Comparison of point injection and top-dressing application of nitrogen fertilizers with sulphur addition in winter rape (*Brassica napus* L.) in the Czech Republic

Porovnání bodové injektáže a povrchové aplikace dusíkatých hnojiv s obsahem síry v porostech řepky ozimé (*Brassica napus* L.) v České republice

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Abstract

In this paper, we are analyzing the yield and yield parameters of winter rape, fertilized using CULTAN system (Controlled Uptake Long Term Ammonium Nutrition) in comparison with top-dressing application of nitrogen fertilizers, which were studied on Haplic Luvisol over 5 years. No significant differences in seed yields between the two systems of fertilization were observed in 2008, 2009 and 2011. The effect of sulphur on a higher seed yield was proved in 2010 and 2012. The seed yield was higher by 11.4% in the treatments with sulphur amendment regardless of the system of fertilization in 2010. The seed yield was higher by 18.2 % in the CULTAN treatment with sulphur adittion in comparison to CULTAN treatment with no sulphur added in 2012. Nitrogen supply was ample in the first flowers open growth stage of winter rape in 2009, 2010 and 2012. The plant height was significantly lower after CULTAN method and as well as higher values of 1000 seed weight were recorded in comparison to top-dressing application in 2009. Nitrogen uptake by seed dry matter was the highest in the year 2009, which corresponds to the achieved seed yields this year.

Keywords: ammonium nitrogen, Haplic Luvisol, seed yield, sulphur, winter rape

Abstrakt

Předmětem tohoto článku je zhodnocení výnosu semen a výnosotvorných parametrů řepky ozimé hnojené systémem CULTAN (Controlled Uptake Long Term Ammonium Nutrition) ve srovnání s povrchovou aplikací dusíkatých hnojiv (konvenční varianty), na půdách typu hnědozem v letech 2008-2012 . Nebyly pozorovány statisticky průkazné rozdíly ve výnosu semen mezi systémy hnojení v roce 2008, 2009 a 2011.Vliv síry na vyšší výnos semen byl prokázán v roce 2010 a 2012 .Výnos semen byl vyšší průměrně o 11,4 % na variantách s přídavkem síry, bez ohledu na systém hnojení v roce 2010. V roce 2012 byl výnos semen u CULTAN variant s přídavkem síry o 18,2 % vyšší ve srovnání s CULTAN variantami, kde síra dodána nebyla. Příjem dusíku na začátku kvetení byl v roce 2009, 2010 a 2012 nadměrný. Výška rostlin byla průkazně nižší po hnojení metodou CULTAN a zároveň vyšší hodnoty hmotnosti 1000 semen byly zaznamenány u tohto systému hnojení ve srovnání s povrchovou aplikací hnojiv v roce 2009. Odběr dusíku semeny byl nejvyšší v roce 2009, což koreluje s dosaženými výnosy semen.

Klíčová slova: amonný dusík, hnědozem, výnos semen, síra, řepka ozimá

Introduction

An injection of a liquid nitrogen fertilizer rich in ammonium nitrogen could be an alternative to surface application of fertilizers. This method is named CULTAN (Controlled Uptake Long Term Ammonium Nutrition) and it means a long-term controlled nutrition with an ammonium form of nitrogen by plants, from a specific supply (depots), which is optimally utilized by plants (Sommer, 2005). To compare with top-dressing N fertlizers, where it is necessary to regulate the dose of nitrogen for plants, in case of the CULTAN method the plant regulates nitrogen uptake itself through gradual growth of roots to the depot. The intensity of root uptake depends on the intensity of carbohydrates supply from aboveground plant parts (Bracht, 1998; Sommer, 2005). No biological activity is in the depot because of high concentrations of ammonium nitrogen. Plants obtain nitrogen only from marginal parts of the depot and therefore a smaller part of the root system contributes to the uptake and plants may intensively receive other nutrients and water (Scharpf et Weier, 1995).

