THE IMPACT OF NITROGEN AND SULPHUR ON SPRING WHEAT PRODUCTIVITY AND THEIR CONTENTS IN GRAIN*

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In order to determine how nitrogen (N) and sulphur (S) fertilizers influence spring wheat cv. 'Munk' productivity, a three-year field studies were carried out at the Lithuanian Institute of Agriculture in Dotnuva, Central Lithuania. The experiments were composed of three N rates (0, 60 and 120 kg ha^{-1}) and three S rates (0, 15 and 30 kg ha^{-1}).Year (or growing conditions) significantly influenced the number of ears per m^2, 1000 grain weight, grain yield ($P \leq 0.01$) and number of grain per ear ($P \leq 0.05$). The highest grain yield (5540 kg ha^{-1} on average) was obtained in moderately cool with optimal moisture regime growing season. N rate increased number of ears per m^2, grain yield, and number of grains per ear ($P \leq 0.01$); however decreased 1000 grain weight ($P \leq 0.05$). S rate positively influenced number of grains per ear ($P \leq 0.05$), only. The use of N60 rate ensured the highest N and S fertilization efficiency (NFUE, SFUE); meanwhile the effect of S rate was inessential for the both mentioned parameters. N and S content in grain highly varied between the years. N120 rate substantially increased N content in grain; the analogous was effect of S30 rate. S application caused a diminishing of N:S ratio, thus substantially improving grain quality.

spring wheat; nitrogen (N); sulphur (S); yield components; fertilization efficiency; grain quality

INTRODUCTION

In the general structure of agricultural crops in Lithuania, spring wheat takes up about 6 percent of all crops. Their area is increasing every year, by cultivating new varieties with at least 5-6 t ha^{-1} grain yields, in addition, winter wheat growing conditions are not always favourable (Petraitis, Baniūnas, 1996). Nitrogen (N) is a key element in ensuring a high level of productivity of Poaceae (Delogu et al., 1998; Balik et al., 1999; Jimenez et al., 2002). However, N nutrition remains a major factor limiting the productivity of wheat under field conditions (Jeufroy, Bouchard, 1999; Salvagiotti et al., 2009), as the optimum N rate is variable and varies depending on the soil, climate conditions, agro-technology and interaction with other nutritional components (Grant, Bailey, 1993; Hrivna et al., 2002).

Nitrogen (N) and sulphur (S) interaction (N × S) is important for plant nutrition due to the presence of S in nitrate reduction and utilization (Khomenko, 1983). Studies show that S and the interaction of N × S had a positive effect on wheat biomass and grain yield (Salvagiotti, Miralles, 2008; Salvagiotti et al., 2009), and N efficiency (defined as seed yield produced per unit of N supplied (Moll et al., 1982). Although cereals have a lower requirement for S, responses to S application of between 5 and 30% obtained in some European countries (Zhao et al., 2002). The data on the effects of N × S interaction on particular cereals yield parameters (particularly on spring wheat), is very limited (Archer, 1974; Haneklaus et al., 1995).

For a long time, insufficient attention was paying for the research of S as a plant nutrient. However, due to increase of plants productivity, increasing use of sulphur-free fertilizers and decreasing of atmospheric deposition of S, the shortage of mobile S in soils (especially in light granulometric texture) was observed in many parts of Europe since the 1980's (Pedersen et al., 1998; Zhao et al., 2002). In Lithuania, the role of S as a nutrient on the productivity of cereals was rarely investigated (Mašauskas, Mašauskienė, 2005).

The role of N to cereals (especially for wheat) productivity is fairly elaborated by many investigators (Petr et al., 1988; Petraitis, Baniūnas, 1996; Janušauskaitė, Mašauskas, 2004; Salvagiotti, Miralles, 2008). Therefore, S fertilization had a greater interest in our experiments. The experiment started with the aim to assess and optimization of N and S fertilization on spring wheat yield's structural parameters and seed quality.

