



Availability of sulfur to alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) as influenced by source and time of sulfur fertilizer applications
by Larry Edward Stoltenberg

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
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Abstract:

Sulfur deficiency in alfalfa in western Montana has created the need for a more satisfactory fertilizer material than gypsum and a method for predicting the need for S (sulfur). Experiments were established on soils where S deficiencies were suspected or were noted in the past.

Three sources of S were used including gypsum (commonly used in western Montana for S deficiency corrections), finely ground elemental S, and 0-40-0-20(S) developed by TVA (Tennessee Valley Authority). Rates ranged from 0 to 40 pounds of S per acre for gypsum and 0-40-0-20(S) and 20 pounds per acre of elemental S. Times of S fertilization were late fall, early spring before alfalfa growth initiation at 4 locations, and at another location one date at 3 to 6 inches of growth and another date between cuttings.

Significant yield responses occurred at the three locations used for evaluation of the rates, times of application and sources of S. At high rates, fall applied 0-40-0-20(S) produced yields comparable with those from gypsum. Low rates of spring applied 0-40-0-20(S) tended to be comparable with low rates of spring applied gypsum. However, higher rates of spring applied 0-40-0-20(S) did not increase yields as much as gypsum.

In general, fall applied S fertilizers were more effective than any other time of application.

Soil samples were collected in the spring from plots fertilized with gypsum and 0-40-0-20(S), either in the previous fall or very early spring, and the check treatment. When acetate soluble SO_4 extracted from the first foot of soil was compared with yield, a correlation $r = .729$ resulted when the 3 locations were grouped. This correlation was not improved by using soil sampled to the four-foot depth.

The increase in yield from S applications at a total of 9 locations, both irrigated and nonirrigated, was correlated with both the N to S ratio and S percentage in whole plants. No significant correlation existed between yield increase and N to S ratio, but all responsive sites except one had a ratio of greater than 11.

Yield increase from S fertilization was related to S percentage in the S checks. There was a correlation of $r = .908$ for the responsive part of the curve. A critical percentage in mature alfalfa plants of 0.228% S was determined below which a response to S fertilization was assured. Indications were that S percentage in alfalfa plants 2 to 3 inches in height might be nearly as precise for prediction of S needs as mature plants. More evaluation of that is needed.

AVAILABILITY OF SULFUR TO ALFALFA (Medicago sativa L.)
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by

LARRY EDWARD STOLTENBERG

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fulfillment of the requirements for the degree

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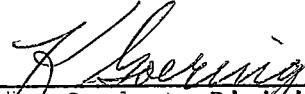
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ABSTRACT

Sulfur deficiency in alfalfa in western Montana has created the need for a more satisfactory fertilizer material than gypsum and a method for predicting the need for S (sulfur). Experiments were established on soils where S deficiencies were suspected or were noted in the past.

Three sources of S were used including gypsum (commonly used in western Montana for S deficiency corrections), finely ground elemental S, and 0-40-0-20(S) developed by TVA (Tennessee Valley Authority). Rates ranged from 0 to 40 pounds of S per acre for gypsum and 0-40-0-20(S) and 20 pounds per acre of elemental S. Times of S fertilization were late fall, early spring before alfalfa growth initiation at 4 locations, and at another location one date at 3 to 6 inches of growth and another date between cuttings.

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Yield increase from S fertilization was related to S percentage in the S checks. There was a correlation of $r = .908$ for the responsive part of the curve. A critical percentage in mature alfalfa plants of 0.228% S was determined below which a response to S fertilization was assured. Indications were that S percentage in alfalfa plants 2 to 3 inches in height might be nearly as precise for prediction of S needs as mature plants. More evaluation of that is needed.

INTRODUCTION

Sulfur deficiency, especially in alfalfa, has been recognized in the western part of Montana since the mid 1930's (22). Since then, and possibly before, farmers and ranchers in the affected areas have consciously applied sulfur by using gypsum or unconsciously by applying fertilizer which contains sulfur as a by-product as superphosphate (20% P_2O_5), ammonium sulfate, 16-20-0 (ammonium phosphate-sulfate), and potassium sulfate. Recently, however, there has been a trend toward high analysis fertilizers, thereby reducing the amount of sulfur present as a by-product. This has placed greater emphasis on the use of gypsum.

Although gypsum, where applied, corrected S (sulfur) deficiencies, it is not without problems: (1) due to its low solubility it must be ground quite finely, which has a tendency to "set up" in a fertilizer spreader; (2) it must be applied in a separate operation from other fertilizers; and (3) accurate spreading is difficult if windy.

To date no reliable or well correlated method of predicting the need for sulfur has been used in Montana. In some cases blanket statements concerning the need for sulfur in a general area have been made without consideration for the individual location.

A study was set up in Western Montana by the Montana Cooperative Extension Service in cooperation with the Montana Agricultural Experiment Station and was financed in part by the Tennessee Valley Authority (TVA). Objectives of the study were:

1. To determine the magnitude of response to S fertilizer.

2. To compare gypsum with a new fertilizer from TVA, 0-40-0-20(S), (elemental sulfur physically combined with high analysis concentrated superphosphate).
3. To compare time of application of S fertilizer.
4. To determine if plant analysis or soil analysis or a combination of the two can be used to predict the need for S fertilization.

LITERATURE REVIEW

It has been recognized since the early 1800's that S (sulfur) is required for plant growth in macronutrient amounts (37). Widespread areas of S deficiency, however, have occurred only recently compared with the need for nitrogen, phosphorus, and potassium (36).

Deficiencies of S which are caused by leaching, crop use, and erosion (15,41) have been made up in incidental ways (31). Due to changing technology and practices, much less S is added to the soil, thus creating a greater need for S fertilizers.

The manufacturing of high analysis fertilizers has effectively eliminated most of the S in N, P, and K fertilizers, ammonium sulfate, and superphosphate (20% P_2O_5), are being replaced by ammonium nitrate and concentrated superphosphate (18). The former contain about 27 and 14 percent S, respectively, while the latter materials contain essentially no S.

Another such practice is using less coal for heating homes and use in industry(14). The combustion of coal yields large quantities of sulfur dioxide. Plants can absorb sulfur dioxide through their leaves (1). It was reported by several investigators that from 30% to 40% of the plant needs for S can be satisfied in this way, even though adequate amounts exist in the soil (1,35). Sulfur dioxide is also absorbed by soil where it can be converted to sulfate, leached downward, and utilized.

It has been suggested that if strict rules concerning air pollution are passed and enforced, the amount of S in the atmosphere will be greatly reduced and the need for S as an added fertilizer may become greater (12).

Other practices which decrease the amount of sulfur available to plants are the decreasing use of elemental sulfur as pesticides (12) and more removal from soil by increasing crop yields (9).

Approximately 90 percent of the S in plants is found in the three sulfur bearing amino acids: methionine, cystine, and cysteine (28). Sulfur is also found in coenzyme A; glutathione; lipoic acid; the vitamins thiamine and biotin; and a nerve and bile constituent, taurine (28). It has been shown that a normal plant will produce several of the nonsulfur bearing amino acids in significantly larger amounts than the sulfur deficient plant (23).

There is apparently no general criterion for predicting whether or not a specific land area might be potentially sulfur deficient. Studies in California indicate no relationship between sulfur deficiencies and parent materials (29). Another study conducted on a nationwide basis determined that soils subjected to little weathering contained more total sulfur than soils severely weathered (22).

The greater part of the sulfur in soil is tied up in the organic portion of the soil with only a very small portion in the soluble state (4). Harward et al. (18) reported no relationship between organic sulfur and corresponding yields. Since there is a high correlation between organic matter and sulfur (16), this would suggest a poor correlation between organic matter and yields.

Sulfur in the form of sulfate is not readily leached from soils (11,13). It was determined by several investigators that the clay portion of the soil is responsible for this retention (24,32). Soil constituents

vary considerably in their ability for sulfate retention with iron and aluminum oxides being the most effective (13). Kaolinite will retain only about one hundredth of what iron and aluminum oxides will, while illite is even less effective. This may explain why many of the soils in the southeastern United States, especially the medium to heavy textured soils, are deficient from 0 to 6 inches and contain adequate amounts from 6 to 48 inches (13,39). Soils containing less clay did not have this accumulation below 6 inches.

There are several factors which antagonize this retention, including heavy phosphate additions (21). Phosphate anions are more firmly attracted to these sites and excessive phosphate will drive off sulfate (21). An increase in pH or an addition of lime will decrease the amount of sulfate retained (24). The exact mechanism is not known. It was also suggested by Chao et al. (11) that organic matter retains sulfate on positive sites. No elaboration was made as to the mechanism.

Attempts have been made to relate S extracted from soil to plant available S using four types of soil tests. They are: total sulfur, reserve sulfur, soluble sulfates, and soluble sulfates plus S released upon incubation (4,19,21,39). It was found that total sulfur was not related to yield (8,42). Harward et al. (19) determined that the organic S content of soil alone was not closely related to plant response. However, organic sulfur may be an indicator of the long term supply.

Differing results are found concerning soluble sulfates as a soil test (19,21,39). The major drawback appears to be the fact that only small amounts of sulfates appear in the soil at a given time. Also, there

is a general consensus that water extracts are not satisfactory (30). Sulfate that is absorbed on clays and organic matter, that is associated with CaCO_3 , and water insoluble sulfate are not extracted with water but are generally considered to be available to the plant.

Extracting solutions used most frequently are acetate salt solutions (ammonium or sodium) (30), calcium phosphate (19), and sodium bicarbonate (25). Several workers have found that phosphate soluble sulfate extraction of soils seemed to give a good indication of available S (19,20).

Calcium phosphate is somewhat of an ideal extracting solution. The function of the phosphate is to replace the sulfate that has been absorbed and yet to be available to the plant. Calcium suppresses extraction of soluble organic matter, eliminating contamination from the soluble organic sulfur. Incubation techniques have been used by several workers but have not greatly improved correlations with response to S additions (10).

Although it is more of a hindsight method, the determination of percent S in plant material may be a valuable diagnostic tool for determining deficiencies. Primarily the two forms of S determined by plant analysis are total S and $\text{SO}_4\text{-S}$ (sulfate-sulfur). The $\text{SO}_4\text{-S}$ test is quicker, but total S has been used more. Apparently total S is more closely related to the S supply for the plant than is $\text{SO}_4\text{-S}$.

The critical percentage of a nutrient element is defined by Macy (27) as the point or portion of a response curve that separates "poverty adjustment" from "luxury consumption". The basis for using a critical percentage is that a certain species is believed to have the same nutrient concentration over a large range of soil types and climatic conditions. For the

most part this has proven to be correct. However, available soil moisture, variety, and maturity influences the critical percentage of S in the alfalfa plant (38).

More work has been done with the alfalfa plant in determining the S critical percentage than any other plant (7,21). The generally agreed critical value is from .20 to .22 percent total S in mature alfalfa plants. Good correlations between the critical value and yield in mature plants have been obtained under field conditions.

An attempt to eliminate critical identification of plant maturity and to permit earlier sampling has been accomplished by using the N to S ratio (3,17,33). The theory behind the N to S ratio is that if sulfur is limiting plant growth, nitrates will accumulate in the plant, sometimes to the point of being toxic to animals (26). If there is adequate S, the rate of nitrogen uptake will be slowed down somewhat, but the uptake of S will be greater.

It has been suggested by Pumphrey and Moore (33) that an N to S ratio of eleven is the critical value for alfalfa. If it is higher than eleven, the plant is deficient of S. They obtained good correlations in Oregon between yield of alfalfa and N to S ratio, but poor correlations were obtained by Sorensen et al. (38) in Nebraska.

Another use of the N to S ratio might be that of determining whether or not an animal feed or forage contains enough sulfur (26). It has been suggested that animal feed should have an N to S ratio of about fifteen. If the N to S ratio is higher than this, poorer feed use efficiency will occur.

PROCEDURES

Selection of Sites

Five locations were chosen in the western part of Montana where sulfur deficiencies had been found in the past. Three of these sites were sampled in detail and were reported in this thesis. Data from the remaining two locations, plus several other locations are reported briefly in correlation studies. These locations are shown in Figure 1.

One of the locations was near Superior. Gypsum has been commonly used in the area as a fertilizer material. Although there was no research data to support this practice, farmer experience had shown good response. The specific location had never been fertilized and had been seeded to alfalfa in 1966. This plot was on a nonirrigated, loamy sand soil and was low in organic matter, Table 1. A general profile description is given in Table II.

The other two locations were in the Bitterroot Valley. Sulfur deficiencies had been found in various parts of the Valley. 1,2/ One of the locations was near Woodside. The rancher had used phosphorus and nitrogen on a mixed stand of orchardgrass and alfalfa. He complained of alfalfa stands which had a tendency to die out after a period of four to five years following planting. This can be a symptom of sulfur deficiency. 1/

1/ Smith, C. M. and DeBree, J. Unpublished reports. Professor and Extension Soil Scientist, Montana State University; and former County Agent, Ravalli County, Montana, respectively, 1964 and 1965.

2/ Graham, Donald R. Personal communication. Assistant Soil Scientist, West Branch Experiment Station, Corvallis, Montana, 1966.