Application time depends on the crop and injection techniques. For rape, the most appropriate is point injection and the same equipment which is used for cereals. It is recommended to fertilize winter rape by the CULTAN system once early in the spring at the beginning of vegetation, based on the results from Germany (Spiess et Meier, 2008).

Phaeozems, together with Chernozems and Haplic Luvisols, represent the most fertile soil types in the Czech Republic (Kozák, et al. 2003). The seed yields of winter rape obtained over the last 5 years at the site of Hněvčeves were analyzed to compare the conventional and CULTAN system of fertilization in winter rape cultivation technology on Haplic Luvisol.

Materials and Methods

Influence of the CULTAN method on seed yield, nitrogen nutrition index (NNI) yield parameters and nitrogen uptake by dry matter of seeds was observed in experimental years 2008-2012. A small-plot experiment was established at the experimental site named Hněvčeves (50°18'46.307"N, 15°42'51.440"E). The weather conditions of the experimental site are given in Tabel 1. The altitude of the site is 265 m a.s. l., the average annual precipitation is 597 mm and the mean annual temperature is 8.1^{o}C (Hněvčeves Meteorological Station, measurements 1970-2000). The soil is clay-loam haplic luvisol developed with a 40 cm thick layer of arable top-soil. The soil's chemical properties according to the Mehlich 3 method (Mehlich, 1984) were: P (43.5 mg*kg^{-1}; low content), K (203 mg*kg^{-1}; good content), Mg (138 mg*kg^{-1}; suitable content), Ca (2632 mg*kg^{-1}). The amount of applied P was 48 kg*ha^{-1} and the amount of applied K was 30 kg*ha^{-1}. The content of sulphur in soil in the spring was 3.5 mg*kg^{-1} in water infusion. The sowing rate was approximately 4 kg per ha of (*Brassica napus* L.) cv. ARTUS, which is a semi-late hybrid of 00-type. Plant density was 45-49 plants m^2 (2008), 50-51 plants m^2 (2009), 44-45 plants m^2 (2010), 43-45 plants m^2 (2011), 36-42 plants m^2 (2012). The preceding crop was spring barley (2008, 2011), winter wheat (2009, 2010) and winter barley (2012). Treatments of the field experiment are given in Table 2. Two treatments included fertilization onto soil surface (A1 and A2) and two treatments included injection fertilization (B1 and B2). Treatments A2 and B2 were fertilized with nitrogen fertilizer with sulphur amendment. Treatments A1 and A2 were fertilized in the spring using top-dressing N fertilizers in 3 split doses of nitrogen, which are commonly used in cultivation technology of winter rape in the Czech Republic. CULTAN treatments (B1 and B2) were fertilized once in the spring regrowth with one total dose of nitrogen using the GFI 3A injector (Maschinen und Antriebstechnik GmbH, Güstrower, Germany) with a working scope of 3 m and the application depth of 5 cm. The injection applicator has 12 application wheels with 12 fertilizing nozzles. The surface of the fertilized plot was 39 m^2. To eliminate the edge effect, only the central area of 15 m^2 of each 16 experimental plot (4 × 4) was used for the determination of yields and biomass samples. For the determination of mineral sulphur demineralized water was used as the extraction solvent. Determination of mineral sulphur was carried out using a segmented flow analysis with colorimetric determination by Skalar SANplus SYSTEM (Skalar, The Netherlands).

Table 1. Weather conditions during 2008-2012.

