Spring malt barley response to elemental sulphur – the prognostic value of N and S concentrations in malt barley leaves

W. Grzebisz, K. Przygocka-Cyna

Department of Agricultural Chemistry, Agricultural University, Poznań, Poland

ABSTRACT

The basic concept of malt barley production is to reach a dilution effect of nitrogen accumulated by grains at maturity. A three-year study was undertaken to establish time courses of nitrogen (N) and sulphur (S) in leaves as the prerequisite tool for total grain yield prognosis. Sulphur application at the lowest rate of 25 kg/ha significantly increased yields of grain in 2001 and 2003. The time course of N and S concentrations in leaves over the growing season showed declining trends for N and variable for S. At mid tillering (BBA-25) both N and S, but at BBA-31 only N concentrations significantly responded to S rates, and in turn affected patterns of N concentration in barley organs up to maturity. Sulphur concentrations and N:S ratios were useful tools to make reliable prognosis of total grain yield of barley at BBA-31 as indicated by the obtained regression equations. The threshold values for N and S in leaves in order to achieve the maximum total grain yield are 0.4% for S and 8.0 for the N:S ratio as presented by the graphical procedure.

Keywords: malt barley; nitrogen; leaves; sulphur concentrations; N:S ratio; total grain yield prognosis

In the last two decades crop plants grown in many regions of the world, including Central Europe, have experienced a deficiency of S (Scherer 2001). The metabolism of S is highly interrelated with N and in turn significantly affects internal nitrogen use efficiency. Consequently, sulphur deficiency in crop plants has become one of the most important challenges in the efficient use of nitrogen resources in crop production. Therefore, each diagnostic procedure for identifying S deficiency should take into account both nutrients, as has been found for wheat (Zhao et al. 1999, Anderson and Fitzgerald 2001).

In the last 50 years, several analytical and diagnostic tools have been developed for determining S deficiency, such as total S or/and sulphate concentrations in plant organs and the N:S ratio. The classical concept of nutrient deficiency assumes restriction or even reduction in plant growth rate for a given nutrient when its concentration drops below the defined range or value, termed the critical value/range (Benton Jones et al. 1991, Schnug and Haneklaus 1998, Zhao et al. 1999).

The main objectives of the current study were to determine N and S concentration patterns in leaves and N:S ratio in the time course of malt barley growth and to evaluate the S concentration and the N:S ratio as prognostic tests for the total grain yield of harvested barley.

MATERIAL AND METHODS

Field experiments were conducted in three consecutive growing seasons, i.e. 2001, 2002 and 2003 in Sielinko, a village located in the south-west of Poznań, Poland (52.40°N, 16.90°E). Soils at the experimental site are loamy sands, classified as Albic Luvisols (LVa). All details of agrochemical characteristics of soils under experiments are reported in Table 1.

The experimental treatments consisted of factorial combinations as follows:

(1) Two types of S fertilizers:
(a) elemental sulphur (S° – 87%),
(b) elemental sulphur with sulphate (S° + SO_4, 80% + 5%).
(2) Four rates of S (0, 25, 50 and 100 kg/ha).

All the treatments were replicated 4 times in a randomized block design.

Table 1. Agrochemical characteristics of soils at experimental plots

Year	pH	P^1	K^1	Mg^2	$S\text{-}SO_4{}^3$	$N_{min}{}^4$ (kg/ha)
		(mg kg/g soil)				
2001	7.1	147	124	64	23	58.6
2002	6.7	121	310	97	81	49.2
2003	7.1	107	262	103	96	52.6

Methods: [1]Egner-Riehm, [2]Schachtschabel, [3]turbidometric, [4]Kjeldahl-distillation

The covariety Brenda, following white mustard in rotation, was sown at the end of March (3/III). Phosphorus and potassium fertilizers were applied during the previous autumn (1/XI) at the rates of 35 kg P and 100 kg K per ha. Nitrogen was applied as ammonium nitrate (34%) at one rate, amounting to 60 kg/ha, just before sowing. Herbicides and all other agro-technologies were performed according to standard practices.