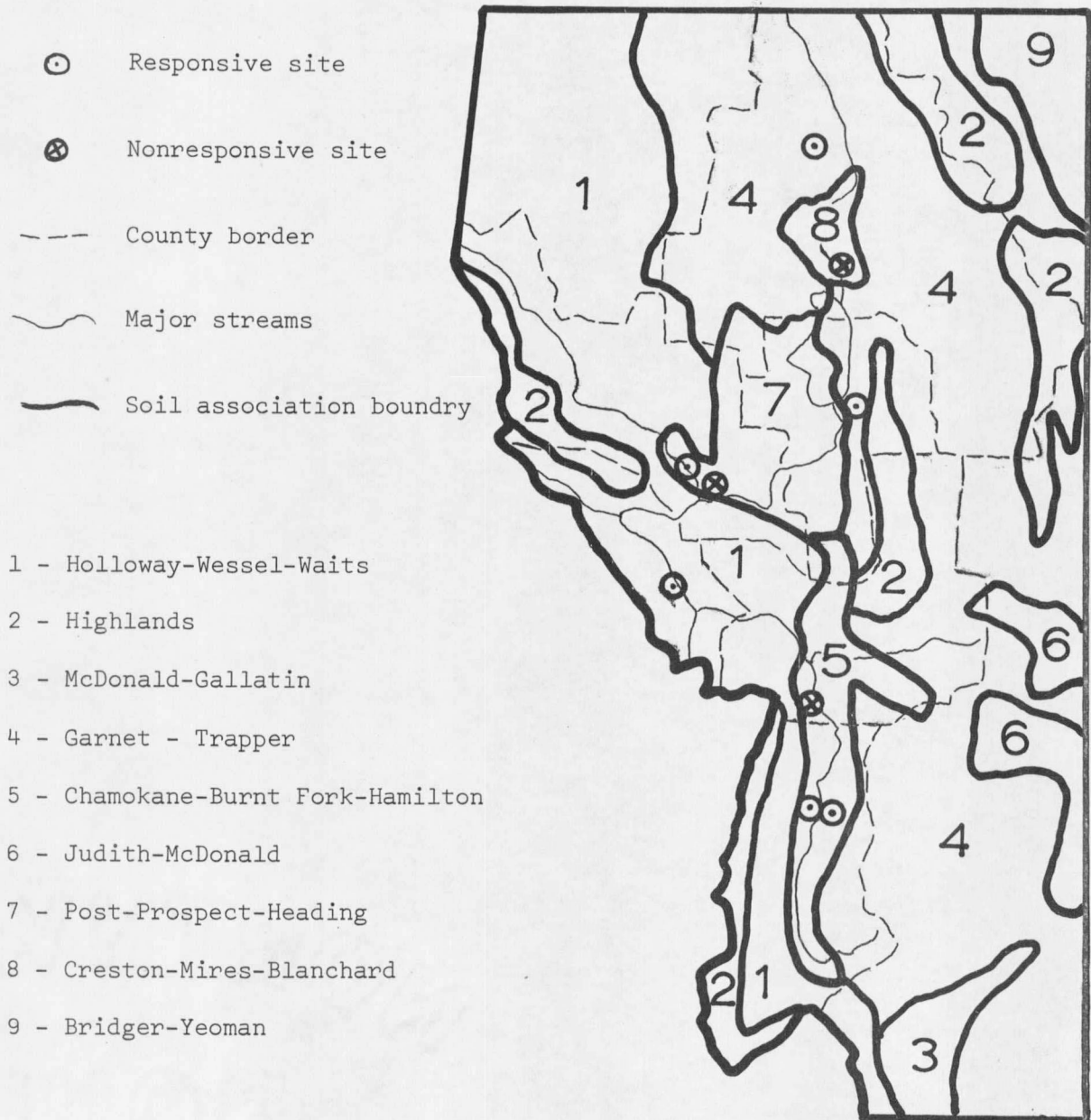


Figure 1. Location of both responsive and nonresponsive sites to S fertilization in western Montana in relation to major soil associations.

Table I. Some chemical 1/ and physical properties of soil samples for three locations--
upper six inches.

Location <u>2/</u>	pH	P Rating		K Rating		O.M.	Series Name	Texture	Slope
		lb/A		lb/A		%			%
Corvallis	6.8	112	medium	310	medium	1.5	Breece	gravelly loamy coarse sand	0-2
Woodside	6.8	34	very low	290	medium	1.7	Chereete	coarse sandy loam	0-2
Superior	6.0	88	low	350	medium	1.6	Hask	loamy fine sandy	0-3

1/ Montana State University Soil Testing Laboratory. 1966.

2/ Legal descriptions for each location are as follows:

Corvallis: SW $\frac{1}{4}$ of NW $\frac{1}{4}$ section 10, R20W, T6N.

Woodside: SE $\frac{1}{4}$ of NW $\frac{1}{4}$ section 35, R21W, T6N.

Superior: NE $\frac{1}{4}$ of NW $\frac{1}{4}$ section 17, R25W, T15N.

Table II. Profile descriptions of the three locations reported in this thesis. Superior 1/, Corvallis 2/, and Woodside 2/.

<u>Hask loamy fine sand (Superior)</u>		
O1	1- 0"	Dark colored, well decomposed organic material.
A21	0- 9"	Light gray loamy fine sand; weak fine and medium sub-angular blocky structure; many uncoated sand grains; soft, very friable; plentiful fine roots; many fine vesicular pores; slightly acid; clear smooth boundary.
A22	9-24"	Light gray loamy fine sand; weak fine subangular blocky structure; soft, very friable; many uncoated sand grains; plentiful fine roots; many fine vesicular pores; slightly acid; clear smooth boundary.
A23	24-36"	White loamy fine sand; massive; soft, very friable; few fine and medium roots; 80 percent uncoated sand grains; many fine vesicular pores; slightly acid; clear wavy boundary.
A % B	36-52"	White loamy fine sand matrix and brown sandy loam discontinuous bands less than ½ inch thick and making up 15 percent of the soil; massive; loamy sand is soft and very friable; sandy loam is slightly hard, firm, slightly plastic and sticky; few medium and fine roots; fine sand matrix has nearly all uncoated sand grains; brown bands have common very fine vesicular pores; neutral; clear wavy boundary.
C	52-66"	White sand matrix making up 90 percent of soil with many darker colored sand grains, grayish when moist; loose; single grain; dark brown wavy loamy sand bands up to ½ inch thick; massive; slightly hard, very friable; neutral for both bands and sandier material; clear wavy boundary.
<u>Breece gravelly loamy coarse sand (Corvallis)</u>		
A ₁	0-18"	Dark gray; very friable loamy coarse sand; weak fine and medium crumb structure; plow layer is usually slightly lighter colored than the lower part; slightly acid.

Table Continued...

Table II, Continued:

<u>Breece gravelly coarse sand (Corvallis) cont.</u>		
B	18-32"	Gray; very friable loamy coarse sand merging into horizons above and below; noncalcareous.
C	32-48"	Somewhat stratified, very friable to loose loamy coarse sand and gravelly loamy coarse sand; generally lighter colored and more yellowish than horizons above; contains coarse angular fragments, mostly granite, and generally less than 1 inch in diameter.
<u>Chereete coarse sandy loam (Woodside)</u>		
A ₀	1- 0"	Litter, the upper half undecomposed pine needles and the lower half a partially decomposed mat containing some mineral matter in the lower part.
A ₂	0- 3"	Light gray; stony coarse sandy loam; contains an abundance of gravel; moderately acid.
B	3-14"	Very pale brown; stony gravelly coarse sandy loam; contains a few spots and streaks of brown gritty fine earth; moderately acid.
C	14-30"	Loose stones; cobbles, gravel, and sand, chiefly from granite.

1/ Dunmire, R. G. Personal communication. Soil Conservation Service, Missoula, Montana, 1968.

2/ Soil Conservation Service. Soil Survey, Bitterroot Valley Area, Montana, pp. 81 and 91, respectively, 1959.

This experimental area near Woodside formerly had been a woodland but had been cleared and leveled. Table I shows the soil was a Chereete coarse sandy loam very low in organic matter. Table II shows a general profile description,

The Corvallis site was observed in November, 1966, showing many S deficient plants and some healthy ones in the same area. Demonstration plots having an S variable had been established by Donald R. Graham with S applied between the first and second cuttings of hay during that summer. Marked response to S was observed. However, it was not decided until later that this location would be used, which accounts for the January date of treatment applications for the so-called "fall" date. 3/

It was also decided that since a response did exist in 1966 from the midseason application, two more dates of application than were used at the other locations should be added using two rates of S and two materials at each date. This was to determine how late in the season sulfur could economically be applied. The soil was classified as Breece gravelly loamy coarse sand.

Fertilizers

Three sources of S were used. Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) which contained 17 percent S was used. It was ground very finely and contained no free S. Another source was chemically pure or 100 percent S. Often referred to as elemental S, this form also was very finely ground. The third form was

3/ Ibid.

0-40-0-20(S). This was a new product from TVA containing 40 percent P_2O_5 and 20 percent S as elemental S. This product is made by introducing concentrated superphosphate, which is in the physical form of small granules, onto a pan granulator. Steam, water, and molten sulfur are sprayed into the pan as it revolves and as the particles grow. The end result is particles with sulfur well distributed throughout. 4/

The source of phosphorus (P) in the field experiment was 0-52-0 (purified concentrated superphosphate containing 52 percent P_2O_5) obtained from TVA. This was the same source of P as used in making 0-40-0-20(S). A higher analysis than the usual 0-45-0 (triple superphosphate) is possible by the use of superphosphoric acid, which drives out the water of hydration and more of the volatiles than does phosphoric acid. 5/ The K used was in the form of 0-0-60 or 60 percent K_2O . It is commonly referred to as muriate of potash (KCl).

The various treatments are listed in Table III. Sulfur was applied at rates of 0, 10, 20, and 40 pounds of S per acre. An 80 pound rate of S as gypsum was also fall applied at the Corvallis location.

Dates of fertilizer application and growth of plants are shown in Table IV. For all locations except Corvallis there were two dates of fertilizer application, fall and spring. At the Corvallis location there was one fall (or winter) date of application and three spring dates, Table IV.

4/ Tennessee Valley Authority, TVA Fertilizer Materials, 1966. Knoxville, Tennessee.

5/ Tennessee Valley Authority, TVA Fertilizer Materials, 1960. Knoxville, Tennessee

Table III. Fertilizer treatments: Superior, Woodside, Corvallis.

Cor- vallis	2/ Others	Fertilizer Treatments								Fertilizers 1/ Fall Spring	
		Fall			Spr. I		Spr. II	Spr. III	S	S	
		P	K	S	P	S	S	S			
		lb/A	lb/A	lb/A	lb/A	lb/A	lb/A	lb/A			
1	1	0	0	0	--	--	--	--			
2	2	0	0	0	--	--	--	--			
	3	0	0	20							4
	4	0	40	20	--	--	--	--			3,4
	5	40	0	20	--	--	--	--	1		4
	6	20	40	20	--	--	--	--			3,4
3	7	40	40	0	--	--	--	--	1		3
4	8	40	40	10	--	--	--	--	1		3,4
5	9	40	40	20	--	--	--	--	1		3,4
6	10	40	40	20	--	--	--	--	1		3,4
7	11	40	40	10	--	--	--	--			1,2,3
8	12	40	40	20	--	--	--	--			1,2,3
9	13	40	40	40	--	--	--	--			1,2,3
10	14	40	40	20	--	--	--	--	1		3,5
11	15	40	40	0	--	10	--	--	1		3 4
12	16	40	40	0	--	20	--	--	1		3 4
13	17	40	40	0	--	20	--	--	1		3 4
14	18	40	40	0	--	20	--	--	1		3 5
15	19	0	40	20	40	--	--	--			3,5 1
16	20	0	40	0	40	10	--	--			3 1,2
17	21	0	0	0	40	20	--	--			3 1,2
18	22	0	0	0	40	40	--	--			3 1,2
19		40	40	20	3/ 4/	--	--	--	1		3,4
20		40	40	20	4/	--	--	--	1		3,4
21		40	40	80	--	--	--	--	1		3,4
22		40	40	0	10	10	--	--	1		3 5
23		40	40	0	--	--	10	--	1		3 5
24		40	40	0	--	--	--	10	1		3 5
25		40	40	0	--	--	20	--	1		3 5
26		40	40	0	--	--	--	20	1		3 5
27		40	40	0	--	--	10	--	1		3 4
28		40	40	0	--	--	--	10	1		3 4
29		40	40	0	--	--	20	--	1		3 4
30		40	40	0	--	--	--	20	1		3 4
	23 5/	80	40	20	--	--	--	--	1		3,4
	24 5/	40	80	20	--	--	--	--	1		3,4

1/ Numbers refer to following: 1, 0-52-0; 2, 0-40-0-20(S); 3, 0-0-60;

4, gypsum; 5, sulfur (100%).

2/ Corvallis location received blanket application of 40 lb K/A.

3/ Application of Zn at 5 lb/A.

4/ Application of B at 5 lb/A.

5/ Woodside location only.

Except for Corvallis, the fall date of application was made after there was no more plant growth but before the onset of winter. The first spring application was about one month before visual growth initiation. The second spring application at Corvallis was after growth had started but before plant height had exceeded three inches in the S check, which was the treatment receiving P and K but no S. The third date was between the first and second cutting.

The individual plots receiving treatments were either 15 feet by 20 feet or 20 feet by 20 feet. Areas of the small plots were calculated as fractions of an acre and the appropriate rate of fertilizer element in pounds per acre was reduced by the same ratio and expressed in grams. The appropriate fertilizer mixture for each plot was applied on top of the soil as a topdressing.

Table IV. Dates of fertilizer application and plant growth at time of spring fertilization:

Location	Dates of fall application	Dates of spring application	Plant height
Corvallis	January 10, 1967	Spr. I March 24, 1967	No growth
		Spr. II May 14, 1967	2" - 3"
		Spr. III July 18, 1967	6" - 12"
Woodside	November 4, 1966	March 24, 1967	No growth
Superior	November 4, 1966	March 23, 1967	No growth

Preharvest Soil and Plant Sampling

Soil samples were taken at the Corvallis, Woodside, and Superior locations around May 15, 1967, when alfalfa height was approximately three inches. Samples were taken with a King tube at depths of 0 to 6 inches, 6 to 12 inches, 1 to 2 feet, 2 to 3 feet, and 3 to 4 feet. The 3 to 4 foot depth could not be sampled at the Woodside location because of excessive gravel at that depth. A sample consisted of three cores taken randomly.

A strip about 3 feet wide and 16 to 17 feet long was mowed through each plot. Care was taken so none of the cut alfalfa from the alley would get into the sample and give a weight too large for the particular plot. The mowed strip was then raked and weighed to the nearest one-tenth of a pound. The cut length of each plot was recorded and plant samples were taken for moisture determination. If there were no visual differences among plots within a replication, one moisture sample was taken per replication. If differences appeared, such as color, vigor, height, wilting or lodging, a sample was taken to represent each condition and/or each treatment.

The moisture samples were taken from within the cut piles after weighing so as to reduce to a minimum the possibilities of obtaining hay that had been subjected to some drying. Small subsamples were taken from each pile and composited in a plastic bag and sealed. The moisture samples were weighed again. Percent moisture was calculated. By substituting into the appropriate formula, oven dry weight was obtained in pounds per acre.

Throughout the thesis, any weight referring to yield will be in terms of oven dry weight.

Plant samples for chemical analysis were also taken from each plot. The manner of obtaining these samples was identical to that for the collection of the preharvest samples.

Soil Test

An acetate soluble sulfate test was used for the soil samples (5). The air dried soil was crushed with a rolling pin and passed through an eighteen mesh per inch screen. Any gravel that would not pass the screen was discarded. Each sample was then redried for forty-eight hours at 50°C prior to testing. It was felt that this temperature was relatively safe, since vegetative matter does not decompose below a temperature of 70°C (20). Several samples were selected randomly and dried at 110°C for forty-eight hours to determine if all water had been removed. A subsample of ten grams was taken from each large sample.

Soil subsamples were placed in 50 ml. erlenmyer flasks along with 25 ml. of extracting solution. An extracting solution was made by adding 39 grams of ammonium acetate to one liter of 0.1N acetic acid. The flasks were then shaken for exactly thirty minutes. The shaker was an oscillating type with a throw of one-half inch at 240 cycles per minute. Approximately one-fourth gram of double acid-washed activated charcoal was then added and the resulting mixture was shaken for an additional three minutes. Since vigor and time of shaking may vary the amount of sulfate, both are critical and should be kept constant.

