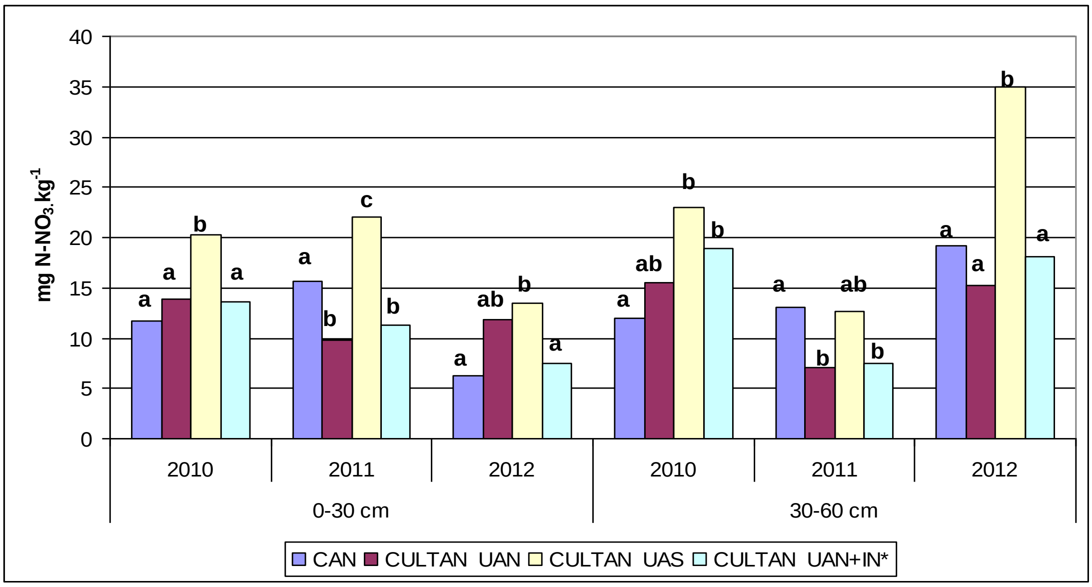
Figure 2. The content of nitrates in soil profile (0-30 cm; 30-60cm) after harvesting (mg.kg^{-1}), Humpolec

The content of mineral nitrogen at site Ivanovice na Hané in 2010 was higher by CULTAN variants, in topsoil as well as subsoil. Presumably, this was caused by an extreme spell of drought in the spring when the maize plants were not able to catch up with the conventional variants – neither in growth nor in nitrogen uptake, and by above average wet months at the end of the vegetation period. A similar conclusion was made by Kozlovský (2011) in wheat fertilized by CULTAN method. Differences in the content of mineral nitrogen were created among variants by the content of the nitrate.

The content of ammonium in 2010 was comparable by all variants, both in topsoil and subsoil. In 2010 nitrate forms of nitrogen shifted from topsoil downwards regardless of the fertilization method (Figure 3), most likely due to the fact that the plants uptake less nitrogen because of a delay in growth. By variants CULTAN UAS and CULTAN UAN + IN there was a higher content of nitrate in subsoil in comparison with the conventional variant. In 2011 a statistically lower content of nitrate was observed in topsoil by variants CULTAN UAN and CULTAN UAN + IN in comparison with variant CAN.

A higher content of nitrate was found in topsoil by the injection variant with sulphur in comparison with the conventional variant, which confirmed the statement of Malhi et al. (2007) that sulphur supports the uptake of nitrogen. Mostly, nitrate moved to subsoil soil by the conventional variant; by variants CULTAN UAN and CULTAN UAN + IN there was a statistically lower content of nitrate in subsoil in comparison with the conventional variant.

In 2012 the content of mineral nitrogen in topsoil was higher by CULTAN variants. Most probably, this was caused by stress situation (frosts) at the beginning of growth, when there was a reduction in the number of plants. We can assume that the maize plants were not able to catch up with the conventional variants neither in growth nor in nitrogen consumption. Differences in the content of mineral nitrogen among variants were created by the content of nitrate nitrogen. No significant difference in ammonium nitrogen was observed in topsoil. The highest content of nitrate in both soil layers was proved by variant CULTAN UAS, which complies with the results of Balík et al. (2003).



Values within experimental years and individual soil profiles marked with the same letter are not statistically different ($P<0.05$).

Figure 3. Content of nitrates in soil profile (0-30 cm; 30-60 cm) after harvesting ($mg.kg^{-1}$), Ivanovice na Hané

CONCLUSIONS

Our results of the three-year experiment showed a tendency towards a lower content of nitrate nitrogen in the soil by injection fertilization by CULTAN method in comparison with conventional surface application Calcium Ammonium Nitrate after maize harvesting. The most favourable seemed to be injection variants CULTAN UAN and CULTAN UAN + IN, which proved a statistically lower content of nitrate throughout the whole soil profile in comparison with the conventional variant. The positive effect of adding sulphur into the fertilizer on the reduction of nitrate in the soil was not confirmed.

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