SULPHUR IN FORAGE QUALITY AND RUMINANT NUTRITION

by

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The Sulphur Institute

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PREFACE TO FIRST IMPRESSION, 1977:

PREFACE

With the steadily increasing cost of agricultural production, it is important to the grower to get the greatest return for every dollar spent on fertilizer and other inputs. This is important, not only to the farmer engaged in crop production, but also to the livestock producer, whether he is raising animals on pasture or in feedlot operations.

It is becoming increasingly recognized that sulphur plays an important part in optimizing crop production. On sulphur-deficient soils, the use of sulphur fertilizers will increase crop yields and enhance the effect of NPK fertilizers. In addition, sulphur fertilization can improve the quality of many crops, particularly forage crops. Since the quality of forage crops is important for their utilization by ruminant animals, and hence for the economics of livestock production, this is of considerable importance in today's agriculture.

Dr. S. L. Tisdale has addressed numerous meetings of extension workers, fertilizer industry personnel, and farm groups on these topics. The interest shown by these groups reflects the increasing concern about the sulphur status of forage crops and its attendant impact on animal performance. To meet this interest, The Sulphur Institute is making available this Technical Bulletin, which represents an expanded version of the lectures given by Dr. Tisdale.

Russell Coleman
President
The Sulphur Institute

The Sulphur Institute

Sulphur—an integral component of the world economy—is a vital commodity used to manufacture a large range of essential products. One world organization is dedicated to promoting sulphur consumption and directing its safe handling and transport: The Sulphur Institute (TSI). Founded in 1960 and supported by the sulphur industry worldwide, TSI is an international, non-profit organization committed to:

Promote and Expand the Use of Sulphur.

Market expansion benefits the industry by increasing consumption and reducing market fluctuations. The Sulphur Institute has identified plant nutrient sulphur as the market with the largest development potential—projected to approach 10.6 million tons of sulphur annually worldwide by 2010. As fertilizer materials become increasingly devoid of sulphur, crop production intensifies and sulphur dioxide emissions decrease, sulphur deficiencies are spreading worldwide, severely limiting agricultural production in affected areas. Through its programs, TSI has developed plant nutrient sulphur to the commercial stage in developed countries—especially in Western Europe and North America, where the major fertilizer concerns are capitalizing on the growing sulphur fertilizer demand. The Sulphur Institute is particularly active promoting plant nutrient sulphur in developing countries, especially China and India, the markets with the largest long-term potential. The Sulphur Institute is also involved in developing markets for other end uses. These include sulphur construction materials, particularly sulphur asphalt (SA) paving products.

Analyze Sulphur Market Conditions.

The Sulphur Institute provides its members with strategic market information essential to assist them in implementing their independent business decisions and developing effective marketing strategies. Along with its Market Study Group, TSI evaluates historical and current trends in the sulphur market, and works in conjunction with industry contacts worldwide to develop its extensive market intelligence, which is reported in TSI's annual publications of *Sulphur Outlook* and *Sulphur Update*. The Institute also sponsors "Sulphur-Phosphate" and "Sulphur Markets — Today and Tomorrow" — two premier international sulphur symposia. These symposia and published reports, including *Sulphur Outlook*, *Sulphur Update,* and a new market report on China, provide in-depth analyses on components relevant to the sulphur industry, including end-use markets, supply/demand forecasts, and environmental issues.

Address Transportation and Regulatory Issues.

Addressing regulatory and environmental concerns is essential in conducting business today. Proposals to change equipment specifications and product identification requirements can readily impact overall shipping costs. The Institute monitors regulatory proposals, and works as a liaison between its members and regulatory agencies to ensure that the latest and relevant scientific information is available to formulate sound solutions, thus minimizing the negative effects of inappropriate regulations.

Provide Technical Support for Members.

As the world authority on sulphur, TSI supplies the public and the industry with accurate scientific information by publishing literature in many languages that encompass virtually all aspects of sulphur. These publications are used worldwide by many industrial and academic institutions as principal components of their educational, public relations, and promotional campaigns.

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1.0 INTRODUCTION

Until comparatively recently, only scant attention was paid to the need for sulphur in plant nutrition, and even less to its need in ruminant nutrition. This is perhaps understandable, since fertilizers were traditionally based on normal superphosphate, ammonium sulphate, and low-grade potash salts, all of which contained sulphur. Sulphur was applied incidentally, thereby preventing a deficiency of this element. As higher analysis fertilizers became available, shortages of sulphur began to appear and it has become increasingly necessary to include this element in the fertilizer program in many areas of North America and other parts of the world.

Yield responses under field conditions have been reported in at least 33 states in the United States and five provinces in Canada. Depending on the soil, crop, and climatic conditions, these responses have ranged from low to dramatically high. With many crops, sulphur fertilization results not only in yield increases, but also in improved quality, particularly in the case of forage crops. In the past, these quality factors have been largely overlooked. However, their impact on ruminant nutrition is now being recognized. It is the purpose of this bulletin to review the effects of sulphur fertilization on crop quality, and the consequent effects on the nutrition of ruminants.

The amount of sulphur required by plants can be related to the requirements of nitrogen and phosphorus. For example, as a rule of thumb, plants require about as much sulphur (S) as they do phosphorus (P). The ratio of % total N to % total S (N:S) in the plant is also an indicator of the adequacy of sulphur. Depending on the crop, the N:S ratio of the plant material associated with optimum growth ranges from 14:1 to about 16:1 when the nitrogen content of the plant is adequate. In some areas, this ratio is used as a diagnostic tool to determine the sulphur nutrition status of the plant. (This is *not* to be confused with the N:S ratio of the applied fertilizer, which should be about 5:1 to 7:1).

Over the past several years, researchers in the field of ruminant animal nutrition have also used the N:S ratio of the total diet of the animal as a measure of the quality of the ration. Research in Australia indicates that, for sheep at least, an N:S ratio of about 10:1 is most favorable for nitrogen recycling by the animal, as well as resulting in greater wool and meat production. Work in the U.S. tends to confirm this figure for sheep and lambs. Other studies have also shown that beef and dairy animal performance is improved when adequate sulphur is included in the diet. Examples of these improvements in animal performance resulting from adequate dietary sulphur will be discussed in this bulletin.

