CROP RESPONSE TO SULFUR AND THE SULFUR SUPPLYING POWER OF SEVERAL SOUTHERN OREGON SOILS

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INTRODUCTION

The fact that sulfur is a limiting factor in the production of legumes on certain soils in Southern Oregon has been known since 1912. Reimer and Tarter (41, p. 6) observed sizeable alfalfa yield increases in 1912 and 1913 following the application of gypsum and superphosphate to the soils. They further observed that the growth of alfalfa, red clover, Canadian field peas, and vetch made more vigorous growth under the spray and drip area of orchard trees that had been sprayed with lime-sulfur. Subsequent experiments confirmed their observations on the sulfur responses shown by legume crops in the area.

Until very recently, many of the fertilizers used on the farm contained certain amounts of sulfur. In the year ending June 30, 1948, more than three-fourths of the tonnage of all the fertilizers consumed in the United States contained more SO_3 than the sum of the tonnages of N, P_2O_5, and K_2O (31). However, the current trend in fertilizer manufacture and usage is toward high analysis, concentrated fertilizers, many of which contain little or no sulfur. It becomes important that we obtain a more complete understanding of the sulfur status of the soils and of the sulfur requirements of crops grown in the area.

The soils of the Southern Oregon area are generally quite low in native sulfur, and the amount of sulfur obtained from precipitation is probably of small consequence. No centers of heavy industry are located in Southern Oregon, and there are no large consumers of coal or crude oil that might release large quantities of SO_2 into the atmosphere. The burning of wood wastes by forest product industries would seem to have an effect only within a limited area.

As one means of obtaining information on the general soil fertility status of the cropland in Southern Oregon, an alfalfa survey was conducted in 1953. Soil and alfalfa samples were taken from a total of 103 randomly selected sites in Jackson and Josephine Counties at the time of the first hay cutting in the spring. Chemical analyses were made of both soil and alfalfa samples. The sulfur content of the alfalfa hay in the samples ranged from 0.16 to 0.84 per cent with approximately one-fourth of the samples containing 0.25 per cent sulfur or less.

A soil fertility research project on field crops in the Southern Oregon area was initiated in 1953. One of its objectives was to determine the need for sulfur in the soils of the area and to determine the sulfur supplying power of the soils. Since 1953, 24 field experiments have been conducted on a variety of crops in the two counties, and one pot trial was conducted with sulfur as a variable in which yield data were taken along with soil and plant samples for laboratory analysis. This thesis reports the results of these investigations.

LITERATURE REVIEW

Historical:

Sulfur has been recognized as an essential element in the growth of plants for many years. As early as 1768, Reverend Meyer, Canton of Berne, used gypsum as a fertilizer in Switzerland. It was used in France and Germany in the last part of the 18th century. Gypsum was being used in England and the United States shortly afterwards (10). Benjamin Franklin wrote "this land has been plastered" with gypsum in a meadow along a well-traveled road where many travelers saw the yield response.

Gypsum was one of the first fertilizer materials promoted for a number of years in the Eastern United States. Superphosphate then became available, and it partly replaced gypsum as a source of sulfur. Elemental sulfur came into use somewhat later. A number of fertilizer materials now contain sulfur in various amounts and combinations (19, p. 672-675).

Hart and Peterson (20, p. 3-4) in 1911, showed that the ash analysis method formerly used resulted in a loss of much sulfur by volatization, and consequently, plants needed more sulfur than was previously thought. Their work showed that legumes and crucifers were especially heavy users of sulfur. They found that cereal crops removed about two-thirds as much sulfur as they did phosphorus from the soil, while alfalfa removed more sulfur than it did phosphorus. They concluded that the average Wisconsin soils that had been cropped 50 to 60 years had lost about 40 per cent of their original sulfur content as compared to virgin soil. They calculated that the amount of sulfur lost by leaching exceeded that brought in the atmosphere and by precipitation.

Yield response to sulfur:

The work of Reimer and Tartar (41, p. 6) beginning in 1912 in Jackson County, first showed the need for sulfur as a fertilizer in Oregon. Superphosphate and gypsum applied at several rates increased the yields of alfalfa on a Medford fine sandy loam soil by 17 to 39 per cent. The responses were attributed to phosphate at first, but the results of field experiments in 1913 confirmed the sulfur response on alfalfa. Experiments conducted from 1914 to 1918 using elemental sulfur, gypsum, ferrous sulfate, and superphosphate resulted in alfalfa and red clover yields being increased 50 to 100 per cent over plots not receiving sulfur.

