SULFUR DEFICIENCY OF SUGAR BEETS[1]

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INTRODUCTION

Sulfur deficiency of sugar beets (Beta Vulgaris L.) was first reported in 1941 by Tolman and Stoker (10) in beets grown for seed in the Willamette Valley of Oregon. The symptoms were described as retarded growth, yellow color, breakdown of leaf tissue, lack of flowering, and increased susceptibility to disease. Since then sulfur deficiency of this crop has been reported in California (11) and Sweden (5). Sulfur deficiency of sugar beets decreases seed yield (10) as well as the yield and percent of sugar in the roots (5). A review of the sulfur requirements of sugar, fiber and oil crops has been published (8).

Dijkshoorn et al. (4) showed that the N/S ratio of the protein fractions of ryegrass grown under various levels of N and S was about 16.2. They concluded that the major proportions of these nutrients are converted into protein in the plant, and thus, if NO_3-N is low relative to total N, the N/S ratio of the herbage approximates that of the protein. A N/S ratio larger than 17 indicates an accumulation of non-protein N which signifies a shortage of S within the plant. A N/S ratio of less than 17 indicates that ample S is present for the synthesis of protein, providing other factors are favorable. Under conditions of N deficiency, or when the capacity of the plant to synthesize protein is reached, inorganic-S accumulates if applied in excess to the plant needs. Ulrich et al. (11) report values as high as 13,600 ppm SO_4-S for the leaves of sugar beets fertilized with high rates of S. The critical level required for normal growth, however, appears to be only about 250 ppm SO_4-S.

Stewart and Whitfield (9) showed that the N/S ratio of wheat plants grown in the greenhouse varied according to treatment and was indicative of the S status of the plants. The N/S ratio of the S-deficient plants was greater than 17, whereas the N/S ratio of the N-deficient or normal plants was 17 or less. The N/S ratio has also been used in diagnosing the S status of alfalfa grown in the field (7).

Sulfur deficiency symptoms developed unexpectedly on sugar beets grown in a P fertilizer experiment near Prosser, Washington. The severity of the symptoms varied because of the difference in previous fertilizer treatments, and thus afforded an opportunity to study the N/S ratio of the foliage in relation to the incidence of deficiency symptoms.

Methods and Materials

The experiment was located on soil classified as Warden very fine sandy

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loam before levelling. In 1962, the calcareous subsoil was exposed by removing approximately 14 inches of the surface soil. The resulting soil was extremely low in available P, K, and Zn and furnished the site for a fertility experiment aimed at studying the residual effects of P fertilizer. Red Mexican beans were grown in 1962, Sudan grass in 1963 and 1964, and sugar beets in 1965.

The main variables in the experiment were rates and year of application of P. Concentrated superphosphate at rates of 33, 66, 132, and 264 pounds of P per acre was applied to previously unfertilized plots in 1962, 1963, and 1964. All plots received 220 pounds of N per acre as NH_4NO_3 and 200 pounds of K per acre as KCl in 1965. The entire area received 10 pounds of Zn and 5 pounds of S per acre as zinc sulfate in 1962 and 1964.

The sugar beets were planted the first of April and thinned to 10-inch spacings on May 10. Furrow irrigation was begun the first of June and continued until mid-September at approximately 10 day intervals. The S^- content of irrigation water used at the location was low (1.7 lb per acre-foot) (6).

In July, the sugar beets in some of the plots unexpectedly became chlorotic and showed symptoms resembling those of N deficiency, except that the entire plant was chlorotic and the older leaves did not dry up. In some plots slight symptoms were present on scattered plants, whereas in other plots all plants were severely affected. Tissue tests on the petioles of the chlorotic plants indicated a high level of NO_3-N. Small test strips were sprayed with three different S-containing solutions. Within one week marked color differences were evident on the sprayed plants, thus identifying the problem as S deficiency.

Each of 13 plots was sampled on August 19 by taking 12 recently matured leaves. At the time of sampling each plot was rated numerically according to the severity of the symptoms. The leaf blades were dried at 55° C and ground. Nitrogen was determined by a Kjedahl method (1) which was not modified to include NO_3-N. For total S, the plant material was digested by a $Mg(NO_3)_2$ procedure (3). The SO_4-S was then determined turbidimetrically by measuring light scatter on a spectrofluorometer (9). Protein N and S were determined by these same methods after extracting the ground leaf material three times with hot 70% ethanol.

