PROJECT REPORT No. 251

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YIELD AND MALTING
QUALITY OF WINTER AND
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EFFECTS OF SULPHUR ON YIELD AND MALTING QUALITY OF WINTER AND SPRING BARLEY

by

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CONTENTS

Summary

The aim of this project was to obtain preliminary information on the effect of S on grain yield of barley, and on the relationship between S and a suite of malting quality parameters. The spring barley variety Chariot was grown in a pot experiment that tested the effects of S additions to a S-deficient soil. The winter barley variety Regina was grown in a field experiment at Woburn in the 1999-2000 season.

Both pot and field experiments showed that grain yield of barley was reduced considerably by S deficiency. In the field experiment, grain yield was increased by 1.1 t ha^{-1} (34.9%) in response to S applications. Unusually in this experiment, Thiovit gave a better response than gypsum. Also in the field experiment, S applications significantly decrease grain N concentration from 1.95% to below 1.8%, probably due to a dilution effect as a result of increased crop growth.

Results of malting tests were not conclusive. In the pot experiment, two grain samples with high S concentrations appeared to be more easily modified during malting than a grain sample with low S concentration, as indicated by higher rootlet growth and higher concentrations of soluble N and sugars in the malt extracts. In the field experiment, the effects of the S treatments were not significant for all of the malting parameters tested. However, wort colour and malt steeliness appeared to increase with increasing S concentration in the barley grain, whereas malt homogeneity appeared to decrease slightly with increasing S in the grain.

1. Introduction

National sulphur (S) emissions have been decreasing more rapidly than expected over the last few years. As a result, S deficiency in cereals has increased rapidly in the major cereal growing areas in the UK. An HGCA-funded project, completed recently (McGrath *et al.*, 1999), showed clear benefits of S fertilisation on yield and breadmaking quality of winter wheat. Grain S concentration was found to correlate better with loaf volume and grain protein concentration (Zhao *et al.*, 1999a, 1999b). This is because S affects the composition of gluten proteins, resulting in more extensible dough made from S rich grain. That project (Project 1221, HGCA Project report No. 197) showed that about 30% and 60% of the field trials with winter wheat responded significantly to S additions in terms of yield and breadmaking quality, respectively.

Most of the previous work on S nutrition has focused on oilseed rape and winter wheat. Barley is often grown on light soils, which are most susceptible to S deficiency. There is very limited information available on the S requirement and yield responses of barley. In particular, we know little about the potential effects of S on malting quality. It is possible that S could affect malting quality in several ways. First, a severely deficient crop may produce grain that has low germination energy. Second, S is likely to affect protein composition of barley grain, thus influencing enzyme modification (breakdown) of the starchy endosperm during malting. Third, S may influence packing of protein and starch granules in endosperm, thus affecting the steeliness/mealiness of grain. Finally, many enzymes are involved in the breakdown of starchy endosperm during malting.

The aim of this project was to obtain preliminary information on the effect of S on grain yield of barley, and on the relationship between S and a suite of malting quality parameters. The project utilised barley grain samples from a field experiment and a pot experiment that had already been set up by researchers at IACR-Rothamsted.

2. Materials and Methods

2.1 Pot Experiment

A pot experiment was conducted during 1999. The malting spring barley variety Chariot was grown. The experiment used a sulphur-deficient soil from Woburn, which contained 2.5 mg kg^{-1} extractable SO_4-S. Soil was air-dried and 4.5 kg was weighed and placed in each pot. There were four rates of S additions: 0, 10, 50 and 150 mg S pot^{-1}, applied as potassium sulphate. Potassium was balanced by additions of KCl. Each treatment was replicated in 10 pots. Basal nutrients included (in mg pot^{-1}): 500 mg N (NH_4NO_3), 100 mg P (KH_2PO_4), 492 mg K (KH_2PO_4, KSO_4 or KCl), 10 mg Fe, 10 mg Mn, 4 mg Zn, 2 mg Cu, 2 mg B and 1 mg Mo. Nutrients were dissolved in solutions and mixed with soil thoroughly. Pre-germinated seeds were sown on 9th March 1999. Plants were grown in a greenhouse with the following conditions: 16h/8h day/night and 16^{o}C/12^{o}C day/night temperature.