The mixture was then filtered through Whatman No. 40 double acid washed filter paper. A 10 ml. aliquot of filtrate was pipetted into a 125 ml. erlenmyer flask and 1 ml. of acid seed solution added. Acid seed solution is made by adding 0.5434 gram of K_2SO_4 in one liter of 6N HCl, resulting in a solution of 20 ppm sulfur.

One-half gram of $BaCl_2$ was added and the flasks were left undisturbed for at least one minute. The flasks were then swirled until the $BaCl_2$ crystals dissolved. The resulting precipitate was then read in a Bausch and Lomb Spectronic 20 colorimeter within two to eight minutes with the machine grid set at 420 mu.

Plant Chemical Analysis

The plant analysis test for S was a modification of the procedure of Bardsley and Landcaster (4). It determined the amount of total sulfur in plant material by the use of oxidizing materials to convert sulfur of any valence to sulfate. The procedure was modified at Washington State University 6/ before it was used there in 1963, and it was again modified for this project at Montana State University.

An extremely fine grind of plant material was necessary to ensure close contact between ashing powder and plant material. To ensure this fine grind, samples were first run through a Wiley mill; then a ball mill. The ball mill was a model 3800 made by the Pitchford Manufacturing Company.

6/ Koehler, Fred E. Personal Communication. Unpublished information, Washington State University, 1967.

A sample of 0.250 grams of plant material was thoroughly mixed with 1.5 grams of ashing powder in a 50 ml. beaker. An additional 0.5 grams of ashing powder was sprinkled uniformly on top of the mixture as a top-dressing. The topdressing was to reduce to a minimum any loss of volatile sulfur compounds during ashing.

A total of 2.0 grams of ashing powder was used instead of 1.5 grams as was originally proposed. This change in procedure was responsible for greater amounts of sulfur extracted, Table V. The increases averaged 41 and 45 percent, respectively, for the first and second cuttings.

The ashing powder contained a ratio of 27 grams of Na_2CO_3 , 3 grams of NaHCO_3 , 1.8 grams of NaNO_3 , and 0.06 grams of KMnO_4 . The addition of the latter two chemicals was a modification made at Washington State University. ^{7/} This mixture was then ground in a power mortar and pestle until there was no greater color intensity from the KMnO_4 --about five minutes. Time varied with how close the pestle was set to the mortar. If set too closely, caking of the powder occurred.

The beakers were placed in a muffle furnace for one hour at 260°C , followed by two hours at 480°C . The resulting ash was treated with 25 ml. of acid solution. The acid solution consisted of 114.2 ml. concentrated HCl , 125.6 ml. of concentrated CH_3COOH , and 8.3 grams $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$. The resulting mixture was made up to two liters with distilled water. Then the ash and acid solution was shaken on a shaker for approximately

^{7/} Ibid.

Table V. Differences in the percent of S extracted by increasing the amount of ashing powder from 1.5 to 2.0 grams using plant material from three locations and two dates of sampling.

Tmt No	Fertilizer			1st Sampling Date		Harvest	
	P	K	S	May 1967		July 1967	
	1b/A	1b/A	1b/A	1.5g %	2.0g %	1.5g %	2.0g %
<u>Superior</u>							
1	0	0	0	.152	.252	.074	.162
9	40	40	20 <u>b,d/</u>	.238	.356	.148	.192
10	40	40	40 <u>b,d/</u>	.255	.390	.150	.268
12	40	40	20 <u>b,d/</u>	.203	.305	.156	.220
13	40	40	40 <u>b,e/</u>	.205	.320	.142	.232
16	40	40	20 <u>c,d/</u>	.242	.346	.119	.199
21	40	40	20 <u>c,e/</u>	.158	.274	.125	.218
			Mean	.208	.321	.131	.213
<u>Woodside</u>							
1	0	0	0	.182	.279	.148	.193
9	40	40	20 <u>b,d/</u>	.253	.395	.172	.266
10	40	40	40 <u>b,d/</u>	.297	.442	.197	.300
12	40	40	20 <u>b,e/</u>	.212	.380	.240	.249
13	40	40	40 <u>b,e/</u>	.232	.371	.200	.355
16	40	40	20 <u>c,e/</u>	.244	.439	.175	.264
21	40	40	20 <u>c,e/</u>	.190	.334	.128	.264
			Mean	.230	.375	.180	.270
<u>Corvallis</u>							
1	0	40	0	.199	.315	.124	.195
3	40	40	0	.190	.302	.143	.179
5	40	40	20 <u>b,d/</u>	.322	.356	.231	.253
6	40	40	40 <u>b,d/</u>	.407	.420	.270	.319
8	40	40	20 <u>b,e/</u>	.217	.258	.191	.329
9	40	40	40 <u>b,d/</u>	.247	.244	.212	.344
12	40	40	20 <u>c,d/</u>	.310	.403	.302	.315
17	40	40	20 <u>c,e/</u>	.199	.257	.194	.259
25	40	40	20 <u>b,e/</u>	.459	.495	.206	.324
			Mean	.283	.339	.208	.280
Means of three locations:				.244	.345	.176	.256

- a/ Each datum is the mean of chemical analysis of three field replications.
b/ S fertilizer was fall applied.
c/ S fertilizer was spring applied.
d/ S fertilizer was gypsum.
e/ S fertilizer was 0-40-0-20(S).

one-half hour. The purpose was to digest the alkali ash in the acidic solution and timing and vigor of the shaker were not critical.

Five drops of 30 percent H_2O_2 was added to each flask to clear the solution. The original procedure suggested the use of activated charcoal for the purpose of clearing solutions. This was omitted because H_2O_2 cleared the solutions adequately and readings were less variable than when charcoal was used. From filtering to determination of light transmittance in the colorimeter, the procedure was the same as that used for the soil test.

Statistical Methods

All three locations were set up using a randomized complete block design with three replications. Each location had two nonfertilized checks which were handled statistically as plots treated alike. This was accomplished by doing an ANOVA (analysis of variance) on the plots that were treated alike. The block S.S. (sum of squares) corrected was subtracted from the total S.S. corrected.

This value had three degrees of freedom when placed in the ANOVA of the entire location because there was one degree of freedom within each of the three replications. This value was subtracted from the S.S. total corrected, along with S.S. for replication corrected and S.S. treatment corrected for determination of the error term. Test of significance used was the F-test.

For comparing individual treatments, least significant difference (LSD) and single degree of freedom comparisons were used. The level of significance in this thesis is 5 percent unless otherwise specified.

RESULTS AND DISCUSSION

There were several field experiments with an S variable. Three were selected for detailed study because it was expected from past evidence that they would be most likely to have significant responses to S fertilization. These were the Superior, Woodside, and Corvallis locations. The three experiments are reported here in detail. In addition to having marked response to S, these were the locations from which pre-harvest plant and soil samples were taken.

Responsive sites were necessary to evaluate yield responses to different kinds of S fertilizer and attempt correlations between soil sulfate concentrations or plant analysis data and yield. It may be helpful to have a site that does not respond for the purpose of determining upper limits. However, the problem of evaluation of sources of S and rates of S would be practically impossible if there were no responsive sites.

Yield

Superior--Phil Donally Ranch

Yield of dry matter for all treatments and some statistical analysis information is given in Table VI. Differences among treatments were significant at the 99 percent level of probability. However, variability was as high as is indicated by the size of the LSD's. Three treatments were significant at the 5 percent level. These were the 40-pound rates of S applied as gypsum and as 0-40-0-20(S) and the 20-pound rate of S applied as elemental S. All three were fall applied.

Using the 10 percent level of significance, there were two more treatments which were significant by greater than the S check. These

Table VI. Yield and statistical data of mature alfalfa; one cut total.
Superior.

Time of Fertilization					Fertilizer Source of S	Yield Oven Dry
Fall			Spring			
P	K	S	P	S		
lb/A	lb/A	lb/A	lb/A	lb/A		lb/A
0	0	0	--	--	none	2159
0	0	20	--	--	gypsum	3411
0	40	20	--	--	gypsum	3551
40	0	20	--	--	gypsum	4026
20	40	20	--	--	gypsum	3961
40	40	0	--	--	none	2642
40	40	10	--	--	gypsum	3257
40	40	20	--	--	gypsum	4163
40	40	40	--	--	gypsum	5241
40	40	10	--	--	0-40-0-20(S)	2513
40	40	20	--	--	0-40-0-20(S)	2672
40	40	40	--	--	0-40-0-20(S)	4810
40	40	20	--	--	elemental	4920
40	40	0	--	10	gypsum	3052
40	40	0	--	20	gypsum	3812
40	40	0	--	40	gypsum	3134
40	40	0	--	20	elemental	4152
0	40	20	--	0	elemental	4885
0	40	0	40	10	0-40-0-20(S)	3770
0	40	0	40	20	0-40-0-20(S)	2936
0	40	0	40	40	0-40-0-20(S)	2774
LSD (.05)						1542
LSD (.10)						1307

Analysis of Variance

Source	df	M.S.
Rep.	2	124572
Tmt.	20	2615041†
Cks./Reps.	3	116376
Error	40	868829

† Denotes 1% level of significance.

were: 20-pound rate of S as fall applied gypsum and the 20-pound rate of S spring applied as elemental S. This was the only spring applied treatment that produced a significant increase in yield.

The average response to S as gypsum, fall applied, was higher than 0-40-0-20(S) by 890 pounds per acre. There was, however, no significance between the two materials at 40 pounds of S per acre. The fall applied 40-pound rates of S as gypsum and 0-40-0-20(S) were compared with the spring applied 40-pound rates of S as gypsum and 0-40-0-20(S). The fall applications averaged higher in yield by 2070 pounds per acre, which was significant at the 1 percent level.

The data indicate that for the specific rates used, highest yields were obtained by using 40 pounds of S as either material fall applied. However, as shown by the slope of the response curve in Figure 2, it might have been possible to have achieved a larger maximum yield with a larger application of S.

From these data, it appears that for use as a topdressing on alfalfa, the best time for S fertilizer application for dryland areas in western Montana like this one would be in the fall. Adequate moisture was necessary to carry sulfate from the surface into the root zone. The additional moisture from winter precipitation may have provided the necessary mode to transport the sulfate into the zone of active uptake.

With 0-40-0-20(S), as with elemental S, another step is necessary before the S can be used by plants, as compared with gypsum. The S in the 0-40-0-20(S) must first be converted to sulfate before it can be moved into the soil and be utilized by the growing plants. This conversion is

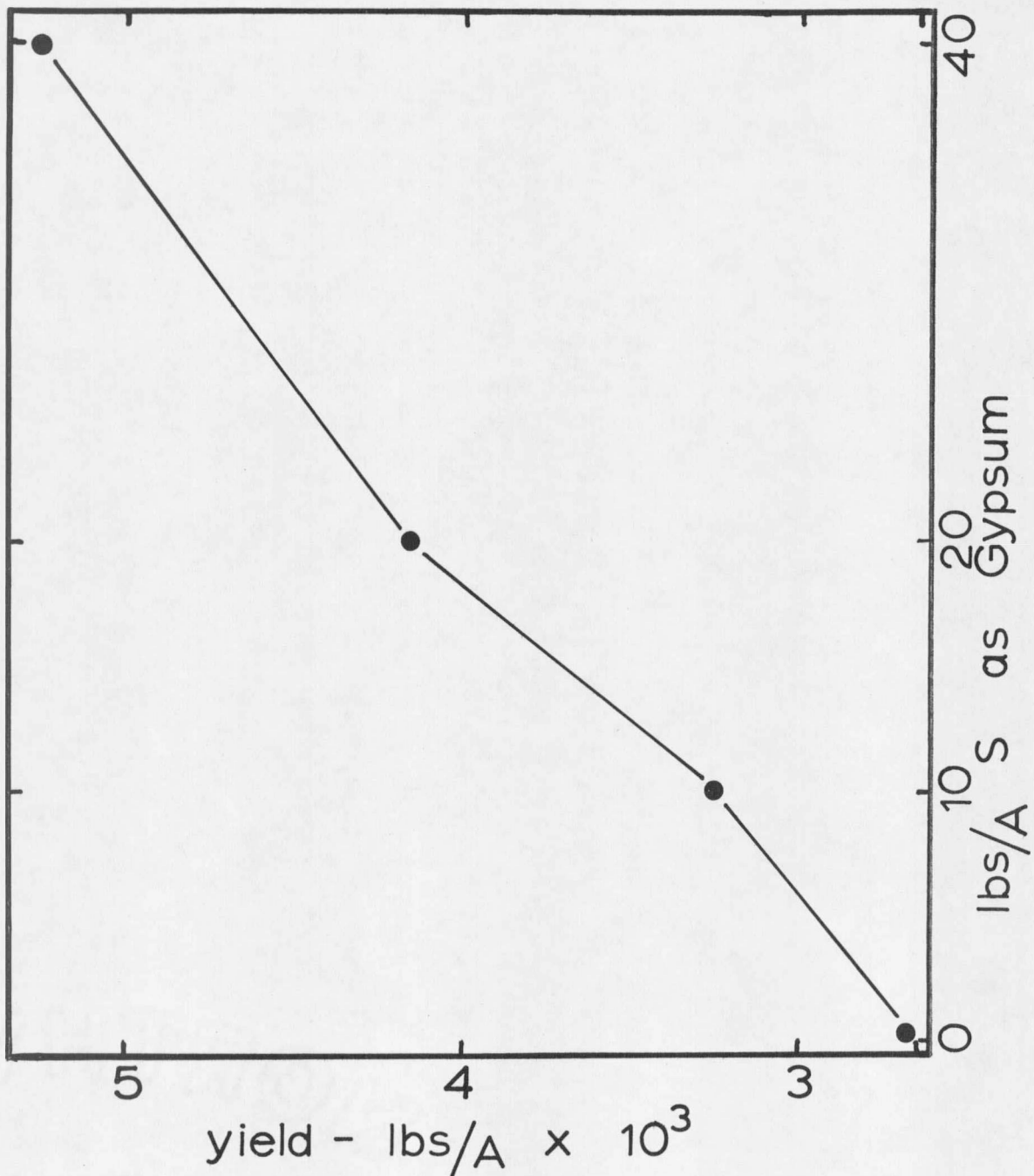


Figure 2. Yield of alfalfa as influenced by various rates of fall applied gypsum. Superior.

caused by microbes, with the rate of reaction increasing markedly when temperatures get about 10° C. The fall application may have received enough extra warmth and time to allow adequate conversion and subsequent movement into the root zone.

Variability was noted among replications within treatments, resulting in a relatively large error term. Since the soil appeared relatively uniform in depth, color, and texture, it was assumed that soil variability was not the major contributing factor to yield variability. The yield variability may have been caused by pocket gophers. Areas of major infestations were avoided when the experiment was laid out. However, some of the low yielding plots bordered these areas of infestation. Other low yielding plots may have been spots of former infestations. With less variability, more treatment differences would probably have been significant.