* The study was conducted under the theme of long term program "Plant biopotential and quality for multifunctional practice"

MATERIALS AND METHODS

Studies with spring wheat investigated in the Lithuanian Institute of Agriculture (Dotnuva, Central Lithuania) (latitude: 55°21´00″N and longitude: 23°54´00″E). The soil in the research location was calcaric shallow gleyic Cambisol (Endocalcari-Epihypogleyic Cambisol, CMG-p-w-can) light loam. Each year, soil samples were taken before the trial establishment for the determination of agrochemical characteristics.

Soil pH evaluated potentiometrically. Plant-available phosphorus and potassium from soil were determined by the spectrophotometry and flame spectrometry methods, respectively, in acetate-lactate ammonium solution (AL) at 3.7 pH, by the A-L method. Organic C was determined by the Tyurin method using dichromate oxidation at 160 °C. 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. Total and mobile sulphur – by turbidimetric method, using extracting solution of 1M KCl. Total nitrogen in soil and plants – by Kjeldahl method. The agrochemical characterization in the research site is presented in Table 1.

Meteorological conditions were determined in the Agrometeorology station located 0.5 km from the test location. In 2003, the first half of vegetation was dominated by changes in temperature and precipitation. From mid-July until the end of the vegetation the weather was dry and warm. The sum of active temperatures (over 10 °C) of that year was 1745 °C, precipitation 157 mm. The year 2004 was dominated by wet and cool weather (especially in the second half of the vegetation) and was the most favourable for wheat growth and development. During the vegetation, the sum of active temperatures was 1778 °C, precipitation 249 mm. In 2005, the temperature and moisture regime during the whole vegetation was changeable. Dry and warm weather prevailed from the second half of June until the middle of July; however, the amount of productive moisture in the topsoil was sufficient. Heavy rainfall prevailed at the end of vegetation. In that year, the sum of active temperatures was 1730 °C and precipitation 216 mm.

Research was carried out at a soil where mobile S content was low. Total N, total S content and plant available phosphorus and potassium levels were average (according to A d o m a i t i s , 1998).

Plants were supplied with N via ammonium nitrate and partly ammonium phosphate, and S from potassium sulphate. Potassium chloride used to adjust equal amounts of potassium in each plot. The source of phosphorus was ammonium phosphate. All fertilizers spread in the pre-sowing tillage period.

Spring wheat experiments composed according to two-factorial scheme. Factor A – N rate, and factor B – S rate. The tests consisted of three nitrogen (0, 60 and 120 kg ha^{-1}) and 3 sulphur (0, 15 and 30 kg ha^{-1}) fertilization levels. The rate of phosphorus and potassium was equal for all the treatments – 40 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O. The trials were composed of 9 treatments and 4 replications. The harvested area of spring wheat plots was 20.37 m^2.

Each year, spring wheat cv. 'Munk' was sown in the 3rd ten-day period of April. The seed rate was 240 kg ha^{-1} (~5.5 million viable seeds per ha). The forecrop plant was spring barley. Each year, the weed, pest and disease control was carried out as needed.

Spring wheat was harvested upon reaching full maturity. Each plot was cut off separately using a 'Sampo-500' combine. The grain yield was recalculated to a standard 14% moisture content. Plant samples harvested to determine the structural parameters of the harvest were taken before the harvesting from each plot, in two places (from the area of 0.25 m^2). The following structural parameters of the harvest were identified: number of ears per m^2, number of grains per ear, 1000 grain weight. At full maturity, the amounts of total nitrogen and sulphur in spring wheat grain were evaluated in two replications of each treatment. Grain N:S ratio was calculated from the N and S contents.