Plants were harvested at crop maturity (23 June 1999). Grain was air-dried and weighed. Subsamples of grain were dried at 80^{o}C, and ground to fine powder. Total S concentration was determined by ICP after digestion with a mixture of HNO_3 and $HClO_4$. The grain samples from the S0 treatment were too small to allow micro-malting tests. For the S10, S50 and S150 treatments, individual replicates were bulked to produce a sufficient sample size for each treatment for micro-malting tests.

2.2 Field Experiment

A field experiment was set up at Woburn in the 1999-2000 season to test the yield response of a winter malting barley variety (Regina). The soil contained 2.1 mg kg^{-1} SO_4-S. The experiment included five treatments: 0, 10, 20 and 40 kg S ha^{-1}, applied as gypsum, and 20 kg S/ha applied as a micronised elemental S (Thiovit). The treatments were replicated in 4 plots (12 x 4 m) in a randomised block design, giving a total of 20 plots. The rate of N was the same for all plots, i.e. 120 kg ha^{-1}.

At crop maturity, grain yields were determined using a plot combine harvester. Grain samples were air-dried prior to micro-malting tests. A subsample of grain was dried at 80^{o}C and ground into a fine powder before chemical analyses. Total S concentration was determined by ICP after digestion with a mixture of HNO_3 and $HClO_4$, and total N by a combustion method (LECO CNS 2000).

2.3 Micro-malting tests

The three barley samples from the pot experiment were tested using a small scale malting trial. Fifty g of grain samples were malted in beakers using tap water at ambient temperature (~20^{o}C). The steeping protocol was: 7 h wet, 17 h air rest, 7 h wet, 17 h air rest, 1 h wet, drain and germinate. Germination was for 4 days, with the samples being turned manually once a day. Beakers were covered during air rests and germination to minimise drying out. Kilning was at 55^{o}C for 2 days. A visual assessment of the malts was made at day four of germination. The malts were then de-rooted and rootlet weight measured as an indication of malting loss. A modified mash was made using approximately the same ratio as used for Institute of Brewing methods (IoB, 1997). Because the samples were small, it was only possible to measure specific gravity, colour, soluble nitrogen and the sugar spectrum.

The twenty grain samples from the field experiment were subjected to a more rigorous test in an automated small scale micromalting unit. The steeping schedule was 8 h wet, 16 h air rest, 8 h wet, 16 h air rest, all at 15 ± 1^{o}C. Germination was for 4 days at 15 ± 1^{o}C with humidified air drawn through the bed. Kilning was carried out in a Mitchell oven set at 60 – 65 ^{o}C for 24 h. The resultant malts were hand rubbed to remove rootlets. Analysis was by standard Institute of Brewing methods (IoB, 1997).

3. Results and Discussion

3.1 Pot experiment

Plants in the S0 treatment showed severe S deficiency symptoms. Additions of S increased grain yield dramatically (Fig. 1a). For example, grain yield was increased by 5 fold in the S150 treatment compared to the S0 treatment. It is apparent that the first rate of S addition did not correct the S deficiency fully, because grain yield in the S10 treatment was only half of that in the S150 treatment.

Compared to the S0 control, the concentration of S in grain was not significantly increased by the addition of 10 mg S pot^{-1}, but was increased markedly (up to 60%) in the S50 and S 150 treatments (Fig. 1b).

