Effect of nitrogen and sulfur fertilization on forages in the Gallatin Valley of Montana

by Raymond George Gavlak

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in AGRONOMY
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Abstract:
Sulfur (S) deficiency of forage crops is being reported in southwestern and western Montana with increasing frequency. Several factors may contribute to this problem. The utilization of relatively high analysis fertilizer materials has reduced the by-product S application formerly derived from lower analysis fertilizers. Crop removal with high yields has also contributed to increased incidence of S deficiency on some soils.

Nitrogen (N) fertilizer application to irrigated orchardgrass in 1978 inhibited growth and development while predisposing plants to secondary infection from disease organisms. This suggests other nutrition problems, including perhaps S. It was determined from a field plot experiment that S was deficient and warranted further investigation. Subsequent field experiments were undertaken in 1979 to determine optimal S level for initial and residual response and to compare soluble and insoluble S sources. Additional studies were conducted in 1980 to clarify the interaction of applied N and S fertilizers on forage yield and chemical composition.

Significant forage yield response to S was found in 1978. Plant tissue levels of total nitrogen and total sulfur in ratio form (N/S)+ successfully predicted S deficiency in orchardgrass. Maximum yields were obtained with at least 34 kg S/ha (kilograms sulfur per hectare) as gypsum with residual S apparent at rates in excess of 67 kg S/ha. Sulfur source comparisons provided data on soluble and insoluble sources. Soil tests for S cannot predict deficient situations, however, the S soil test can identify incremental applications of spring applied S. Nitrogen-sulfur interaction was apparent in forage yield and chemical composition with maximum yield occurring only when both N and S were adequately supplied.

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by

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A thesis submitted in partial fulfillment of the requirements for the degree

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ABSTRACT

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Nitrogen (N) fertilizer application to irrigated orchardgrass in 1978 inhibited growth and development while predisposing plants to secondary infection from disease organisms. This suggests other nutrition problems, including perhaps S. It was determined from a field plot experiment that S was deficient and warranted further investigation. Subsequent field experiments were undertaken in 1979 to determine optimal S level for initial and residual response and to compare soluble and insoluble S sources. Additional studies were conducted in 1980 to clarify the interaction of applied N and S fertilizers on forage yield and chemical composition.

Significant forage yield response to S was found in 1978. Plant tissue levels of total nitrogen and total sulfur in ratio form (N/S), successfully predicted S deficiency in orchardgrass. Maximum yields were obtained with at least 34 kg S/ha (kilograms sulfur per hectare) as gypsum with residual S apparent at rates in excess of 67 kg S/ha. Sulfur source comparisons provided data on soluble and insoluble sources. Soil tests for S cannot predict deficient situations, however, the S soil test can identify incremental applications of spring applied S. Nitrogen-sulfur interaction was apparent in forage yield and chemical composition with maximum yield occurring only when both N and S were adequately supplied.

CHAPTER 1

GENERAL INTRODUCTION

Sulfur (S) deficiency of irrigated orchardgrass was identified in the Gallatin Valley, Montana by Christensen and Kresge (1978). Highly significant yield responses were obtained with the application of S as ammonium nitrate-sulfate (ANS). This thesis is the culmination of a three year study designed to investigate methods of identification and correction of S deficiencies of forage crops in the mountain valleys of southwestern Montana.

The objectives of the study were 1) to define the magnitude of the S deficiency in forages and attempt to determine the level of S required by the crop to provide optimum yield; 2) to determine what commercially available S sources would correct the deficiency the year of application and what residual effect these sources had on yield and chemical composition; 3) to assemble a data base of plant tissue chemical analyses to assist in the development of a diagnostic tool for the identification of S deficient forage; 4) to assess the effects of spring applied S fertilizer on post-harvest soil sulfate-S levels.

A multi-phase approach was utilized to address the problems. Chapter 1 summarizes the initial work on irrigated orchardgrass (1978) and includes data designed to check the residual effect of S fertilization with a single source. Chapter 2 describes experiments conducted on high elevation nonirrigated hayland designed to compare the initial and residual effects of several S sources on total forage yield and chemical composition. Chapter 3 deals with the interaction effects of nitrogen (N) and S fertilization on yield and plant tissue N and S concentrations through the growing season. Summarized data from this chapter describe the integration of a combination of plant tissue tests that successfully predict the need for S fertilization when optimum N requirements are met. Chapter 4 describes methods used to quantify the post-harvest soluble S fraction in the soil as a result of S applied in the spring.

