RESULTS OF FERTILIZATION OF WINTER OIL SEED CROP USING NITROGEN CULTAN IN THE CZECH REPUBLIC*

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The influence of fertilization using the CULTAN (Controlled Uptake Long Term Ammonium Nutrition) method on winter rape yield, content of dry matter in aboveground biomass, and nitrogen content in seed was studied in 2008–2009 in small-plot experiments at three different soil-climatic sites. Plants with CULTAN treatments were fertilized once in spring with a whole dose of nitrogen injected into the soil. Plants with conventional treatments were fertilized using the system of three divided doses applied on the soil surface. The overall dose of nitrogen was 200 kg N ha^{-1} in each treatment. In 2008, the seed yield at CULTAN treatments compared to that at conventional treatments was by 0.8 t ha^{-1} lower on the average at sites Čáslav and Humpolec. In 2009, no significant differences in seed yield between the two systems of fertilization were observed. Higher dry matter content in aboveground biomass at CULTAN treatments was observed in 2008 at sites Čáslav and Humpolec. Significantly lower nitrogen content in the seed at CULTAN treatments was observed at all sites in 2008.

ammonium injection; seed yield; dry matter content; nitrogen content in the seed

INTRODUCTION

The principle of the CULTAN (Controlled Uptake Long Term Ammonium Nutrition) method is that the plants are able to intake ammonium nitrogen using root hair, provided that it is stored in the vicinity of the root system. Biosynthesis of amino acids takes place in the roots and these amino acids are then distributed to the phloem of the plant (Šabatka, 2001). When applying nitrogen using the CULTAN method, the plants are provided ammonium at high concentration to the root area in special depots (Sommer, 1991) into which ammonium is applied in one precise dose. Higher concentration of ammonium can suppress the biological activity in the depot (Scharpf, Weier, 1995). The principle of the ammonium intake from the depot is based on the fact that ammonium is accepted from the concentrated depot only if the root tips are in peripheral areas of the depot and received ammonium can be immediately taken over to the nitrogen metabolism (Bracht, 1998). The attractive growth of the roots toward the centre of the depot is caused by the constant consumption of ammonium on the edge of the depot. When nitrogen is delivered using the CULTAN method, it improves the nutrient uptake and increases drought tolerance. Stem bases are more resistant to disease. The whole stem is a source of stored assimilates during the flowering period. These assimilates quickly move to the flowers and photosynthetic leaves during flowering. Because of life prolongation of stem basal parts, the time of storing assimilates is also prolonged (Sommer, 2005). Plants fertilized through CULTAN method are more resistant to drought than those fertilized with nitrate nitrogen or urea during dry season (Sommer, Kreusel, 1992). Injection of liquid fertilizers into the soil is a common alternative application of fertilizers and it alleviates some of the disadvantages of conventional nitrogen fertilization in practice (Sommer, 2005).

MATERIAL AND METHODS

The influence of the CULTAN method of fertilization on yield, dynamics of aboveground biomass production, and nitrogen content in seed was studied in small-plot trials at Čáslav, Hněvčeves and Humpolec sites. Soil characteristics of these sites were specified by Kozlovský et al. (2009). The temperatures and amount of precipitation at individual sites in the experimental years are shown in Tables 1 and 2. Average long-term temperature and precipitation were calcu-

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Table 1. Average temperatures (°C) at the experimental sites

Site	Year/month	Vegetation period of winter rape											
		VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Čáslav	2008	18.8	13.1	8.8	2.7	0.9	2.6	3.3	4.2	8.9	14.6	18.6	19.0
	2009	19.1	13.5	9.0	5.4	1.8	–3.6	0.3	4.6	13.3	14.4	15.7	19.3
	long-term annual average	18.6	14.0	8.9	4.1	1.0	–0.1	1.3	4.8	8.7	14.2	17.2	18.8
Hněvčeves	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
	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
	long-term annual 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
Humpolec	2008	20.0	12.7	8.1	2.4	–0.4	1.7	2.7	4.2	9.6	14.8	18.9	19.8
	2009	18.0	12.3	8.5	4.6	0.6	–3.8	–1.1	2.8	12.6	13.8	15.2	18.6
	long-term annual average	16.4	12.0	6.8	1.3	–2.3	–3.4	–2.1	1.6	6.2	12.0	15.1	16.8