Where soils are low in sulphur, yield responses to the application of sulphur fertilizers can be expected, along with improvements in the quality of the crop. The research work summarized in the following pages suggests that there is an important connection between sulphur level of the plant, quality of the crop, and animal performance. It further suggests that additional research by agronomists and animal scientists is needed to more clearly define the effects of sulphur fertilization of forage crops on ruminant animal performance.

2.0 EFFECT OF SULPHUR ON FORAGE CROP QUALITY

The effect of sulphur on the yield of many crops, including forages, is well known and documented. Less well known perhaps is the effect of adequate sulphur fertilization on forage crop quality.

Growth responses to applied sulphur can be dramatic, both in terms of plant appearance and the yield increases obtained. What is not usually observed, or even realized, is the accompanying improvement in the quality of the fruit (or grain) and vegetative portions of the crop. Results of experimental work over the past several years have shown the following improvements in crop quality:

- Increase in Vitamin A content of alfalfa
- Increase in chlorophyll content of red clover
- Increase in the protein content of legumes and grasses
- Decrease in N:S ratio of forages
- Decrease in NPN and nitrate contents of grasses
- Improvement in the protein quality of alfalfa

2.1 Vitamin A Content

Work done in Nebraska (28) indicated that fertilizing alfalfa with *both* phosphorus and sulphur gave an almost 100% increase in the carotene content over that fertilized with P alone. This is illustrated by the data shown in Figure 1.

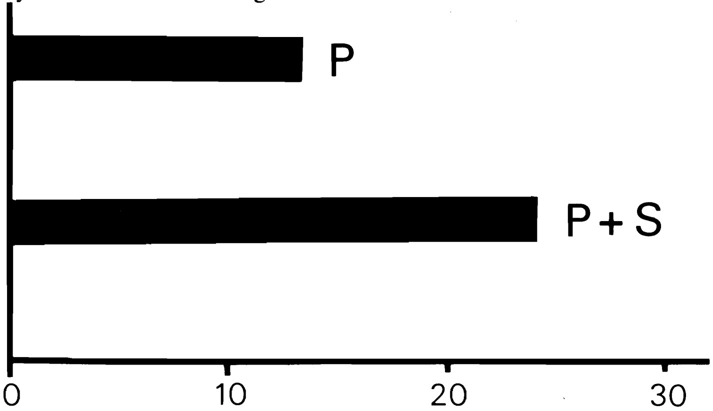

Fig. 1: Effect of P and S fertilization on the increase in carotene content of alfalfa hay (28).

While ruminant animals are able to synthesize a number of amino acids, protein, and water-soluble vitamins in the rumen, they are unable to synthesize the fat-soluble Vitamin A. This vitamin is essential for the health and development of the ruminant and is frequently included in feed additives. Assuming an adequate supply in the forages fed these animals, the amounts of supplemental Vitamin A needed could be reduced, thus lowering feed costs.

2.2 Chlorophyll Content

Chlorophyll, the green coloring matter in plants, is the medium through which the energy of the sun is converted to sugars, starches, and other organic compounds needed by both plants and animals. Sulphur has been shown to markedly affect the chlorophyll content of many crop plants which, of course, can markedly influence the color of properly cured hay. The yellowing of the leaves of sulphur-deficient plants is due to the inadequate synthesis of this important plant constituent. Some work done in California (62) illustrates the pronounced effect of added plant-nutrient sulphur on the chlorophyll content of red clover. This is shown in Table 1.

Table 1. Effect of sulphur level on chlorophyll content of Kenland red clover (62).

Applied sulphate ppm S	Chlorophyll content % d.w.
0	0.49
5	0.54
10	0.50
20	1.02
40	1.18

Increasing the sulphur content of the nutrient solution from 0 to 40 ppm increased the chlorophyll content of the clover from 0.49% to 1.18%. The practical consequences of this effect are self-evident — the greater the chlorophyll content, other factors being favorable, the greater the amount of solar energy converted, and the greater the amount of dry matter produced.

2.3 Protein Content

Protein content is one of the important properties contributing to the quality of forage crops. Within limits, the higher the protein content, the higher the quality. The supply of sulphur available to the growing crop has a profound influence on protein synthesis, and hence the protein content of the plant. With legumes, the effect is doubly important because an adequate supply of sulphur in the rooting medium is essential to the *Rhizobial* fixation of nitrogen, as well as for the subsequent synthesis of protein by the host plant.

Table 2 and Figures 2 and 3 illustrate the effect of sulphur on the protein content of plants.

Table 2. The effect of N source and S on the protein content of 4 grasses (6).

	% Protein (% N x 6.25)				
Grasses	Check	NH_4NO_3	Urea	NH_4NO_3 + S	Urea + S
Brome grass	7.4	12.0	11.9	13.4	13.4
Crested wheat grass	9.9	15.0	14.8	15.5	15.2
Timothy grass	7.8	12.5	12.5	13.6	13.1
Russian wild ryegrass	7.5	12.4	11.9	12.1	12.6

The data in Table 2 illustrate the importance of including adequate sulphur when grasses are fertilized with nitrogen. The inclusion of sulphur with both sources of nitrogen (urea and ammonium nitrate) resulted in a marked increase in the percent protein in the grasses.

The data in Figure 2 illustrate the tremendous increase in the yield of protein produced by alfalfa resulting from the inclusion of sulphur in the fertilizer (28). As alfalfa is grown largely for its protein content, the importance of including adequate sulphur in the fertilizer program for this crop is self-evident.

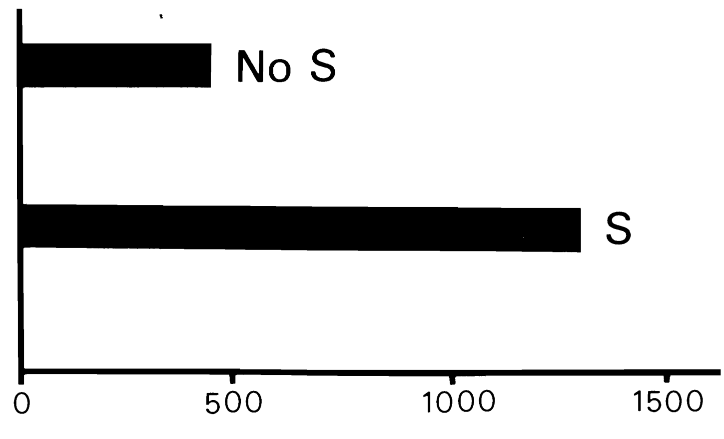

Fig. 2: Effect of sulphur fertilization on protein yield of alfalfa (28).