Data generated in this study are presented in Appendix I. Forage yield, total N, total S, and N to S ratios $(N/S)_t$ are calculated for all sites. Results of further tissue chemical analyses conducted on selected treatments are presented.

Soil profile descriptions for the experimental sites are shown in Appendix II. Procedures used in the analysis of plant tissue and selected soil analysis procedures are presented in Appendix III. Appendix IV provides data on growing season precipitation for 1979 and 1980.

CHAPTER 2

LITERATURE REVIEW

The increased utilization of high analysis, by-product-free fertilizer materials and sub-optimal S mineralization characteristics of many soils have helped cause S deficient soil-plant systems on many continents of the world.

Sulfur fertilization of alfalfa (Medicago sativa L.) has become necessary in many areas to maximize yields. Long term field experiments were conducted with alfalfa in Queensland, Australia. Dickson and Asher (1974) found that various S carriers equally maintained stand vigor, reduced weed populations and increased both the N and S content of the forage.

The yield response of alfalfa to S fertilizer was checked in a pot experiment (Martel and Zizka, 1977) with two types of soil, a sandy-loam and silty-clay. Dry matter yields were significantly increased in both soils by the application of S with the greatest response in the silty-clay soil.

Cairns and Carson (1961) found that S treatments effectively increased alfalfa yields on S deficient soils. Gypsum was more available than elemental S in the year of application. Similar responses were observed in

Merced County, California (Rendig, 1956) where gypsum treatments yielded more than double the unfertilized check plots at all five cuttings. Seim et al. (1968) showed that alfalfa in Minnesota, when fertilized with gypsum, outyielded unfertilized alfalfa every year of the study. Yields in the gypsum fertilized plots were three times that of the check plots in the third year of the experiment.

Workers in various geographic locations have attempted to establish methods to detect S deficiency in alfalfa. Simple soil analysis results are not consistent, therefore, a trend toward tissue analysis resulted.

Plant tissue contains nutients at a consistent level in a given plant part, at a particular stage of maturity. Plant growth should not be inhibited when the concentration of an essential element exceeds a critical range (Westermann, 1975). The critical nutrient level of alfalfa was investigated by many scientists. Bear and Wallace (1950), McNaught et al. (1961), Andrew (1977) and Graham (1973) suggest that the critical level of S in mature alfalfa should be 0.20%. A greenhouse experiment conducted by Harward et al. (1962) proposed a 0.22% critical level for alfalfa in the early bloom stage of growth. Later field work in Oregon by Pumphrey and Moore (1965b) confirmed the findings of Harward et al. Significant yield increases were measured only in field experiments where the alfalfa plant tissue S content was initially less than 0.22%.

The critical nutrient level may be utilized as a diagnostic tool for deficiency identification when the stage of growth and plant part sampled are well defined. The $(N/S)_t$ ratio, or the ratio of total N to total S in the herbage, was proposed by Dijkshoorn et al. (1960) as a method for diagnosing S deficiency. The stage of maturity of alfalfa seems to have more influence on the total S content than on the $(N/S)_t$ ratio of alfalfa (Pumphrey and Moore, 1965a). Ratios of N to S reflect the S status of the plant. Sulfur is adequately supplied to alfalfa when the $(N/S)_t$ ratio is 11:1 (Pumphrey and Moore, 1965b; Aulakh et al., 1976).

Sulfur deficiency of grasses and the grass-legume mixture has received considerable attention in recent years. As with alfalfa, response to S fertilization is a global occurrence. Workers have investigated not only responsive locations but also rates and sources of S fertilizer applied. Baker et al. (1973) observed drastic $(N/S)_t$ ratio reduction in irrigated orchardgrass (Dactylis glomerata L.)

with increasing levels of S fertilizer. Gypsum, potassium sulfate, and ammonium sulfate provided more rapid response than did elemental S. The relatively reduced solubililty of elemental S however, resulted in greater residual effect. Experiments conducted on dryland pasture in California (Jones, 1964) showed significant yield response to applications of 22, 45 and 90 kg S/ha as gypsum when harvested in May. Residual S response was only apparent in the 45 and 90 kg S/ha rates. Jones et al. (1970) compared 45 Kg S/ha levels of an elemental S-bentonite mixture with elemental S and gypsum treatments on grassland pasture. Elemental S with bentonite was less effective the year of application than gypsum or elemental S alone. Residual yield response showed that the soluble gypsum produced significantly less forage than elemental S or the elemental S-bentonite complex.