At maturity (1/VIII), crops were harvested from the area of 9 m^2 using a plot combine-harvester. Total grain yields were adjusted to 14% moisture content. For the purposes of this study, plants were sampled during the growing season from an area of 0.25 m^2 at 8 consecutive stages of barley growth according to the BBA scale: 25, 31, 37, 49, 65, 75, 85 and 91. At each stage the harvested plant sample was partitioned according to its stage of development into subsamples of leaves, stems, ears, grain, and then dried (65°C). The concentration of total N in barley organs was determined for each plant organ using the Kjeldahl method (Kjeltec Auto Distillation). For the determination of S in plant samples the turbidometric method was used (Bardsley and Lancaster 1960). The concentrations of N and S in all organs are expressed on a dry matter basis.

The obtained data were subjected to conventional analysis of variance and simple regression. Least significant difference values (LSD at $P = 0.05$) were calculated to establish the significance of mean differences. The Cate-Nelson graphical procedure was used to evaluate the critical concentration of S and the N:S ratio in barley plants (Nelson and Anderson 1977).

RESULTS AND DISCUSSION

Total grain yield

Total grain yields of malt barley harvested from the S control treatment plots, i.e. fertilized with 60 kg N/ha, varied from about 2.7 t/ha in 2002 up to 4.1 t/ha in 2001 (Table 3). A high seasonal variability of total grain yields is generally attributed to the impact of stress factors such as water deficiency and high temperatures (Eagles et al. 1995, Garcia del Moral et al. 1999). In the conducted study the optimum set of temperatures was noted only at tillering stage (optimum temperatures at critical stages of barley growth are as follows: 5–6°C for germination, 8°C for tillering, 12–15°C during shooting and 15–18°C

Table 2. Meteorological characteristics of the malt barley growing seasons

		March	April	May	June	July
Temperature (°C)	2001	5.3	8.1	14.8	15.3	20.3
	2002	5.1	8.8	16.7	18.3	20.4
	2003	3.4	8.2	16.0	19.8	19.6
	1960–2000	2.7	7.5	12.8	16.2	17.7
Precipitations (mm)	2001	31.0	37.3	34.7	75.6	53.4
	2002	58.1	33.2	48.9	52.6	40.6
	2003	19.9	21.1	20.1	35.0	96.7
	1960–2000	34.8	38.9	54.6	65.0	77.1

Table 3. Effect of sulphur fertilizers and S rates on total grain yield (t/ha)

Factor	Level of factor	Total grain yield		
		2001	2002	2003
Fertilizer type	S°	5.00	3.36	3.96
	S° + SO_4	4.92	3.27	4.35
$LSD_{0.05}$		–	–	–
S rates (kg/ha)	0	4.14	2.86	2.68
	25	5.18	3.23	5.32
	50	5.19	3.63	4.91
	100	5.33	3.54	3.70
$LSD_{0.05}$		0.695	–	0.732

during grain filling). At shooting stage in 2002 and 2003, temperatures were much higher than the required optimum (Table 2). In addition, the optimum set of precipitations was only noted in 2001. In 2002, malt barley yield was affected by a low amount of precipitation during the grain filling period and in 2003 at shooting. The low grain yields in 2002 can be explained by a negative effect of both high temperatures and low precipitation during grain filling, which are decisive external factors for the length of grain filling period (Savin et al. 1997). However, as indicated by yields harvested on the S control treatment plots in 2003, the critical period for barley growth and yielding should be extended down to shooting.

In the present study, sulphur S fertilizers based on elemental sulphur were applied to increase N yielding effects. Barley plants receiving both N and S responded to environmental factors in quite different manner than those fertilized only with N. It was also found that harvested total grain yields showed no response to the type of applied S fertilizer but were significantly affected by the year and S rates interaction (Table 3). In the first year of our study (2001), a significant yield increase in comparison to the S control treatment was noted for the lowest S rate, i.e. 25 kg S/ha; it increased grain yield up to 5.18 t/ha. In the second year (2002), the highest grain yield amounting to 3.63 t/ha (27% increase in comparison to the control plot) was noted for the 50 kg S/ha treatment, but it was not significant. In the third year (2003), yields of barley were significantly affected by all S rates and the highest yield increase was obtained on plots fertilized with 25 kg S/ha and amounted to 5.32 t/ha (99% increase in comparison to the control plot). The high yield increase was not surprising; quite recently, Potarzycki (2003, personal communication) reported a yield increase of malt barley of over 1.0 t/ha due to S application in the form of single superphosphate.