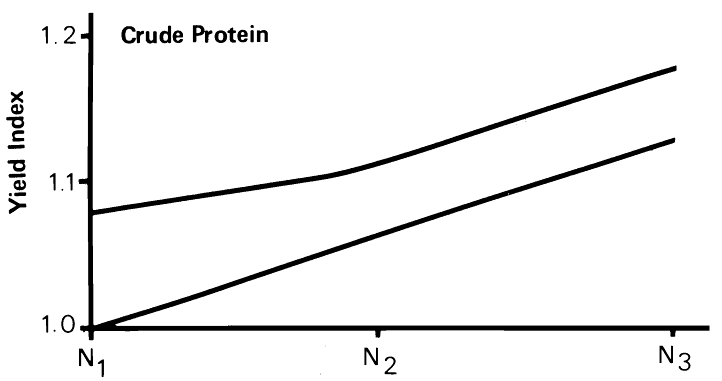

Fig. 3: Protein yield of corn silage as a function of 3 levels of N fertilization, with and without sulphur. $N_1 S_o$ = 1.0 (14).

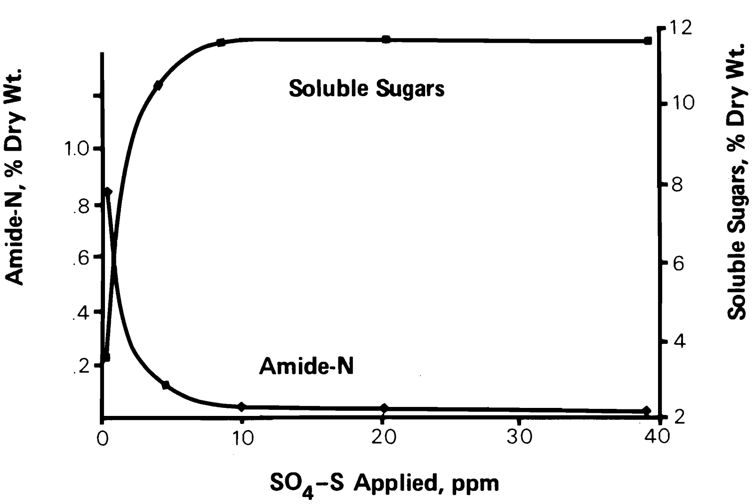

Fig. 4: Effect of applied sulphur on amide nitrogen and soluble sugar content of young corn plants (63).

Corn silage is one of the most important of the forages fed to both beef and dairy cattle. The TDN (total digestible nutrient) content of properly managed silage corn is among the highest of any crop grown for feeding livestock, and the tonnages of this crop which can be produced with high fertilization and good management are prodigious. However, corn silage is frequently low in sulphur, thus making for a wide N:S ratio. As will be discussed in a subsequent section, this results in its less efficient utilization by the animal.

The data illustrated graphically in Figure 3 show the effect of including sulphur in the fertilizer program for silage corn. At each of the three levels of added N, the inclusion of S in the fertilizer increased the yield of protein produced by the silage corn (14).

2.4 Protein Quality

While the quantity of a protein produced by a crop is important, the quality of the protein is of equal or greater importance because, as a general rule, the better the quality, the better its utilization by the animal. This is especially true for non-ruminants, but it is also true to a certain degree for ruminants. The quality of a protein is a function of its content of the essential amino acids. This quality factor is usually expressed in terms of the EAA value, which is the essential amino acid content of the protein in question relative to the content of these same amino acids in egg albumin. Sulphur is a component of the amino acids cystine and methionine which are essential for the synthesis of high-quality proteins.

As might be expected, the supply of sulphur available to the plant can influence the synthesis of the sulphur-containing amino acids and hence the quality of protein. A number of years ago, research carried out in Indiana indicated that both the cystine and methionine contents of alfalfa could be increased up to a certain point by increasing the amount of sulphur supplied to the plant (71). A portion of the data resulting from this study is shown in Table 3.

Table 3. Effect of sulphate concentration in the nutrient solution on methionine, cystine, and total sulphur contents of alfalfa (71).

SO_4 Concentration (ppm)	Methionine (%)	Cystine (%)	Total S (%)
0	0.071	0.116	0.095
1	0.097	0.129	0.101
3	0.122	0.143	0.125
9	0.143	0.149	0.193
27	0.157	0.160	0.228
81	0.160	0.165	0.243

Two points of interest are indicated. First, the cystine and methionine contents of the alfalfa increased as the level of sulphate in the rooting medium increased. Second, the total sulphur content of the plant increased, but to a slightly greater extent relative to the added sulphate than was the case with cystine and methionine.

Another indication of the effect of sulphur on protein synthesis is illustrated by the data shown graphically in Figure 4. The accumulation of amide nitrogen in a plant is an indication of a blockage of protein synthesis. It can be seen from Figure 4 that increasing the level of S in the rooting medium drastically reduced the amide nitrogen level in the plant, and at the same time brought about a marked increase in the soluble sugar content. The change in these two properties with increasing rates of added S contributes to an improvement in the quality of the forage produced.

2.5 Non-Protein Nitrogen and Nitrate Content

The percent of non-protein nitrogen (NPN), an example of which is amide nitrogen, and nitrate are two important items associated with the quality of forages. The higher the level of these two components, the lower the quality. Several recent studies have demonstrated the effect of sulphur fertilization on lowering the level of both these constituents in nitrogen-fertilized grasses. The first data come from England and are shown in Table 4.

Table 4. Effect of applied N and S on N:S ratio, N content, and nitrate content of ryegrass (25).