Workers in New Zealand compared yield response of a grass-clover mixture to various levels of S provided by elemental S, potassium sulfate, and gypsum (Adams, 1973). The clover portion of the stand responded to gypsum the year of application with clover yields significantly higher than yields with postassium sulfate or elemental S at the 22 kg S/ha rate. The response of clover to gypsum was only detectable in the year of application at the 22 kg S/ha with no additional response above 22 kg S/ha. No significant differences were noted between sources at the 88 kg/ha level. This suggests that elemental S at the higher rate provided a sufficient quantity of available S to the stand as did the lower level of gypsum.

McLachlan and DeMarco (1971) applied gypsum to a grass-clover pasture at four levels: 8, 17, 34, and 50 kg S/ha in each of four years. The pasture responded to S in all years of application if at least 34 kg of S was applied. The residual value of the first year application in the second year was greater than the response from similar levels of S applied the second year, excluding the 8 Kg S/ha rate. By the fourth year of the study the residual response from applications the first year had decreased to similar levels which were not significantly different from the control.

McLachlan and Demarco (1973) continued to study the effects of S on similar pastures in New South Wales by applying four initial levels of S and four maintenance levels each of the succeeding years. They found that maximum dry matter production and optimum fertilizer efficiency was accomplished at the 34 kg S/ha initial rate with subsequent 8 kg S/ha levels as annual dressings. The residual value of the initial S application was enhanced by relatively low maintenance levels applied the following years. McLachlan (1975) suggested the utilization of soluble S sources to provide for early crop growth with applications of less soluble sources for residual availability.

Several experiments in New Zealand were designed to assess the effect of S fertilization on the yield and chemical composition of mixed-species grazed and ungrazed swards. Walker et al. (1956) found that the grass portion of an ungrazed mixed-species sward received supplemental N from underground transference from the S fertilized clover. The yield response to S of the entire plant population was three times that of the control. Metson (1978) reported a higher total S content in grasses than in clovers in a mixed-species pasture. This occurrence was attributed to the increased tendency of grasses to absorb non-protein S.

The interaction of plant N and S resulting from N and S fertilization has been addressed by several workers. Goh and Kee (1978) noted that increasing rates of applied N increased the total N content of perennial ryegrass (Lolium perenne L.) dry matter in all S treatments. Similarly, the total S concentration of the dry matter was significantly increased with additional S at all N levels. The maximum total S content was found in the N_0S_3 treatment due to the accumulated S in the N deficient grass. Nitrogen to S ratios were consistently higher in treatments with N but lacking S. With applied S, the $(N/S)_t$ ratios were significantly reduced. Tahtinen (1977) found that timothy (*Phleum pratense* L.) in S deficient soils of Finland exhibited S contents under 0.13%. In S deficient soils, S application reduced the $(N/S)_t$ ratio. With sufficient S the $(N/S)_t$ ratio remained under 14, which is consistent with critical $(N/S)_t$ ratio values of other plants in the *Graminaceae* family (Metson, 1973).

A followup study was conducted (Tahtinen, 1978) to determine the effect of S deficiency and S fertilization on the compounds in timothy. Nitrogen fertilization had little effect on the protein-N content of plants deficient in S. Sulfur fertilization increased protein-N content by 26%. Fertilizer S applications decreased the concentrations of amino-, ammonium-, and nitrate-N in the plant suggesting that these soluble forms were incorporated into protein-N. Significant increases in hay yields were attained with S fertilizer in a study conducted in Iceland

(Helgadottir, 1977). The critical S level of the grasses was 0.095% with an $(N/S)_t$ ratio of 16 estimated as the upper limit of optimum yield.