Woodside--Jack Iman Ranch.

There were two cuttings taken from this location. Since the pattern of response differed between the two cuttings, they will be reported separately.

First Cutting. There were significant differences among treatments at the 1 percent level, Table VII. There were four treatments which contributed most to these effects. These were the 10- and 20-pound rates of S fall applied as gypsum, the 20-pound rate of S applied in the fall as elemental S, and the 20-pound rate of S spring applied as 0-40-0-20(S). Also, the 40-pound rate of S fall applied as gypsum and the 40-pound rate of S spring applied as gypsum were significant at the 10 percent level.

Table VII. Yield and statistical data of mature alfalfa for both cuttings. Woodside.

Fertilizer Treatments					Fertilizer Source of S	Yield		
Fall			Spring			Oven Dry		Total
P	K	S	P	S		1st Cut.	2nd Cut.	
lb/A	lb/A	lb/A	lb/A	lb/A		lb/A	lb/A	lb/A
0	0	0	--	--	none	2267	1011	3278
0	0	20	--	--	gypsum	1800	1335	3135
0	40	20	--	--	gypsum	3438	2683	6121
40	0	20	--	--	gypsum	3639	1629	5268
20	40	20	--	--	gypsum	3721	2386	6107
80	40	20	--	--	gypsum	4417	2991	7408
40	80	20	--	--	gypsum	3780	2041	5821
40	40	0	--	--	none	2554	924	3478
40	40	10	--	--	gypsum	4681	2587	7268
40	40	20	--	--	gypsum	4170	2121	6291
40	40	40	--	--	gypsum	4029	3448	7477
40	40	10	--	--	0-40-0-20(S)	3383	2153	5536
40	40	20	--	--	0-40-0-20(S)	3192	2324	5516
40	40	40	--	--	0-40-0-20(S)	3653	3137	6790
40	40	20	--	--	elemental	4782	3851	8633
40	40	0	--	10	gypsum	2542	2543	5085
40	40	0	--	20	gypsum	3597	2973	6570
40	40	0	--	40	gypsum	3969	3508	7477
40	40	0	--	20	elemental	2825	2610	5435
0	40	20	40	0	elemental	3067	2536	5603
0	40	0	40	10	0-40-0-20(S)	3373	2553	5926
0	40	0	40	20	0-40-0-20(S)	4194	2791	6985
0	40	0	40	40	0-40-0-20(S)	2809	2987	5796
LSD (.05)						1475	1150	
LSD (.10)						1238	968	

Analysis of Variance

Source	df	M.S.	M.S.
Rep.	2	1740626	1450762
Tmt.	22	2035729†	1943578†
Cks./Rep.	3	83459	102981
Error	44	813660	443826

† Denotes 1% level of significance.

Comparing rates of gypsum with rates of 0-40-0-20(S), there was a significant difference between the two sources of S when they were fall applied, with gypsum treated plots averaging about 980 pounds per acre more yield than the 0-40-0-20(S). There was no significance when materials at various rates were spring applied; however, the 0-40-0-20(S) yielded more, numerically, at all rates.

When rates of gypsum fall applied were compared with gypsum spring applied, the fall applied treatments were significantly higher. The average yield difference between the dates of application was 720 pounds per acre. When rates of fall applied 0-40-0-20(S) were compared with rates of spring applied material, there was no significant difference.

As was true at the Superior location, the plot area contained variability among replications within treatments. Soil variability was the main problem at this location. The cause of the variability was apparently land leveling of a rough surface many years ago.

Again, the fall application seemed most ideal for this cutting and location. Smallest rates of S, however, gave highest yields. Maximum yields were not as large as expected, since this location was irrigated. This was most likely caused by less than optimum water management. Only two applications of water were made before the first cutting and only one between cuttings. No information was available as to the amount applied each time. Because of excessive drainage or low water-holding capacity, irrigation should have been more frequent.

Second Cutting. All rates, materials, and dates of application of S on plots with constant amounts of P and K were significantly different

from the S check as indicated in Table VII. Many of the treatments that were nonsignificant for the first cutting were significant for the second cutting. All yields were less for the second cutting, but the yield of the S check dropped much more than did the other treatments.

The 20-pound rate of sulfur applied as gypsum in the fall yielded over 400 pounds below the 10-pound rate. This drop was not significant but was a reflection of two of the three replications that were very low in yield. These two plots were in areas where sand or gravel was close to the surface, apparently a result of the land leveling indicated previously. The affects of these sandy areas were undoubtedly accentuated by the shortage of irrigation water, especially for the second cutting.

There was no significant difference in yield between all rates of S as gypsum fall applied and rates of S as gypsum spring applied. No significance existed between rates of 0-40-0-20(S), fall applied and spring applied 0-40-0-20(S).

Dates of application and materials had no affect on yield. By the second cutting, the spring applied gypsum and 0-40-0-20(S) had apparently become more available to the plant and had moved into the zone of absorption.

Both Cuttings. For both cuttings, the rates of gypsum fall applied seemed to give the maximum yield. If gypsum is to be spring applied or 0-40-0-20(S) is to be fall applied, the 40-pound rate must be used to insure maximum yields.

Corvallis--Morris Ranch

First Cutting. The yields from treatments were significantly larger than from the S check. These all had the same rates of applied P and K and included all rates of S as gypsum, both "fall" and spring applied, Table VIII. Both dates averaged about 1100 pounds per acre of yield over the S check. The average yield of the rates of 0-40-0-20(S) was significantly higher than the S check by about 650 pounds per acre. However, only the 20-pound rate of S applied as 0-40-0-20(S) was significant when this material was spring applied. The 80-pound rate of S applied as gypsum was significant over the S check but was not significant over the 10-pound rate of S as gypsum.

Rates of gypsum "fall" applied averaged the same yield as rates of gypsum spring applied. Also, there was no significant difference between "fall" and spring applied rates of 0-40-0-20(S). This indicated for at least the first cutting that it didn't matter whether gypsum was applied "fall" (mid-January) or late March.

The 40-pound rate of S applied in the spring as 0-40-0-20(S) was significantly lower than the 20-pound rate. The same trend was observed at the nonirrigated Superior location and for the first cutting at the Woodside location, Table VI and VII, respectively. At these locations, however, the differences were not significant. There is no explanation for this effect at this time. More work would be necessary to determine how serious the problem is and its possible cause.

Yields for the 10-pound rates of "fall" applied gypsum and 0-40-0-20(S) were nearly equal. However, there was a significant difference of nearly

Table VIII. Yield and statistical data of mature alfalfa for both cuttings. Corvallis.

Fertilizer Treatments				Fertilizer Source of S	Yield		
Fall		Spring 1/			Oven Dry		Total
P	S	P	S		1st. Cut.	2nd Cut.	
lb/A.	lb/A	lb/A.	lb/A		lb/A	lb/A	
0	0	--	--	none	2372	1636	4008
40	0	--	--	none	2390	1225	3615
40	10	--	--	gypsum	3180	3387	6567
40	20	--	--	gypsum	3525	3507	7032
40	40	--	--	gypsum	3772	3344	7116
40	80	--	--	gypsum	3728	3554	7282
40	20+Zn	--	--	gypsum	3579	2935	6514
40	20+B	--	--	gypsum	3675	3569	7244
40	10	--	--	0-40-0-20(S)	3106	2551	5657
40	20	--	--	0-40-0-20(S)	2830	2982	5812
40	40	--	--	0-40-0-20(S)	3191	4111	7302
40	20	--	--	elemental	3558	3220	6778
40	0	0	10 3/24	gypsum	3236	2244	5480
40	0	0	20 3/24	gypsum	3410	3748	7158
40	0	0	40 3/24	gypsum	3841	3481	7322
0	0	40	10 3/24	0-40-0-20(S)	2636	2231	4867
0	0	40	20 3/24	0-40-0-20(S)	3177	3153	6330
0	0	40	40 3/24	0-40-0-20(S)	2511	2739	5250
40	0	0	10 3/24	elemental	2813	2404	5217
40	0	0	20 3/24	elemental	2858	2822	5680
0	20	40	0 3/24	elemental	3320	3524	6844
40	0	0	10 5/12	gypsum	2714	2841	5555
40	0	0	20 5/12	gypsum	2556	3480	6036
40	0	0	10 5/12	elemental	2406	2420	4826
40	0	0	20 5/12	elemental	2632	2304	4936
40	0	0	10 7/18	gypsum	2470	2031	4501
40	0	0	20 7/18	gypsum	2655	2121	4776
40	0	0	10 7/18	elemental	2488	1814	3403
40	0	0	20 7/18	elemental	2124	2247	4371
LSD (.05)					530	1242	
LSD (.10)					276	1037	

Analysis of Variance

Source	df	M.S.	M.S.
Rep.	2	1537283	2359838
Tmt.	28	199527†	1659024†
Cks./Rep.	3	57950	102648
Error	56	105409	443826

†. Denotes 1% level of significance.

1/ Dates of spring application.

700 pounds per acre between the two materials at the 20- and 40-pound rates of S. The rates of spring applied gypsum averaged nearly 700 pounds per acre higher than spring applied 0-40-0-20(S) with the largest differences at the 10- and 40-pound rates of S.

When considering only the spring application dates, generally the later the application, the lower the yield. Dates of application are shown in Table VIII. When S was applied at the rates of 10 and 20 pounds per acre, the spring I (March 24) date of application was significantly higher by 700 pounds per acre than the spring II (May 12) date of application. The same was also true for the rates of elemental S. Of all the late spring dates of application, only the 10-pound rate of S applied spring II as gypsum was significantly higher at the 10 percent probability level than the S check. The 0-40-0-20(S) was not applied at these later spring dates because of the P variable that would be imposed.

Second Cutting. Yields for the second cutting are also shown in Table VIII. Yield of the S check was much lower for the second cutting than the first, in proportion to the other treatments. As was noted at the Woodside location, this indicated less S was available in the soil for a second growth than was available for the first growth.

As was true for the first cutting, the 80-pound rate of S applied as gypsum in the fall was not significantly higher than the other rates. This was only for one year and does not take into consideration any residual effects which may appear in subsequent years. There was a significant difference between the S check and the 10-pound rate of S fall applied

as gypsum. However, no differences existed among the rates from the 10- to 80-pound rates of S per acre.

The 20- and 40-pound rates of S per acre as spring applied gypsum were significantly larger than the check, as were the 20- and 40-pound rates of "fall" applied 0-40-0-20(S). The 20-pound rate of S for the spring applied 0-40-0-20(S) was significant at the 5 percent, and at the 10 percent level the 40-pound rate was significant.

There was no significant difference between "fall" and spring I application dates of gypsum, although the spring 10-pound rate was lower than the others. When fall and spring were compared for 0-40-0-20(S), there was no significance when the 10- and 20-pound rates were combined; but there was a 10 percent level of significance when the 40-pound rates were compared. This difference was due largely to a much higher yield from the fall treatment. There was no significance when rates of S as gypsum were compared with rates of S as 0-40-0-20(S), for either "fall" or spring I dates.

All rates and materials of spring II (May 12) gave yields which were significantly higher than the S check. Differences between yields at this date of application and S check were much greater for this cutting than for the first. The large variability, however, in the second cutting was probably caused by similar problems of water availability and soil variability as explained for the Woodside location.

The third spring date of fertilizer application gave results for S applications between the first and second cuttings of hay. All rates and materials yielded considerably higher than the S check. However, because

of the large experimental error, only 20 pounds of S per acre applied as gypsum was significantly higher than the S check ($P = .10$). This would suggest that if a sulfur deficiency was noted during or slightly before the first cutting, it might be economically sound to apply S fertilizer at that time but at probably higher rates than the maximum of 20 pounds S per acre used here.

Soil Test Data

Soil samples were taken at various depths, as given in Figure 3 and Table IX, to determine the relative amounts of sulfate in the soil for the different sources, rates, and times of sulfur fertilizer application. The dates of fertilizer applications and sampling dates are given in Table IX.

Gypsum is considered quite insoluble when compared with other fertilizer materials. However, sulfate from gypsum moved into the soil profile quite readily when adequate precipitation occurred. Ensminger (14) reported an increase from 39 to 58 ppm in sulfate at the three-foot level 21 days after a rate of 400 pounds per acre of gypsum was applied on a sandy loam. The experiment was near Auburn, Alabama, on cotton where rainfall was described only as heavy. Considerable movement occurred in the three soils under consideration.

Precipitation in western Montana would not be considered "heavy", as referred to above for the Auburn, Alabama, area. Therefore, movement of sulfate into the soil would be expected to be less for our conditions.

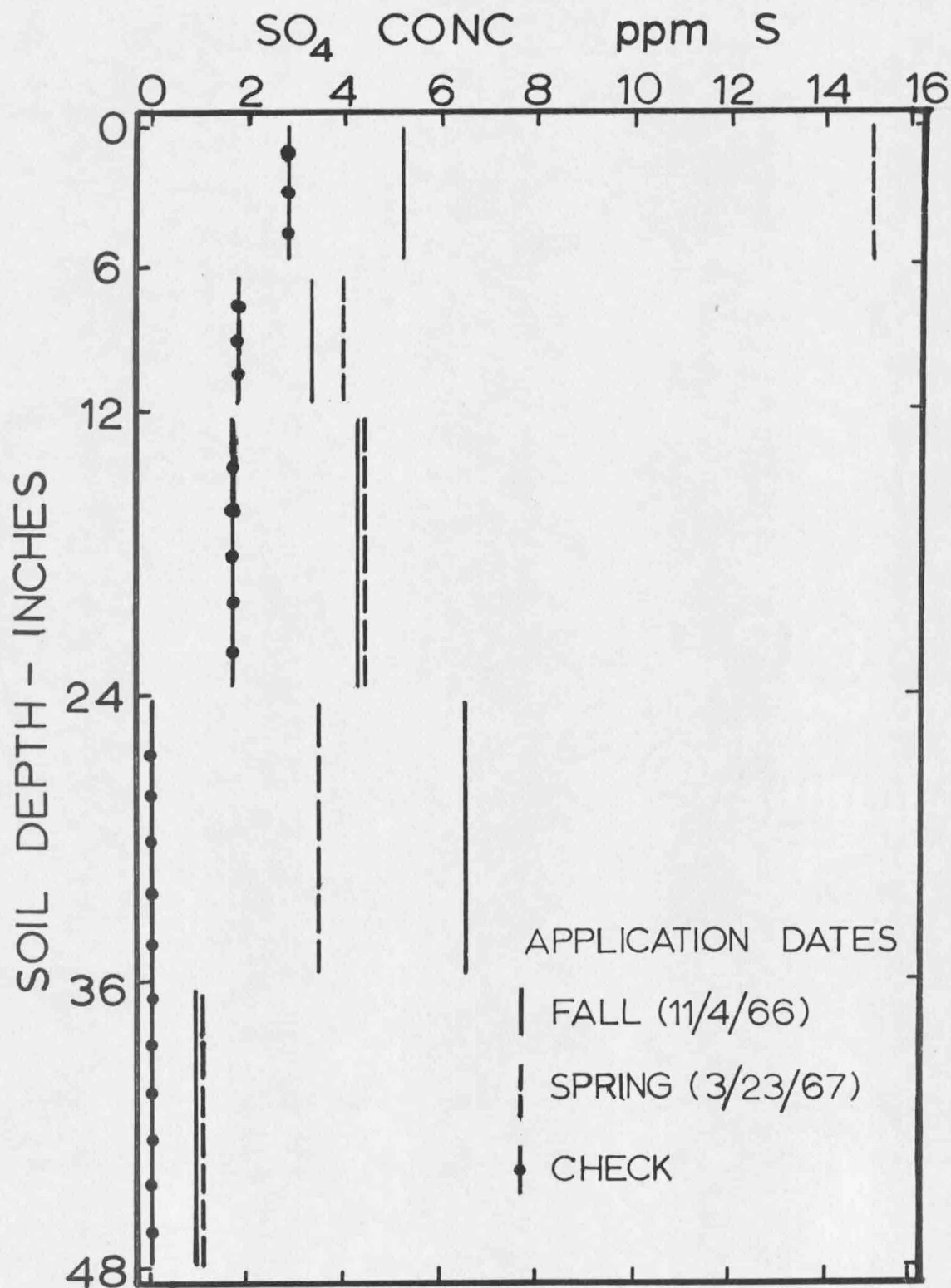


Figure 3. Sulfate concentration in parts per million (ppm) S at various depths from 20 pounds S as gypsum applied in the fall of 1966 or in the spring of 1967. Superior.