N fertilization efficiency (in other terms, the agronomic efficiency) was calculated as follows: (the

Table 1. Soil characteristic for the experimental area

Indicator	2003	2004	2005
pH_{KCl}* (potentiometrically)	6.7	6.0	6.8
Organic C (%)* (Tyurin method)	0.91	0.74	1.24
Total N (%)* (Kjeldahl method)	0.92	0.10	0.14
Mineral N ($N\text{-}NO_3^-$ + $N\text{-}NH_4^+$) (mg kg^{-1})** (colorimetrically)	9.65	8.29	9.10
Total S (mg kg^{-1})** (turbidimetrically)	140	160	125
Mobile S (mg kg^{-1})** (turbidimetrically)	3.5	0.2	3.4
K_2O (mg kg^{-1})* (A-L method)	135	169	149
P_2O_5 (mg kg^{-1})* (A-L method)	133	112	115

* 0–25 cm soil layer; ** 0–40 cm soil layer

obtained grain yield with N fertilizer) – (grain yield without N fertilizer)/N rate (D e l o g u et al., 1998; G a n et al., 2008); SFUE (grain yield per unit of S fertilizer) was calculated by analogy).

The data of all tested parameters were statistically analysed with the method of the analysis of variance (ANOVA) using an option of three-factor randomised replication blocks using the following three factors: year × N fertilizer rate × S fertilizer rate; materiality was determined significant differences between means (*$P \leq 0.05$ and **$P \leq 0.01$), LSD_{05} and LSD_{01} (at 95% and 99% probability levels). The amounts of N and S in spring wheat seeds were evaluated by S_x – the standard error of the mean (SEM) (T a r a k a n o v a s , R a u d o n i u s , 2003).

RESULTS AND DISCUSSION

Analysis of variance was used to evaluate the effect of year (Yr), nitrogen (N rate) and sulphur (S rate), as well as the interactions between these variables to spring wheat yield, number of ears per m^2, number of grains per ear, 1000 grain weight, N and S fertilization efficiency (NFUE and SFUE). The data are presented in Table 2.

According to the Fisher's criterion, the year (Yr) (otherwise, the growing conditions), and the N rate were the main factors that influence the productivity of spring wheat ($P \leq 0.01$). Yr substantially affected the grain yield, number of ears, 1000 grain weight and the NFUE (nitrogen fertilizer efficiency), but had no effect on grain number per ear and the SFUE (sulphur fertilization efficiency). N rate positively interacted with all of the parameters presented in the table ($P \leq 0.01$) with the exception of 1000 grain weight. S rate (as well as Yr × S interaction) was positively influenced the grain number per ear, only.

Mutual interaction of studied factors showed that Yr × N interaction reliably influenced grain yield, number of ears per m^2, 1000 grain weight ($P \leq 0.01$) and the SFUE ($P \leq 0.05$). Yr × N interaction significantly influenced only the number of grains per ear. Many other authors emphasize the significant role of N rate and environmental conditions to yield's productive components (O t t e s o n et. al., 2007). N × S interaction significantly influenced number of grains per ear ($P \leq 0.01$), grain yield, NFUE and SFUE ($P \leq 0.05$). It is worth to notice, that the impact of S rate to spring wheat productivity highly depends of N fertilization.

Besides, the intection of three variables (Yr × N × S) significantly inluenced number of ears per m^2 ($P \leq 0.05$) and number of grains per ear ($P \leq 0.01$).

The effect of N and S on yield components

The mean values of spring wheat yield components as well as their dependence on year (growing conditions), nitrogen (N) and sulphur (S) rates during three successive years are presented in Table 3.

Number of ears per m^2 (or productive tillers) is the most important yield component in cereals productivity. Number of ears per m^2 (or number of productive tillers) was highly influenced by seasonal weather conditions ($P \leq 0.01$). In 2003, the average number of ears per m^2 was lowest among experimental seasons – 358 ears per m^2. In 2004, due to more favorable moisture and temperature regime at the second half of vegetation, plants were able to maintain bigger number of tillers and thus to produce significantly more ears – 418 per m^2. Other researches reported that optimal number of ears of spring wheat per m^2 under light loamy soil conditions (Middle Lithuania) should be from 450 to 550 ears (productive tillers) per m^2 (P e t r a i t i s , B a n i ū n a s , 1996). Without reference to growing conditions, N fertilization significantly influenced number of ears all three experimental ears ($P \leq 0.01$). The significant effect of N to number of productive tillers is reported by many authors (M a s l e , 1985; P e t r a i t i s , B a n i ū n a s , 1996; P e t r et al., 1988). Experimental data agree with consistent pattern that both N fertilization and moisture are most important

