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The effect of nitrogen and sulphur fertilisation on the elemental composition and seed quality of spring oilseed rape

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Abstract

The present study was aimed to examine the impact of nitrogen and sulphur fertilisation on spring oilseed rape cv. ‘Maskot’ quality parameters. The experiments were carried out at the Lithuanian Institute of Agriculture in Dotnuva during 2003–2005 on a sod gleyic, *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*), light loam with moderate mineral nitrogen and low mobile sulphur contents.

An increase in nitrogen application had a positive effect on the concentration of nitrogen in the above-ground biomass during the growing season (at the stages of stem elongation and pod development), and at complete maturity – in seeds and straw. In turn, sulphur fertilisation significantly increased sulphur concentration at the above-mentioned stages; however, at complete maturity it had an obvious positive effect on total sulphur concentration in seeds and straw in 2003, only. Despite high sulphur rates used (to 40 kg ha^{-1}), the N:S ratio (an indicator of sulphur deficiency) revealed the shortage of sulphur in seeds in 2004 and 2005.

The highest crude protein content was observed in a warmer and drier year 2003. The 150 kg ha^{-1} nitrogen rate was optimal for crude protein content in rape seeds, while in 2005 it was 90 kg ha^{-1}. Crude fat content in seeds (2004 and 2005) decreased with increasing nitrogen application up to 150 kg ha^{-1} and was not influenced by different growing conditions during the experimental years. The application of nitrogen up to 150 kg ha^{-1} and sulphur up to 40 kg ha^{-1} tended to increase glucosinolate content. The highest glucosinolate content was obtained in 2005, more favourable for glucosinolate accumulation. Besides, glucosinolate content was positively influenced by N x S interaction in some cases.

Key words: nitrogen, sulphur, N x S interaction, N:S ratio, crude protein, crude fat, glucosinolates.

Introduction

The effect of nitrogen as a key nutrient for oilseed rape quality parameters has been broadly investigated abroad as well as in Lithuania. However, the efficiency and nitrogen uptake highly differs and depends of pedoclimatic conditions, management or cultivar peculiarities (Grant, Bailey, 1993; Šidlauskas, Tarakanovas, 2004).

From the physiological aspect, the interaction between nitrogen and sulphur is essential as it influences crop growth, development, yield and quality. Crop yield and its quality primarily depend on mobile nitrogen in the soil. In turn, the efficiency of nitrogen nutrition is highly dependent on mobile sulphur content in the soil, since deficiency of mobile sulphur is the cause of decrease of assimilation and further reduction of nitrate nitrogen (Хоменко, 1983). A ratio of nitrogen to sulphur (N:S) is often used as an indicator to demonstrate the sufficiency level of sulphur in plants, because it is a relatively constant rate which is better than the amounts of total sulphur or sulphates. The high demand of oilseed rape for nitrogen and sulphur is the reason of their presence in the synthesis of both proteins and glucosinolates (Zhao et al., 2003).

Higher plants assimilate nitrogen and sulphur in proportion to their contents in proteins. Deficiency or surplus of one of them has a negative impact on protein synthesis (Хоменко, 1983). The influence of nitrogen fertilisers on protein content in rape seeds has been broadly investigated in many countries likewise in Lithuania (Butkutė et al., 2005). Generally, the increase of nitrogen fertiliser rates and nitrogen concentration in seeds causes the accumulation of proteins in seeds, whereas oil content, contrarily, reduces it. There is a negative dependence between the protein and oil concentration in rape seeds (Butkutė et al., 2000; Butkutė et al., 2005; Hassan et al., 2007).

Nevertheless, the importance of interaction between nitrogen and sulphur in plant nutrition has not been clarified suitably, since in addition to mineral nutrition, the quality composition of rapeseed varies depending on the environmental factors (soil, moisture, temperature), cultivar, and agricultural management (Butkutė et al., 2005).

The decreasing amount of mobile sulphur is becoming a grave problem in many European countries. Already in 1998, the estimated shortage of mobile sulphur in topsoil (<6.0 mg kg^{-1}) encompassed about 45.4% of soils nationwide (Adomaitis, 1998). Little attention was paid to the investigations of sulphur as a plant nutrient by Lithuanian researchers. So far, some research work concerning the impact of sulphur on rape qualitative indicators has been done in Lithuania's research institutions (Rimkevičienė et al., 2007; Šimatonytė, 2010). However, the effect of sulphur may differ as it may be affected also by different pedoclimatic conditions. There are few data concerning the influence of meteorological conditions on the variation of seed chemical content (Butkutė et al., 2005; Rimkevičienė et al., 2007).