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

Site	Year/month	Vegetation period of winter rape											
		VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Čáslav	2008	84	112	18	71	20	20	17	47	41	44	89	56
	2009	60	24	39	49	26	23	78	66	24	65	75	100
	long-term annual average	65	49	34	41	34	29	25	41	36	67	76	79
Hněvčeves	2008	47	27	37	56	20	25	26	43	30	59	31	67
	2009	52	11	52	46	36	20	49	48	6	56	100	92
	long-term annual average	67	48	41	40	40	36	25	33	28	55	61	75
Humpolec	2008	56	123	26	107	25	31	22	61	38	86	62	83
	2009	74	41	37	66	29	20	91	95	56	74	117	108
	long-term annual average	85	56	40	49	45	44	37	45	42	70	78	88

Table 3. Fertilization scheme (kg N ha^{-1})

Treatment	BBCH 25	BBCH 26*	BBCH 30	BBCH 58	Total
Conventional 1	57 (CAN)	–	93 (CAN)	50 (CAN)	200
CULTAN 1	–	200 (UAN)	–	–	200
Conventional 2	57 (AS)	–	93 (CAN)	50 (CAN)	200
CULTAN 2	–	200 (UAS)	–	–	200

CAN = calcium ammonium nitrate, 27% total N (13.5% NO_3^-, 13.5% NH_4^+); AS = ammonium sulphate, 20% total N (1.4% NO_3^-, 18.6% NH_4^+, 20.5% S); UAN = urea ammonium nitrate, total N 30% (15% NH_2, pH 7.0–7.9); UAS = urea ammonium sulphate, total N 19% (11.4% NH_2, 7.6% NH_4^+, 5% S, pH 6–8); BBCH = identification key of phenological growth stages

*2008 = 26.3 (Čáslav), 25.3 (Hněvčeves), 28.3 (Humpolec); 2009 = 10.4 (Čáslav), 9.4 (Hněvčeves), 11.4 (Humpolec)

lated for the period 1971–2001. Based on the weather system evaluation of Kožnarová, Klabzuba (2002), January of 2008 was exceptionally warm and February very warm. In the trial, seeds of winter oil seed rape (*Brassica napus* L.) cv. Artus, a semi-late hybrid of 00-type, were used. The seeding rate was 4 kg ha^{-1}. At Čáslav the pre-crop was spring barley in both experimental years. In Hněvčeves the pre-crop was spring wheat (2008) and winter wheat (2009). At Humpolec the pre-crop was winter barley in both experimental years. The trial consisted of four treatments with four replications. Scheme of the trials is given in Table 3. Two treatments included fertilization onto soil surface (conventional 1 and conventional 2) and in the other two treatments injection fertilization (CULTAN 1 and CULTAN 2) was used. Treatments conventional 2 and CULTAN 2 were fertilized with nitrogen fertilizer amended with sulphur. CULTAN treatments were fertilized using the GFI 3A injector (Maschinen und Antriebstechnik GmbH, Güstrow,

Table 4. Seed yield (t ha^{-1}, 12% moisture)

Treatment	Čáslav		Hněvčeves		Humpolec	
	2008	2009	2008	2009	2008	2009
Conventional 1	3.08^{a}	4.80^{a}	4.04^{a}	7.03^{a}	3.13^{c}	3.94^{ab}
CULTAN 1	2.19^{b}	4.75^{a}	4.15^{a}	7.16^{a}	2.44^{b}	3.80^{a}
Conventional 2	3.43^{a}	5.47^{b}	4.46^{a}	7.26^{a}	3.45^{a}	3.93^{ab}
CULTAN 2	2.75^{b}	4.85^{a}	4.17^{a}	7.71^{a}	2.55^{b}	4.03^{b}

$^{a–c}$values within the column marked with the same letter are not statistically different ($P < 0.05$)