Table. 2. Mean squares for wheat yield components, grain yield and N and S fertilization efficiency (NFUE, SFUE) for 3-year analysis

Source of variation	df	Grain yield (kg ha^{-1})	Number of ears per m^2	Number of grains per ear	1000 grain weight	Nitrogen fertilization efficiency (NFUE)	Sulphur fertilization efficiency (SFUE)
Fisher's criterion							
Year (Yr)	2	34.5**	160.0**	0.96	196.31**	13.92**	1.1
N rate (N)	2	123.52**	42.46**	30.68**	1.81	8.48**	15.00**
S rate (S)	1	0.11	0.86	5.98**	1.66	1.12	0.07
Yr × N	4	7.75**	6.89**	2.46	4.06**	0.5	3.10*
Yr × S	2	0.23	1.73	5.43**	0.54	0.3	0.39
N × S	2	3.37*	1.45	3.89**	0.16	4.08*	3.54*
Yr × N × S	4	0.8	2.34*	5.48**	0.28	0.87	0.47

*, ** significant at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively

Table 3. The influence of N and S fertilization on mean values of wheat yield components and grain yield in 2003–2005

Variation	Number of ears per m^2	Number of grains per ear	1000 grain weight (g)	Grain yield (kg ha^{-1})
Cultivation year		means		
2003	358	28.66	46.30	4668
2004	418	27.94	46.72	5540
2005	374	27.89	42.11	5350
LSD_{05}	15.18	0.72	0.30	127
LSD_{01}	20.13	0.95	0.39	168
N rate kg ha^{-1}		means		
N0	352	25.39	45.18	4232
N60	380	29.13	45.19	5398
N120	418	29.98	44.76	5930
LSD_{05}	15.18	0.72	0.30	127
LSD_{01}	20.03	0.95	0.39	168
S rate kg h^{-1}		means		
S0	390	26.96	45.23	5158
S15	375	29.05	45.12	5188
S30	384	28.48	44.78	5212
LSD_{05}	15.18	0.72	0.30	127
LSD_{01}	20.03	0.95	0.39	168

factors, the shortage of which causes the number of productive tillers (or number of ears) (M a s l e , 1985). Although the influence of S application was insignificant to number of ears per m^2, some other researches suggest that S application has a positive hormonal effect by stimulating the formation of a higher number of final ears and hence the higher final grain yield (G a r c i a d e l M o r a l et al., 1999; H u s s a i n , L e i t c h , 2005; S a l v a g i o t t i , M i r a l l e s , 2008).

Number of grains per ear. In 2003, despite the shortage of productive moisture at the second half of vegetation, number of grains per ear reached 28.66, and was highest in comparison with other seasons ($P \leq 0.05$). Perhaps, the smaller number of ears was compensated by relatively higher number of grains per ears to a certain extent. Although spring wheat retained higher level of productive tillers (ears) during 2004 growing season (in comparison with 2003 and 2005), plants were not able to mature higher number of grains in the ears, in spite of favorable weather regime. The susceptive influence of environmental factors (water and temperature regimes) to final number of grains per ear was described by other authors (P e t r et al., 1988). According to the results of the previous investigation, the number of grain in spring wheat ears varied from 38 to 42 (P e t r a i t i s , B a n i ū n a s , 1996). Number or grains increased by increasing N fertilization up to N120 rate ($P \leq 0.05$). The application of S15 significantly affected final grain number ($P \leq 0.01$).

Other researches state that the effect of S on grain number per ear might be the result primarily on the number of grains per ear, indicating that S deficiency either reduces the initiation of spikelet and/or floret, or increases the mortality of florets (Z h a o et al., 1999).