The research was aimed to determine the effects of nitrogen and sulphur and their interaction on the accumulation of both elements in spring rape during vegetation, in seeds and straw; and to establish the effect of nitrogen and sulphur on the concentrations of crude proteins and crude fat concentrations and glucosinolate contents in oilseed rape seeds.

Materials and methods

Experiments with spring oilseed rape cv. 'Maskot' were carried out at the Lithuanian Institute of Agriculture in Dotnuva during 2003–2005. The soil of the experimental site was calcaric shallow gleyic Cambisol (*Endocalcari-Epihypogleyic Cambisol*, *CMg-p-w-can*) light loam. Each year, soil analyses were made before the trial establishment. Soil indicators are presented in Table 1.

Table 1. Soil characteristics of the experimental site

Indicator	2003	2004	2005
pH_{KCl}*	6.7	5.0	6.8
Organic C %*	0.91	0.74	1.24
Total N %*	0.92	0.105	0.135
Mineral N ($N\text{-}NO_3^-$ + $N\text{-}NH_4^+$) mg kg^{-1}**	9.65	8.29	9.10
Total S mg kg^{-1}**	140	160	125
Mobile S mg kg^{-1}**	3.5	0.2	3.4
K_2O mg kg^{-1}*	135	169	149
P_2O_5 mg kg^{-1}*	133	112	115

Note. * – 0–25 cm soil layer, ** – 0–40 cm soil layer.

All soil analyses were made at the Agrochemical Research Centre of LIA.

The experiments were established in the soil which contained a medium amount of total sulphur according to the classification currently used in Lithuania (Adomaitis, 1998), meanwhile the amount of mobile sulphur was low. Among other indicators analysed, the amounts of mineral nitrogen, mobile phosphorus and potassium were moderate.

Each year, spring rape seeds were sown in the 3rd ten-day period of April. The seed rate was 8 kg ha^{-1} (~2.5 million of viable seeds ha^{-1}). The preceding crop was spring barley.

Nitrogen was applied as ammonium nitrate and partly as monoammonium phosphate, sulphur was applied as potassium sulphate. To adjust equal amounts of potassium in all treatments, potassium chloride was applied. Phosphorus was applied as monoammonium phosphate. All the fertilisers were broadcast in spring prior to drilling.

During the growing seasons, the oilseed rape plots were sprayed with herbicides: Treflan (2.5 l ha^{-1}) (for dicotyledonous and some monocotyledonous weeds) (in 2003 and 2005), Agil (1.0 l ha^{-1}) (against couch-grass *Elytrigia repens* L. Nevski) (in 2004) and with insecticides:

Fastac (0.10 l ha^{-1}) (in 2003 and 2004) and Karate (0.13 l ha^{-1}) (in 2005) (for pollen beetle *Meligethes aeneus*), Furry (0.10 l ha^{-1}) (against crucifer flea beetle *Phyllotreta spp.*) (2004 and 2005).

The plots were harvested at full maturity stage, particularly in 2003 on the 14th of August, in 2004 on the 1st of September, in 2005 on the 24th of August. Each plot was harvested by a "Sampo-500" combine separately. When measuring seed moisture, spring rape seed weights were adjusted to 8.5% moisture content.

The spring rape experiment was a two-factor design. Factor A – nitrogen fertiliser rate, factor B – sulphur fertiliser rate. Both factors consisted of three levels of fertilisation. The experimental plots were arranged in a two factorial randomized block design with four replications. The harvested area of spring rape plots was 30.80 m^2.

The amounts of total nitrogen (by Kjeldahl method) and total sulphur (turbidimetric method) in the above-ground biomass were evaluated at four treatments (N_0S_0, N_0S_{40}, $N_{150}S_0$ and $N_{150}S_{40}$) during the stem elongation (2.01–2.03) and the end of the pod development stage (5.7–5.9). At full maturity, the amounts of total nitrogen and sulphur were evaluated in each treatment separately in seeds and straw. Chemical analyses were done on samples dried at 105°C and milled. The spring rape growth stages presented in the article have been proposed by Sylvester-Bradley and Makepeace (1984).