	Harvest year	Vegetation period of winter rape											
		VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Temperature	2007/2008	19.6	13.0	8.4	2.8	0.7	2.5	3.5	4.6	9.7	15.4	19.8	18.9
	2008/2009	18.7	13.5	8.8	5.3	1.8	-4.3	-0.4	4.3	13.3	14.3	15.7	18.9
	2009/2010	19.9	16.2	7.9	5.9	-0.6	-4.6	-1.2	3.5	9.1	12.4	17.4	21.5
	2010/2011	18.3	12.7	7.4	5.8	-4.7	-1.1	-1.3	4.8	11.8	14.4	18.1	17.6
	2011/2012	19.7	15.7	8.9	2.5	-0.7	0.4	-4.4	6.2	9.4	15.7	17.3	19.7
	long-term average	18.4	13.8	8.8	2.7	-0.5	-2.0	-0.6	3.5	8.6	14.0	16.5	18.5
Precipitation	2007/2008	47	27	37	56	20	25	26	43	30	59	31	67
	2008/2009	52	11	52	46	36	20	49	48	6	56	100	92
	2009/2010	37	9	59	36	51	64	9	31	56	184	31	66
	2010/2011	148	103	12	53	52	56	26	24	12	60	45	126
	2011/2012	79	39	41	48	53	77	35	5	43	83	66	207
	long-term average	67	48	41	40	40	36	25	33	28	55	61	75

Table 2. Nitrogen applied to winter rape in kg*ha^{-1} in each year of the experiment. CA-calcium ammonium nitrate (27 % N); AS-ammonium sulphate (20 % N, 23 % S); UAN - urea ammonium nitrate (30 %); UAS-urea ammonium sulphate (19 % N, 5 % S); BBCH-identification key of phenological growth stages

Treatment	BBCH 25	BBCH 26	BBCH 30	BBCH 58	Total
A1	57 (CAN)	-	93 (CAN)	50 (CAN)	200
B1	-	200 (UAN)	-	-	200
A2	57 (AS)	-	93 (CAN)	50 (CAN)	200
B2	-	200 (UAS)	-	-	200

Nitrogen nutrition index (NNI) of the crop was determined by dividing the N concentration of the shoot biomass by the critical N concentration (N_c) (Lemaire, et al. 2008; Lemaire et Gastal, 1997). Critical N concentration, the minimum N concentration required to achieve maximum shoot growth, was defined as a function of shoot biomass, as proposed for winter oilseed rape by Colnenne, et al. (1997), $N_c = 4.48 \times W^{-0.25}$. Where W is the total shoot biomass expressed in t*ha^{-1}. The data used came from sampling from the growth stage: the first flowers open (BBCH 60).

Statistical evaluation was done in the Statistica 12.0 programme (StatSoft, Tulsa, USA) with One-way ANOVA and repeated measures ANOVA followed by the Tukey's HSD post hoc test at the level of significance P<0.05.

Results

The repeated measures ANOVA showed a significant effect of the year ($F=177.3$, $P<0.05$) and treatment ($F=5.3$, $P<0.05$) on seed yields of winter rape (Figure 1). The significant effect of treatments generated by the system of fertilization was not observed during experimental years. The significant effect of sulphur resulted in an increase in seed yield regardless of the system of fertilization in 2010. Seed yield of treatment A2 was higher by 0.44 $t*ha^{-1}$ in comparison to treatment A1. Seed yield of treatment B2 was higher by 0.59 $t*ha^{-1}$ in comparison to treatment B1. There was seed yield higher by 0.87 $t*ha^{-1}$ in treatment B2 in comparison to treatment B1 in 2012.