1000 grain weight is the latest forming yield parameter. The mean values were highly influenced by growing conditions. In 2003, 1000 grain weight reached 46.30. In more favorable for growing 2004, 1000 grain weight was highest between the seasons and reached 46.72. In 2005, 1000 grain weight was substantially lower among experimental years and reached 42.11 g. As it was mentioned, heavy amount of precipitation fell to the second half of generative growth. There is a proposition that due to high amount of precipitation at the second half of vegetation, the respiration of already formed grains is increasing, thus total grains weight is decreasing (K o n o v a l o v , 1981). The impact of N fertilization to grain weight was unambiguous in different years. Although the mean values of three years show that N fertilization had a diminishing effect to grain weight. Both the application of N120 and S30 caused the substantial decrease in grain weight ($P \leq 0.01$).

Some authors present the data, which reveal the positive impact of high N rates (up to N150) on 1000 grain weight (F a l l a h i et al., 2008); meanwhile others present entirely opposite results (P e t r a i t i s , B a n i ū n a s , 1996; O t t e s o n et al., 2007). The high variation of 1000 grain weight and dependence on varied environmental factors is reported by many authors as well (P e t r et al., 1988). In crops with marginal S deficiency, application of S may actually decrease 1000 grain weight by producing grain with smaller specific weight (Zhao et al., 1997).

The effect of cultivation year (or growing conditions) on grain yield was significant between experimental years ($P \leq 0.01$). The vegetation period for spring wheat in 2003 was less favorable than in other experimental years. Spring wheat periodically suffered the shortage of soil moisture at 0–50 cm soil layer. Particularly, the hot and dry weather prevailed during generative development stages. Usually, drought and high temperature occur simultaneously. Both stresses affect photosynthesis and related processes in wheat in a number of ways (Shah, Paulsen, 2003). Such meteorological conditions were not beneficial for the wheat grain development, formation and ripening; thus, the average yield was 4668 kg ha^{-1}. It was also found by other investigators that shooting, flowering and maturity stages are most susceptible to soil moisture deficiency (Singh, 1981). Contrarily, moderately cool weather with optimal moisture regime dominated in 2004, thus spring wheat productivity was highest (5540 kg ha^{-1} on average) among three experimental seasons. The weather from flowering until the end of vegetation was cool with optimal moisture amount. In 2005, growing conditions during the generative growing stages were less favorable in comparison with 2004. The average yield was 5350 kg ha^{-1}. Our results in great scale correspond to the findings of other studies carried out in Lithuania because of the different agrometeorological conditions and the same N fertilization level a low or medium variation of 3.0–18.0% of spring wheat yield data are identified, and the optimum rate of N fertilizers is 116 kg ha^{-1} (Janušauskaitė, Mašauskas, 2004). More precise studies in Canada revealed that over 60% of the variability in grain yield was attributed to water supply, with mean grain yield increasing by 16.3 kg ha^{-1} for each millimeter of increase in water use during the growing season (Gan et al., 2000). Nevertheless, despite the fact that an experimental site contained low amount of mobile S, the application of S mineral fertilization just marginally affected yield structure, although positively effected grain quality. Likewise, many authors emphasize that mineral S fertilization positively effects grain S content, meanwhile the effect on grain yield formation is unambiguous (Randall, Moss, 1990; Hussain, Leitch, 2005; Malhi, 2006). It is also known that foliar application of S at 40 and 60 kg ha^{-1} (particularly at tillering stage) caused a significantly higher spring wheat yield grain as well as grain N and S contents comparing with soil S fertilization before drilling. Foliar S application promotes the higher number of tillers and higher green leaf area formation that caused the higher grain yield (Hussain, Leitch, 2005; Salvagiotti, Miralles, 2008). Other authors reported that S requirements for cereals vary from 10 to 30 kg ha^{-1} S (in the form of sulphate-S), with the best response

Table 4. The influence of N and S fertilization on mean values of N and S efficiency (NFUE and SFUE), 2003–2005

Varieties / Cultivation year	NFUE	SFUE
2003	12.62	6.05
2004	23.39	–2.45
2005	14.28	4.30
LSD_{05}	2.55	7.02
LSD_{01}	3.40	9.36
N rates kg ha^{-1}	means	
N0	–	3.49
N60	19.38	18.78
N120	14.15	–14.36
LSD_{05}	1.80	7.02
LSD_{01}	2.40	9.36
S rates kg ha^{-1}	means	
S0	15.12	–
S15	16.75	1.96
S30	18.41	3.31
LSD_{05}	2.55	4.96
LSD_{01}	3.40	6.62

to S fertilization on the lighter soils (Pedersen et al., 1998, Malhi, 2006; Zhao et al., 2002).