Soil pH was measured potentiometrically. Plant-available phosphorus and potassium in the soil were determined by the spectrophotometry and flame spectrometry methods, respectively, in acetate-lactate ammonium solution (A-L) at 3.7 pH, by the Egner-Riehm-Domingo method (Egner et al., 1960). Organic carbon content was determined by the Tyurin method modified by Nikitin using dichromate oxidation at 160ºC (Nikitin, 1999). Soil mineral nitrogen was determined colorimetrically: $N\text{-}NO_3$ using hydrazinesulfate and sulfanilamide, and $N\text{-}NH_4$ using natrium phenolate and natrium hypochlorite (Markus et al., 1985). Total and mobile sulphur in the soil and plants were determined by turbidimetric method (Chesnin, Yien, 1950), using extracting solution of 1 M KCl. Total nitrogen in the soil and plants was estimated by Kjeldahl method (Guebel et al., 1991). Crude fat and glucosinolates were analysed by near infrared spectroscopy. Intact seed samples were scanned on a monochromator NIR Systems model 6500 equipped with Spinning Module using a small ring cup (d = 4.7 cm). The reflectance spectra (log 1/R) from 400 to 2500 nm were recorded and quality components of seed were predicted by the equations developed at the LIA (Butkutė, 2004). The crude protein content (per cent dry matter) in seeds was assessed by multiplying the amount of total nitrogen by a coefficient of 6.25.

The amounts of nitrogen and sulphur in plants, seeds and straw were evaluated by S_x – the standard error of the mean (SEM). The data of crude protein, crude fat and glucosinolates as well as correlation-regression analysis were processed using analysis of variance (*Anova*) as a two factorial randomised block variant, by employing LSD_{05} (by choosing 95% probability level) to assess significance (Tarakanovas, Raudonius, 2003).

In 2003, varying weather prevailed in the first half of the growing season. Hotter days were alternating with cooler days. Precipitation was distributed unevenly, thus oilseed rape experienced the lack of soil moisture. Steady warm and dry weather prevailed from the beginning of July up to the end of growing season. In general, warm and dry weather prevailed during the growing season in 2003. During the growing season, the sum of active temperatures (over 10°C) was 1745°C, precipitation was 157 mm.

In 2004, up to the mid June, the weather was cool and dry, later the weather was cool with a high rate of precipitation up to the end of the growing season. However, the growing conditions were most favourable compared with other experimental years. During the growing season, the sum of active temperatures was 1778°C, precipitation was 249 mm.

In 2005, from the beginning of germination until June, the weather was changeable. Later on, warm weather with sparing rain prevailed until the beginning of August. There was a lot of precipitation at the end of the growing season. During the growing season, the sum of active temperatures was 1730°C, precipitation was 216 mm.

Results and discussion

The 0–40 cm soil layer in the experimental site contained a medium amount of nitrogen from 92 to 165 g kg^{-1}. The amount of total sulphur was also medium, however, the content of mobile sulphur varied from 0.2 to 3.5 g kg^{-1}. It is known that oilseed rape has a deep root system, therefore it can assimilate nutrient elements from deeper layers. Nevertheless, the soil analysis from 60–90 cm layer revealed that the amount of mobile sulphur did not exceed 5.0 g kg^{-1}.

The variations of total nitrogen and sulphur concentrations in the above-ground biomass are shown in Table 2. During the time of growing, the concentrations of both elements gradually decreased. Other researchers have also emphasized the high fluctuation of nutrients during the growing season (Šidlauskas, Tarakanovas, 2004).

Table 2. The variation of nitrogen and sulphur concentrations in the above-ground biomass of rapeseed plants at two growth stages, 2003–2005