Table IX. Dates of fertilization, sampling and harvest.

Location	Dates of Fall Application	Dates of Spring Application	First Date Plant Samples and Soil Samples	Second Date Plant Samples	First Cutting	Second Cutting
Morris, Corvallis	Jan. 10, 1967	Spr. I March 26, 1967 Spr. II May 14, 1967 Spr. III July 18, 1967	May 12	May 30	June 20	Aug. 7
Iman, Woodside	Nov. 4, 1966	March 24, 1967	May 14	May 30	June 16	Aug. 7
Donally, Superior	Nov. 4, 1966	March 23, 1967	May 16	May 30	July 6	none

The most striking difference between time of application and depth to which sulfate moved was at the Superior location. Figure 3 and Table X show the sulfate concentrations for spring applications of 20 pounds S per acre as gypsum. Sulfate sulfur from the fall application of gypsum was moved into the fourth foot of soil. The largest concentration was in the third foot, with only slightly less in the surface six inches.

The spring application resulted in a sulfate concentration of 15 ppm of S in the surface six inches as compared with 5 ppm for the fall date. The third-foot concentration was less for spring than fall. Concentrations were about equal for the two dates at other soil profile depths.

Depth of soil samples at the Woodside location was limited to three feet because of coarse gravel at this depth. However, when gypsum was applied, sulfate concentrations as shown in Table XI and Figure 4 followed a similar pattern as was found at the Superior location. However, an exception was the third foot at Woodside where differences among dates did not occur.

The largest differences in sulfate between the fertilized plots and check treatments at this location were in the top foot. The high concentration of sulfate in the 0- to 6-inch depth from spring applied gypsum was probably caused by a combination of low solubility of gypsum, limited water movement into the soil, and less time for movement to occur as compared with fall application.

At the Corvallis location, these differences as shown in Figure 5 and Table XII were more obscure. The sulfate concentration in the soil for the S treatments was higher than the check for the 0- to 6-inch depth

Table X. Sulfur extracted as sulfate from soil sampled at certain depths. Superior.

Fertilizer Treatments				Depth inches	Fertilizer Material		
Fall			Spring		SO ₄ concentrate as ppm S		
P	K	S	S		none	gypsum	0-40-0-20(S)
lb/A	lb/A	lb/A	lb/A		ppm	ppm	ppm
0	0	0	--	0- 6	2.83	--	--
				6-12	1.92	--	--
				12-24	1.79	--	--
				24-36	--	--	--
				36-48	--	--	--
40	40	20	--	0- 6	--	5.29	6.50
				6-12	--	3.33	2.71
				12-24	--	4.38	2.91
				24-36	--	6.50	0
				36-48	--	.96	1.79
40	40	40	--	0- 6	--	6.04	7.83
				6-12	--	4.29	5.63
				12-24	--	4.50	3.46
				24-36	--	4.38	3.04
				36-48	--	2.91	1.66
40	40	0	20	0- 6	--	15.00	2.96 ^{1/}
				6-12	--	3.96	1.66
				12-24	--	4.38	5.42
				24-36	--	3.54	2.83
				36-48	--	.96	.96

^{1/} P and S applied in the spring as 0-40-0-20(S).

Table XI. Sulfur extracted as sulfate from soil sampled at certain depths. Woodside.

Fertilizer Treatments				Depth inches	Fertilizer Material		
Fall			Spring		SO ₄ concentrate as ppm S		
P	K	S	S		None	gypsum	0-40-0-20(S)
lb/A.	lb/A	lb/A	lb/A		ppm	ppm	ppm
0	0	0	--	0- 6	3.75	--	--
				6-12	3.79	--	--
				12-24	3.92	--	--
				24-36	3.75	--	--
40	40	20	--	0- 6	--	7.50	9.50
				6-12	--	5.50	5.54
				12-24	--	4.54	3.46
				24-36	--	3.75	6.50
40	40	40	--	0- 6	--	9.58	16.04
				6-12	--	11.67	11.04
				12-24	--	3.04	6.70
				24-36	--	3.38	5.21
40	40	0	20	0- 6	--	13.54	5.41 ^{1/}
				6-12	--	6.43	4.21
				12-24	--	5.13	3.04
				24-36	--	3.38	3.04

^{1/} P and S applied in the spring as 0-40-0-20(S)

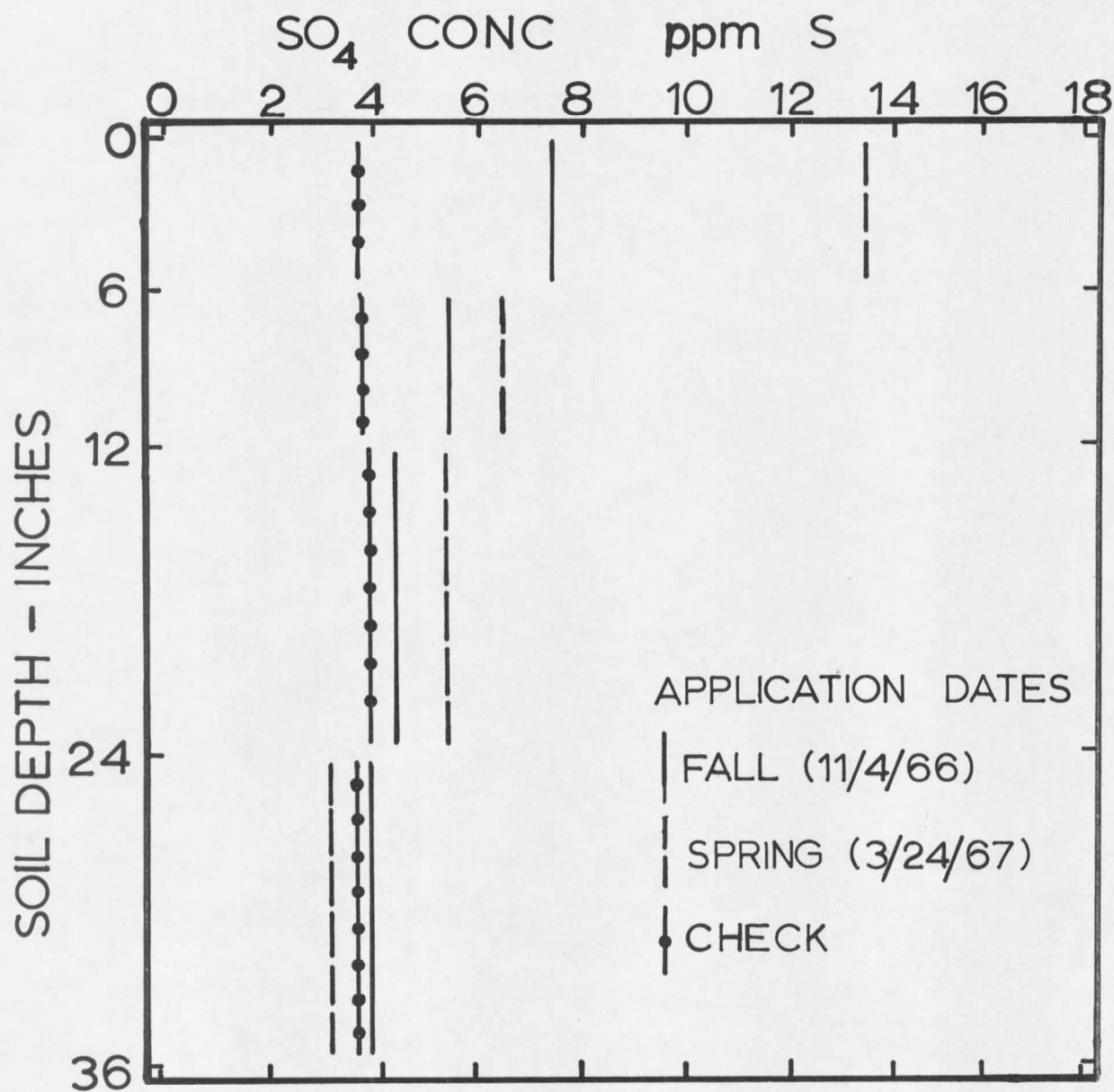


Figure 4. Sulfate concentration in ppm S at various depths from 20 pounds S as gypsum applied winter 1967 or spring 1967.

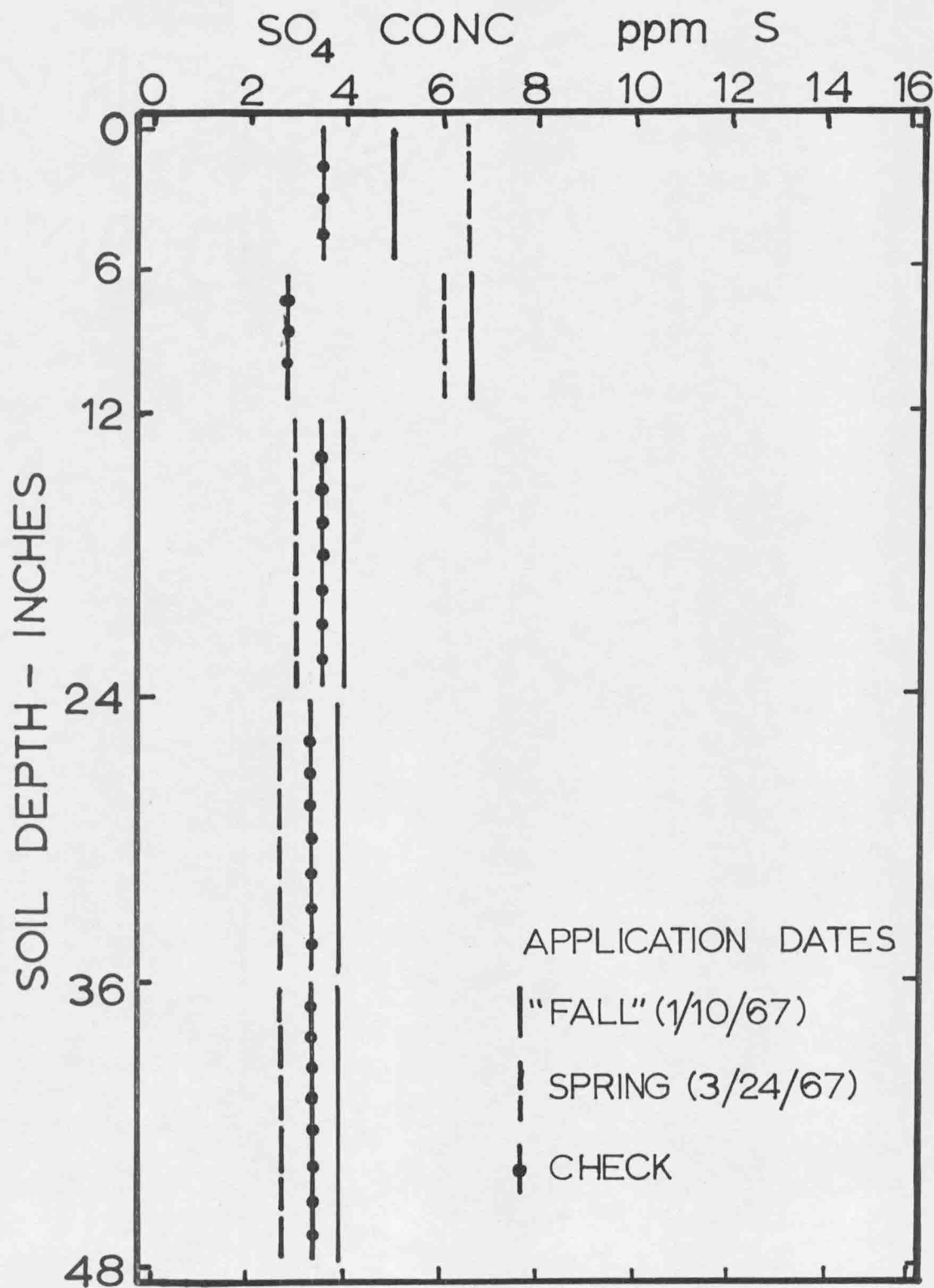


Figure 5. Sulfate concentration in ppm S at various depths from 20 pounds S as gypsum applied winter 1967 or spring 1967.

Table XII. Sulfur extracted as sulfate from soil sampled at certain depths. Corvallis.

Fertilizer Treatments 1/			Depth inches	Fertilizer Materials			
Fall		Spring		SO ₄ concentrate as ppm S			
P	S	S		none	gypsum	0-40-0-20(S)	Elemental S
lb/A	lb/A	lb/A		ppm	ppm	ppm	ppm
40	0	--	0- 6	3.75	--	--	--
			6-12	2.88	--	--	--
			12-24	3.54	--	--	--
			24-36	3.33	--	--	--
			36-48	3.33	--	--	--
40	20	--	0- 6	--	5.00	4.88	4.78
			6-12	--	6.50	4.21	4.44
			12-24	--	3.88	4.42	3.80
			24-36	--	2.69	3.12	3.95
			36-48	--	3.75	3.67	3.00
40	40	--	0- 6	--	7.00	5.41	--
			6-12	--	6.21	5.83	--
			12-24	--	6.00	3.96	--
			24-36	--	3.33	3.25	--
			36-48	--	2.63	2.71	--
40	80	--	0- 6	--	5.50	--	--
			6-12	--	6.08	--	--
			12-24	--	5.25	--	--
			24-36	--	4.92	--	--
			36-48	--	6.67	--	--
40	0	20	0- 6	--	6.50	5.33 2/	4.85
			6-12	--	6.08	4.71	4.78
			12-24	--	2.83	3.04	4.44
			24-36	--	2.71	2.50	3.46
			36-48	--	2.71	2.83	2.75
40	0	40	0- 6	--	9.17	5.83 2/	--
			6-12	--	7.00	4.58	--
			12-24	--	5.33	4.38	--
			24-36	--	2.71	3.46	--
			36-48	--	2.75	2.75	--

1/ The Corvallis location received a 40 lb/A blanket application of K.