Immediately after plant sampling, the entire area was treated with 240 pounds of gypsum (16% S) per acre dissolved in the irrigation water. Within 10 days a marked improvement in color and growth was evident on the severely affected plants. The plots sampled on August 19 were again sampled on September 17 to determine any change in the S status of the plants resulting from the application of S.

Results and Discussion

Occurrence of S Deficiency Symptoms

The N/S ratios for the leaf blades and the leaf protein for the two samplings are presented in table 1 along with the numerical ratings of the S deficiency symptoms and the P treatments. The listing of P fertilizer treatments is appropriate because these treatments have a direct bearing on the incidence of S deficiency symptoms. Where 0 or 33 lb of P per acre had been applied, the plants sampled in August were normal or only slightly affected in appearance,

except that they were small. These plants were obviously P deficient; beet yields resulting from these treatments ranged from 50 to 77% of the 30-ton-per-acre- maximum yield in the experiment.

The plants were normal where 264 lb of P per acre was applied in 1964. Where the same rate of P was applied in 1963 and 1962, the beets in 1965 were moderately and severely S deficient. These differences in severity of symptoms are attributed to the residual effect of the S contained in the P fertilizer. Concentrated superphosphate is reported to contain about 1% S (2). Thus, at the highest rate of P fertilization, approximately 13 lb of S per acre was also applied. The residual from this amount of S applied in 1964, along with that applied as zinc sulfate, and that contained in the irrigation water, furnished adequate S for the sugar beet crop. When the fertilizer was applied in 1963 or 1962, however, the carry over of S was less than adequate.

All sugar-beets, regardless of when the P was applied, were severely S deficient where fertilized with 66 or 132 lb of P per acre. The amount of S applied at these levels of P fertilization in 1964 was too little for appreciable carry over to occur.

Nitrogen-Sulfur Relations in Sugar Beet Leaves

The N and S percentages in the alcohol-washed residues for the August sampling are shown in Figure 1. The N/S ratios of the protein in the 13 samples ranged from 14.5 to 17.8 and averaged 16.6, a value close to those reported for ryegrass (4) and wheat (9). For the September samples, the N/S ratios of the protein were generally lower than those for the earlier samples. The values ranged from 13.6 to 15.7 and averaged 14.8. The reason for these values being lower than those for the August samples is not known.

The N/S ratios of the leaf samples taken in August ranged from 13.0 to 27.2, thus indicating an imbalance between N and S in some of the plants. The data presented in table 1 indicate that the greater the N/S ratio of the leaves, the more severe the S deficiency symptoms; the average N/S ratio for the normal, chlorotic, and severely chlorotic plants was 15.1, 21.0, and 23.5, respectively. At the time of the September sampling, none of the plants showed S deficiency symptoms. In fact, the plants at this time were well supplied with S as a result of the S applied in August. The total S in the leaves ranged from 0.37 to 0.61%, about twice that for the August samples, and consequently the N/S ratios were all less than 12.

On the basis of previous work and the value of 16.6 determined in this study for the N/S ratio of the leaf protein, a N/S ratio of 17 was used as a guide for assessing the S status of the various samples. When the N and S percentages for the leaf samples taken in August are plotted and the line representing a N/S ratio of 17 is included (see Figure 2), the separation of S-deficient and normal plants is good, except for three borderline cases. For plants showing severe S deficiency symptoms, the N/S ratio was greater than 17, whereas for normal or slightly affected plants the N/S ratio was 17 or less.

Figure 2 also shows that the total S in the leaf blades for the August sampling is inversely related to the severity of the S deficiency symptoms. The average S content of the normal, chlorotic, and severely chlorotic leaves was 0.29, 0.22, and 0.19%, respectively. At the relatively narrow range of N levels encountered here, a total S content of about 0.27% was required for

normal growth of the plants. This value would be expected to change with different N levels, however, and thus the percent S alone would not reflect the S status of the plants. On the other hand, because of the constancy of the N/S ratio of the plant protein over wide ranges of N and S levels, this index would remain a valid criterion for assessing the S status of the crop.