	N, S fertiliser rates									
	N, S concentration at stem elongation stage (2.01–2.03)					N, S concentration at pod development stage (5.7–5.9)				
	N_0S_0	N_0S_{40}	$N_{150}S_0$	$N_{150}S_{40}$	SEM	N_0S_0	N_0S_{40}	$N_{150}S_0$	$N_{150}S_{40}$	SEM
	2003									
N % DM	34.3	31.2	34.7	40.2	3.7	16.4	16.6	19.2	24.0	3.5
S % DM	5.5	7.8	3.4	5.8	1.8	3.2	2.8	2.8	4.4	0.8
N:S	6.24	4.0	10.2	6.93	2.57	5.12	5.93	6.86	5.45	0.76
	2004									
N % DM	25.8	26.0	26.2	33.8	3.9	19.2	16.7	16.9	23.0	2.9
S % DM	2.3	3.2	2.6	3.1	0.4	2.8	2.7	2.3	3.1	0.3
N:S	11.2	8.12	10.1	10.9	1.39	6.86	6.18	7.35	7.42	0.57
	2005									
N % DM	27.4	33.6	45.6	42.3	8.3	10.6	10.1	16.1	15.6	3.2
S % DM	3.3	8,0	3.4	7.5	2.5	2.3	2.6	1.6	2.7	0.5
N:S	8.3	4.2	13.4	5.64	4.05	4.61	3.88	10.1	5.78	2.76

Nitrogen fertilisers significantly increased the concentration of nitrogen in the above-ground biomass at the stages of stem elongation (2.01–2.03) and end of pod development (5.7–5.9). The later the growing stage, the lesser the concentration of nutrients was in the above-ground dry biomass. However, the highest nitrogen concentration at both stages and, herewith, during the growing season was in 2003 – from 31.2 to 40.2 g kg^{-1} (2.01–2.03) and to 16.4–24.0 g kg^{-1} (5.7–5.9).

The effect of nitrogen fertilisers on sulphur concentration was uneven. At the stem elongation stage, the effect of nitrogen fertilisation on sulphur concentration was not definitely expressed; meanwhile it caused a declining effect at the end of the pod development.

The nitrogen to sulphur (N:S) ratio in plants is a reliable indicator in diagnosing sulphur deficiency. During the growing season, oilseed rape is sulphur sufficient when N:S ratio is no higher than 10 (Blake-Kalff et al., 2003). In these investigations, the N:S ratio varied depending on sulphur and nitrogen fertilisation. At the early growing stages, the application of nitrogen (particularly high rates) caused the excess of N:S ratio of more than 10, which is defined as a possible sulphur deficiency in rape. At the pod development stage, the N:S ratio did not show the lack of sulphur in plants. However, it was mentioned that total sulphur concentration in the above-ground mass was lower than the critical level for the stage. The contradiction between the two assessments could be explained that the low N:S ratio could result from insufficient concentration of both nitrogen and sulphur (Sumner, 1978). The N:S ratio declined during the second half of the growing season and did not exceed the critical N:S ratio.

At full maturity, nitrogen and sulphur fertilisation had a positive impact on nitrogen and sulphur concentration in oilseed rape seeds (Table 3). In a warmer and drier year 2003, the content of both elements in seeds was higher than in other experimental years: nitrogen concentration varied from 34.6 to 39.1 g kg^{-1}, sulphur content from 3.6 to 5.1 g kg^{-1}. The season 2004 could be characterized as the most favourable for rape cultivation and development, therefore the concentration of both nutrients was lower than in 2003. The least concentration of both nutrients was in 2005, when nitrogen content varied from 3.04 to 3.30% and sulphur from 0.26 to 0.34%. In this year, the nitrogen and sulphur concentration in the above-ground mass (seeds and straw) was also the lowest during all experimental years. The dependence of nutrient concentration on climatic conditions is consistent with the observations of other authors (Šidlauskas, 2000; Malhi et al., 2007).

According to other authors, critical values for the N:S ratio ranging between 6 and 10 have been proposed (according to Zhao et al., 2003). In 2003, the N:S ratio did not exceed the critical level of 10 and varied from 7.67 to 9.61. In 2004 and 2005, the ratio exceeded the critical level which indicates that the concentration of total sulphur in seeds is too low. Insufficient concentration of sulphur in seeds could be partly caused by low ability of plants for sulphur translocation from vacuoles of older leaves to new developing parts (as well as seeds) (Hawkesford, De Kok, 2006).