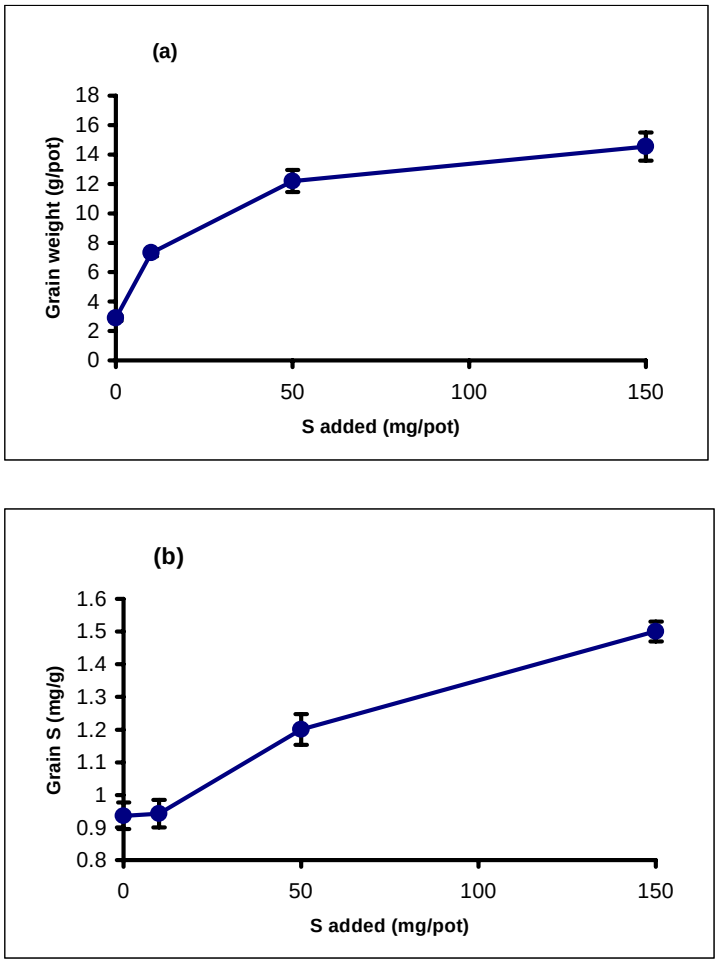

Figure 1. Effects of S additions on grain yield and S concentration in the pot experiment.

The three bulked samples from the S10, S50 and S150 treatments showed different rootlet growth, with the S50 and S150 samples being particularly vigorous (Fig. 2). The differences in rootlet growth are likely to relate to the ease of modification of barley grain. The malt extracts from the highest S treatment also showed increased

colour and total soluble N (Table 1). This indicates that the high S sample was more modified than the low S sample, resulting in a greater amount of N being solubilised and more amino N being available to interact in colour reactions during kilning. There was no clear effect of S on the specific gravity.

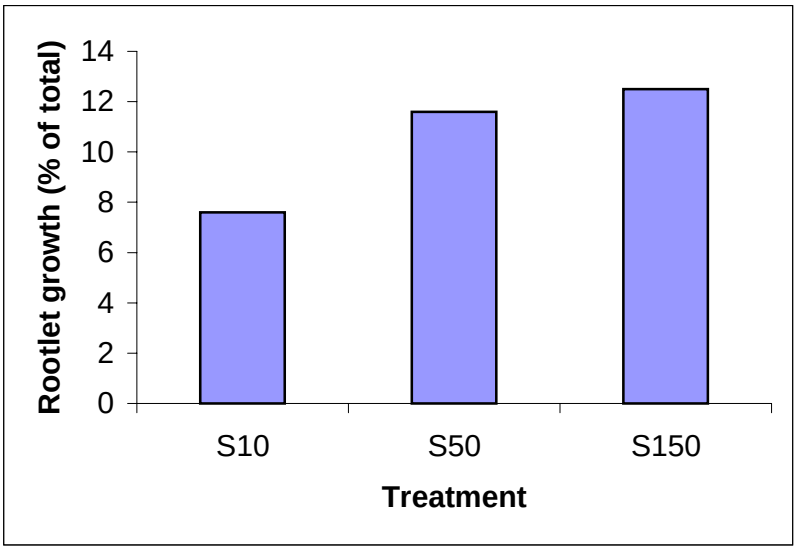

Figure 2. Effect of S treatments on rootlet production.

Table 1. Effects of S treatments on the specific gravity, colour and total soluble nitrogen in the malt extract.

Treatment	Specific gravity (^{o})	Colour (EBC)	Total soluble N
S0	1028	5.5	1.00
S50	1018	6.0	1.10
S150	1026	7.0	1.33

Sugar analysis also revealed a slightly increased modification in the S50 and S150 samples compared to S10 (Table 2). There was a slight increase in maltose and sucrose in maltose and sucrose at higher S treatments, which was consistent with the higher indices of modification.

