MONTANA STATE UNIVERSITY

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 MASTER OF SCIENCE in Soils
Montana State University
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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 be-tween 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(3) 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 SO4 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.

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AVAILABILITY OF SULFUR TO ALFALFA (*Medicago sativa* L.)
AND ORCHARDGRASS (*Dactylis glomerata* L.) AS INFLUENCED
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by

LARRY EDWARD STOLTENBERG

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ABSTRACT

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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 concensus 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 SO_4-S (sulfate-sulfur). The SO_4-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 SO_4-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. Ths 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.

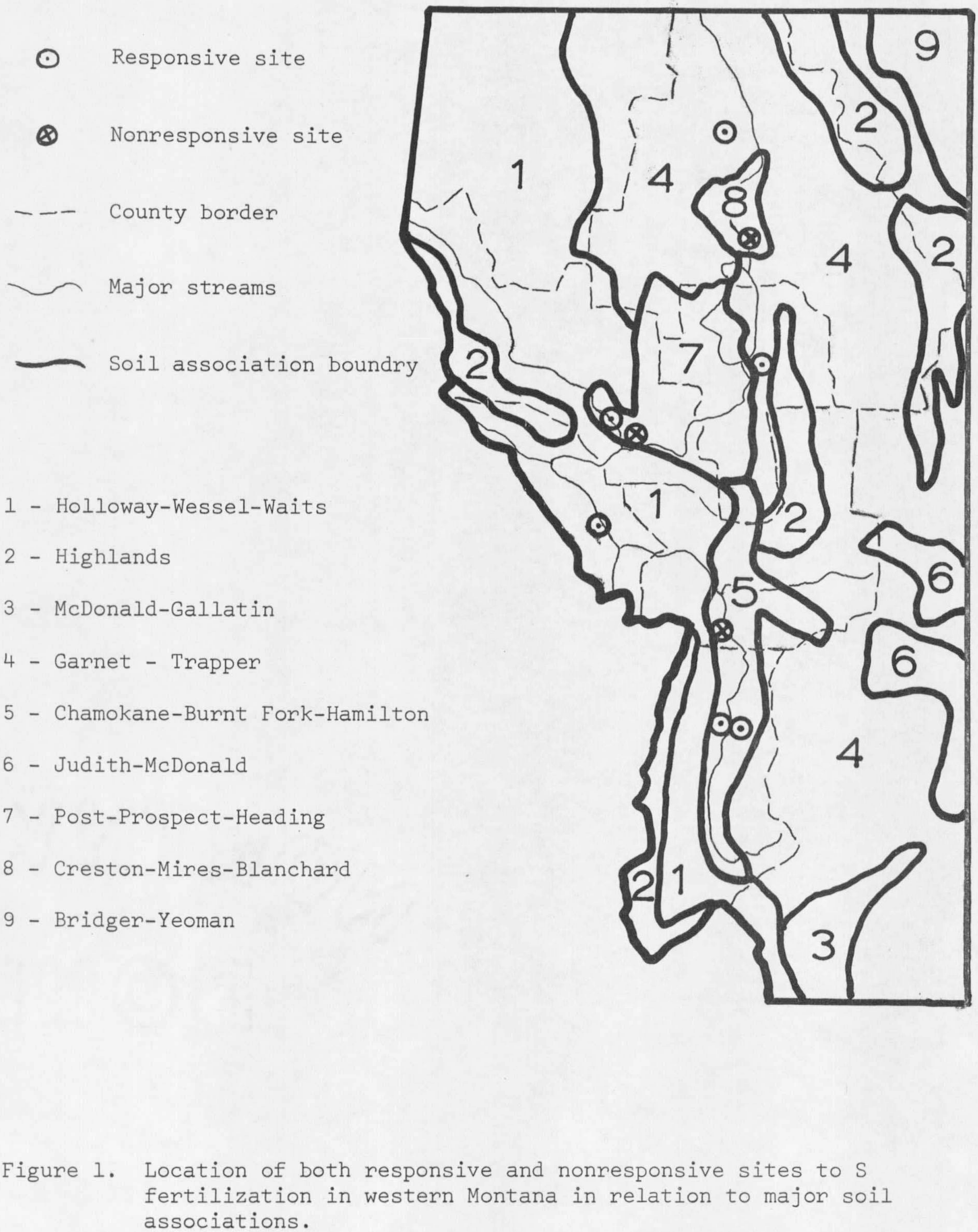

Figure 1. Location of both responsive and nonresponsive sites to S fertilization in western Montana in relation to major soil associations.

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

Location 2/	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: SW¼ of NW¼ section 10, R20W, T6N.

Woodside: SE¼ of NW¼ section 35, R21W, T6N.

Superior: NE¼ of NW¼ section 17, R25W, T15N.