Table 5. Content (%) of dry matter at BBCH 60 stage

Treatment	Čáslav		Hněvčeves		Humpolec	
	2008	2009	2008	2009	2008	2009
Conventional 1	9.17^{a}	13.58^{a}	9.27^{a}	10.72^{a}	11.19^{a}	13.02^{a}
CULTAN 1	10.25^{b}	12.54^{a}	11.17^{a}	10.66^{a}	12.26^{b}	13.01^{a}
Conventional 2	9.81^{a}	12.61^{a}	8.50^{a}	10.05^{a}	10.37^{c}	13.82^{a}
CULTAN 2	10.44^{b}	12.55^{a}	9.14^{a}	10.90^{a}	11.20^{a}	12.97^{a}

$^{a–c}$values within the column marked with the same letter are not statistically different ($P < 0.05$)

Germany) with a working scope of 3 m, application distance of 7 cm, distance from plant rows and the application depth of 5 cm. Injection applicator had 12 application wheels. Each wheel had 12 fertilizing nozzles over the circumference. Surface of the fertilized plot was 39 m^2 out of which 15 m^2 was harvested with a small-plot combine-harvester. Seed nitrogen content was determined by the Kjeldahl method using the Vapodest 50s (Gerhardt Gmbh & Co. KG., Königswinter, Germany). The statistical evaluation of the experiment was carried out using STATISTICA software (Version 8.0, 2007) with the single-factorial ANOVA followed by the Tukey's test at the level of significance $P < 0.05$.

RESULTS

In 2008, at Čáslav and Humpolec sites the average seed yields of both conventional treatments and both CULTAN treatments were identical (Table 4). The average yield of conventional treatments reached 3.3 t ha^{-1} and the average yield of CULTAN treatments was 2.5 t ha^{-1}. The difference in seed yield was 0.8 t ha^{-1}. By both CULTAN treatments at Čáslav and Humpolec the seed yield was significantly lower compared to conventional treatments. In the same year no significant differences in the seed yield between the systems of fertilization at Hněvčeves were observed. In 2009, conventional treatment 2 gave a significantly higher yield, on average by 0.6 t ha^{-1}, compared to CULTAN 2 at site Čáslav. Like in 2008, there were no significant differences observed between the systems of fertilization at Hněvčeves site. Here the highest yield was recorded at CULTAN 2 treatment, by 0.7 t ha^{-1} higher on the average than at treatment conventional 1. There were no differences in seed yield between treatments of fertilization at site Humpolec this year. Here the yield values were equalized at all treatments.

At site Čáslav, a lower seed yield at CULTAN 2 treatment compared to conventional 2 treatment was observed in both experimental years. The same situation happened in 2008 at Humpolec. The average difference at site Čáslav made 0.7 t ha^{-1} and at site Humpolec 0.6 t ha^{-1}.

The significantly higher dry matter contents at growing stage BBCH 60 after using the CULTAN method were found at sites Čáslav and Humpolec in 2008 (Table 5). At site Čáslav conventional treatment 1 gave on average by 1.1% lower dry matter content in the aboveground biomass compared to treatment CULTAN 1. Treatment CULTAN 2 here reached by about 0.6% higher dry matter content compared to treatment conventional 2. In the same year at site Humpolec conventional treatment 1 yielded by 1.1% lower dry matter content in aboveground biomass on average compared to treatment CULTAN 1 and treatment conventional 2 reached on average by 8% lower values if compared to treatment CULTAN 2. In 2009, a similar trend of rising dry matter content at CULTAN treatments was not observed at any of the study sites.

In 2008 at Čáslav, the nitrogen content in seed at CULTAN treatment was significantly lower in comparison with conventional treatment 1, on average by 0.2% (Table 6). The difference between conventional treatment 1 and CULTAN 2 treatment was statistically inconclusive at this site. In the same year at Hněvčeves, the nitrogen content in seeds was at both CULTAN treatments significantly lower compared to both conventional treatments. The same situation also

Table 6. Content (%) of nitrogen in seed

Treatment	Čáslav		Hněvčeves		Humpolec	
	2008	2009	2008	2009	2008	2009
Conventional 1	3.22[a]	3.55[a]	3.14[a]	3.29[a]	2.98[a]	3.15[a]
CULTAN 1	2.98[b]	3.59[a]	2.82[b]	3.49[ab]	2.62[b]	3.08[a]
Conventional 2	3.23[a]	3.55[a]	3.09[a]	3.37[ab]	2.93[a]	3.44[a]
CULTAN 2	3.17[ab]	3.52[a]	2.87[b]	3.64[b]	2.58[b]	3.48[a]