2/ P and S were applied in the spring as 0-40-0-20(S).

and the 6 to 12-inch depth. For the 40- and 80-pound rates, it was higher in the second foot as well; and at the 80-pound rate, the sulfate concentration was higher to the fourth foot.

Since the soil test used here will measure only acetate soluble sulfate, none of the sulfur yet to be converted would show up in the test. At the Woodside and Superior locations, the concentration of sulfate in the 0- to 6-inch level was higher where 0-40-0-20(S) was fall applied than where gypsum was fall applied, regardless of the rate of application. In general, the concentration of sulfate decreased more quickly with depth on 0-40-0-20(S) treatments than where gypsum was applied.

When the two materials were spring applied, gypsum showed over 8 ppm S higher sulfate concentration at the 0- to 6-inch depth than 0-40-0-20(S). There was essentially no difference between materials in the second and third foot at the Woodside location and the 1- to 2-foot depth at the Superior location..

At the Corvallis location, both the mid-winter and spring applications of gypsum and 0-40-0-20(S) responded like the spring applied materials at the other two locations. The concentration of sulfate was higher in the 0- to 6-inch layer for the gypsum treatments. In subsequent layers, the concentration of sulfate from gypsum decreased until the concentrations of both treatments were approximately equal. The amount of sulfate recovered by chemical extraction in the gypsum treated plots was higher than from 0-40-0-20(S) when rates were kept constant.

The next step was to determine the correlation coefficient and a regression equation between sulfate concentration and plant yield and to

determine if the relationship was meaningful. Although two cuttings were taken from Corvallis and Woodside while only one cutting was taken from the Superior location, the yields used were in terms of total yield harvested for the growing season. These yields are given in Tables VI, VII, and VIII.

For predictive purposes for soil testing a better way to determine a correlation would be to have a number of locations, both responsive and nonresponsive, then plot in terms of percent maximum yield and amount of extractable sulfate in the soil. To do this, measurement was needed on a wide range of soil conditions. Since that type of study was beyond the scope of this investigation, the correlation was limited to the three locations from which soil samples were taken. It was felt the fall applied gypsum would be closer to natural conditions than would any other material or date of application. This was because there was more time for the sulfate to distribute itself and to equilibrate within the profile.

When comparing the level of sulfate in the upper six inches of soil with yield, it was found that although the 20-pound rate spring applied as gypsum had a high level of sulfate, it did not yield accordingly. This suggests that sulfate located primarily in the surface six inches of soil may not be absorbed readily by the plant. In these experiments, it may have been a function of available soil moisture. However, at the nonirrigated Superior location, moisture stress may not have been very great as suggested by the large maximum yield of up to three tons per acre, oven dry weight, for one cutting.

This suggested that it might be important to compare yields with sulfate concentrations at depths greater than six inches. Yields were correlated with sulfate at depths of six inches, one foot, and three feet, giving "r" values of .678, .729, and .712, respectively. The three-foot depth showed relatively no advantage over the one-foot depth. The one-foot depth is shown in Figure 6.

Seven percent more of the variation in these experiments was accounted for by using the 0- to 1-foot depth as compared with the 0- to 6 inch-depth. It is questionable whether or not accounting for this extra variation is worth the extra effort of the deeper sampling because of only a slight advantage in eliminating error.

Perhaps the greatest weakness in this correlation was that all three soils dealt with are coarse textures, low in organic matter, and low in clay content. Clay and organic matter have an important bearing on S status; since clay has some positive sites which hold the sulfate in an available form. Organic matter also has positive sites and is a storehouse of organic sulfur (11).

Plant Chemical Analysis

Percent Sulfur at Various Stages of Maturity

Pumphrey and Moore (33) reported that the percent sulfur in immature alfalfa was higher than in the mature plant. They reported the decrease in percent of S seemed to be fairly uniform until maturity. In most cases all of the S was taken up by the alfalfa plant by the time it was six inches tall.

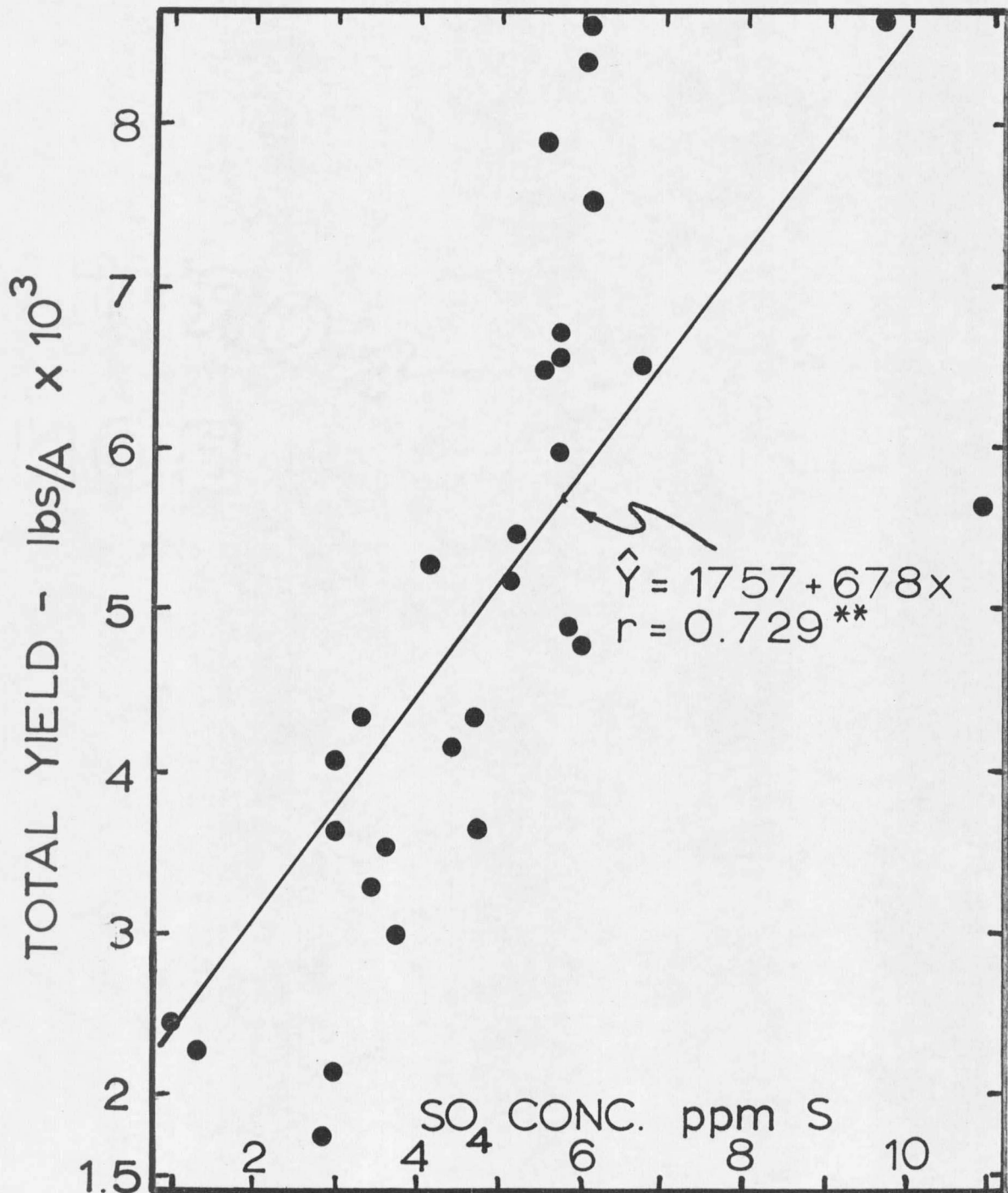


Figure 6. Relationship between yield and SO_4 content in 0- to 1-foot layer of soil. Corvallis, Woodside, and Superior.

Data shown in Tables XIII, XIV, and XV agree for the most part with that reported by Pumphrey and Moore (33) for S concentration. No yield samples were taken when the preharvest samples were collected; so nothing can be said about the absolute yield of sulfur for any given time except at maturity.

Percent S in the plants generally decreased with maturity of the alfalfa and at a fairly uniform rate for all locations. There were exceptions to this trend at the Corvallis location, Table XIV. The 20- and 40-pound rates of fall applied as 0-40-0-20(S) had an initial S percentage of nearly .250 percent, while the mature alfalfa contained close to .350 percent S. This initial percent S was significantly lower than the S check and is shown graphically in Figure 7.

One possible reason for this initially low percentage could have been slower release of sulfur from 0-40-0-20(S) as compared with gypsum, but just enough to stimulate growth and cause a dilution effect. In support of this postulation, when observed May 12 and May 30 both the gypsum and the 0-40-0-20(S) treated alfalfa appeared the same, both appearing greener and more vigorous than the S check. As time progressed and spring temperatures rose, there should have been more conversion from sulfur to sulfate. If that occurred and with a possible lower yield potential because of the low S percentage in early growth, sulfate could have been absorbed in "luxury" amounts as plants approached maturity.

The 20-pound rate of S as 0-40-0-20(S) spring applied did not change the percent S from the first sampling date until harvest. Since it is

Table XIII. Percent sulfur at preharvest sampling dates and harvest.
Superior.

Fertilizer Treatments					Fertilizer Source of S	1st S.D.	2nd S.D.	1st Cut.
Fall		Spring						
P	K	S	P	S				
lb/A	lb/A	lb/A	lb/A	lb/A		%	%	%
0	0	0	--	--	none	.252	.239	.160
0	0	20	--	--	gypsum	--	--	.213
0	40	20	--	--	gypsum	--	--	.209
40	0	20	--	--	gypsum	--	--	.243
20	40	20	--	--	gypsum	--	--	.223
40	40	0	--	--	none	--	--	.164
40	40	10	--	--	gypsum	--	--	.197
40	40	20	--	--	gypsum	.356	.342	.192
40	40	40	--	--	gypsum	.390	.360	.268
40	40	10	--	--	0-40-0-20(S)	--	--	.169
40	40	20	--	--	0-40-0-20(S)	.305	.289	.220
40	40	40	--	--	0-40-0-20(S)	.320	.277	.343
40	40	20	--	--	elemental	--	--	.230
40	40	0	0	10	gypsum	--	--	.179
40	40	0	0	20	gypsum	.346	.318	.199
40	40	0	0	40	gypsum	--	--	.228
40	40	0	0	20	elemental	--	--	.242
0	40	20	40	0	elemental	--	--	.239
0	40	0	40	10	0-40-0-20(S)	--	--	.185
0	40	0	40	20	0-40-0-20(S)	.275	.236	.218
0	40	0	40	40	0-40-0-20(S)	--	--	.194
LSD (.05)						.033	.037	.049
LSD (.10)						.027	.031	.040

Source	Analysis of Variance					
	df	M.S.	M.S.	df	M.S.	
Rep.	2	.00090	.0005	27	.000100	
Tmt.	6	.00690†	.00697†	20	.002873†	
Error	12	.00032	.00041	42	.000882	

† Denotes 1% level of significance.

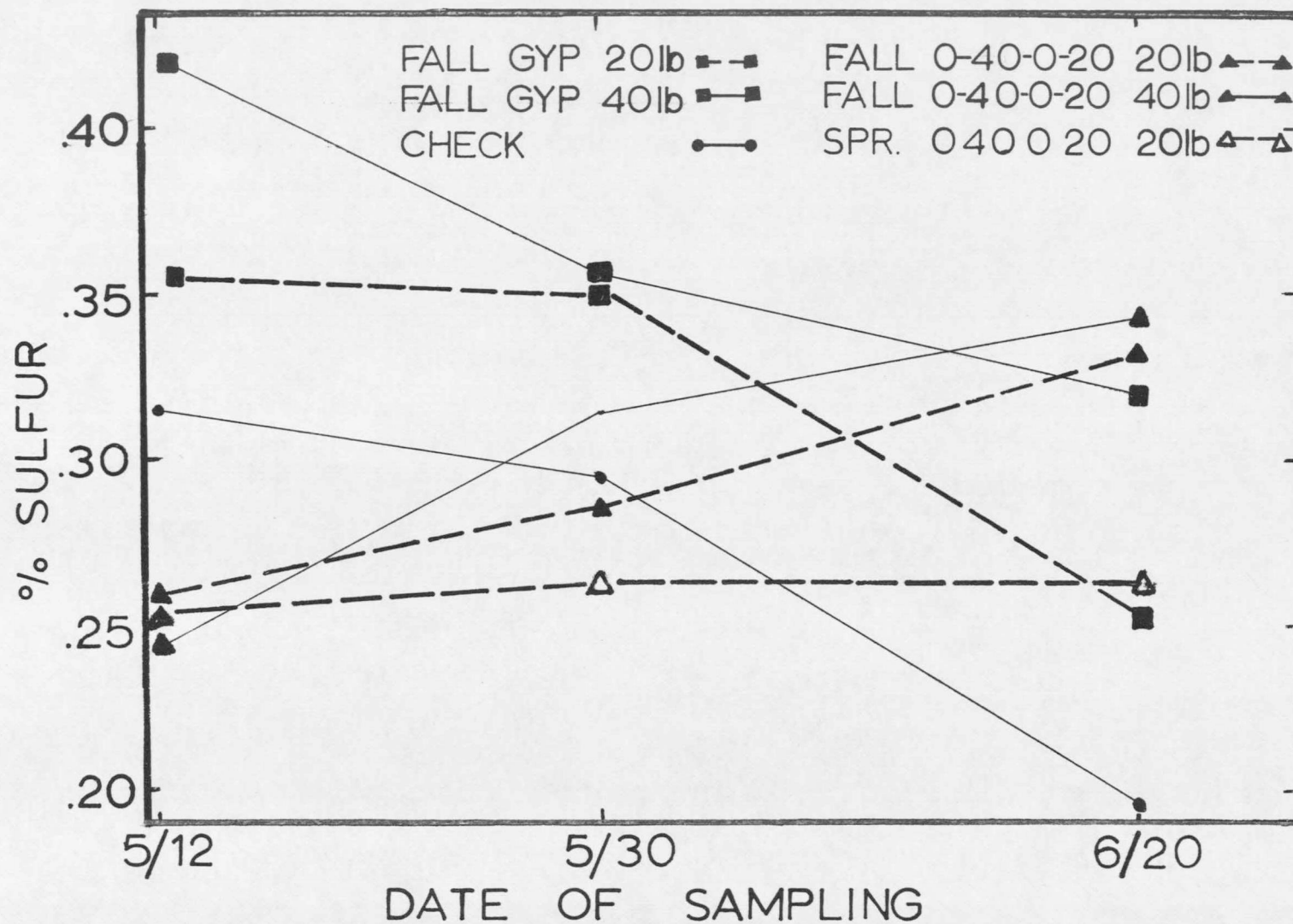


Figure 7. Percent S in alfalfa at three dates of sampling as influenced by time and rates of application and different sources of S. Corvallis.