Table 3. The variation of nitrogen and sulphur concentration in fully matured rape seeds and straw, 2003–2005

	N, S fertiliser rates									
	N, S concentration in seeds					N, S concentration in straw				
	N_0S_0	N_0S_{40}	$N_{150}S_0$	$N_{150}S_{40}$	SEM	N_0S_0	N_0S_{40}	$N_{150}S_0$	$N_{150}S_{40}$	SEM
					2003					
N % DM	34.6	36.3	41.6	39.1	3.1	3.4	3.2	4.1	4.7	0.7
S % DM	3.6	3.8	4.6	5.1	0.7	1.4	3.8	1.5	3.0	1.2
N:S	9.61	9.55	9.04	7.67	0.9	2.43	0.84	2.73	1.57	0.86
					2004					
N % DM	32.4	32.2	35.3	36.3	2.1	7.2	7.4	11.5	11.3	2.4
S % DM	3.2	3.1	3.2	3.4	0.1	1.8	1.6	2.2	2.4	0.4
N:S	10.1	10.4	11.0	10.7	0.39	4.00	4.62	5.23	4.71	0.50
					2005					
N g kg^{-1} DM	31.4	30.4	33.0	32.8	1.2	5.6	4.8	6.6	6.5	0.8
S g kg^{-1} DM	2.6	2.7	2.8	3.4	0.4	1.4	1.4	1.1	1.4	0.1
N:S	12.1	11.3	11.8	9.65	1.08	4.00	3.43	6.00	4.64	1.10

The alteration of nitrogen in straw is highly depended on nitrogen fertilisers and growing conditions during vegetation. The effect of sulphur on nitrogen concentration was unambiguous and less evident. In 2003, nitrogen accumulation was the lowest and varied from 3.2 to 4.7 g kg^{-1}. Conversely, in 2004 the concentration of nitrogen in rape increased by more than twice (in comparison with 2003) – from 7.2 to 11.5 g kg^{-1}. This shows, that with prolonged vegetation, rape tends to accumulate higher amount of nitrogen, whose considerable share is utilized to grow the vegetative mass. Sulphur concentration in straw highly varied in different years, however was significantly affected by sulphur fertilisation, only. There is a consistent pattern that by increasing nitrogen and sulphur concentration in straw, lesser amount of both elements remains in seeds, and vice versa. These data agree with the findings of other researchers (Šidlauskas, Tarakanovas, 2004; Malhi et al., 2007).

The N:S ratio was lower in straw than in seeds. The N:S ratio indicated the insufficient level of total sulphur in the above-ground biomass at the pod development stage, whereas later analyses revealed the uneven total sulphur distribution in straw and seeds. The highest amounts of sulphates usually accumulate in vacuoles of more mature leaves; however the ability of sulphur remobilization to younger developing parts of plants (also in seeds) is insubstantial. The mechanisms for the regulation of distribution of sulphate intake by the root to various sink tissues and then subsequent redistribution is unclear (Hawkesford, De Kok, 2006).

The experimental results revealed that the nitrogen and sulphur concentrations to high extent are influenced by external factors (temperature, moisture), among others. High variability of nutrient concentration in seeds depending on climatic conditions was observed by other authors (Malhi et al., 2007). More precise investigations are required to explain the impact of plant nutrition better as well as the external parameters on the oilseed rape qualitative content.

Irrespective of the level of sulphur application, there were no external visible signs of sulphur deficiency. It has been noted by other authors, that when sulphur deficiency is mild, the physiological features of deficiency could not be visible (Grant, Bailey, 1993).

In 2003, crude protein content accumulated in rape seeds was 21.47–26.03% (Table 4). This is the highest concentration during the experimental years. Increase in protein content is associated with high temperatures following anthesis (Gunasekera et al., 2006). Protein content was positively affected by 150 kg ha^{-1} nitrogen rate alone, but the application of 40 kg ha^{-1} sulphur rate had a reverse effect.

In 2004, protein content in seeds ranged from 20.25 to 22.69%. The increase in nitrogen rates from 90 to 150 kg ha^{-1} increased proteins, although not always significantly at 95% probability level. The significant impact of sulphur as well as the N x S interaction was observed in several cases.

The lowest protein content recorded in 2005 was 19.66–21.09%. The positive effect of nitrogen was noticed by the application of 90 kg ha^{-1} alone; meanwhile the interaction with 40 kg ha^{-1} of sulphur application had a negative effect.