The results from the pot experiment indicate that S deficiency can lead to substantial losses of grain yield. In addition, S deficiency may also affect malt production and modification. However, because the malting tests were based on a bulked sample for each treatment, the statistical significance of the treatment effects cannot be established.

Table 2. Effect of S treatment on sugar analysis of malt

Sugar (%)	S treatment		
	S10	S50	S150
Fructose	0.4	0.5	0.5
Dextrose	4.0	4.5	4.7
Sucrose	0.9	2.2	2.3
Maltose	26.0	29.3	29.5
Maltotriose	6.8	7.8	6.4
Total fermentable sugar	38.1	43.8	43.4

3.2 Field experiment

Sulphur deficiency symptoms were visible at the stem extension stage. The yield response to the applications of S was substantial (Fig. 3). The average yield of all +S treatments was 1.1 t ha^{-1} higher than that of the S0 treatment, representing a 34.9% yield increase. Despite this large yield increase, the effect was not quite significant (P=0.08) in the analysis of variance. This was mainly due to considerable variations between blocks in crop growth and yield. At the same rate of fertiliser (20 kg ha^{-1}), Thiovit appeared to produce higher yield than gypsum, although the difference was not statistically significant.

The concentration of S in barley varied between 0.74 and 1.2 mg g^{-1} dry weight. This range is lower than that normally found with wheat (Zhao *et al.*, 1999b), probably as a result of the lower protein concentration in malting barley than breadmaking wheat. Grain S concentration was low in the S0 treatment, and was increased significantly (P<0.001) by the applications S (Fig. 4). Applied at 20 kg ha^{-1}, gypsum and Thiovit increased grain S concentration by 10 and 51%, respectively, suggesting that Thiovit was more effective than gypsum in this experiment.

Grain N concentration ranged from 1.4 to 2.0% on a dry weight basis. It is clear that applications of S decreased grain N concentration significantly (P<0.001; Fig. 4). Grain N concentration was 1.95% in the S0 treatment, whereas in all +S treatments grain N concentrations were below the value 1.8%, which is required for malting purposes. Despite a reduction in grain N concentration, total N uptake in grain was actually increased by the S treatments. This suggests that the effect of S on grain N concentration was probably due to a dilution of N in the crop, which resulted from a growth stimulation and yield increase in response to S, particularly with a relatively low dose of N fertiliser used in this experiment (120 kg ha^{-1}).

Grain N:S ratio was affected markedly by the S treatments (P<0.001; Fig. 4). The ratio decreased from 25.5 in the S0 treatment to 12.4 in the T20 treatment. Previous studies with breadmaking wheat showed that changes in the grain N:S ratio due to S applications were associated with changes in the composition of proteins in grain (Zhao *et al.*, 1999b). Sulphur nutrition has also been shown to influence protein composition of barley (Shewry *et al.*, 1983).