Correlation analysis revealed that grain yield correlated strongly and positively with number of ears per m^2 (+0.74) and number of grains per ear (+0.89). Thus, the latest mentioned parameters determined 93.9% of the whole yield's variation. The interdependence of these three parameters was described quantitatively by polynomial equation: y (grain yield) = –4.84 + 0.11x (number of ears per m^2) + 0.21z (number of grains per ear) (Fact. = 46.28**). The correlation between grain yield and 1000 grain weight was unambiguous in different years. Other authors also remark a plausible correlation between grain yield and 1000 grain weight (Talgre et al., 2009).

The effects of N and S on NFUE and SFUE

N fertilization efficiency NFUE (or the agronomic efficiency) much depended on the growth conditions prevailing during the particular year, i.e., the moisture and temperature regimes (Table 4). In 2003, the NFUE (or the agronomic efficiency) values were the lowest – 1 kg of N increased the grain yield by 12.62 kg. During almost the entire growing season the soil moisture was insufficient, so the effects of N fertilizers on the grain growth rate were relatively low. The favorable moisture and temperature regimes during 2004 season increased N efficiency almost twice – 1 kg of

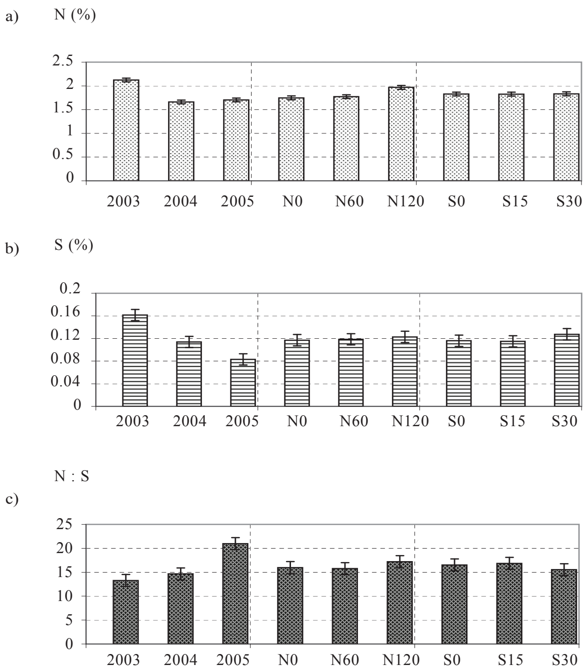

Fig. 1. The influence of N and S fertilization on mean values of N (a), S (b) and N:S (c) ratio in grain, 2003–2005

N increased grain yield by 23.39 kg. In comparison with 2004, N fertilization efficiency substantially decreased in 2005; although the mean grain yield was only by 4.32% lower.

In all three years, the highest NFUE value was obtained using the average – N60 rate ($P \leq 0.01$). Using the N120, the N fertilization efficiency was substantially reduced. With the increasing N rate, the NFUE is gradually declining, whereas N is no longer a limiting factor to plants (D e l o g u et al., 1998). The impact of S was not statistically reliable, although the use of S was significant for N efficiency in some cases. According to other authors, S fertilization has a positive impact on NFUE values, especially when N was not a limiting factor, showing a positive interaction between these two nutrients in a higher NFUE (S a l v a g i o t t i, M i r a l l e s, 2008; S a l v a g i o t t i et al., 2009).