Table 4. The influence of nitrogen and sulphur fertilisation on crude protein content in spring rape seed, 2003–2005

Crude protein content %									
	2003			2004			2005		
	S_0	S_{20}	S_{40}	S_0	S_{20}	S_{40}	S_0	S_{20}	S_{40}
N_0	21.62	21.47	22.69	20.25	20.50	20.16	19.66	19.91	19.00
N_{90}	23.81	25.53	25.00	20.31	21.78	21.22	21.09	20.53	19.16
N_{150}	26.03	25.53	24.41	22.06	22.00	22.69	20.59	20.00	20.50
LSD$_{05}$ N and S		0.69			0.45			0.45	
LSD$_{05}$ N x S		1.38			0.90			0.90	

Commonly, the role of sulphur was controversial and inconsistent during the experimental years. It has been noted that sulphur plays an important role for rape because of relatively high rates of S-amino acids accumulated in seeds. Some authors suggest that sulphur fertilisers have a positive effect on protein concentration in rape seeds (Malhi et al., 2007), though others maintain that sulphur fertilisation has no significant influence (Govahi, Saffari, 2006).

In general, the effect of growing conditions on crude fat content had a negligible effect and varied between 44.05–45.52% (in 2004) and from 44.35–46.60% (in 2005). Nitrogen fertilisers reduced crude fat content in seeds. The least fat concentration was observed in the treatment without nitrogen and sulphur application (N_0S_0). Contrarily, the increasing fertilisation to the highest rates ($N_{150}S_{40}$) caused the decrease of fat content. Sulphur fertilisers had no significant effect on crude fat content.

Most scientific articles note that irrespective of climatic conditions, nitrogen fertilisers decreased crude fat content by a linear trend (Hassan et al., 2007). The data concerning the effect of sulphur fertilisers on crude fat content are inconsistent. Some researches emphasize that sulphur has a positive effect on fat concentration in rape seeds (Malhi et al., 2007), while others state that sulphur fertilisation has no significant influence (Hassan et al., 2007).

There is an inverse relationship between protein and fat content in seeds – the increasing of protein concentration prompts the decrease of fat, and vice versa. The sum of protein and fat in seeds is nearly a constant value, which faintly depends on growing conditions, soil management and varies no more than by 6% (Holmes, 1980).

Table 5. The influence of nitrogen and sulphur fertilisation on fat content in spring rape seed, 2004 and 2005

Crude fat content %						
	2004			2005		
	S_0	S_{20}	S_{40}	S_0	S_{20}	S_{40}
N_0	45.52	45.18	45.32	45.60	44.98	45.28
N_{90}	44.78	44.45	44.42	44.52	44.70	45.35
N_{150}	44.08	44.22	44.05	44.68	44.88	44.35
LSD$_{05}$ N and S			0.44		0.38	
LSD$_{05}$ N x S			0.87		0.77	

In our experiments, there was a strong negative correlation between crude protein and crude fat content – $r = -0.92$. The total sum of both parameters varied from 65.09 to 66.74% (in 2004) and from 64.51 to 65.61% (in 2005). In average, the dependence of both parameters is described by a linear equation – $y_{(proteins)} = 91.129 - 1.565x$ ($r = -0.92^{**}$).

The glucosinolate amount of secondary organic compounds in seeds differed in different experimental years (Table 6). In 2004, the amount of accumulated glucosinolates in seeds ranged from 9.80 to 12.18 μmol g^{-1}. In most treatments, the amounts of glucosinolates gradually increased through the application of both nitrogen and sulphur fertiliser rates. In 2005, the content of glucosinolates in seeds varied from 11.72 to 14.58 μmol g^{-1}. Without sulphur fertilisation, 150 kg ha^{-1} nitrogen rate caused the decrease of glucosinolates by 11.72 μmol g^{-1}. Yet, by the application of 150 kg ha^{-1}, sulphur fertilisation significantly increased the amount of accumulated glucosinolates up to 14.58 μmol g^{-1}.

Table 6. The influence of nitrogen and sulphur fertilisation on glucosinolate amount in spring rape seed, 2004 and 2005

	Glucosinolate amount μmol g^{-1}					
	2004			2005		
	S_0	S_{20}	S_{40}	S_0	S_{20}	S_{40}
N_0	10.65	9.08	12.18	12.75	11.72	13.70
N_{90}	10.00	10.82	11.08	13.08	13.05	12.60
N_{150}	11.15	11.05	11.92	11.72	12.32	14.58
LSD_{05} N and S	0.62			0.48		
LSD_{05} N x S	1.24			0.95		

The substantial differences between the numeral values could occur due to uneven climatic regimes during vegetation. With the lack of soil moisture (especially at the early growth stages), oilseed rape has a feature to accumulate higher amounts of secondary organic compounds (Malhi et al., 2007).