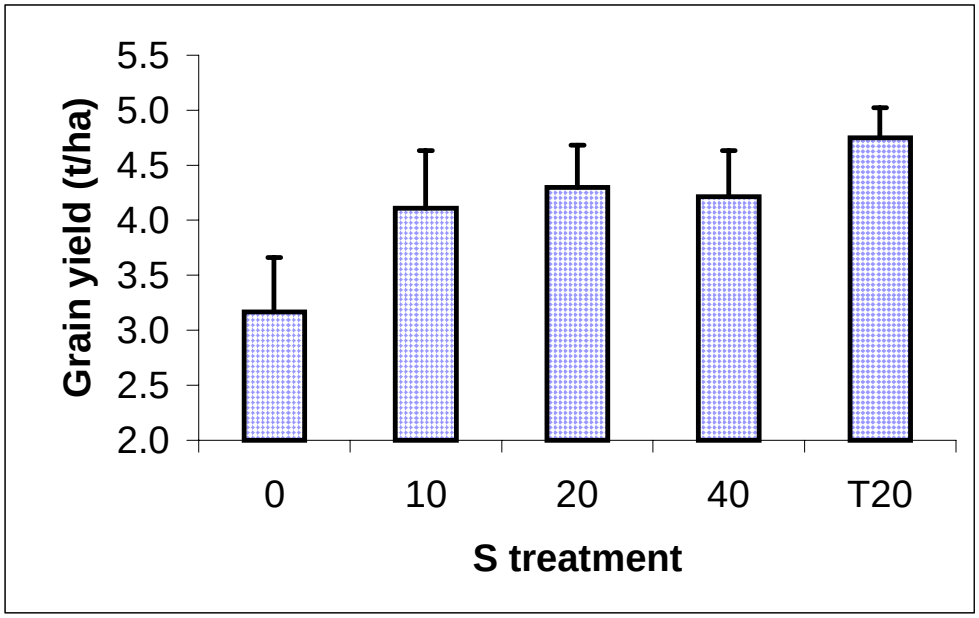

Figure 3. Effect of S on grain yield of barley in the field experiment at Woburn, 2000.

Full results of micro-malting tests for the field barley samples are shown in the Appendix. In general, the micro-malting test results were within normal ranges for all the samples tested. In the analysis of variance, the effect of the S treatments did not reach a statistically significant level for any of the parameters tested. This is perhaps not surprising in light of the relatively large experimental error of this field experiment. However, several micro-malting parameters showed some trends in response to the S treatments; and these are presented in Fig. 5. Wort colour and malt steeliness appeared to increase with increasing S concentration in the barley grain, whereas malt homogeneity appeared to decrease slightly with increasing S in the grain. To answer the question as to whether these trends are consistent and significant for quality requires further field experiments that produce smaller experimental errors.

Sulphur-containing compounds such as SMM (S-methyl methionine) and DMS (dimethysulphide) in the malts influence the flavour of beer. It is surprising that the S treatments had no clear effect on both SMM and free DMS contents in the malts, particularly considering that the S concentration of grain was significantly influenced by the S treatments. Further work is required to establish the role of S nutrition on beer flavour.