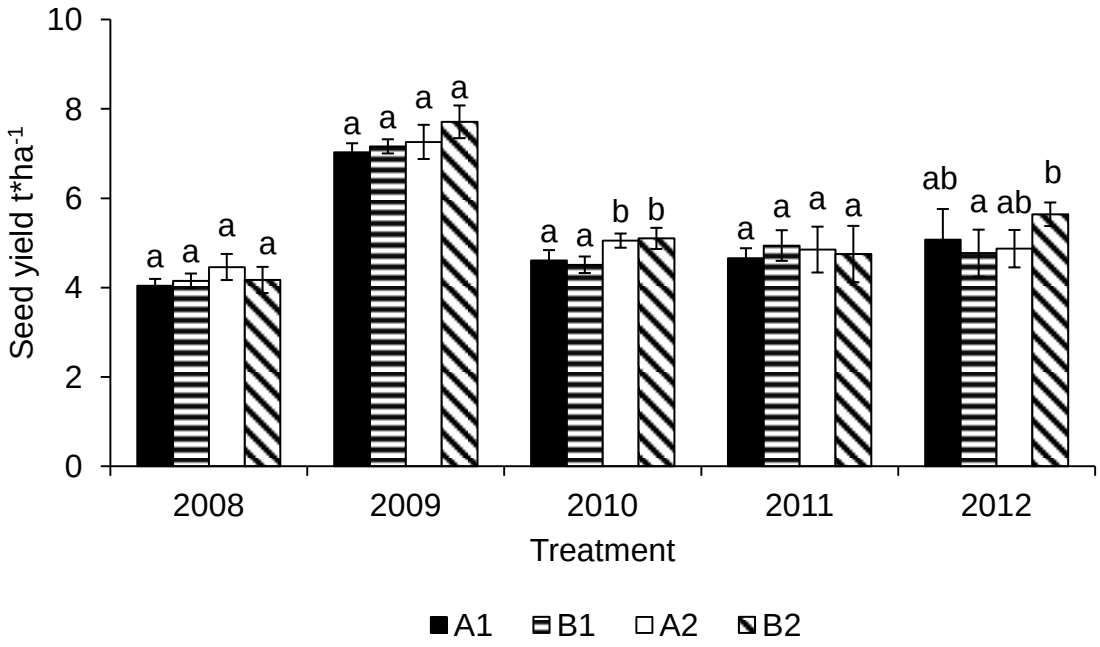

Figure 1. Seed yield ($t*ha^{-1}$) at 12% moisture.

The vertical bars represent the standard error (SE) of the means. Treatments with the same letter are not significantly different ($P<0.05$). Treatments abbreviations are given in Table 1.

Nitrogen nutrition indices varied from 0.83 to 1.55 across years (Table 3). A value of NNI≥1 indicates a crop with ample N supply (N non-limiting); NNI=1 represents optimal N nutrition. The more NNI falls below 1, the more deficient the crop in N is. Nitrogen nutrition indices were not generally significantly affected by treatments during experimental years. Values of NNI were substantially higher than 1, which indicates excessive uptake of N throughout all treatments in 2009, 2010 and 2012. It can be concluded that N nutrition was excessive in all these years. On the the other hand, values of NNI were very close to optimal N nutrition in 2008 and 2011.

Table 3. Values of NNI during growth stage: first flowers open (BBCH 60).

Treatment	2008	2009	2010	2011	2012
A1	1.04[a]	1.41[a]	1.37[a]	0.96[a]	1.49[a]
B1	1.00[a]	1.39[a]	1.28[a]	0.90[a]	1.46[a]
A2	1.05[a]	1.45[a]	1.45[a]	0.92[a]	1.50[a]
B2	0.83[a]	1.24[a]	1.40[a]	1.01[a]	1.55[a]

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

The repeated measures ANOVA showed a significant effect of the treatment (F=6, P<0.05) and year (F=449, P<0.05) on plant height (Table 4) and a significant effect of the year (F=90, P<0.05), treatment (F=3, P<0.05) and year × treatment interaction (F=2.3, P<0.05) on 1000 seed weight (Table 5). The effect of treatment on plant height was significant in 2009. Lower plant height was recorded by the CULTAN method (B1, B2) in comparison to conventional treatments (A1, A2). The difference was 12 and 7 cm, respectively. Plant height varied from 125 to 184 cm across years. In the treatments B1 and B2 (CULTAN) there were values higher on average by 0.37 g of 1000 seed weight in comparison to treaments A1 and A2 (conventional) in 2009. Significant effect of nitrogen fertilizers with sulphur addition regardless the system of fertilization was observed in 2010. A significantly lower 1000 seeds weight of treatments with sulphur addition A2 and B2 in comparison to the treatments with no sulphur addition A1 and B1 was recorded. There was 0.39 g higher 1000 seed weight in treatment B2 in comparison to treatment A2 in 2012.