Sulfur requirements of various crops have been reviewed by Saalbach (1970), Metson (1973), and Martin and Walker (1965). Saalbach (1970) showed that grasses were adequately supplied with S when the $(N/S)_t$ ratio was 14.5. A controlled environment pot experiment conducted by Bolton et al. (1976) at the Rothamsted Experiment Station indicated that increased yields of perennial ryegrass due to S fertilization occurred when the grass S content was less than 0.20%. Maximum yields were associated with $(N/S)_t$ ratios of approximately 10. Lancaster et al. (1971) significantly increased total S in five forage species grown in pots with incremental increases in S. Dramatic reductions of $(N/S)_t$ ratios were apparent with all species. Ratios of total N to total S, $(N/S)_t$, were reduced from 32 with no S applied to 10 with an 11 ppm S treatment. O'Connor and Vartha (1968) completed studies which indicated that orchardgrass response to S fertilizer was partially dependent on the level of N uptake. Therefore, in S deficient situations, applications of N fertilizer without additional S would widen the $(N/S)_t$ ratio (McLaren, 1976). Similarly, with the potential of the soil organic matter to mineralize a constant amount of S, heavy additions of N fertilizer would cause an imbalance of N and S in the plant, impeding protein formation (Stewart, 1966).

CHAPTER 3

EFFECTS OF SULFUR FERTILIZER LEVELS ON THE INITIAL AND RESIDUAL RESPONSE OF FORAGE: YIELD AND CHEMICAL COMPOSITION.

INTRODUCTION

The increased utilization of high analysis fertilizer materials low in S or lacking S combined with the limited S mineralization potential of many soil-organic matter complexes has created areas deficient in adequate S for optimal crop production. Locations found to be S deficient are not limited to specific soil types or geographic regions, as S responses have been reported on several continents (Martin and Walker, 1966; Helgadottir, 1977; McLachlan and Demarco, 1973).

The identification of potential S deficient soils is difficult due to poor correlations of soil SO_4-S concentrations with crop response, therefore, a trend toward plant tissue analysis resulted. Several analytical criteria have been presented to assess the S status of plants (Metson, 1973): total S (S_t), sulfate-S (SO_4-S), and the total N to total S ratio $(N/S)_t$ which is the result of earlier work (Dijkshoorn et al. 1960) based on the proportional S and N content of vegetable protein.

Researchers have utilized the $(N/S)_t$ ratio as an indicator of crop S status. Generally, data have been generated to provide a range in which crops can be identified as S sufficient or S deficient. Pumphrey and Moore, (1965b) in Oregon and Aulakh and Dev, (1976) in India found that alfalfa was adequately supplied with S when the $(N/S)_t$ ratio was 11. Critical $(N/S)_t$ ratios have been established for legumes and grasses and are summarized by Metson (1973) and Saalback (1970).

Yield responses of forage crops have been demonstrated by many workers (Jones, 1964; McLachlan and Demarco, 1971; Helgadottir, 1977) with a variety of S sources and S levels. In general, applications of S result in increased yields and reductions of $(N/S)_t$ ratios. The residual effect of first year S applications generally appear at the maximum levels of applied S.

This study was conducted to evaluate the effect of different S levels on the initial and residual forage yield response and chemical composition.

MATERIALS AND METHODS

Three experimental areas were selected to evaluate the effects of S fertilizer levels on $(N/S)_t$ ratios and total forage yield. These sites were maintained one additional growing season to identify any residual fertility response. The study areas included an irrigated orchardgrass (*Dactylis glomerata* L.), hay stand 6 km southwest of Bozeman, Montana (Dr. Jim Boyd) and two dryland fields, predominately orchardgrass, timothy (*Phleum pratense* L.) and bromegrasses (*Bromus sp.*) located approximately 1 km southeast of Bozeman (Myers 1W and 2E). Soils of the Bridger series (fine, mixed Argic Cryoborolls) dominate these locations.

Fertilizer treatments were topdressed to a 335 m^2 area (Boyd) in a randomized, complete block design with three replications on 9 June 1978 (Table 1). Plant tissue samples (leaves only) were collected from each test plot on 26 June, 25 July, and 1 August, 1978. A 0.915 m by 5.33 m area of each plot was harvested using Jari mowers 1 August, 1978. Fertilizer sources included ammonium nitrate (34-0-0), urea (46-0-0), and ammonium nitrate-sulfate (30-0-0-6.5) at the Boyd location.