Treatment ppm N	S	Harvest No. 4 N:S	% N	% NO_3–N	Harvest No. 5 N:S	% N	% NO_3–N
200	0	83.0	4.64	1.40	34.7	4.34	1.20
200	20	5.9	1.26	0.015	10.3	2.82	0.29

Table 5. Effects of elemental S on yield and composition of orchardgrass (7).*

Cutting	S rate† kg/ha	Yield tons/ha	N:S ratio	NPN %	NO_3–N %
1st	0	3.74	21.3	1.05	.064
	23	3.72	15.3	.64	.037
	45	3.63	14.3	.59	.051
	90	3.40	12.2	.51	.037
	113	3.40	10.8	.49	.033
3rd	0‡	1.77	21.4	1.22	.211
	23‡	2.55	18.7	.85	.184
	45‡	2.62	14.8	.49	.144
	90	2.89	13.4	.44	.137
	113	2.76	10.0	.37	.106
5th	0‡	1.93	21.5	1.30	.500
	23‡	2.02	18.5	.97	.569
	45‡	2.46	16.7	.72	.526
	90	2.87	11.7	.48	.457
	113	2.69	9.9	.57	.396

*Plots received 113 kg/ha N per cutting in 1968
†S applied in 1967; none applied in 1968
‡S deficiency symptoms observed at cutting time

The impact of including sulphur along with the applied nitrogen is impressive. The reduction in the N:S ratio is pronounced. As will be discussed in a subsequent section, utilization of forages by ruminants is often closely, and inversely, related to the N:S ratio — the lower the ratio (to about 9.5:1), the greater the utilization of the forage by the animal.

The other property, nitrate content of the forage, was significantly reduced by the inclusion of sulphur in the fertilizer. Nitrate nitrogen, when present in large amounts in forage crops, can be detrimental and even fatal to grazing animals. It is to the interest of the grazier to keep the level of this substance to a minimum in his forage crops while at the same time producing high yields through adequate fertilization. The inclusion of adequate sulphur, along with good management and high rates of N, P, K, the secondaries, and micronutrients, will help to effect this goal.

A second example of the value of sulphur fertilization is shown by the data in Table 5.

The effect of increasing the rates of S applied to heavily N-fertilized orchardgrass was to markedly reduce the N:S ratio, % NPN, and % NO_3-N in the forage. In this particular experiment, it is of interest and importance to note that, while there were significant increases in the yield of orchardgrass from the application of sulphur, these yield increases were not nearly so prominent as the increases in quality due to the decreases in the three plant properties studied. The data in this table emphasize the importance of sulphur in improving the quality of nitrogen-fertilized grass even though only modest increases in yield are obtained.

3.0 EFFECT OF SULPHUR CONTENT ON DIGESTIBILITY

The forage crop qualities influenced by S fertilization discussed in the preceding section are important because of their impact on ruminant nutrition. When forage crops contain inadequate sulphur and dietary deficiencies of this element are not compensated for by other components of the ration, supplemental S in some form must be fed to the animal if top performance is to be obtained. This section will address itself to some of the effects of inadequate dietary sulphur on forage quality as measured by digestibility studies. The following section will relate this to animal performance as measured in laboratory and live feeding trials.

Digestibility experiments have been used to study the effect of sulphur on the behavior of rumen microorganisms. These organisms are responsible for the conversion of cellulose to other polysaccharides which can be utilized by the host animal. They also synthesize much of the protein and most of the water-soluble vitamins needed by the host. Several criteria have been used to measure the effect of sulphur on rumen microbial activity. These include:

Microbial gas production
Cellulose digestion
Starch digestion
Utilization of urea
Protein synthesis

3.1 Microbial Gas Production

The effect of sulphur level and N:S ratio of subclover on rumen microbial activity was investigated using a gas manometric technique (36). It was found that gas production *in vitro* was greatly increased as the sulphur level of the subclover substrate used in these studies increased. This relationship is shown in Table 6. It is clear from these data that gas production (and presumably microbial growth and activity) increased with an increase in the sulphur content of the clover (a decrease in the N:S ratio).

Table 6. Effect of sulphur fertilization and N:S ratio of subterranean clover on rumen microbial gas production (36).

Added S (ppm)	N:S	Rumen Microbial Gas Production (moles/0.1 (g)
0	38	0.77
5	26	0.93
10	19	1.03
15	14	1.04

3.2 Cellulose Digestion

Cellulose digestibility is another measure of the effect of sulphur on rumen microbial activity. By digesting cellulose, the ruminant is able to utilize low-quality roughage as a source of energy, ultimately converting it to meat, milk, and wool. Several investigators have studied the relationship *in vitro* between sulphur level and cellulose digestion (8, 9, 21). Some of their results are shown in Table 7. In this particular study, purified cellulose was used. Increasing the sulphur level of the medium from 0.08 to 0.43% increased the digestibility of the cellulose from 36.6 to 83.2%.

Table 7. Effect of sulphur on *in vitro* digestibility of purified cellulose (8).

% S in DM	% Cellulose digestibility
0.08	36.6
0.13	56.1
0.18	73.2
0.23	82.3
0.33	83.0
0.43	83.2

The effect of sulphur level of the medium on the digestibility of non-purified corn-fodder cellulose has also been studied (21). Some of these results are shown in Table 8. The digestibility of the corn-fodder cellulose at the lowest level of S was greater than for the purified cellulose. Nonetheless, with increasing levels of S, the digestibility of the corn-fodder cellulose increased from 70.7 to 81.2% at the highest sulphur level (0.23%).

Table 8. Effect of sulphur on *in vitro* digestibility of corn-fodder cellulose (8).

% S in DM	% Cellulose digestibility
0.07	70.7
0.12	73.9
0.17	78.7
0.23	81.2

Table 9. Effect of added sodium thiosulphate on *in vitro* digestibility of starch (39).

μg S/ml	% digestion Trial 1	% digestion Trial 2
0.0	23.3	29.8
0.5	–	49.3
1.0	50.7	62.6
2.0	61.2	70.2
3.0	64.3	69.2
10.0	66.2	75.6

3.3 Starch Digestion

Starch digestion by ruminal microflora as a function of S level of the medium has been reported (38, 39). Using different sources of S, the digestibility of starch at different levels of added S was measured using *in vitro* techniques. Table 9 shows some of these results using

$Na_2S_2O_3$ as the source of sulphur. The data indicate that the digestion of starch increased with increasing levels of $Na_2S_2O_3$. Maximum starch digestion occurred between 2.0 and 3.0 mg of S per ml of medium.