Table 4. Plant height (cm).

Treatment	2008	2009	2010	2011	2012
A1	180[a]	169[a]	150[a]	128[a]	133[a]
B1	178[a]	157[b]	148[a]	126[a]	132[a]
A2	184[a]	164[a]	150[a]	128[a]	134[a]
B2	176[a]	157[b]	147[a]	125[a]	134[a]

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

Table 5. 1000 seed weight (g).

Treatment	2008	2009	2010	2011	2012
A1	4.96[a]	5.40[a]	5.41[a]	6.07[a]	5.43[a]
B1	4.86[a]	5.76[b]	5.32[a]	5.90[a]	5.34[a]
A2	4.99[a]	5.46[a]	5.05[b]	5.97[a]	5.06[b]
B2	4.92[a]	5.83[b]	5.10[b]	6.03[a]	5.45[a]

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

Repeated measures ANOVA showed a significant effect of treatment (F=8, P<0.05), year (F=190, P<0.05) and year × treatment interaction (F=3, P<0.05) on uptake nitrogen by seed dry matter (Figure 2). It was observed no significant difference in nitrogen uptake by seed dry matter generated by the system of fertilization during experimental years. Nitrogen uptake significantly decreased, on average by 15.8 kg*ha^{-1} in treatment B2 in comparison to the conventional treatment A2 in 2008. On the other hand, nitrogen uptake significantly increased on average by 31.9 kg*ha^{-1} and 43.7 kg ha^{-1} in treatment B2 in comparison to the treatments A2 and A1 in 2009, respectively. A positive effect of sulphur amendment on higher uptake of nitrogen by seed dry matter regardless of the system of fertilization was recorded in 2010. The difference was on average by 19.8 kg*ha^{-1}. The significant effect of years indicates nitrogen uptake fluctuation. The significant interaction of year and treatments indicates differences in nitrogen uptake between treatments during experimental years 2008–2012.