Table XIV. Percent S in alfalfa of preharvest sampling dates and the two harvests. Corvallis.

Fertilizer Treatment				S Fertilizer Material	1st S.D. 5/14 I/ %	2nd S.D. 5/30 I/ %	1st Cut. 6/20 %	2nd Cut. 7/7 %
Fall		Spring						
P	S	P	S					
1b/A	1b/A	1b/A	1b/A					
0	0	--	--	none	.315	.284	.195	.170
40	0	--	--	none	.302	.206	.179	.160
40	10	--	--	gypsum	.316	.351	.236	.176
40	20	--	--	gypsum	.356	.358	.253	.207
40	40	--	--	gypsum	.420	.349	.319	.275
40	80	--	--	gypsum	.495	.388	.354	.293
40	10	--	--	0-40-0-20(S)	.318	.274	.268	.181
40	20	--	--	0-40-0-20(S)	.258	.285	.329	.231
40	40	--	--	0-40-0-20(S)	.244	.316	.344	.280
40	20	--	--	elemental	.275	.339	.302	.265
40	0	--	--	gypsum	.372	.319	.230	.171
40	0	--	--	gypsum	.403	.322	.315	.227
40	0	--	--	gypsum	.373	.342	.291	.242
40	0	0	10	elemental	.267	.271	--	--
40	0	0	20	elemental	.290	.307	.223	.164
0	20	40	0	elemental	.338	.304	--	--
0	0	40	10	0-40-0-20(S)	.259	--	.201	.167
0	0	40	20	0-40-0-20(S)	.257	.265	.259	.209
0	0	40	40	0-40-0-20(S)	.312	.283	.272	.213
40	0	0	20	elemental	--	--	.259	.274
40	0	0	20	gypsum	--	--	--	.264
LSD (.05)					.059	.045	.120	.035
LSD (.10)					.049	.028	.100	.029

Source	Analysis of Variance							
	df	M.S.	df	M.S.	df	M.S.	df	M.S.
Rep.	2	.00668	2	.00480	2	.0037	2	.00020
Tmt.	18	.01277†	17	.00400†		.00831	18	.00582†
Error	37	.00128	34	.00075	35	.00512	36	.00031

1/ Plant height at early sampling dates were: 5/14, 2-3 inches;
5/30, 8-14 inches.

† Denotes 1% level of significance.

Table XV. Percent S in alfalfa of perharvest sampling dates and the two harvests. Woodside.

Fertilizer Treatment									
Fall			Spring		S Fert.	1st S.D.	2nd S.D.	1st Cut.	2nd Cut.
P	K	S	P	S					
lb/A	lb/A	lb/A	lb/A	lb/A	%	%	%	%	%
0	0	0			none	.279	.240	.188	.191
0	0	20			gypsum	--	--	.333	--
0	40	20			gypsum	--	--	.258	--
40	0	20			gypsum	--	--	.288	--
20	40	20			gypsum	--	--	.283	--
80	40	20			gypsum	--	--	.244	--
40	80	20			gypsum	--	--	.268	--
40	40	0			none	--	--	.190	.171
40	40	10			gypsum	--	--	.237	--
40	40	20			gypsum	.395	.360	.266	.265
40	40	40			gypsum	.442	.381	.300	.310
40	40	10			TVA <u>1/</u>	--	--	.244	--
40	40	20			TVA	.380	.308	.240	.297
40	40	40			TVA	.361	.339	.355	.314
40	40	20			elem. <u>2/</u>	--	--	.320	.293
40	40	0	0	10	gypsum	--	--	.262	--
40	40	0	0	20	gypsum	.439	.350	.264	.235
40	40	0	0	40	gypsum	--	--	.315	--
40	40	0	0	20	elem.	--	--	.289	--
0	40	20	40	0	gypsum	--	--	.322	--
0	40	0	40	10	TVA	--	--	.215	--
0	40	0	40	20	TVA	.334	.292	.264	.185
0	40	0	40	40	TVA	--	--	.243	--
LSD (.05)						.048	.027	.033	.044
LSD (.10)						.039	.022	.028	.036

Analysis of Variance

Source	df	M.S.	df	M.S.	df	M.S.	df	M.S.
Rep.	2	.00016	2	.00016	2	.00028	2	.00021
Tmt.	6	.01000†	6	.00685†	22	.00645†	8	.00861†
Cks./Reps.	--	--	--	--	3	.00034	--	--
Error	12	.00072	12	.00024	44	.00041	16	.00064

1/ TVA refers to 0-40-0-20(S)

2/ Elem. refers to elemental S or 0-0-0-100(S)

† Denotes 1% level of significance.

reasonable to assume an increase in dry matter of alfalfa from May 12 to June 20, this would imply that uptake varied as did growth.

Gypsum treatments yielded higher when comparing the 20- and 40-pound rates of S as gypsum and as 0-40-0-20(S). This suggests that early uptake was important for optimum yield, and perhaps there is a minimum S percentage in young plants of about 0.30.

The Superior and Woodside locations did not exhibit this reversal, Tables XIV and XV. Trends were usually a uniform decrease in the percent of S as the plant approached maturity. Only the 40-pound rate of S as 0-40-0-20(S) showed no significant change during all three dates.

Sulfur Yield

The sulfur yield as a measure of the S absorbed by plants should be a more valid estimate of the availability of S in the soil than yield of plant material. It is determined by multiplying the dry matter yield times the S percentage. Because nutrient content is subject to less variability than yield, S yield should have less errors associated with differences than yield of total dry matter.

The stands at the Corvallis and Woodside locations were a mixture of alfalfa and orchardgrass. Chemical tests were run on grass samples of selected treatments, but the S percentage for the grass fraction was ignored when S yield was determined. There were several reasons for this:

The first is that S percentage in grass was usually 0.05 percent less than the S percentage in alfalfa taken from the same treatment. No

information was found in the literature as to what the critical percent of S is in orchardgrass.

Another reason for excluding grass was its relatively small percentage in the stand. Usually, the weight of grass was 30 percent or less of the total. If the yield was 4000 pounds per acre and if 30 percent of it was grass, this would equal 1200 pounds of grass. With a S percentage difference of 0.05 percent, this would mean a drop of only 0.8 pounds per acre of sulfur, which is much less than the calculated LSD for S yields, Table XVI.

Many of the rates of applied S as different sources resulted in a significant S yield increase over the S check. In many of the treatments, the increase in S yield was due to both an increase in yield and an increase in the S percentage.

At the Corvallis location when S yield for the rates of fall applied gypsum was compared respective rates of fall applied 0-40-0-20(S), there were virtually no differences. The spring applied gypsum gave an S yield comparable with fall applied gypsum or 0-40-0-20(S). However, the S absorbed from spring applied 0-40-0-20(S) was lower than for gypsum. Differences became greater with increasing rates of S.

At the Woodside location, differences between the 20- and 40-pound rates of S as gypsum and the 20- and 40-pound rates of S as fall applied 0-40-0-20(S) were not significant. No differences were observed when comparing the 20-pound rates of spring applied gypsum and 0-40-0-20(S).

Since only one cutting was taken from the Superior location, the total S yield was less than for the Corvallis and Woodside locations.

Table XVI. Yield of sulfur in mature alfalfa. Superior, Woodside, Corvallis.

Treatments			Superior	Woodside		Corvallis	
P	K	S		1st Cut.	2nd Cut.	1st Cut.	2nd Cut.
lb/A	lb/A	lb/A	%	%	%	%	%
October, 1966 1/							
0	0	0	3.42	4.26	2.56	4.42	2.98
0	0	0	7.17	6.00	--	--	--
0	40	20	7.32	8.74	--	--	--
40	0	20	9.79	7.54	--	--	--
20	40	20	8.95	10.60	--	--	--
40	40	0	4.27	4.87	1.68	4.28	1.94
40	40	10	6.12	11.10	--	7.48	5.93
40	40	20	7.75	10.92	5.32	8.90	7.21
40	40	40	14.09	12.26	10.69	11.95	9.24
40	40	80	--	--	--	12.86	10.47
40	40	10 2/	4.32	8.08	--	8.32	4.59
40	40	20 2/	5.72	7.97	6.89	9.32	6.89
40	40	40 2/	10.93	13.08	9.73	10.99	11.48
40	40	20 3/	11.35	15.47	13.32	10.77	8.55
80	40	20	--	10.88	--	--	--
40	80	20	--	9.86	--	--	--
March, 1967							
40	40	10	5.42	6.71	--	7.49	3.88
40	40	20	7.48	9.68	6.98	10.67	8.45
40	40	40	7.09	12.45	--	11.25	8.43
40	40	10 2/	7.01	7.32	--	5.29	3.74
40	40	20 2/	6.13	9.93	5.22	8.23	6.53
40	40	40 2/	5.32	6.78	--	6.84	5.82
40	40	20 3/	9.93	8.30	--	6.38	4.67
LSD (.05)			3.23	4.25	2.74	2.30	2.83
LSD (.10)			2.60	3.54	2.25	1.91	2.35

Analysis of Variance

Source	df		df		df		df		df	
Rep.	2	.809	2	8.523	2	.215	2	9.798	2	4.866
Tmt.	20	25.381†	22	22.273†	8	34.843†	17	19.315†	18	20.029†
Cks./Reps.	3	.104	3	.448	--	--	--	--	--	--
Error	40	3.613	44	6.646	16	2.516	35	1.943	36	2.908

† Denotes 1% level of significance.

1/ Date for Corvallis was 10/67.

2/ Source of sulfur is 0-40-0-20(S).

3/ Source of sulfur is elemental sulfur.

The 10- and 20-pound fall applied rates of S as gypsum produced a greater S yield by about 3.2 pounds per acre than those treatments with 0-40-0-20(S).

When spring applied gypsum and 0-40-0-20(S) were compared, there was a tendency for a 0-40-0-20(S) to yield more S at the 10-pound rate whereas the gypsum resulted in more S yield at the 20- and 40-pound rates. These trends may be important, but variance was such that the observed differences were not significant.

The S yield from elemental S was highest of all the sources for comparable rates of fertilizer application at the nonirrigated Superior location. For the fall dates, S yield from elemental S was higher than other sources at all locations. The reasons for this were not determined in these experiments.

Percent P vs. Kind of S Fertilizer

It has been noted in some past work in Montana near Ronan (Linse location) done with spring applied 0-40-0-20(S) on alfalfa that the percentage of phosphorus in the mature plants was significantly lower than that of the plots fertilized with gypsum, with the same rate of P added as 0-52-0. 8/

Selected treatments were analyzed for P as given in Table XVII. When comparing the same rates of gypsum and 0-40-0-20(S) at the Superior location, there were no significant differences in P percent for the

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Table XVII. Percent phosphorus in mature alfalfa. Superior, Woodside, Corvallis.

Treatments			Superior	Woodside		Corvallis	
P.	K	S		1st Cut.	2nd Cut.	1st Cut.	2nd Cut.
lb/A	lb/A	lb/A	%	%	%	%	%
November, 1966 1/							
0	0	0	.242	.164	.197	.300	.267
0	0	20	.187	--	.185	--	--
0	40	20	.209	--	.194	--	--
40	0	20	.205	--	.208	--	--
20	40	20	.223	--	.195	--	--
40	40	0	.248	.235	.295	.246	.261
40	40	10	.205	.243	.237	--	--
40	40	20	.196	.245	.257	.316	.256
40	40	40	.222	.251	.226	.299	.261
40	40	10 2/	.248	.264	.229	.256	.281
40	40	20 2/	--	.243	.240	.279	.256
40	40	40 2/	.249	.237	.228	.354	.269
40	40	20 3/	.237	.240	.257	--	--
40	40	20 3,4/	.215	--	.263	--	--
80	40	20	--	.269	.238	--	--
40	80	20	--	--	.240	--	--
March, 1967							
40	40	10	.203	.235	.223	.259	.232
40	40	20	.258	.208	.232	.272	.248
40	40	40	.171	.240	.231	.281	.251
40	40	10 2/	.257	.264	.265	.275	.240
40	40	20 2/	.242	.262	.259	.272	.267
40	40	40 2/	.251	.243	.246	.288	.267
40	40	20 3/	.232	.235	.277	--	--
LSD (.05)			.057	.026	.045	.042	.035
LSD (.10)			.048	.022	.037	.035	.029

Analysis of Variance

Source	df	M.S.	df	M.S.	df	M.S.	df	M.S.	df	M.S.
Rep.	2	.003574	2	.001632	2	.001357	2	.000424	2	.000700
Tmt.	19	.001955*	16	.001716†	22	.002617†	12	.02118†	12	.016046*
Cks./Reps.	3	.000865	-	----	3	.000376	-	----	-	----
Error	39	.001181	32	.000247	41	.000734	25	.001263	25	.00640

* Denotes 5% level of significance.

† Denotes 1% level of significance.

1/ Date for fall application.

2/ Source of sulfur was 0-40-0-20(S).

3/ Source of sulfur was elemental sulfur.

4/ Phosphorus was spring applied.

10- and 20-pound rates of spring applied S. There was a significant difference at the 1 percent level of probability for the 40-pound rate between gypsum and 0-40-0-20(S), but the 0-40-0-20(S) fertilized alfalfa had the greater percent of P. For fall applied material, there was no significant difference for respective rates at any level of significance.

Comparing spring applied gypsum and 0-40-0-20(S) for the first cutting at the Woodside location, there was a significant difference between materials for both the 10- and 20-pound rates of S; but again, the largest P percentage was for the 0-40-0-20(S). No significant difference existed between respective treatments when the fertilizer was fall applied. For the second cutting, a significant difference of 0.042 percent existed for the 10-pound rate of S as 0-40-0-20(S). There was no significant difference between comparable rates of gypsum and 0-40-0-20(S) spring applied at the Corvallis location for either cutting.

Data from these three locations indicated that 0-40-0-20(S) had no detrimental affect upon absorption of phosphorus by alfalfa as was suggested by previous data. However, other soil factors may be involved in observed differences between these sets of data because the Linse location data, referred to at the beginning of this section, do not fit relationships of other locations such as "yield increase vs. plant S percentage in the S check", as given in the next section.