The percent N in the alcohol-washed residues as compared to the percent N in the leaves for all samples reflects the differences in the non-protein N content of the leaves and consequently the S status of the plants. For the normal and slightly affected leaves sampled in August, the percent N was higher in the residue than in the leaf blades (compare Figures 1 and 2). The same relationship existed for all of the September samples, which showed no signs of S deficiency. This difference resulted from concentrating the protein in the residue by removal of sugars and other soluble compounds that did not contain appreciable N. For the S deficient plants, however, concentrating the protein in the alcohol-washed residue was more than offset by removal of soluble non-protein N. Consequently, the percent N in the residue was lower than in the leaves.

The results presented here indicate that the N/S ratio of sugar beet leaves is a promising indicator of the S status of the crop. Before the reliability of the test can be established, however, its relationship to the yield and percent sugar of the beets should be determined over wide ranges of N and S fertility levels.

Table 1. The ratios of total N (N_t) to total S (S_t) and protein N (N_p) to protein S (S_p) of sugar beet leaves as affected by severity of S deficiency symptoms.

P Fertilization		Severity of S deficiency symptoms*	N/S ratio of leaves			
			Sampled 8/19		Sampled 9/17	
Rate	Year		N_t/S_t	N_p/S_p	N_t/S_t	N_p/S_p
Lb/A						
0		0	13.0	15.6	10.8	14.4
33	1962	0+	17.4	16.8	11.5	14.4
66		2	21.7	17.0	9.1	15.7
132		2	24.9	17.2	11.0	14.8
264		2	24.7	16.5	9.7	15.6
33	1963	1	16.7	16.6	8.5	14.4
66		1+	24.6	14.5	10.5	15.0
132		2	27.6	17.5	9.9	14.4
264		1	21.6	17.8	7.4	13.6
33	1964	0+	15.9	15.7	8.5	14.4
66		2	22.5	17.5	7.9	14.8
132		2	20.0	15.9	6.8	15.2
264		0	14.3	16.6	8.4	15.6

* Symptoms were rated as follows: 0 = no symptoms; 1 = chlorotic; 2 = severely chlorotic when sampled on 8/19. All plants were free of S deficiency symptoms when sampled on 9/17.

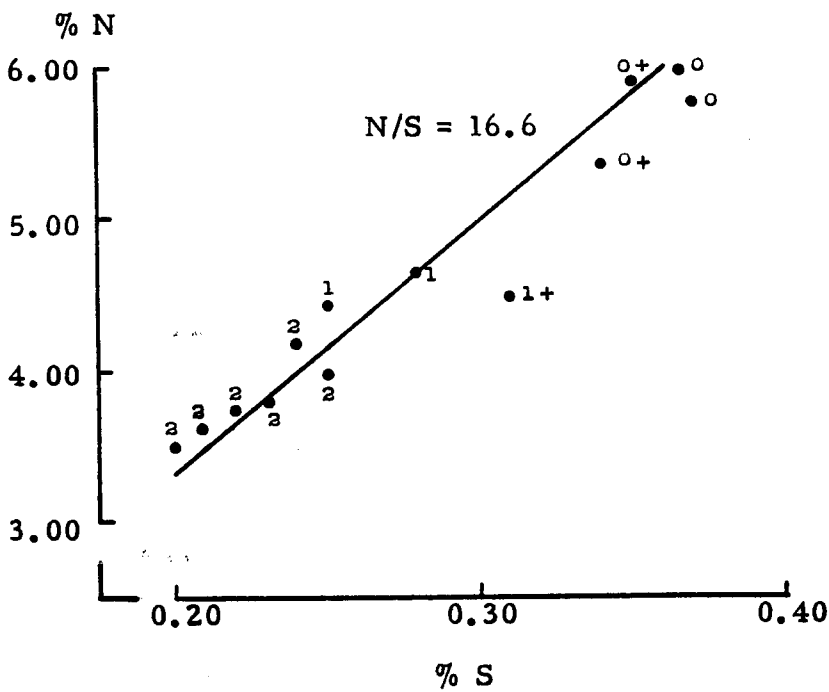

Figure 1. The percent N and S in the alcohol-washed residues of sugar beet leaves sampled in August. (0 = no symptoms, 1 = chlorotic, and 2 = severely chlorotic leaves.)