The role of nitrogen in the amount of glucosinolates in seeds is not substantially explored. Some investigation shows the increase of glucosinolates in seeds (Butkutė et al., 2000). Yet, other researchers present the results which reveal that the high nitrogen rates decrease the content of glucosinolates (Fismes et al., 2000), since in that case the availability of sulphur to plants via roots is being blocked, especially in the soil with low amount of mobile sulphur (Griffith, Rossel, 1995).

A number of authors emphasize that the glucosinolate amount is in close correlation with total nitrogen and sulphur ratio (Fismes et al., 2000). However, the correlation-regression analysis did not indicate any relation between glucosinolates and both nitrogen and sulphur contents in rape seeds. The feeble correlation between glucosinolate amount and total sulphur in seeds could be explained by the fact that although oilseed rape accumulates appropriately large amounts of sulphates, the utilization efficiency as well as their incorporation into organic matter is poor, since the highest share of sulphates is being accumulated in the cell vacuoles' leaf blade. The significantly positive relation was estimated between the N:S ratio and the glucosinolate amount ($r = -0.71$). Thus, glucosinolate amount depended rather on the nitrogen and sulphur ratio than on total nitrogen and sulphur concentration in seeds (Fismes et al., 2000).

In this study we raised a hypothesis that by cultivating oilseed rape in soil with average amount of total nitrogen and sulphur but low amount of mobile sulphur, the fertilisation with nitrogen and sulphur will affect the rape qualitative parameters.

Accumulations of contents of total nitrogen and sulphur in the above-ground biomass as well as in seeds and straw have a high variance in different experimental years. Despite that, nitrogen and sulphur fertilisation normally had a positive effect on the accumulation of both nutrients.

Sulphur fertilisers significantly affected the glucosinolate amount. Meanwhile, the contents of crude protein and crude fat in seeds depended entirely on nitrogen fertilising. High demand of oilseed rape for sulphur may be explained by the fact, that the amount of sulphur contained in glucosinolates typically accounts for less than 10% of the total sulphur in vegetative tissues (Blake-Kalff et al., 1998).

The crop yield is not only determined by nutrient availability but also by prevailing climatic conditions, soil type and structure, pests or water availability (Blake-Kalff et al., 2003). Like other soil chemical analyses, the amount of mobile sulphur was assessed in spring – just before the establishment of experiments. However, the amounts of mobile sulphur are usually lowest particularly in early spring, since the greatest amounts of sulphates are leaching to deeper soil layers in winter. Beside, the processes of mineralization are slow in early spring due to low soil temperature (Zhao et al., 2003). Moreover, such kind of investigations were carried out in pot trials rather than in natural field conditions. The peculiarities of sulphur transformation in Lithuanian soils were not objects of investigations.

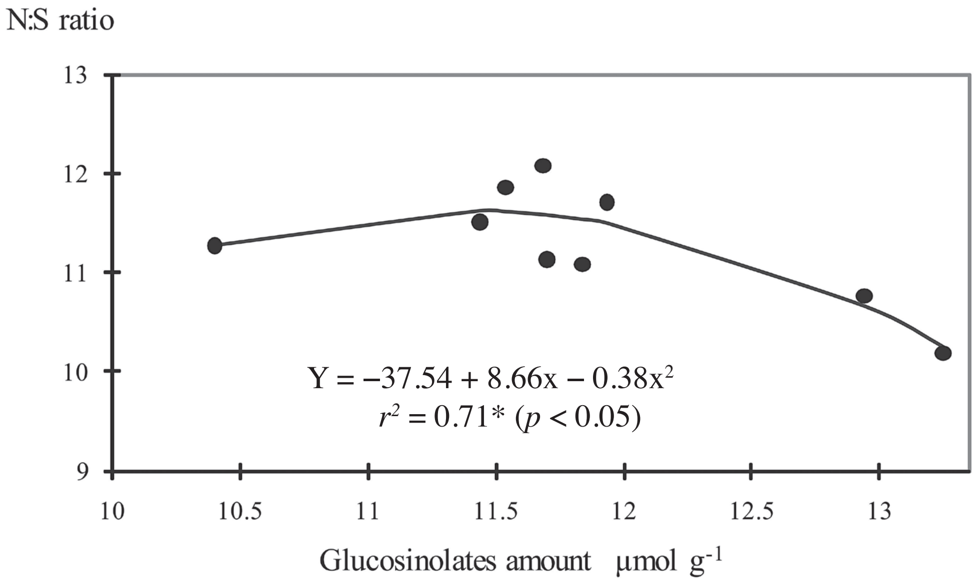

Figure. The correlation between glucosinolate amount and N:S ratio in seeds (average 2004–2005)

Besides, *Epihypogleyic Cambisol* could be supplied with mobile sulphur from decayed pyrites and gypsum during the decay of these minerals, when the mobile sulphur by capillary rise entering root zone. Hereby plants could be better supplied with sulphur from the soil stock than via precipitation (Schnug et al., 2003).