Sodium sulphate was also used as a source of sulphur. A portion of the digestibility data for this material is given in Table 10. Here again, digestibility increased with increasing levels of S. In trial 1, maximum digestion occurred at 4.00 mg of S/ml, and in the other two at 2 mg of S/ml.

Table 10. Effect of added sodium sulphate on *in vitro* digestibility of starch (39).

μg S/ml	Trial 1	% Digestion Trial 2	Trial 3
0.0	24.1	20.5	30.8
0.5	27.3	27.0	39.8
1.0	34.8	39.0	42.1
2.0	51.9	44.8	55.0
3.0	56.1	43.8	–
4.0	60.8	43.0	–

Methionine is frequently used as a feed supplement for both ruminant and non-ruminant animals. Non-ruminants must have their sulphur in the organic form, usually as methionine. Ruminants, however, through the rumen microorganisms, can synthesize their methionine (and protein sulphur) from inorganic sulphur and NPN. The inorganic sources, including the sulphate-sulphur contained in plant materials, are usually less expensive than equivalent amounts of S contained in methionine. A portion of the results of an *in vitro* experiment in which the effect of the level of methionine on starch digestibility was studied is shown in Table 11.

Table 11. Effect of added methionine on *in vitro* digestibility of starch (39).

μg S/ml	Trial 1	% digestion Trial 2	Trial 3
0.0	23.4	30.8	31.5
0.25	32.0	38.4	31.5
0.5	33.3	32.2	31.6
1.0	32.0	41.0	33.7
2.0	42.3	44.0	41.8
3.0	43.0	46.4	–
4.0	47.7	48.1	–

Starch digestibility increased with increasing levels of added methionine. It is interesting to note, however, that the methionine did not appear to be as effective a source of sulphur as the $Na_2S_2O_3$ or Na_2SO_4 as shown in Tables 10 and 11.

3.4 Utilization of Urea

Another measure of the effect of sulphur on the activity of ruminant microorganisms is on their ability to synthesize protein from urea. This relationship has been investigated in *in vitro* studies comparing the effect of various sources of S on the synthesis of bacterial nitrogen compounds, the utilization of NH_3, and cellulose digestion over a 48-hour incubation period. A portion of these data is shown in Table 12. It is clear that the three sources of sulphur used in this study significantly affected the value of these three quantities in comparison with the no-sulphur check.

Table 12. Effect of sulphur source on utilization of urea and cellulose digestion by rumen bacteria *in vitro* (29).

	Control	MHA*	DLM†	Na_2SO_4
Bacterial N (mg/bottle)	23.9	30.2	31.1	33.2
Ammonia N (mg/bottle)	20.4	12.2	12.9	8.8
Cellulose digestion (%)	59.0	74.8	75.3	71.7

*Methionine hydroxy analogue
†DL-Methionine

Other *in vitro* work (33) has shown that the addition of various sulphur compounds to artificial rumen substrates had a pronounced influence on the synthesis of riboflavin, the amount of cellulose digested, and the utilization of ammonia by the ruminal microflora, as illustrated in Table 13. Of the sources studied, cystine was the least effective, but all materials had a significant positive impact on the three activities indicated.

Table 13. Effect of sulphur source on *in vitro* synthesis of riboflavin, cellulose digestion, and urea utilization (33).

	Control	50 mg S as: Na_2SO_4	Methionine	Cystine
Riboflavin (μg/flask)	34.7	170.7	267.7	126.7
Cellulose digested (%)	9.5	50.0	52.0	20.0
NH_3 utilized (mg)	27.0	239.0	243.0	127.0

3.5 Protein Synthesis

In a recent study (34), twelve inorganic sulphur compounds were compared *in vitro* for their effectiveness in promoting the synthesis of rumen microbial protein and several volatile fatty acids. Protein synthesis from these materials decreased in the following order:

$(NH_4)_2SO_4 > S > Na_2SO_4 > K_2SO_4 > CaSO_4 > Na_2S_2O_5 > BaSO_4 > Na_2SO_3 > MgSO_4 > K_2SO_3 > CaS$

All materials resulted in significantly greater protein synthesis than the no-sulphur check.

It is apparent from this brief review of the effect of sulphur on ruminant microbial activities that a number of biochemical reactions beneficial to the microbial population, as well as to the host organism, are enhanced by the presence of adequate sulphur in the substrate on which these organisms feed.

4.0 EFFECT OF SULPHUR ON ANIMAL PERFORMANCE

In the foregoing sections, the role of sulphur in forage quality as measured by chemical and biological tests has been discussed. However, the effect of dietary sulphur on animal performance must ultimately be measured in terms of live animal performance. In the following section, the effect of dietary sulphur level on the performance of sheep and beef and dairy cattle will be briefly reviewed.

4.1 Sheep

There have been numerous reports of increases, both in wool and meat production, related to an increase in the dietary intake of sulphur by sheep and lambs. A number of examples, especially from Australia, of dramatic increases in wool production through abomasal infusions of certain high-sulphur proteins and amino acids have been reported. In this bulletin, however, improvements in animal production resulting only from normal feeding trials will be discussed.

Results of several studies conducted comparatively recently in the USSR and other European countries have shown increases in wool growth, meat production, and wool quality. A study carried out in Rumania (65) showed that pastures fertilized with sulphate and elemental S produced 24.66% and 10.30% longer wool than was produced on the no-sulphur plots. Increases in wool yield were 33 and 22% greater than the check for the sulphate and S-treated plots, respectively.

Increasing the sulphur content of lamb rations to about 0.27% with sodium or ammonium sulphate or elemental S resulted in a higher wool clip and improved wool strength, according to recent work in the USSR (52). Other work from that country (49) indicates that supplementation of ewe rations with a colloidal solution of monosulphides, thiosulphates, and polysulphides had a favorable effect on lamb productivity, survival, and body weight.