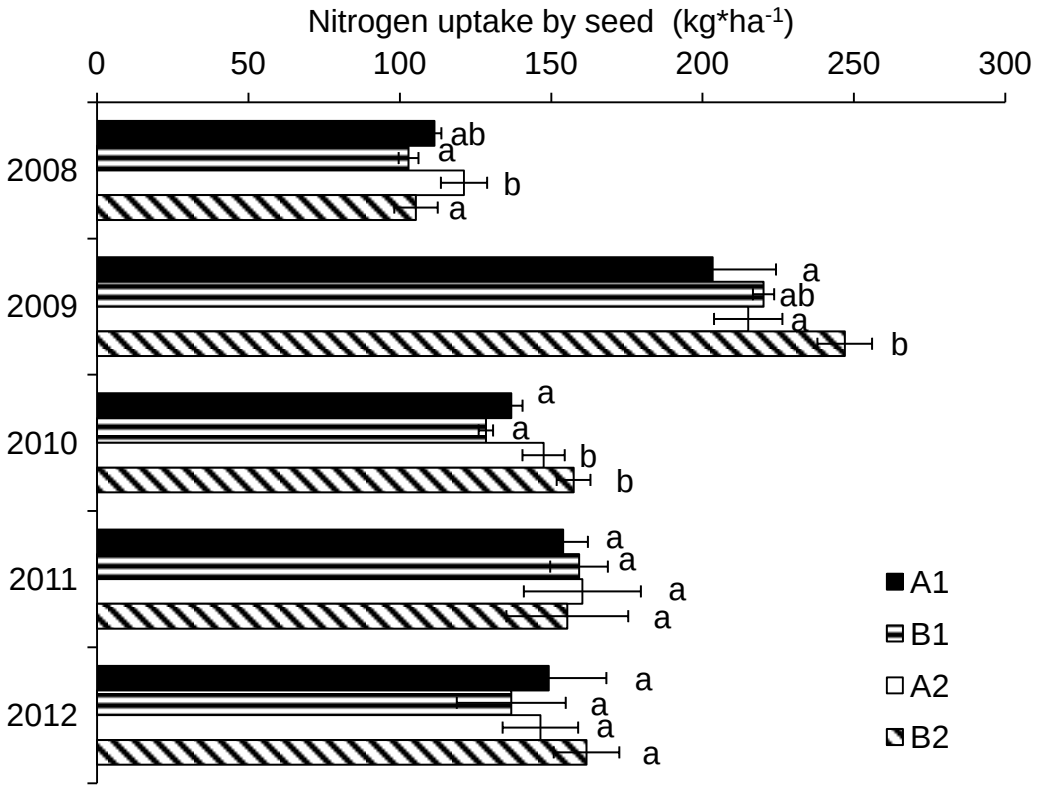

Figure 2. Effect of treatments on the nitrogen uptake by seed dry matter (kg*ha^{-1}) during experimental years 2008-2012.

The vertical bars represent the standard error (SE) of the means. Treatments with the same letter were not significantly different (P< 0.05). Treatments abbreviations are given in Table 1.

Table 6. Effect of treatment on seed yield, plant height and 1000 seed weight (five-year average).

Treatment/ Parametr	Seed yield (t*ha^{-1})	Plant height (cm)	1000 seed weight (g)
A1	5.1^{a}	152^{a}	5.5^{a}
B1	5.1^{a}	148^{a}	5.4^{a}
A2	5.3^{a}	152^{a}	5.3^{a}
B2	5.5^{a}	148^{a}	5.5^{a}

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

The significant effect of treatment on seed yield, plant height and 1000 seed weight was not observed in five-year average (Table 6). Comparable results were achieved at both system of fertilization. The addition of sulphur in nitrogen fertilizer had no

effect on observed parameters, regardless the system of fertilization. Lower plant height (but not statistically significant) was achieved at the CULTAN treatment (B1 and B2).

Discussion

No significant differences in seed yields between the two systems of fertilization were recorded in 2008, 2009 and 2011, which is in agreement with Felgentreu (2003), who carried out a similar two-year experiment in Germany with a hybrid variety of winter rape and also recorded no significant differences in seed yield between the injection system of fertilization (CULTAN) and top-dressing N fertilization. Record seed yields of both systems of fertilization at our experimental site were observed in 2009. The reason was probably a combination of weather conditions (rich precipitation, a slight decrease in temperatures and almost no occurrence of fungal diseases from May till July) and the fact that Haplic Luvisols represent one of the most fertile soil types in the Czech Republic (Kozák, et al. 2003). A significant effect of sulphur on seed yield was proved regardless of the system of fertilization in 2010. Despite high precipitations in May 2010 (199% of normal), an injection of N-S fertilizers had the same effect on achieved yields as N-S top dressing. This result is in contrast to Menge-Hartmann and Schittenhelm (2008), who claim that ammonium applied in the depot is a stable form of nitrogen. The positive effect of sulphur amendment in CULTAN system was clearer in 2012. It can be assumed that the significantly lower seed yield in treatment B1 in comparison to B2 was probably caused by insufficient S nutrition rather than by other factors, which is in accordance with Sommer (2005) that fertilizers for winter rape in CULTAN system should be as concentrated as possible, with a high proportion of ammonium nitrogen and sulphur amendment. Although Kulhánek, et al. (2011) recorded in a three-year experiment a lower content of bioavailable sulphur on Cambizem than on Luvisol, there was observed a significantly lower grain yield after using CULTAN method with sulphur amendment in comparison to top dressing fertilization with sulphur amendment in a two-year experiment with winter wheat on Luvisol (Kozlovský, et al. 2009).