With the purpose of evaluating the importance of sulphur as a nutrient for oilseed rape, a more detailed investigation is required covering the entire growing season, and including all possible available sulphur sources.

Conclusions

1. The concentration of nitrogen and sulphur in oilseed rape highly varied depending on the growing conditions during the experimental years. Nitrogen fertilisation increased the total nitrogen concentration in the above-ground biomass during the growing season, as well as in seeds and straw.

2. Sulphur fertilisation positively affected the sulphur concentration during the growing season in all experimental years. The obvious positive effect on sulphur concentration in seeds and straw was observed in 2003, only. The supply of sulphur was often below critical levels at the pod developing stage and in rape seeds (particularly in 2004 and 2005).

3. Nitrogen fertilisation significantly increased the crude protein content in rape seeds. In 2004 and 2005, the highest crude protein content was obtained having applied 150 kg ha^{-1} nitrogen rate, while in 2005 – 90 kg ha^{-1}.

4. The crude fat content gradually decreased with the increase in nitrogen fertilisation up to 150 kg ha^{-1}. There was a strong, negative correlation between protein and fat contents in seeds.

5. The glucosinolate amount significantly increased through the application of 150 kg ha^{-1} (in 2004) and 90 kg ha^{-1} (in 2005) of nitrogen as well as 40 kg ha^{-1} of sulphur.

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Azoto ir sieros trąšų įtaka vasarinių rapsų elementinei sudėčiai bei sėklų kokybiniams rodikliams

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Santrauka

Straipsnyje aptariami 2003–2005 m. Lietuvos žemdirbystės institute Dotnuvoje, lengvo priemolio karbonatiniame sekliai glėjiškame rudžemyje (RDg8-k2), vykdytų veislės ʻMaskot’ vasarinių rapsų tręšimo tyrimų rezultatai. Jų metu vertinta azoto ir sieros trąšų įtaka rapsų kokybiniams rodikliams.

Azoto trąšų naudojimas vegetacijos metu didino suminio azoto, kai kuriais atvejais – ir sieros koncentraciją augalų antžeminėje dalyje, o pasiekus pilną brandą – sėklose bei šiauduose. Šiais tarpsniais sieros trąšos turėjo esminės teigiamos įtakos sieros koncentracijai augalų antžeminėje dalyje, tačiau esminė teigiama įtaka suminės sieros koncentracijai sėklose ir šiauduose nustatyta tik 2003 m. Sieros trąšų įtaka azoto kaupimuisi augaluose buvo nevienareikšmė. N:S santykis (aprūpinimo siera rodiklis) parodė, kad 2004 ir 2005 m. rapsų sėklose suminės sieros koncentracija galėjo būti nepakankama.

Didžiausias žalių baltymų procentas sėklose buvo šiltesniais ir sausesniais 2003 m. Baltymų kiekio kaupimuisi 2003 ir 2004 m. optimaliausia buvo 150 kg ha^{-1}, o 2005 m. – 90 kg ha^{-1} norma azoto trąšų. Žalių riebalų kiekis sėklose mažėjo (2004 ir 2005 m.) azoto trąšų kiekį didinant iki 150 kg ha^{-1}, o metų klimatinės sąlygos įtakos neturėjo. Palankiausios agrometeorologinės sąlygos gliukozinolatų kaupimuisi buvo 2005 m. Jų kiekis sėklose didėjo patręšus 150 kg ha^{-1} (2004 m.) bei 90 kg ha^{-1} (2005 m.) azoto ir 40 kg ha^{-1} sieros trąšų. Kai kuriais atvejais gliukozinolatų kaupimuisi pastebėta esminė N x S sąveikos įtaka.

Reikšminiai žodžiai: siera, azotas, N x S sąveika, N:S santykis, žali baltymai, žali riebalai, gliukozinolatai.