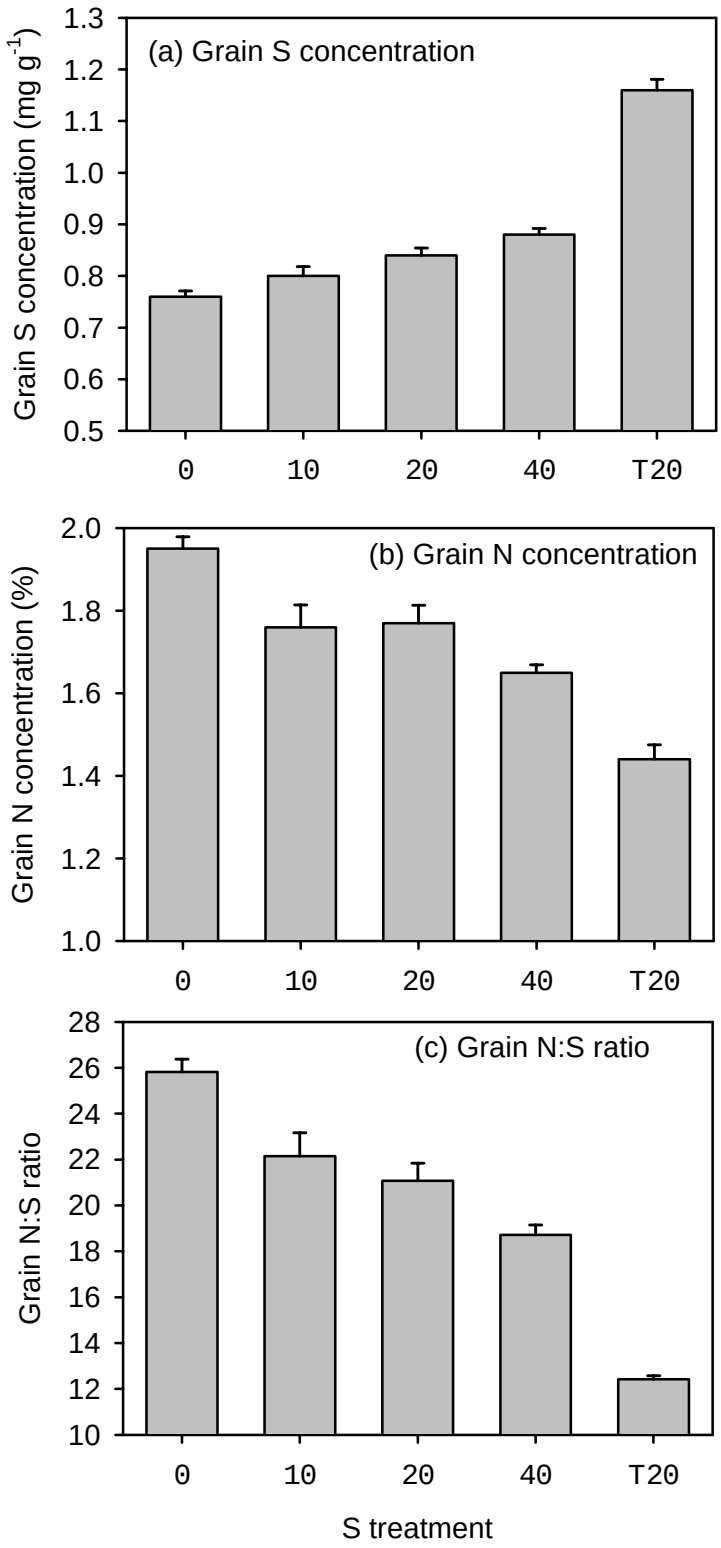

Figure 4. Effects of S applications on grain S, and N concentration, and on N:S ratio (Woburn, 2000).