It is estimated, that approximately 45.4% of Lithuanian soils contain small amount of S (bellow 6.0 mg kg^{-1}) of mobile S, (M a ž v i l a et al., 2007). Although the amount of mobile S in the experimental site was low, the effect of S fertilization on SFUE significantly varied in large-scale throughout three years period. In comparison with N fertilization efficiency, sulfur fertilizer efficiency (SFUE) had completely the opposite character. Thus in 2003, SFUE was highest in the experimental years and reached 6.05. Conversely in 2004, the mean value of SFUE was lowest between seasons and decreased below zero –2.45. N60 rate significantly and positively increased S fertilization efficiency –18.78 ($P \leq 0.01$). On the contrary, the use of highest N120 rate caused the hasty decrease of SFUE –14.36. In other words, grain yield had a diminished tension.

Although the amount of mobile S deficiency was low in soil of the experimental site, the effect of S fertilization on SFUE was not significant. The highest effect to SFUE was reached by application of S30 rate – the use of 1 kg of S produced 3.31 kg grain yield; however the increment was not statistically reliable at 95% level of significance.

We can suggest, that the use high mineral fertilization rates (particularly S) and therefore their low or negative impact to grain yield indicates the low production profitability or loss-making outcome due to high expenses for mineral fertilizers.

The effects of N and S on N, S content and N:S ratio in grain

The variation of N and S contents in grain as well as N:S ratio is presented in Fig. 1. The highest N content in spring wheat grain was in drier and less productive 2003 –2.12%, on average (Fig. 1a). On the contrary, under more favorable growing conditions in 2004 and 2005, the N content in grain was lower –1.66% and 1.70%, respectively. The use of highest N120 rate caused the substantial increase of N content in grain –1.98%. The rule of S fertilization to N content in grain had a negligible character. It could be explained by the fact that increase of grain yield usually decreases N (or protein) content of the grain due to the dilution of N by the increased biomass (C l a r k e et al., 1991; G a n et al., 2000).

S content in wheat grain sharply decreased from 0.16% (in 2003) to 0.08% (in 2005) (Fig.1 b). Thereby in the last experimental year, the mean S content in grain was below the critical level of 0.12%. S30 rate substantially increased S content in grain (up to 0.13%), meanwhile the influence of N rates to S content in grain was less noticeable. The most frequently used indicator of S sufficiency is the N:S ratio, which is based on the interactions between N and S metabolism (Z h a o et al., 2002). The values of N:S ratio in grain were inversely proportional to grain S content (Fig. 1c).

The results of our experiments correspond to the conclusions of other authors, that grain S application increases S content and decreases N:S ratio (Z h a o et al., 1999; 2002). Since S ir a constituent of amino acids (cysteine and methionine), it has a great importance for bread baking quality. If S content in grains is lesser than 0.12% and N:S ratio wider than 17:1, such the indicators lead to excessively tough flour and lower baking volumes (H a n e k l a u s et al., 1992). Although it is stated that grain S content is largely unaffected by temperature regime, both S and high temperatures are closely linked and significantly improves rheological properties of dough and breadmaking quality (Randall, Moss, 1990; Zhao et al., 1999). These indicators were not investigated in our experiments. Some authors assert that S and N:S ratio better than N content in grain reflects bread baking qualitative indicators (Zhao et al., 1997).

It is worth to emphasize that despite the low content of mobile S in the soil and insufficient S content in grain, there were no visible external symptoms of S deficiency. Nevertheless, the data of three years; results indicate that the use of high N rate without S fertilization could significantly impair wheat grain quality.

The influence of S is harder to notice, because without S fertilizer, spring wheat can utilize a significant part of the required S from other sources. A large part of the S is accumulated in soil organic matter (about 90% of the total soil S), which decomposes and the released mobile S becomes available to plants (McGill, Cole, 1981). A large part of S can reach soil surface through the air with the rain (Marschner, 1995). Although during the last 2–3 decades many European countries reduced significantly the average S emission, S emission via air and precipitation in our experimental site was unknown. The shortage of S as a nutrient is easily noticeable in soils of lighter texture with higher mineralization levels and where S available to plants is quickly leached out into deeper layers (Zhao et al., 2002). The soil analyses (including mobile S) were done in spring – just before the drilling. The amounts of mobile S are usually lowest particularly in early spring, because the processes of S mineralization are slow in early spring due to low soil temperature (Zhao et al., 2002).