[a,b]values within the column marked with the same letter are not statistically different (P < 0.05)

Table 7. Effect of site, year, treatment, and sulphur addition on seed yield, content of dry matter at BBCH 60 stage, and content of N in seeds in 2008–2009

Parameter	Seed yield (t ha^{-1})	Content of dry matter at BBCH 60 (%)	Content of N in seed (%)
Site			
Čáslav	3.91[a]	11.4[a]	3.35[a]
Hněvčeves	5.75[b]	10.1[b]	3.21[b]
Humpolec	3.41[c]	12.2[c]	3.03[c]
Year			
2008	3.32[a]	10.3[a]	2.97[a]
2009	5.39[b]	12.2[b]	3.43[b]
Treatment			
Convetional (1, 2)	4.50[a]	11.01[a]	3.24[a]
CULTAN (1, 2)	4.21[b]	11.45[b]	3.15[b]
Sulphur			
S*	4.20[a]	11.40[a]	3.16[a]
S**	4.50[b]	11.05[b]	3.24[a]

[a–c]values within the column for each parameter marked with the same superscript are not statistically different ($P < 0.05$)

*means of treatments Conventional 1 and CULTAN 1

**means of treatments Conventional 2 and CULTAN 2

happened at Humpolec. Both CULTAN treatments reached significantly lower values of nitrogen content in comparison with both conventional treatments, on average by 0.4%. In 2009, the nitrogen content in seed varied at particular treatments, especially at Hněvčeves and Humpolec. However, these differences were not statistically significant. At Čáslav no greater differences in the nitrogen content in seeds between different systems of fertilization were observed.

The influence of site on seed yield, content of dry matter at BBCH 60, and content of nitrogen in seed, regardless of the way of fertilization, was proved in 2008–2009 (Table 7). The highest yield was achieved at site Hněvčeves. At this site the yield was by 1.8 t ha^{-1} higher on average compared to site Čáslav and by 2.3 t ha^{-1} higher on average compared to site Humpolec. The lowest nitrogen content in seed was recorded at site Humpolec, on average by 0.3% lower than the highest value reached at site Čáslav. The year 2009 had a significant influence on higher seed yield (on average by 2.1 t ha^{-1}), on higher content of dry matter in aboveground biomass (on average by 1.9%), and on higher content of nitrogen (on average by 0.5%) if compared to the year 2008. Differences based on the way of fertilization were proved in all observed parameters during the experimental year. The conventional (1 and 2) treatments gave by about 0.3 t ha^{-1} higher seed yield and by about 0.1% higher nitrogen content in seeds compared to CULTAN (1 and 2) treatment. Higher values of dry matter content (on average by 0.4%) were proved at CULTAN (1 and 2) compared to conventional (1 and 2) treatment. The addition of sulphur to the fertilizer, regardless of the way of fertilization, had a signifiant effect on higher seed yield (on average by 0.3 t ha^{-1}) if compared to the application of nitrogen fertilizer without sulphur.