Nitrogen and sulphur concentration patterns in leaves

Yielding effect of sulphur application on grain yields was conspicuous. It can be explained only by a detailed evaluation of nitrogen and sulphur characteristics of barley organs during the course of plant growth. The time course of N concentration in barley leaves, as the main indicatory organ, was typical for such a nutrient as nitrogen. As expected, the maximum N concentration occurred in the very early stage of barley growth, i.e. at mid-tillering (BBA 25), and then systematically declined reaching the lowest value at the stage of grain soft dough (Table 4). The effect of applied S on N concentration pattern was quite evident, as indicated by a significant increase in N concentration at the beginning and also a significant decline at the end of barley growth, in comparison to the S control treatment. The optimum N concentration in barley plants at BBA-31 is assumed to be in the range of 2.0–5.0% dm (Benton Jones et al. 1991). In the conducted study, the N concentrations in barley plants grown on the S control treatments in two consecutive stages, i.e. at BBA-25 and BBA-31, were 3.4% and 3.1%, respectively; those fertilized with S amounted to 3.8% and 3.4%, respectively. However, the switch point of the developed patterns of N concentration took place in much later stages, i.e. from flowering (BBA-65) to mid-milk grain growth (BBA-75). At this particular period, plants fertilized with S decreased N concentration in leaves in a significantly faster rate than those fertilized only with N. Hence, at the end of the vegetation (BBA-91), leaves from S treated plants contained significantly lower amount of N than those from the control, i.e. fertilized only with N. This phenomenon can be explained by a higher rate of grain growth and a higher amount of easily hydrolyzed leaf proteins of S treated plants. The first hypothesis assumes a higher rate of C accumulation in barley grains, which is a prerequisite both for higher grain yield and lower grain N concentration (Table 3).

The general time course of sulphur concentration in leaves of barley plants was quite different

Table 4. Total nitrogen concentration in barley leaves in the course of the growing season (% dm)

Factor	Level of factor	Growth stages of barley, according to the BBA scale							
		25	31	37	49	65	75	85	91
Sulphur fertilizers	S°	3.62	3.27	3.32	2.60	2.42	1.74	1.06	1.08
	S° + SO_4	3.76	3.35	3.41	2.64	2.31	1.67	1,06	1.10
$LSD_{0.05}$		–	–	–	–	*	–	–	–
S rates (kg/ha)	0	3.40	3.07	3.32	2.51	2.30	1.82	1.11	1.15
	25	3.78	3.29	3.44	2.59	2.33	1.68	1.04	1.09
	50	3.69	3.42	3.34	2.69	2.41	1.62	1.06	1.06
	100	3.89	3.47	3.37	2.69	2.43	1.71	1.03	1.06
$LSD_{0.05}$		0.231	0.262	–	–	–	–	–	0.058
Year	2001	4.79	3.00	3.30	2.84	2.38	1.35	1.48	1.45
	2002	2.95	3.13	2.78	2.26	2.13	1.95	0.88	0.87
	2003	3.33	3.80	4.02	2.75	1.16	1.82	0.82	0.95

*within treatment and years

than that found for nitrogen (Table 5). Sulphur concentration in barley leaves increased up to the stage of barley growth when flag leaf was just visible (BBA-37) and then systematically decreased up to full ripening (BBA-91). The found pattern of S concentration in leaves indicates that the BBA-37 stage is of a great importance for nutritional homeostasis of barley plants. In three consecutive stages, i.e. BBA-25, BBA-31 and BBA-37, plants grown on the S control treatments contained 0.14%, 0.19% and 0.35% of total S, but those fertilized with 50 kg S/ha 0.19%, 0.31% and 0.40%, respectively. As indicated by the data from the BBA-31, barley plants fertilized with elemental S were able to reach the supposed S homeostasis earlier than those supplied only from soil S resources. This result is supported by the well know fact that sulphate ions availability is directly related to soil moisture conditions over the growing season (Scherer 2001).