The experiment (Boyd site) was reestablished in the spring of 1979. Test plots went untreated in 1979 to

Table 1. Treatments applied to irrigated orchardgrass (Boyd site) June, 1978

Treatment No.	Fertilizer Rate kg/ha				Source
	N	P_2O_5	K_2O	S	
1	0	0	0	0	--
2	168	0	0	0	Urea
3	168	0	0	0	AN
4	168	112	0	0	AN
5	168	112	56	0	AN
6	168	112	56	37	ANS

clarify residual effects of fertilizer treatments applied in 1978. Soil samples were collected from each plot in June, 1979. Plant tissue sampling (leaves only) occurred 14 June, 17 July, and 26 July, 1979. Plots were harvested 26 July, 1979, with a Rem forage plot harvester.

Two 128 m by 100 m experiments were established on nonirrigated mixed species hayland (Myers 1W and 2E) in a randomized complete block design having three replications on 22 May, 1979, (Table 2). Soils in the rolling upland area are fine, mixed Argic Cryoborolls. All fertilizer treatments were topdressed 22 May except the S portion of treatment 11 which was applied 5 June. Soil samples were collected before fertilizer application. In the analyses reported in Table 3, pH was determined with a glass electrode (soil/water ratio of 1:2); organic matter colorimetrically (Sims and Haby, 1970); K from ammonium acetate extraction (Bower et al., 1952); P by the acid fluoride method of Smith et al. (1957); acetate-soluble S by Bardsley and Lancaster (1965). Plant tissue samples (leaves only) were taken through the growing season; 13 June, 29 June, 17 July, and 25 July, 1979. A 0.609 m by 6.75 m area of each plot was harvested 25 July, 1979, with a Rem forage plot harvester.

To quantify residual effects of both N and S fertilizers on forage yield and $(N/S)_t$ ratios, background fertilizer rates of 67 kg N/ha as urea and 45 kg P_2O_5/ha (diammonium phosphate) were applied 2 May, 1980, to both experiments at the Myers locations (1W and 2E). Soil sampling of all plots occurred 29 April, 1980. Plant tissue samples (leaves only) were collected on 6 June and 8 July at the 1W site and 13 June and 8 July, 1980, at the 2E site. Test plots were harvested using a Rem forage plot harvester 8 July for the 1W site and 11 July, 1980, at the 2E site.

Table 2. Treatments applied to nonirrigated hayland (Myers 1W and 2E sites) May, 1979.

Treatment[1/] No.	Fertilizer Rate kg/ha				Sulfur Source
	N	P_2O_5	K_2O	S	
1	0	0	0	0	--
2	168	0	0	0	--
3	168	112	0	0	--
4	168	112	56	0	--
5	168	112	56	34	Gypsum
6	168	112	56	67	Gypsum
7	168	112	56	101	Gypsum
8	168	112	56	34	ANS
9	168	112	56	34	APS
10	168	112	56	34	Amm.Thio.
11	168	112	97	0	--
12	168	112	97	34	Pot.Sulf.
13	168	0	0	0	--
14	168	112	56	0	--
15	168	112	56	100	Gypsum
16	168	112	56	100	SCU

1/ Treatments 1-12, N as Ammonium Nitrate (34-0-0); treatments 13-16, N as Urea (46-0-0).

Table 3. Soil analysis at Myers 1W and 2E sites, May, 1979.

Site Sampled	Depth cm	Texture	pH	OM %	P	K ppm	SO_4-S
1W	15	Cl	6.2	5.8	44	303	9.4
2E	15	Sil	6.0	6.0	51	265	10.3

Plant material harvested from each plot for the three experiments was weighed in the field. A subsample was weighed, dried at 65 degrees C for 72 hours, and reweighed for moisture content determination. Plant tissue samples were ground in a Wiley mill to pass a 40 mesh screen and stored in manila coin envelopes pending chemical analyses.