Therefore, considering the levels of supply of wheat crop with S, considering the efficiency of mineral S fertilizer and their need for a particular area, it is worthwhile to evaluate all the main sources of sulphur access to the plants.

CONCLUSIONS

According to the results of three years' at the Lithuanian Institute of Agriculture, on a sod gleyic loam soil, we can conclude that both cultivation years (growing conditions) and N rate were determinants for spring wheat cv. 'Munk' productivity. Cultivation year significantly influenced number of ears per m^2, 1000 grain weight, grain yield ($P \leq 0.01$) and number of grains per ear ($P \leq 0.05$). The use of N120 rate substantially increased number of ears per m^2, grain yield ($P \leq 0.01$) and grain number per ear ($P \leq 0.05$); however, decreased 1000 grain weight ($P \leq 0.01$). The effect of S to yield formation was less noticeable. Except the substantial influence of S15 rate on number of grains per ear, there was no reliable influence of S fertilization to other yield components. Number of ears per m^2 and number of grains per ear determined 93.9% of the whole yield's variation. N and S fertilization efficiency (NFUE and SFUE) highly varied between cultivation year and N rate. N60 rate positively and substantially affected the increase of NFUE and SFUE ($P \leq 0.01$).

NFUE and SFUE values were sharply diminished by the application of N120 rate. Neither NFUE nor SFUE were affected by S fertilization. N and S content in grain were markedly influenced by the growing conditions. The highest was influence of N120 rate, which substantially increased N content in grain in all three years. Although the S application just marginally affected wheat yield components and the final grain yield, there was substantial effect on grain quality in all three years. The use of S30 rate substantially increased grain S content and decreased N:S ratio, which is often used as an important indicator of S deficiency.

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Vliv dusíku a síry na produktivitu jarní pšenice a obsah těchto prvků v zrnu

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K určení vlivu dusíkatého a siřičitého hnojení na produktivitu jarní odrůdy pšenice cv. Munk, byly založeny tříleté pokusy na Litevském ústavu zemědělství Střední Litva. V experimentu byly použity 3 dávky dusíku (0, 60 a 120 kg ha^{-1}) a tři dávky siřičitého hnojení (0, 15 a 30 kg ha^{-1}). Ročník (nebo vegetační podmínky) značně ovlivnily počet klasů na 1 m^2 , hmotnost 1000 zrn, výnosnost ($P \leq 0{,}01$) a počet zrn za rok ($P \leq 0{,}5$). Nejvyšší výnos zrna (5540 kg ha^{-1} v průměru) byl dosažený za mírně studených podmínek s optimální vlhkostí. Dusíkaté hnojení zvýšilo výnos klasů na 1 m^2, výnos zrna a počet zrn na klas ($P \leq 0{,}01$), i když se snížila jenom hmotnost tisíc zrn ($P \leq 0{,}05$). Siřičité hnojení podstatně ovlivnilo počet zrn na klas. Použití dusíkatého hnojení v dávce 60 kg ha^{-1} zajistilo nejvyšší účinnost dusíkatého a siřičitého hnojení (NFUE, SFUE); zatímco účinek siřičité dávky nebylo podstatné pro oba uvedené parametry. Obsah dusíku a síry v zrně se značně měnil v průběhu pokusů. Dávka dusíku 120 kg ha^{-1} podstatně zvýšila obsah dusíku v zrně; analogický byl i účinek dávky siřičitého hnojení 30 kg ha^{-1}. Aplikace síry sice snížila poměr N:S, ale podstatně zlepšila kvalitu zrna.

jarní pšenice; dusík (N); síra (S); výnosové hodnoty; účinnost hnojení; kvalita zrna

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