No significant effect of fertilization in N nutrition index between the two systems was recorded. In three out of five experimental years there was obsereved an excessive uptake of nitrogen by plants in BBCH 60. One explanation is that the soil type and quality of organic matter play the key role in these findings because Balík, et al. (2012) determined high levels of mineral N on Luvisols. Peklová et al. (2012) recorded no significant effect on Luvisol between the two systems of fertilization in shoot dry matter content and nitrogen content in above ground biomass in BBCH 60. There was observed higher dry matter content in above ground biomass before heading in the experiment with *Hordeum vulgare* L. under CULTAN method Sedlář, et al. (2011a). NNI can be used as a tool for N diagnosis of winter oilseed rape from emergence to the beginning of flowering (Colnenne, et al. 1998).

The plant height was significantly lower and 1000 seed weight was significantly higher in the CULTAN treatments (B1, B2) in comparison to the treatments A1 and A2 in 2009. This result is in accordance with principles of the CULTAN method because seed yield per unit area after using the CULTAN method should be higher because of the shortened plant branching and a prolonged time when assimilates are stored in seeds, which is caused by redirecting the phytohormonal flow. It was observed that after using the CULTAN method the number of branches and also

siliques was higher by 20 % in comparison with the conventional way of fertilization (Sommer, 2005).

Significantly lower 1000 seeds weight of treatments A2 and B2 was recorded in 2010. On the other hand, significantly higher seed yields were observed in the same treatments this year. One explanation could be the fact that sulphur had a positive effect on a higher number of fertile branches in comprison to A1 and B1 which might have negatively influenced the weight of 1000 seeds. After using the CULTAN method with added sulphur higher 1000 seed weight was recorded in comparison to a conventional way of fertilizing in 2012. This is not consistent with results published by Sedlář, et al. (2011b), who reported in the experiment with spring barley yields lower dependence of grain yield on sulphur amendment in CULTAN treatments. On the other hand, Christen et Sieling (1995) reported that 1000 seed weight is influenced more by the year than by the treatment and it has a small impact on achieved seed yields.

A significant effect of sulphur on nitrogen uptake by seed dry matter was observed regardless of the system of fertilization in 2010. N and S nutrition of winter oilseed rape during the growth are metabolically linked (Fismes, et al. 2000), which explains significantly higher seed yields in the same treatments. The positive effect of injection of N-S fertilizers on N uptake by seed dry matter was more distinct in 2009. The combination of weather and soil properties caused the highest seed yield in the treatment, where the sulphur was injected into the depot. On the other hand, significantly lower nitrogen uptake in comparison to top dressing was recorded in the same treatment in 2008. CULTAN plants could be more stressed from black frosts, which lasted for almost 14 days in February 2008, and from the subsequent injection of fertilizers rich in ammonium. This fact had no negative effect on achieved seed yields because no significant differences among treatments were observed.

No significant differences in seed yields between the two systems of fertilization were observed in three out of five experimental years. An effect of sulphur amendment on higher seed yield was proved regardless of the system of fertilization. N supply was ample in 2009, 2010 and 2012 and was probably caused by the the fertility of the experimental site. Plant height was significantly lower after using the CULTAN method in one experimental year. Higher values of 1000 seed weight in CULTAN treatments were proved in comparison to conventional treatments in 2009 and also in the treatments with sulphur amendment in 2012. Differences among treatments in nitrogen uptake by seed dry matter correspond to a certain extent to the achieved seed yields and nitrogen status of plants in the first flowers open growth stage.

There were observed no significant differences between the conventional system of fertilization and CULTAN system in five-year average results of seed yield, plant height and 1000 seed weight. The positive effect of the method CULTAN follows from the fact that application of fertilizers is carried out once during vegetation, which is to a certain extent economical and ecological.

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