In other Russian work (27), supplementing the diet of sheep with sodium thiosulphate to the extent of 3.8 g of S/kg of dry matter gave significant increases in wool clip and the most efficient feed utilization by the animal. In still other studies (68), the sulphur supplementation of the diet of Ascanian fine-wooled lambs increased wool production by 10 to 20% and brought about increases in weight gain. The quality of the wool was also said to have been enhanced. Still another report from Russian workers (50) indicates that supplementing the diet of sheep with colloidal sulphur increased dietary nitrogen utilization by the animals and increased the rate of wool growth.

A considerable amount of work has been done in Australia showing that increased dietary sulphur leads to increased meat and wool production and also that it can:

1. increase feed intake
2. increase dry matter, fiber, and cellulose digestibility
3. improve the animal's nitrogen balance.

These points are illustrated by the data shown in Tables 14 and 15.

Table 14. Effect of N:S ratio of diet on feed digestion in sheep (19).

Dietary N:S ratio	Percentage of ration consumed	Apparent digestibility (%) of dry matter	Apparent digestibility (%) of crude fiber
24.0	84	46.6	43.3
9.7	94	51.9	51.4
4.3	98	58.8	58.2

Table 15. Effect of N:S ratio of diet on N-balance in sheep (32).

Dietary N:S ratio	N-balance g/day
34.3	2.93
10.9	3.46
11.5	4.21
6.4	4.85

It is apparent from the data in Table 14 that the N:S ratio of the animals' diets had a pronounced effect on feed intake and digestibility. The latter point is especially significant for it indicates that a greater percentage of cellulose and fiber was utilized by the animals at higher levels of dietary sulphur. This in turn implies a greater feed use efficiency and conversion of an otherwise unusable source of energy to a form that can be utilized by the animal and, ultimately, by man.

The data in Table 15 are of equal interest for they too indicate the positive effect of dietary sulphur on increasing nitrogen use efficiency by the animal. Nitrogen (protein) is perhaps one of the most expensive of the dietary inputs fed to ruminants. Its recycling and subsequent use by the animal is enhanced by an adequate supply of dietary sulphur. This is another point of considerable import to the producer of meat, wool, and milk, for it means a decrease in the cost of gain per pound of meat, milk, or wool produced.

Recent work carried out in Queensland, Australia, compared the effectiveness of sulphur fertilization of forage with dietary supplementation of sulphur added to the feed on dry matter intake and digestibility. A portion of the results of this study is shown in Table 16. It is apparent from these data that both sulphur fertilization and dietary supplementation with this element resulted in significant increases in both dry matter intake and digestibility. While both treatments proved to be beneficial, dry matter intake was greater where forage was fertilized with sulphur than where the lower-quality forage was supplemented with this element.

Table 16. Effect of sulphur on feed intake and digestion (5).

	No sulphur fertilizer		Sulphur fertilizer	
	No supple-ment	Sulphur supple-ment	No supple-ment	Sulphur supple-ment
Total sulphur in diet (g per day)	0.6	1.4	1.4	2.0
Intake of dry matter (g per kg $W^{0.75}$)	44	57	64	65
Digestibility of dry matter (%)	55	61	60	59
Retention time in rumen (hours)	24	–	20	–

The effect of the dietary N:S ratio on daily lamb gains is illustrated by data from California (64), shown graphically in Figure 5. It is obvious that as the N:S ratio increased from 10.8 to 17.0, the average daily gain of lambs dropped from 0.153 lbs to 0.084 lbs, a decrease of almost 50%.

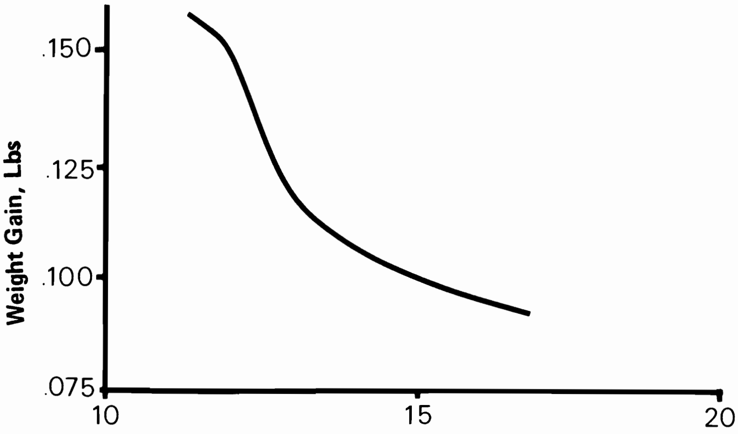

Fig. 5: Relationship between N:S ratio of diet and average daily weight gain of lambs (64).

Many other examples of the effect of dietary sulphur on the performance of sheep and lambs could be offered. However, the foregoing represents a cross section of existing data. For further reading on this topic, numerous references may be found in the Bibliography included at the end of this bulletin.

4.2 Beef Cattle

Per pound of body weight, beef cattle do not appear to require as much dietary sulphur as do sheep, which need this element for the synthesis of wool in addition to their other body requirements. However, there have been several reports of beef cattle responding to dietary sulphur and some examples of these follow.

Recent work carried out in Australia (40) with steers fed on speargrass with and without supplementations of urea or urea plus sulphur showed significant increases in both N and S retention by the animals. A portion of the data is shown in Table 17.

Table 17. Effect of adding supplements to speargrass or Townsville Stylo fed to steers (40).

	Speargrass	+ urea	+ urea + H_2SO_4	Townsville Stylo	+ H_2SO_4
Nitrogen intake (g/day)	17.8	36.7	43.6	55.4	57.4
Nitrogen retention (g/100 g N intake)	−122.0	9.0	18.0	5.2	9.5
Sulphur intake (g/day)	3.8	2.5	6.1	7.4	10.7
Sulphur retention (g/100 g S intake)	−5.4	−39.7	34.3	18.9	39.0
VFA concentration (mM/1)	68.8	72.8	78.8	80.8	90.0

Volatile fatty acid (VFA) production was similarly increased when both speargrass and Townsville stylo were supplemented with sulphur, as shown in Table 17. Volatile fatty acids produced in the rumen are utilized by the animal as a source of energy, and their increased production in the rumen is a measure of an increase in the efficiency of feed utilization by the animal.