Table 5. Total sulphur concentration in barley leaves in the course of the growing season (% dm)

Factor	Level of factor	Growth stages of barley, according to the BBA scale							
		25	31	37	49	65	75	85	91
Sulphur fertilizers	S°	0.18	0.30	0.39	0.26	0.24	0.24	0.20	0.20
	S° + SO_4	0.18	0.29	0.39	0.27	0.25	0.23	0.20	0.21
$LSD_{0.05}$		–	–	–	–	–	–	–	–
S rates (kg/ha)	0	0.14	0.19	0.35	0.23	0.24	0.22	0.18	0.19
	25	0.19	0.31	0.39	0.26	0.24	0.24	0.21	0.20
	50	0.19	0.31	0.40	0.26	0.24	0.23	0.21	0.20
	100	0.21	0.38	0.42	0.33	0.26	0.25	0.21	0.20
$LSD_{0.05}$		0.189	*	0.026	*	–	*	0.013	0.013
Year	2001	0.31	0.44	0.51	0.22	0.21	0.22	0.11	0.13
	2002	0.11	0.15	0.30	0.24	0.21	0.19	0.22	0.22
	2003	0.11	0.30	0.36	0.35	0.31	0.30	0.27	0.27

*within treatment and years

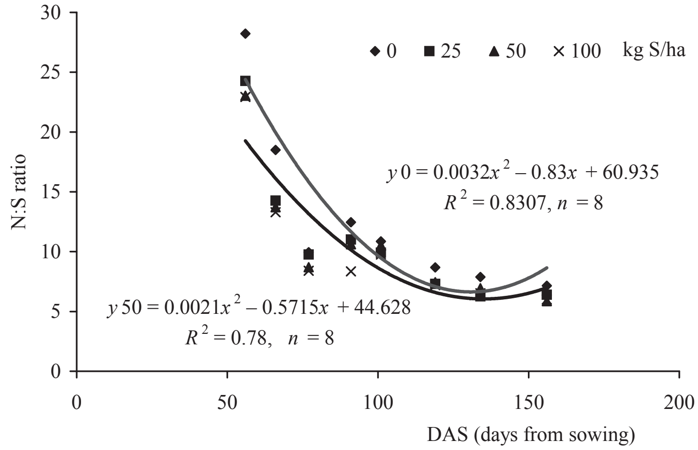

Figure 1. Effect of S fertilization on the pattern of the N:S relationship in leaves of malt barley during the vegetation

The time course of the N:S ratio in leaves was not constant in the consecutive stages of barley growth. During barley vegetation the time dependent N:S courses followed the same general pattern and were described by the quadratic regression model (Figure 1). Based on the consecutive sets of N:S ratios, the growing season of barley growth can be divided into 2 main phases using two line crossing models, irrespective of S rates (detailed data available by the authors). The first part of the developed models, mainly related to the vegetative growth of barley organs (leaves and stems), extended up to the BBA-37 and showed extremely high rates of the N:S ratio decline, which significantly responded to S rates. For plants grown on the S control treatment plot, the N:S ratio decreased from 28 at BBA-25 to 10 at BBA-37. At the same time for plants fertilized with 50 kg S/ha decreased their N:S ratio decreased from 23 to 8. In the second part of the growing season, initiated when first awns were visible (BBA-49) and related to the growth of generative organs (ears), the N:S ratios declined progressively, irrespective on S fertilizer rates, reaching the N:S ratio below 7.0 at maturity.