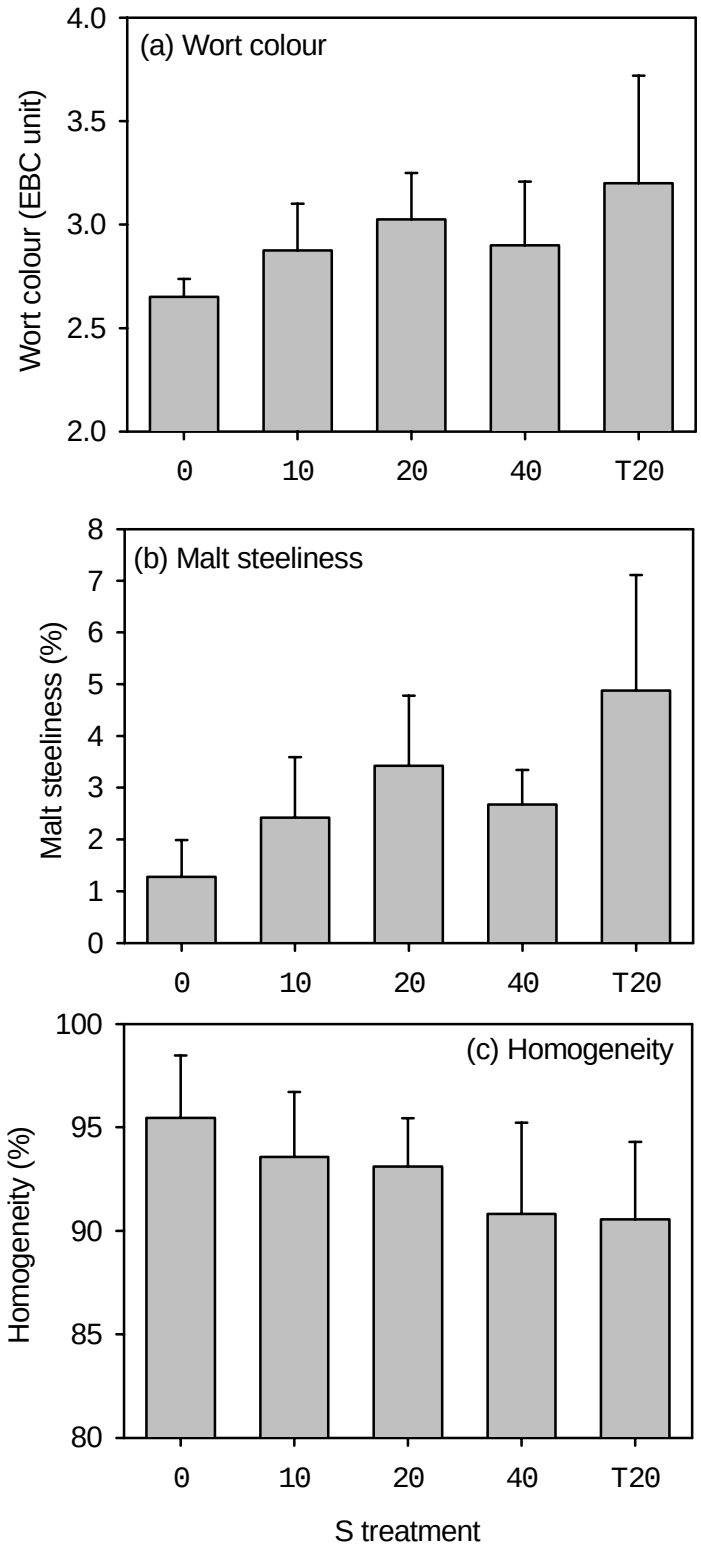

Figure 5. Effects of S on wort colour, malt steeliness and homogeneity (Woburn, 2000).

4. Conclusions

Both pot and field experiments showed that grain yield of barley can be reduced considerably by deficiency of S. The yield increase in response to S application at Woburn, a S-deficient site, was about 1.1 t ha^{-1} on average, and Thiovit appeared to be more effective than gypsum. In the field experiment, S applications significantly decreased grain N concentration from 1.95% to below 1.8%.

Results of malting tests were not conclusive. In the pot experiment, two grain samples with high S concentrations were more easily modified than a grain sample with low S concentration. In the field experiment, the effects of the S treatments were not significant for all of the malting parameters tested. However, wort colour and malt steeliness appeared to increase with increasing S concentration in the barley grain, whereas malt homogeneity decreased slightly with increasing S in the grain.

5. References

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6. Appendix: Results of micro-malting tests for the barley samples from the field experiment

Part I.

	Barley analysis		Malt analysis				
S treatment	Germination energy at 72 h	Water sensitivity at 72h	IoB Extract (0.7mm) dwt L°Kg	IoB Fine/Course Difference L°Kg	Total Nitrogen %dwt	IoB Total Soluble Nitrogen %dwt	Soluble Nitrogen Ratio
0	99.8	63.5	295	11.8	1.67	0.60	37.0
10	96.0	59.5	291	10.0	1.73	0.64	37.2
20	98.3	60.3	293	11.8	1.71	0.65	38.0
40	94.5	47.8	292	14.0	1.76	0.63	36.0
T20	90.8	39.3	294	13.0	1.71	0.64	37.6
SED	3.5	12.0	4.5	2.8	0.12	0.024	1.7
LSD	7.7	26.2	10.7	6.2	0.26	0.052	3.7

Part II.

	Malt analysis										
S treatment	IoB Wort pH	IoB Wort colour EBC units	IoB Wort viscosity cP	Friability %	Homogeneity %	Steeliness %	Diastatic power °IoB	α-Amylase dwt, DU	SMM ppm	Free DMS ppm	Total DMS ppm
0	6.01	2.7	1.53	70.4	95.5	1.28	76.0	42.8	6.28	1.95	8.23
10	6.01	2.9	1.53	74.1	93.6	2.43	68.8	38.0	5.40	1.95	7.35
20	6.00	3.0	1.52	67.4	93.1	3.43	72.3	39.8	5.45	1.28	6.43
40	6.05	2.9	1.57	65.8	90.8	2.68	79.0	40.8	5.35	1.75	7.08
T20	6.05	3.2	1.56	65.9	90.6	4.88	70.5	33.5	3.25	1.60	4.83
SED	0.039	0.41	0.05	6.1	4.0	1.90	5.6	5.0	1.79	0.48	2.07
LSD	0.084	0.90	0.11	13.3	8.8	4.15	12.1	10.9	3.91	1.04	4.51