Work reported from Iowa State University (24) showed several improvements in animal performance resulting from the addition of both methionine hydroxy analog (MHA) and inorganic sulphur to an Iowa-105 control supplement. Some of the data are shown in Table 18. While both sources of sulphur resulted in improved performance, the inorganic sulphur supplement gave the better results.

Table 18. Effect of added methionine hydroxy analogue (MHA) and inorganic sulphur to all-urea (Iowa-105) supplements for finishing yearling steers (24).

		MHA			
Treatment	Control	3 g	4.5 g	9 g	Inorganic sulphur
Average daily gain (lbs)	2.78	2.95	2.91	2.70	3.11
Feed/100 lb gain (lbs)	713	664	691	722	650
Feed cost/lb gain (cents)	13.4	12.6	13.2	14.0	12.3

California workers reported that sulphur fertilization of annual-type ranges resulted in substantial increases in both stocking rates and average steer gains during the green- and dry-forage seasons (73).

An extensive feeding trial conducted in Mississippi (59) with steers fed high-energy corn silage with and without S supplementation showed some interesting improvements in animal performance resulting from the sulphur additions. A portion of the data appears in Table 19.

Table 19. Feedlot performance and carcass characteristics of steers fed high-energy, urea-treated corn silage with and without added sulphur (59).

Treatment	Control	Na_2SO_4	$(NH_4)_2SO_4$
Average gain (lbs)	359	364	377
Average daily gain (lbs)	2.69	2.73	2.82
Feed cost/lb gain (cents)	6.14	6.01	6.03
Beef produced/acre (lbs)	1559	1619	1618
Carcass grade Choice or better (%)	54.1	62.5	62.5

Of particular significance in this table are the data showing decreases in feed cost per pound of gain, and the increase in the percent of carcasses grading "Choice" or better resulting from sulphur supplementation. Though the decreases in feed costs are small on a cost-per-pound-of-gain basis, these figures assume a significant proportion when one considers the amount of beef produced per feed lot, where thousands of steers per year are fed out.

The information presented in this section represents only a portion of the data available dealing with this topic. Additional references appear in the Bibliography.

4.3 Milk Production

The effect of dietary sulphur level on milk production has been reported in several cases. Work done in Russia (42) indicated that supplementation of dairy cow rations with 30 g of sodium sulphate per day for 30 days increased cellulose digestibility by 13%. It was also found that, as a result of the sulphur treatment, the production of milk solids, fat, protein, and casein was increased.

Other work in Russia (56) showed that supplementing the diet of dairy cattle with 0.03 g of elemental S per kg of body weight increased the Vitamin A content of the milk by 62.5%.

The effect of adding potassium monophosphate and sodium sulphate on milk and cheese quality was also reported by Russian workers (76). The additions of P and S resulted in increased casein content of the milk and improved aroma and flavor. A higher content of protein and fat in cheese was also reported.

Several sulphur-containing compounds have been investigated experimentally in the U.S. to determine their effect on milk production. These include the hydroxy analog of methionine (MHA), sodium sulphate, calcium sulphate, a mixture of potassium and magnesium sulphates, and elemental sulphur. In a rather extensive series of trials carried out in Virginia, Delaware, California, and Maryland (13), it was found that the production of milk and cream was significantly increased by the addition of MHA to the feed. In these tests, the average treated heifer receiving the MHA outproduced the average control by 2.9 lbs of milk and 0.14 lbs of fat per day in the first half of a complete lactation. On a 305-day projection, this amounted to a gain of 819 lbs of milk and 38 lbs of fat.

Other work from Wyoming (1) indicated that fortifying the diet of dairy cows increased milk production between 0.9 and 1.6 kg/day. Butter fat production was also increased.

A series of studies recently carried out in Ohio and Quebec (15, 16, 17, 18) compared the effectiveness of several inorganic sources of S and MHA on the performance of lactating dairy cows. Some of the results obtained are discussed in the following paragraphs.

In one study four dietary levels of sulphur were compared, 0.1%, 0.15%, 0.18%, and 0.18% (15). The 0.1% level was the basal diet, the 0.15% and 0.18% levels were supplemented with sodium sulphate, and the last 0.18% level was supplemented with MHA. A portion of the results is shown in Table 20. It is apparent from these data that S supplementation with both sodium sulphate and MHA increased daily milk production. The sodium sulphate treatments also increased dry matter absorption and N intake and absorption, in contrast to the MHA which had no effect on these three factors. Dry matter digestibility was increased at both levels of added S by both the MHA and the sodium sulphate.

Table 20. Effect of added dietary sulphur on performance of lactating dairy cows (15).

Ration	Basal (0.10%S)	Na_2SO_4 (0.15%S)	Na_2SO_4 (0.18%S)	MHA (0.18%S)
DM absorbed (g/kg/day)	17.9	19.2	19.0	17.4
Milk produced (g/kg/day)	33.6	35.6	34.7	34.6
Apparent DM digestibility (%)	70.6	72.1	72.9	72.1
N:S ratio in diet	19.6	14.4	11.9	12.4

In the same study, a comparison of two sources of sulphur (potassium-magnesium sulphate and sodium sulphate) at two levels of S (0.18 and 0.24%) was made with a basal ration containing 0.06%S. A portion of the results is shown in Table 21. The data indicate that there was an increase in dry matter digested and absorbed, and an increase in milk production resulting from the addition to the ration of both sources and amounts of sulphur.

Table 21. Effect of added dietary sulphur on performance of lactating dairy cows (15).

Ration	Basal (.06%S)	K_2SO_4+ $MgSO_4$ (.18%S)	Na_2SO_4 (.18%S)	K_2SO_4+ $MgSO_4$ (.24%S)	Na_2SO_4 (.24%S)
DM absorbed (g/kg/day)	18.1	20.3	20.2	20.5	19.7
Milk produced (g/kg/day)	35.0	39.7	40.4	40.9	40.2
Apparent DM digestibility (%)	67.8	71.1	72.0	71.6	72.0
N:S ratio in diet	35.7	12.9	13.2	9.4	8.9

In another study, calcium sulphate, molasses, and lignin sulphonate were compared as sources of dietary S (16). Results of this test showed that the lignin sulphonate was poorly digested, and that the sulphur in the molasses was slightly less available than that contained in sodium sulphate. Calcium sulphate was utilized equally as well as sodium or potassium-magnesium sulphate at dietary levels of 0.15% S. At levels of 0.3% S or greater, feed intake decreased and there was an excessive retention of S by the animals.