Yield prognosis

In the present study, malt barley plants responded significantly to the applied S as indicated both by (i) response of basic nutritional characteristics such as N, S, N:S and (ii) total grain yield. In the prognostic procedures for identifying nutrient

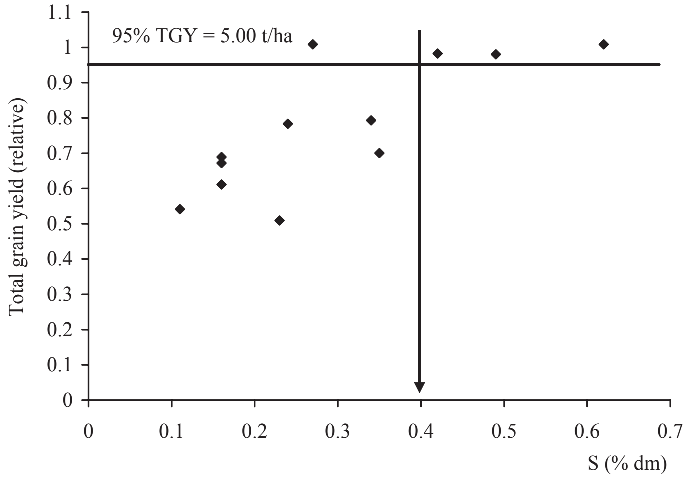

Figure 2. The scatter diagram of relative yields of total grain malt barley versus S concentration in barley plants at BBA-31

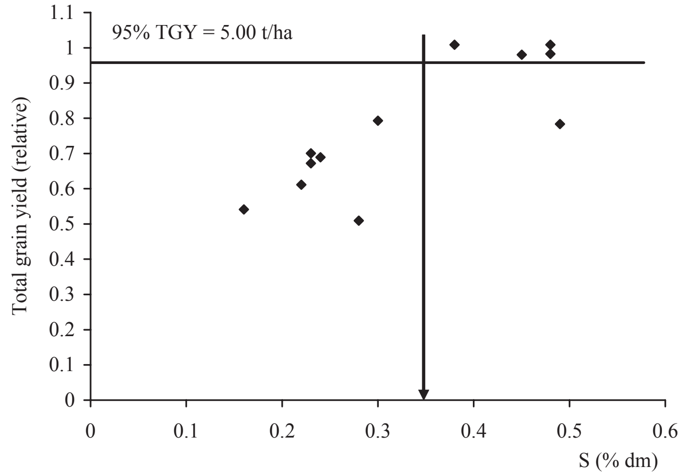

Figure 3. The scatter diagram of relative yields of total grain malt barley versus S concentration in barley plants at BBA-37

deficiencies, leaves are the most frequently used plant organ. The obtained data concerning total S concentrations and N:S ratios are of great value for making reliable prognosis of total malt barley yield. First, the best fit of experimental data to total grain yield was found at two stages of barley growth, i.e. BBA-31 and BBA-37. The first one is of great practical value for farmers in order to take remedial action if it is necessary. Some regression models of almost the same reliability were developed on the basis of S concentrations and N:S ratios:

BBA-31 for S: $y = 0.95x + 0.47$ for $n = 11$ and $R^2 = 0.76$

BBA-31 for N:S: $y = -0.020x + 1.05$ for $n = 11$ and $R^2 = 0.73$

where: y – relative grain yield of barley (100% = 5.28 t/ha, i.e. mean of the 4th quartile of yearly yields of all S rate treatments), x – S, or N:S ratio, % dm for S

These two equations are only the first step of the S nutritional standards evaluation for malt barley. The obtained linear model does not allow calculating the optimum S concentration for forecasting the maximum total grain yield. In the second step of yield evaluation, the Cate-Nelson procedure was applied (Nelson and Anderson 1977) to determine the critical value of S concentration or the N:S ratio. Based on the elaborated scatter diagrams barley plants were found to suffer due to S deficiency, when their leaf S concentration at BBA-31 will be lower than 0.4% (Figure 2). This conclusion was supported by the analytical procedure repeated with stems one stage later, i.e.