Plant tissue analyses were conducted on all treatments at each sampling date. Dried, ground tissue was analyzed for total N and total S (Appendix III). The total S procedure for plant material was developed by Dr. D. T. Westermann, USDA, ARS, Snake River Conservation Research Center, Kimberly, Idaho, and is described in its entirety in Appendix III.

A nitric-perchloric acid digest (Appendix III) was used to prepare selected plant tissue samples for further analyses. Calcium, Mg, K, Zn, and Mn levels were determined using flame atomic absorption spectrophotometry. Phosphorus analysis (Appendix III) was accomplished colorimetrically from aliquots of the nitric-perchloric acid digest.

Two-factor analysis of variance and least significant difference (LSD) values were calculated for all experiments for comparison of treatments.

RESULTS AND DISCUSSION

The experiment at the Boyd site was established on irrigated orchardgrass which received 110 kg N/ha earlier in the spring (Christensen and Kresge, 1978). Significant yield response was apparent only in the treatment receiving 37 kg S/ha (Table 4). Treatments 2 and 3 received 168 kg N/ha as ammonium nitrate and urea resulting in a substantial yield reduction.

Table 4. Response of irrigated orchardgrass to N and S fertilization, August, 1978.

Treatment No.	Yield[1/] kg/ha	$(N/S)_t$ Ratio
1	2345	34
2	1744	53
3	1360	53
4	3489	47
5	3252	53
6	5499	11
$LSD_{0.01}$	1300	12.96

1/ Forage at 0.0% moisture.

With the application of N alone, the ratio of non-S-containing amino acids to S-containing amino acids becomes extremely wide. The ratio of these amino acids in protein of adequately fertilized grass is appoximately 14:1. When excess N is applied in the absence of adequate S the plant accumulates amide N, nitrate and other nitrogenous compounds. Protein synthesis (plant growth) is inhibited by the lack of S containing amino acids, thereby reducing yield and widening the $(N/S)_t$ ratio. The addition of N alone reduced yield in treatments 2 and 3 and forced the $(N/S)_t$ ratios to 53. Phosphorus and K application did not change the $(N/S)_t$ ratio but did result in greater yields than the control and N treatments. Sulfur applied at 37 kg S/ha significantly increased yield and reduced the $(N/S)_t$ ratio to 11 which is within the normal range of 11 - 14 proposed by others (Metson, 1973, Tahtinen, 1977).

The Boyd site was maintained through 1979, without further fertilizer addition, to determine what residual effect the 37 kg S/ha treatment would have on second year yield and chemical composition. Results displayed in Table 5 indicate that there was residual S available the second year of the study. Orchardgrass yields were drastically lower than in 1978 (no additional fertilizer), however, significant yield response to residual S was apparent in 1979. The $(N/S)_t$ ratio of the S treatment was not significantly different from treatments 1 and 3.

Table 5. Residual response of irrigated orchardgrass to N and S fertilization, July, 1979.

Treatment No.	Yield[1/]	$(N/S)_t$ Ratio
1	977	20
2	633	25
3	916	21
4	685	31
5	700	25
6	2080	15
$LSD_{0.05}$	666	7.78

[1/] Forage at 0.0% moisture.

Nitrogen to S ratios of treatments 2, 4, and 5 were significantly greater than treatment 6 which indicates that the crop did benefit from residual S. The effect of residual S on forage yield in 1979 was significant.

However, the forage yield produced was less than half of that produced in the year of S application.

Having demonstrated the need for S fertility and the effect of S on crop yield and composition, two studies were established in 1979 to assess the potential residual effectiveness of gypsum at three S levels. A portion of the treatment set (Table 6) shows yield response to N at both Myers 1W and 2E locations. Significant response to S as gypsum was detected only with the S_2 (67 kg S/ha) level at the 2E site.

Table 6. Response of nonirrigated grass hay to N and S fertilization, July, 1979.

Treatment[1/] (and no.)	Yield[2/] kg/ha		$(N/S)_t$ Ratio	
	1W	2E	1W	2E
(1) Check	213	315	16	16
(4) NPK	2671	2369	30	25
(5) S_1	3026	2630	12	13
(6) S_2	3131	3202	13	10
(7) S_3	3000	2760	10	10
$LSD_{0.05}$	601	637	6.86	13.58

1/ Refer to Table 2 for complete fertilizer rates.
2/ Forage at 0.0% moisture.