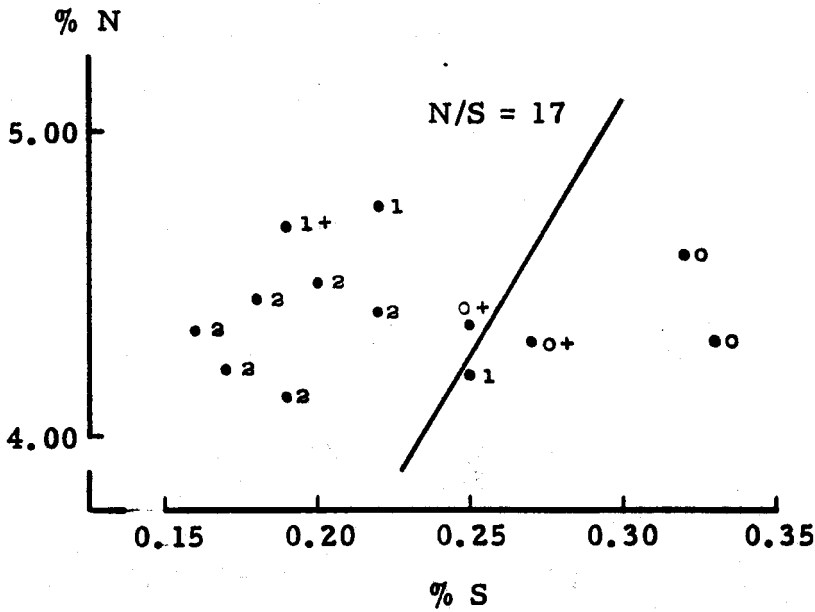

Figure 2. The percent N and S in sugar beet leaves sampled in August. (0 = no symptoms, 1 = chlorotic, and 2 = severely chlorotic leaves.)

Literature Cited

1. Bremner, J. M. 1960. Determination of nitrogen in soil by Kjeldahl method. J. Agr. Sci. 55:11-33.

2. Caro, Joseph H. 1964. Characterization of superphosphate. In Superphosphate, pp. 272-305. U. S. Dept. Agr. - Tenn. Val. Authority, U. S. Government Printing Office, Washington, D. C.

3. Chapman, H. D. and P. F. Pratt. 1961. Methods of analysis for soils, plants, and waters. Univ. of California, Div. of Agr. Sciences, Berkeley

4. Dijkshoorn, W., J. E. M. Lampe, and P. F. J. Van Burg. 1960. A method of diagnosing the sulfur nutrition status of herbage. Plant and Soil 13:227-241.

5. Gunnarsson, O. 1960. Some data from pot and field experiments with sulfur. Grundforbattring 13:13-38. Abstr. in Soils and Fertilizers 23:428. 1960.

6. Nelson, C. E. 1953. Quality of irrigation waters from eight locations in the Columbia Basin, 1950. Washington Agr. Exp. Sta. Circular 226, August 1953. 8pp.

7. Pumphrey, F. V., and D. P. Moore. 1965. Sulfur and nitrogen content of alfalfa herbage during growth. Agron. J. 57:237-239.

8. Stanford, George and Howard V. Jordon. 1966. Sulfur requirements of sugar, fiber and oil crops. Soil Sci. 101, pp. 258-266.

9. Stewart, B. A. and C. J. Whitfield. 1965. Effect of crop residue, soil temperature, and sulfur on the growth of winter wheat. Soil Sci. Soc. Amer. Proc. 29:752-755.

10. Tolman, B. and G. L. Stoker. 1941. Sulfur and nitrogen deficiency relationships in sugar beets grown for seed in Oregon. J. Am. Soc. Agron. 33:1072-1079.

11. Ulrich, A., D. Ririe, F. J. Hills, A. G. George, and M. D. Morse. 1959. Plant analysis--a guide for sugar beet fertilization. California Agr. Exp. Sta. Bul. 766.