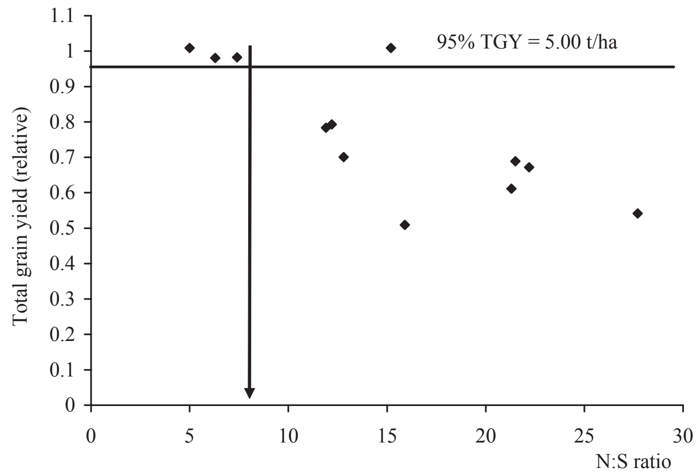

Figure 4. The scatter diagram of relative yields of total grain malt barley versus N:S relationships in barley plants at BBA-31

at BBA-37; the threshold S value of 0.35% was delimited there (Figure 3).

Nutritional diagnosis based on total S concentration was supported by N:S ratio indices. In that case, however, the relative barley yields were inversely related to the N:S ratios, i.e. the higher the ratio, the lower yields can be expected (Figure 4). At the beginning of the shooting stage, the threshold value of the N:S ratio was fixed at 8.0. The found N:S critical values are twice as low as frequently published data for cereals, for example fixed at 17.0 as found for wheat (Zhao et al. 1999) at the stage of just visible flag leaf (BBA-37). In the present study at this particular stage of malt barley growth the optimal N:S value amounted only to 10.0. The obtained experimental data were used to predict the critical N value in barley leaves needed at BBA-31 to reach the maximum total yield of grain. It was calculated that N concentration of 3.2% was sufficient to produce 5.3 t/ha of total grain yield. At BBA-37 the threshold N:S ratio should not be lower than 6.5 and the highest N concentration 2.3%. All these data sets are aimed at providing the maximal total grain yield, which amounted to 5.3 t/ha in the present study.

REFERENCES

Anderson J., Fitzgerald M. (2001): Physiological and metabolic origin of sulphur for the synthesis of seed storage proteins. J. Plant Physiol., *158*: 447–456.

Bardsley C.E., Lancaster J.D. (1960): Determination of reserve sulfur and soluble sulfates in soils. Soil Sci. Soc. Am. Pro., *24*: 265–8.

Benton Jones J., Wolf B., Mills H.A. (1991): Plant Analysis Handbook. Athens Georgia, USA.

Eagles H.A., Bedggood A.G., Panozzo J.F., Martin P.J. (1995): Cultivar and environmental effects on malting quality in barley. Aust. J. Agr. Res., *46*: 831–844.

García del Moral L.F., De la Morena I., Ramos J.M. (1999): Effects of nitrogen and foliar sulphur interaction on grain yield and yield components in barley. J. Agron. Crop Sci., *183*: 287–295.

Nelson L., Anderson R. (1977): Partitioning of soil test – crop response partitioning. In: Soil Testing: Correlating and Interpreting the Analytical Results. ASA Spec. Publ., No. 39: 19–38.

Savin R., Stone P., Nicolas M., Wardlaw I. (1997): Effects of short period of drought and high temperature on grain growth and starch accumulation by malting barley cultivars. Aust. J. PIant Physiol., *23*: 201–210.

Scherer H.W. (2001): Sulphur in crop production. Eur. J. Agron., *14*: 81–111.

Schnug E., Haneklaus S. (1998): Diagnosis of sulphur nutrition. In: Schnug E., Beringer H. (eds.): Sulphur in Agroecosystems. Kluwer Academic Publ., Dordrecht: 1–38.

Zhao F., Hawkesford M., McGrath S. (1999): Sulphur assimilation and effects on yield and quality of wheat. J. Cereal Sci., *30*: 1–17.

Received on May 2, 2007

Corresponding author:

Prof. Dr. Witold Grzebisz, Agricultural University, Department of Agricultural Chemistry, ul. Wojska Polskiego 28, 60-637 Poznań, Poland
e-mail: witegr@au.poznan.pl