DISCUSSION

Because of weather conditions in the spring of 2008, the regeneration of roots was probably accelerated and the leaf area was not sufficiently reduced, which did not correspond with changes in the physiology of plants expected after the application of the CULTAN method. The temperature suitable for regeneration of the root system is +2 °C. Depending on the year, this temperature period occurs mostly in the first decade of March (Baranyk et al., 2010). In our experiment late CULTAN application could be the reason of lower seed yield at both CULTAN treatments in the spring of 2008. Boelcke (2003) reported comparable results in seed yield between conventional treatment and CULTAN treatment if the whole dose of nitrogen fertilizer was injected 10 days after the beginning of oil seed rape vegetation. Success in the use of the CULTAN method for winter rape is conditioned by redirection of 'shoot dominant system' nutrition to 'root dominant' nutrition (Sommer, 2005). It positively affects the synthesis of cytokinins in root tips against gibberellins and auxins synthesized in shoots (Sommer, Six, 1981). This way it can affect the growth rate of aboveground biomass and roots in favour of enhanced growth of aboveground biomass (Gerendas et al., 1997). Because of shortened plant branching, which causes redirection of phytohormonal flow, the total number of pods is increased by 20% compared to the conventional system of fertilization (Sommer, 1991). Lower temperatures in winter season support physiological principles of nutrition of the CULTAN method, because of the higher destruction of leaf area. This finding follows from the results in 2009, when apart from one exception at Čáslav, seed yields between the systems of fertilization were not statistically conclusive. N metabolism is strongly affected by the sulphur status in the plant (Fazili et al., 2008). Sommer (2005) in the CULTAN system for oil seed rape recommends fertilizers with a high content of sulphur and ammonium. The lower grain yield of CULTAN treatments with sulphur compared to the conventional treatments with sulphur was also observed by Kozlovský et al. (2009) in the experiment with *Triticum aestivum* in the same year and at the same experimental sites. Dry matter content of aboveground biomass should be higher after fertilization with the CULTAN method (Sommer, Schrerer, 2007). Significantly higher dry matter content at stage BBCH 60 after fertilization with the CULTAN method was found in 2008 at Čáslav and Humpolec. Also Sedlář et al. (2011) observed, over the period of three years, a higher dry matter content in the aboveground biomass of barley after fertilization with the CULTAN method in later stages of growth in comparison with the conventional system of fertilization. It was found out that high levels of available nitrogen in soil extend vegetative growth phase and increase the production of dry matter and nitrogen content in plants (Bailey, 1990).

In 2008, at all sites, significantly lower levels of nitrogen were found in the seed of winter rape at the treatment where plants were fertilized with the CULTAN method compared to the conventional alternatives regardless of the addition of sulphur to the fertilizer. These results contradict the findings of Felgentreu (2003) who, during a two-year experiment with winter oil seed rape in field conditions, observed higher protein content in the seed after fertilization using the CULTAN method in comparison to the split dose of nitrogen. The nitrogen content in mature seeds and straw of winter rape may vary over a wide range, even if the plant takes in an adequate amount of nitrogen. The seed yield and protein content go up along with increasing doses of nitrogen fertilizers (Holmes, 1980). During two experimental years Kozlovský et al. (2009) found a lower protein content in the grain of winter wheat after supply of the total dose using a local application of nitrogen fertilizer.

Based on the data from the Czech Statistical Office the 2008–2009 average yield of winter oilseed rape in the Středočeský Region (Čáslav) was 3.15 t ha^{-1}, in the Královehradecký Region (Hněvčeves) 3.4 t ha^{-1}, and in the Vysočina Region (Humpolec) it was 2.95 t ha^{-1} (Anonymous, 2009). At a fertile locality like Hněvčeves, if compared with other experimental sites, the highest seed yield is being achieved in the long term. Zukalová et al. (2006) stated that the highest oiliness of seeds is usually reached in colder compared to warmer areas. This statement fits the case of the Humpolec site exhibiting the lowest content of nitrogen in seed. In 2009 nationwide on-year-on increase in seed yield of rape was 8.2% compared to 2008 (CSO). Christen, Sieling (1995) regarded the weather (year) as the factor strongly affecting the seed yield, thousand seed weight, and number of plants per m^2. Positive effect of the CULTAN method compared to conventional way of fertilization on the seed yield of winter oil seed rape at four different experimental sites in the conditions of the Czech Republic during 2006–2007 was not proved (Balík et al., 2007). The lack of sulphur in soil is considered a major factor of reduced seed quality (Asare, Scarisbrick, 1995) and seed yield reduction by up to 40% (Scherer, 2001).

CONCLUSION

During 2008–2009, a higher seed yield after the CULTAN application compared to the conventional system of split doses of nitrogen was not proved. In 2009, the seed yields at each particular system of fertilization were very balanced at all experimental sites. Regardless of the fertilization system, the crops fertilized with a nitrogen fertilizer with added sulphur reached higher yields than crops without sulphur amendment. The content of dry matter in aboveground biomass was observed to be higher after using the CULTAN method. The content of nitrogen in seeds was mainly influenced by year, because of significantly lower nitrogen content in seed at CULTAN treatments at all sites in 2008. We can thus conclude that in some observed parameters the CULTAN method gave results comparable to the conventional way of fertilizing.

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