The tendency for yield to increase with S application was apparent. Ratios of total N to total S in the plant were widened from 16 in the check to 30 and 25 with the addition of N, P and K fertilizer. The addition of S at all levels reduced the $(N/S)_t$ ratio to the normal range for grasses (11-14).

The residual effect of the treatment set applied at Myers 1W and 2E sites in 1979 can be seen in the selected results of the 1980 harvest data (Table 7). The S_2 and S_3 levels of gypsum at the 1W site significantly increased hay yields the year following application, while the S_1 rate (34 kg S/ha) did not provide enough carryover S for similar yields. The 2E location also showed significant yield response to residual S fertilizer but did so at the S_1 and S_3 levels. The residual response at the 2E site to the S_1 level in 1980 could be a function of the amount of S mineralized in 1980. Less of the available S may have been utilized in 1979 because of low rainfall condition (Appendix IV) thereby leaving it for crop use in 1980. The $(N/S)_t$ ratios reflected the yield response to S by falling into the 11-14 range with the maximum S levels at both locations.

Table 7. Residual response of nonirrigated grass hay to N and S fertilization, July, 1980.

Treatment[1/] (and no.)	Yield[2/] kg/ha		$(N/S)_t$ Ratio	
	1W	2E	1W	2E
(1) Check	110	333	10	19
(4) NPK	1590	1916	30	31
(5) S_1	2092	3131	16	16
(6) S_2	2346	2794	15	15
(7) S_3	3018	3194	13	13
$LSD_{0.05}$	747	889	5.33	5.51

1/ Refer to Table 2 for complete fertilizer rates.
2/ Forage at 0.0% moisture.

CHAPTER 4

INTERACTION EFFECTS OF NITROGEN AND SULFUR FERTILITY ON YIELD AND CHEMICAL COMPOSITION OF DRYLAND FORAGE.

INTRODUCTION

Diagnosis of S deficiency is difficult due to poor correlation of soil sulfate-S (SO_4-S) concentration with crop response. The lack of a soil test capable of identifying S deficient soils has led to the use of plant tissue analysis as an indicator of the system's S status. Due to the dynamic nature of nutrient concentrations in plant tissue as a function of anatomical position or stage of maturity, the use of tissue analysis must be standardized to a specific plant part at a specific growth stage (Westermann, 1975). By measuring the level of total N and total S in tissue, workers have been able to identify plant S status with the ratio of the two elements (Metson, 1973). With the absence of a soil test to accurately predict S deficiency, western Montana forage producers are not able to identify potential S deficient production areas.

Yield responses of forage crops to S fertilizers has been documented over the years in many geographical locations (Jones, 1964; Walker et al., 1956; Rendig, 1956; Seim et al., 1968). In general, the application of S fertilizer to forages resulted in yield increases and reduced $(N/S)_t$ ratios.

Recent investigations have identified S deficient soil/plant systems in southwestern Montana. Results of work by Christensen and Kresge (1978) showed that additions of N increased S deficiency on irrigated orchardgrass. Orchardgrass plants appeared stunted and pale yellow which is indicative of S deficiency. The application of 37 kg S/ha as ammonium nitrate-sulfate corrected the crop's S deficiency. Visual symtoms of S deficiency were apparent only in the treatments not receiving S. The S treated plots maintained a healthy, green orchardgrass stand which eventually produced yields in excess of 5,000 kg/ha. A later study (Kresge and Gavlak, 1980) found that S deficiency on nonirrigated hayland could be corrected with the application of S. Approximately 34 kg S/ha as gypsum was necessary to alleviate the deficiency when the N fertility level was optimized.

This study was initiated to establish a method or procedure to assist southwestern Montana forage producers with the identification and correction of potential S deficient crop production acreage. A further objective was to define the agronomic effectiveness of varying N and S levels on forage yield and chemical composition.