In other studies conducted by these same workers, it was concluded that supplemental inorganic sulphur from sodium, calcium, and magnesium sulphates sustained the optimal utilization of S when fed in the diet at levels amounting to 0.2% S to cows producing as much as 35 kg of milk per day (18). Higher concentrations did not have any effect on N, S, or dry matter digestibility, but concentrations of 0.35% S and above were associated with diminished dry matter intake.

Recent studies conducted in Ohio (53, 57) have indicated that finely chopped corn silage, supplemented with either sodium sulphate or potassium-magnesium sulphate, increased dry matter intake and digestibility by pregnant and lactating ewes. It was concluded from these studies that corn silage alone, *when supplemented with one of the inorganic sulphate salts*, would provide ewes in this condition with all of the nutrients needed for top performance.

5.0 SUMMARY AND CONCLUSIONS

The data presented in this bulletin suggest that an adequate supply of sulphur is associated with several factors which determine the quality of forage crops. These include Vitamin A content, chlorophyll content, amount and nature of plant protein, nitrate level and the content of non-protein nitrogen. It has also been shown that the sulphur level of the forage, and its N:S ratio, are related to cellulose and dry matter digestibility, dry matter intake, microbial protein synthesis, and nitrogen recycling and utilization. In live animal performance studies, adequate sulphur levels and low N:S ratios have been associated with high performance of sheep, cattle, and dairy cows.

In some of the work discussed, animal performance was related to the sulphur content (and N:S ratio) of the forage itself. In other work, the animal performance was related to different dietary levels of S obtained by adding desired amounts of several sulphur-containing compounds to the forages or diets. In both situations, the results were about the same — increases in animal performance with increases in the sulphur content of the total diet, up to a level of about 0.20 to 0.25% S.

This bulletin does not suggest that supplemental dietary sulphur, nor sulphur fertilization of crops, will in all cases improve animal performance. If dietary sulphur levels are adequate (0.20 to 0.25% S, and N:S ratios of 10:1 to 12:1), no improvement in performance can generally be expected. On the other hand, if dietary sulphur levels are inadequate (0.15 to 0.18% S or less, and N:S ratios wider than 13:1), improvements in ruminant performance may frequently be observed.

It is important that information on the composition of the animals' diets, including the sulphur content, be known with a reasonable degree of accuracy. Frequently in feed and forage analyses crude protein (total N $\times$ 6.25) is reported. This can be misleading for such analyses would be based on the content of *all* N compounds (including non-protein nitrogen and nitrates), with no estimate of the quality of the protein being fed. If a sulphur analysis is included, some estimate can be made of the protein quality by calculating the N:S ratio of the diet. If this ratio is of the order of 10:1 to 13:1, and the total S content is 0.20 to 0.25%, it can generally be assumed that the protein is of high quality and that the animal will make maximum utilization of the ingested feed. If these conditions regarding sulphur do not obtain, then supplementation with some suitable form of this element should be considered. While the N:S ratio of forages and feeds is not an infallible indication of protein quality and the adequacy of sulphur in these materials, it can serve to indicate, within limits, the quality of the protein being fed. In short, in the opinion of the author, crude protein *plus* the N:S ratio is a much better indicator of the value of the protein than is the content of crude protein alone.

Another point suggested by the information presented is whether it is more efficient, from both the standpoint of animal performance and economy of operation, to fertilize forages with sufficient sulphur to increase their sulphur content, or to bring the sulphur level of the diet up to the required level by additions of suitable sulphur supplements.

The work from Queensland, Australia, referred to earlier suggests that sulphur fertilization may be superior to dietary supplementation with this element, at least as far as dry matter intake is concerned. It was indicated by these workers that this was probably the result of increased palatability of the forage resulting from sulphur fertilization. This work is perhaps one of the few reported cases in which the effect of fertilization on animal performance has been compared with dietary supplementation. The results suggest that further studies in this area may have merit.

As a rule, plants make adequate growth when the N:S ratio of the forage is between 14:1 and 16:1. However, ruminants seem to perform most satisfactorily when the ratio of N to S in their feed is between 10:1 and 12:1. If the N:S ratio of the forages is to be made optimum for animal utilization, then it would mean fertilizing with sulphur at a rate that might be above the optimum for plant growth alone. As the N:S ratio of plant proteins is on the order of 14:1 to 16:1, N:S ratios more narrow than this suggest the accumulation of non-protein sulphur in the plant. This will usually be in the form of sulphate sulphur. Since accumulations of $SO_4^{=}$ in plants (up to a level of about 0.6 to 0.7% total S) do not seem to be harmful to growth, and since ruminants can effectively utilize sulphates in the synthesis of proteins (other dietary inputs being adequate), it follows that crop fertilization with greater than normal amounts of applied sulphur may be one way of optimizing the N:S ratio of forages. It would appear that this represents an area where a joint research effort by both agronomists and ruminant nutritionists could provide information of considerable value to both the producers of forage and livestock. This is, in fact, one of the primary reasons for the publication of this bulletin.

Based on the information presented in this bulletin, it may be concluded that:

1. On soils low in sulphur, yield and quality of forages can be improved through sulphur fertilization.
2. Increasing the level of sulphur in forages so that the N:S ratio is lowered to about 10:1 to 12:1 can result in improvement in feed utilization and performance of ruminant animals.
3. Total sulphur levels in the complete ruminant diet should be between 0.18 and 0.25% for best animal performance.
4. In numerous instances, meat, milk, and wool production have been increased by lowering the N:S ratio of the diet to between 10:1 and 13:1 and ensuring a level of total dietary S of from 0.18 to 0.25% S.
5. Additional work by both agronomists and animal nutritionists is needed to compare the merits of forage fertilization versus feed supplementation as a means of most efficiently supplying ruminants with their sulphur requirements.

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