Percent S as Related to Yield

Before percent S in the plant can be used for predictive purposes, there first must exist a correlation between percent S and yield.

Correlations were determined between percent S at first sampling date (about May 14 and 2 to 3 inches in height) and first cutting absolute yield, also percent S in mature plants at harvest and absolute yield at first cutting.

Treatments utilized were from the three locations and limited to fall applied gypsum only. The 0-40-0-20(S) treatments were eliminated because of unusual changes in concentration during growth as compared with gypsum, and the high percent S in the mature alfalfa plants which was not reflected in higher yields. The correlation between percent S at the first sampling date and yield was $r = .514$, with the regression equation being $\hat{Y} = 9,335 X + 207$. When the percent S in mature alfalfa plants was compared with first cutting yield, the correlation was $r = .516$, or almost identical with the correlation value obtained using the first sampling date. The regression equation was $\hat{Y} = 11,221 X + 834$. Since the correlation values were practically identical for both dates, this would suggest either could be used if the resulting correlations are sufficiently precise for predictive purposes.

Use of the earlier date would be more advantageous. The advantage would be that a rancher could send in a sample of alfalfa at the time of initial growth. The sample could be processed, and the results sent to the rancher in time for a late fertilizer application. This late application may not be as ideal as if it were fall applied, but it would be more economically sound than waiting until the next fall. Use of S percentage for predictive purposes is discussed more in detail later.

Plant Analysis for Prediction of S Deficiency

Two methods were evaluated for predicting the need for S fertilization by utilizing plant analysis. These were N to S ratio and S percentage.

N to S Ratio. The relationship of plant yield response to N to S ratio of the nonfertilized S check has been suggested as a reliable means of predicting S deficiencies (34). This method has an advantage over using percent S in that theoretically, stage of growth can be ignored.

In this study the N and S percentages were measured in plant samples. This included three additional locations, not referred to earlier, which had an S variable representing a total of fifteen harvest dates and locations, Figure 1. Yield increase from the S treatment producing maximum yields as compared with the S check was plotted against the N to S ratio and a poor relationship resulted.

Although a linear correlation was nonexistent, a trend existed. For this evaluation, it was assumed that a yield increase of at least 1000 pounds per acre was necessary for decidedly significant difference and that below 300 pounds per acre yield increase was no longer significant, even with experiments having high precision. A critical ratio of eleven was used, as determined by Pumphrey and Moore (34). The graph was divided into four quadrants and a "gray" area where a yield increase or where significance is questionable, Figure 8.

Any point in quadrant I represents a responsive site, but one which has an N to S ratio of below eleven indicating that it should not respond.

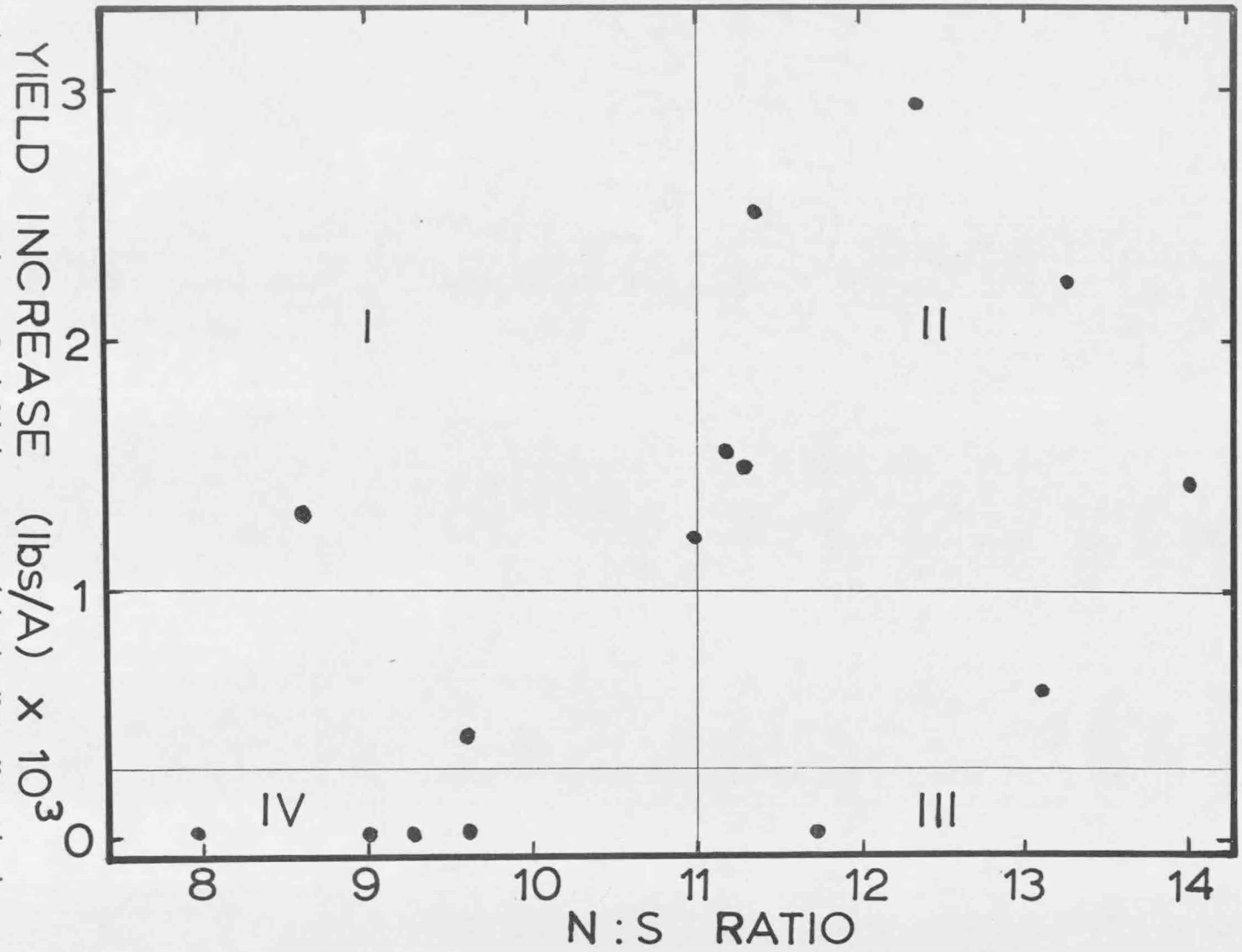


Figure 8. Comparison of yield increase with the N to N ratio in mature alfalfa plants.

Any point in quadrant II represents a responsive site with an N to S ratio greater than eleven or in keeping with the concept. Supposedly, locations represented in this area should respond well. A point in quadrant III shows a nonresponsive site with an N to S ratio greater than eleven or a violation of the N to S ratio concept, because no yield response would be obtained; but the N to S ratio would be high. Quadrant IV represents nonresponsive sites with an N to S ratio of less than eleven or in keeping with the N to S ratio concept. Of the fifteen points, only two are in quadrants I and III.

Since stage of growth could be ignored, this method might be very useful. However, for the locations in this study, it would appear that its main value was to indicate which ones would be likely to respond, but not to indicate magnitude of deficiency. Should it prove to be highly reliable over a broader range of soils, it may have the necessary requirements for being a helpful diagnostic tool.

Percent Sulfur. The second method considered in this study was the comparison of absolute yield increase which was the highest yielding treatment containing an S variable minus the S check and percent S in plants from the S check. The S check was always the treatment receiving fertilizer nutrients other than S. The same locations used in the N to S ratio study, plus one more, were used in this study, Figure 1.

Two points were plotted but omitted from the regression line calculations because of their inability to fit into the relationship. These were the first and second cuttings taken from the Linse location in Lake

County in 1966, referred to in the section on "Percent P vs. Kind of S Fertilizer." That location failed to relate with others using different criteria.

The same area of questionable significance was used as with the N to S ratio, that being 300 to 1000 pounds per acre. The method of determining a critical percentage was patterned after Harward et al. (19). When the data were plotted, as shown in Figure 9, a curve resulted which would be subdivided into two sections. A linear regression line was calculated for each part; with points in the "gray area" as defined by the 300- to 1000-pound zone common to both lines. According to Harward et al. (19) the point where the two lines intersect is the critical percentage. It has been agreed by several authors (7,21) that this critical level is between .20 and .22 percent.

In this study, the linear regression line fitting the responsive portion had an "r" value of -.908, with a regression equation of $\hat{Y} = 8981 - 38387X$. The nonresponsive portion had an "r" value of -.650 with a regression equation of $\hat{Y} = 844 - 2802X$. The point where the two lines intersected was .228 percent, or only slightly above the "accepted" values.

The linear correlation obtained for the responsive section of the curve explained 82.4 percent of the variability ($r^2 = 82.4\%$). This relationship would have been much poorer if the two points for the Linse location in Lake County would have been included. That soil was located in the area classified as MacDonald gravelly loam, a dark colored soil developed on glacial till under grass in the 1929 survey of The Lower

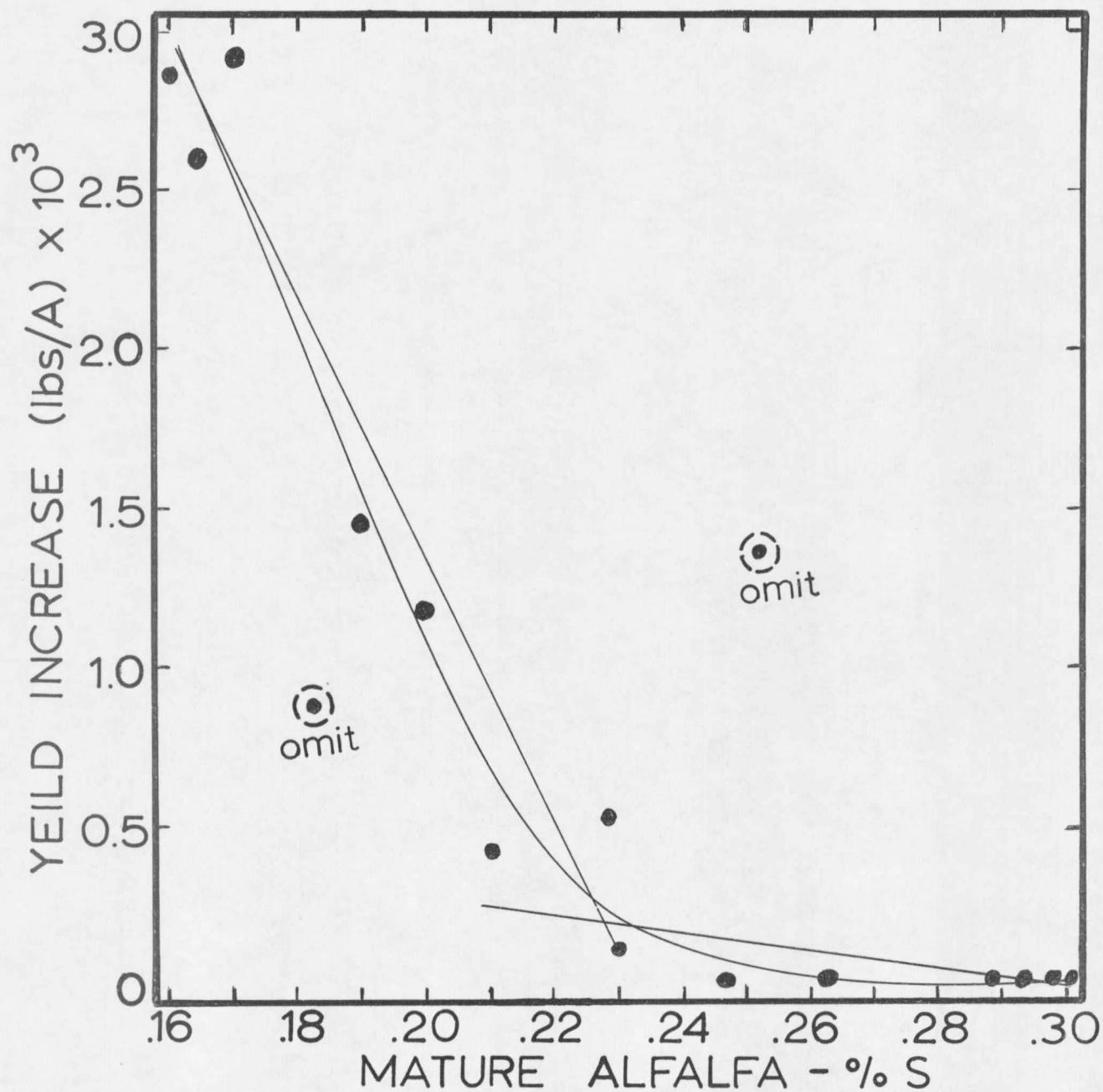


Figure 9. Comparison of yield increase and percent S in mature alfalfa.

Flathead Valley; and this could be an indication of a poorer relationship between yield increase and 5 percent when more soils are included.

More data are needed for more soils, and including S analyses for the 2- to 3-inch growth, to further define the relationships discussed above. Then, more S-rate studies are needed to determine the most economical rate of S to apply on alfalfa having different S percentages.

CONCLUSIONS

From the foregoing discussion, several conclusions were drawn. They are as follows:

1. Maximum yields of alfalfa obtained for gypsum and 0-40-0-20(S) (a TVA experimental product) were virtually the same when the rate of .40 pounds per acre S was fall applied.
2. When 10- or 20-pound fall applied rates of S were used, the gypsum generally resulted in alfalfa yields that were higher than with 0-40-0-20(S).
3. Regardless of material, fall applied S fertilizer gave larger yields than spring applications on the nonirrigated location.
4. On irrigated sites, there was little difference whether gypsum was fall or spring applied. With 0-40-0-20(S), higher alfalfa yields were realized with the fall applications.
5. A correlation of $r = .729$ between yield and acetate extractable sulfate in the 0- to 1-foot depth was determined, which would suggest it might be suitable for a sulfur soil test in western Montana.
6. Yields, percent S in alfalfa plants, and S-yield data indicated that S from 0-40-0-20(S) was not as available to the plant early in the growing season as from gypsum, especially from spring application.
7. Percent S in alfalfa plants was not related to yield increase for 0-40-0-20(S). It either increased with time during growth towards maturity or decreased more slowly than did alfalfa treated with gypsum.

8. Correlations of $r = .514$ and $r = .516$ were obtained between yield increase and percent S for the first sampling date (2 to 3 inch) and mature plants, respectively. This suggests that early sampling might be just as effective in predicting the need for S as using the mature plant.
9. The correlation between the yield increase and N to S ratio was nonexistent, but all except one responding site had an N to S ratio greater than 11.
10. Sulfur percent in mature plants from the nonfertilized S check treatments was a good indicator for predicting the need for S fertilizer.
11. The critical percentage of S in mature alfalfa plants was 0.228% S, below which response to S fertilization was assured.

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