MATERIALS AND METHODS

Three nonirrigated locations approximately 1 km apart, 15 km southeast of Bozeman, Montana were selected for experiments designed to investigate the agronomic effectiveness of varying levels of N and S fertilizer on $(N/S)_t$ ratios and total forage yield. The predominant species were orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.) and bromegrasses (*Bromus sp.*) at the 3W and 4E locations. The 5E site maintained an established mixed species stand of sainfoin (*Onobrychis viciifolia* Scop.) and orchardgrass. Soils at these locations are fine, mixed Argic Cryoborolls lying approximately 1525 meters above sea level (Appendix II).

Similar randomized, complete block designs were established at each site. Treatments, shown in Table 8, were applied to 2.5 m by 7 m plots. Experiments 3W and 5E contained four replications and the 4E site had three replications. The treatment set consisted of three levels of N (20, 80 and 140 kg/ha) as urea phosphate (TVA 17-44-0) and four levels of S (0, 20, 40 and 60 kg/ha) as gypsum in all combinations. A constant background rate of 52 kg P_2O_5/ha from urea phosphate and 30 kg K_2O/ha as KCl.

Table 8. Treatments applied to nonirrigated hayland (Myers 3W, 4E, and 5E sites) May, 1980.

Treatment No.[1/]	Fertilizer Rate kg/ha	
	N	S
1	20	0
2	20	20
3	20	40
4	20	60
5	80	0
6	80	20
7	80	40
8	80	60
9	140	0
10	140	20
11	140	40
12	140	60

1/ N source 17-44-0, S source Gypsum.

Prefertilizer soil samples were collected by replication from each site followed by fertilizer topdressing between 2 May and 6 May 1980. Soil sample analyses included pH by glass electrode (soil/water ratio of 1:2); organic matter colorimetrically (Sims and Haby, 1970); K from ammonium acetate extraction (Bower et al., 1952) P by the acid fluoride method of Smith et al., (1957); and acetate-soluble S by the procedure of Bardsley and Lancaster (1965).

Plant tissue samples (leaves only) were collected from all plots at the three sites during the growing season. A 0.609 m by 6.75 m area of each plot was harvested between 11 July and 15 July with a Rem forage plot harvester.

Plant material harvested from each plot for the three experiments was weighed in the field. A subsample was weighed, dried at 65 degrees C for 72 hours, and reweighed for moisture content determination. Plant tissue samples were ground in a Wiley mill to pass a 40 mesh screen and stored in manila envelopes pending chemical analyses.

Plant tissue analyses were accomplished on all treatments at each sampling date. Dried, ground plant tissue was analyzed for total N and total S (Appendix III). The total S procedure for plant material was provided by Dr. D. T. Westermann, USDA, ARS, Snake River Conservation Research Center, Kimberly, Idaho, and is described in its entirety in Appendix III.

A nitric-perchloric acid digest (Appendix III) was used to prepare selected plant tissue samples for further analyses. Calcium, Mg, K, Zn, and Mn levels were determined using flame atomic absorption spectrophotometry. Phosphorus analysis (Appendix III) was accomplished colorimetrically from aliquots of the nitric-perchloric acid digest.

Two-factor analysis of variance, and least significant difference (LSD) values were calculated for all experiments for comparison of treatments.

RESULTS AND DISCUSSION

Forage yield responses to applied N and S are illustrated for the three sites in Figures 1-3. The figures represent data listed in Appendix I. Analysis of variance indicates significant yield response to both N and S when applied in the proper proportion (Table 12).

Yield of forage was significantly increased at the Myers 3W site (Figure 1) by application of 140 kg N/ha. Little change in yield was detected with S application when only 20 kg N/ha was applied. Greater yield differences between S levels were seen at the 80 kg N/ha level suggesting that N was limiting the potential yield response of applied S. It appears that the crop was N deficient at the 80 kg N/ha level when S was increased to 60 kg/ha at both the Myers 3W and 4E locations (Figures 1 and 2) by the distinct depression seen in the response surfaces. This yield depression was eliminated with adequate N at the 140 kg/ha level. Yield response to incremental application of S at the maximum N rate was significant at locations 3W and 4E (Figures 1 and 2).

The N to S ratios consistently reflected the S status of the forage at harvest. Additions of N without S nearly doubled the $(N/S)_t$ ratio from 14 with 20 kg N/ha to 27 with the 140 kg N/ha level at the Myers 3W location (Figure 4).