Yield responses to sulfur were measured by Powers (40, p. 11-16) on alfalfa in Central Oregon as early as 1912. A number of field experiments were conducted from

1913 to 1921 in Deschutes County on several medium sandy loam soils. Rates of elemental sulfur up to 100 lbs. per acre were used along with several other carriers of sulfur on alfalfa. Yield increases of 10 to 60 per cent were obtained with alfalfa growing on many of the soils. The yields of clover, potatoes, and cereal grains were also increased by the use of sulfur, although the non-legumes generally responded to a lesser degree than the legumes.

Many other investigators have reported increased yields when sulfur was applied to the soil. McKibben (30, p. 106-109) reported yield increases in pot trials with soils from Maryland, Washington and Oregon. He grew soybeans, tomatoes, tobacco, grains and potatoes. Tolman and Stoker (51) increased the yield of sugar beet seed in Western Oregon from a check yield of 1,235 to 1,578 lbs. per acre with the application of 94 lbs. of sulfur per acre. They noticed that the sulfur treated plots withstood dry soil conditions better, had greener leaves, set more seed, and resisted a leaf spot fungus that caused a breakdown of leaves. Most of the sulfur responses were found in plots that also received nitrogen. Plots receiving nitrogen without added sulfur yielded no more than the unfertilized checks, indicating a strong interaction between sulfur and nitrogen existed. The seed quality, as indicated by germination tests, test weight per bushel, and percentage cleanout, was not affected significantly by sulfur treatment.

The yields of bur clover in the Ojai Valley of California were increased 300 to 400 per cent by sulfur fertilizers (9). Crops of barley and pasture grass benefited during the succeeding two years following an application of sulfur to clover.

Effect of sulfur on the chemical content of crops:

The addition of sulfur to the soil, in addition to basic slag, rock phosphate, and phosphoric acid, increased the sulfur content and the nitrogen content of red clover grown in Florida (6) as compared to clover grown on plots not receiving sulfur application.

White clover grown on seven Southeastern soils without added sulfur had total sulfur contents ranging from 0.08 to 0.14 per cent (2). An application of 47 lbs. of sulfur per acre resulted in sulfur contents of from 0.20 to 0.31 per cent. The S:N ratios in the clover, without added sulfur ranged from 1:20 to 1:30, while the S:N ratios with 47 lbs. of sulfur per acre ranged from 1:10 to 1:17. The contents of cystine and methionine, two sulfur-containing amino acids, were lower where no sulfur was added.

Rendig and Weir (43) fed alfalfa hay grown on soil deficient in sulfur to lambs in a feeding trial. The sulfur content of the hay from check plots was 0.125 per cent, while the sulfur content of the hay grown on plots fertilized with sulfur was 0.275 per cent. Rather consistent, but not always significant, trends indicated that animal performance was improved by the application of sulfur fertilizer to alfalfa as compared to hay grown on soils deficient in sulfur. Methionine added to the ration containing the low sulfur hay did not improve the feed value of the hay. A low sulfur intake of the lambs resulted in lower levels of inorganic sulfate in the blood serum of the lambs as compared to lambs fed the hay with the higher sulfur content.

Bently et al. (3) fed legumes grown on a sulfur deficient grey wooded soil to rabbits. The rates of gain of the rabbits were slower than those of the rabbits being fed legumes that were grown on plots that had been fertilized with sulfur. The feed efficiency was greater with the rabbits eating legumes grown on sulfur treated plots.

Studies of the sulfur metabolism of plants:

A deficiency of sulfur studied in relation to the metabolism of tomatoes, was found to result in stems of small diameter, woody stems, yellowing of leaves, and a poorly developed cambium layer (36, p. 574). Sulfur deficient plants were higher in nitrates and carbohydrates, but the reduction of nitrates and the oxidation of sugars were slowed. Plants deficient in sulfur were also low in sulfhydryl sulfur.

Wood (54) assumed that the sulfate ion reduces to the sulfhydryl form and combines with ammonia and a carbon source, probably glycolytic breakdown products, to form sulfur-containing amino acids.

Tisdale et al. (50) found a considerable difference between two alfalfa strains in their ability to synthesize methionine and cystine, particularly at low sulfur levels in the growth medium.

Needham and Hauge (35) found that the vitamin B content of alfalfa grown on a sulfur deficient soil was lower than where there was an adequate supply of sulfur in the soil.

Forms of sulfur in the soil:

The forms of sulfur in 39 Minnesota soils were studied by Evans and Rost (14, p. 133-135). The soils in the study included podzols, chernozems, and black prairie groups. The water soluble sulfur contents of the soils were found to be variable. In only seven of

24 soils was organic sulfur less than 30 per cent of the total, and in prairie types, it accounted for more than 60 per cent of the total sulfur. The organic matter of Minnesota soils acted as a reservoir of sulfur. Non-sulfate sulfur, which included insoluble compounds and sulfur adsorbed and held by clay particles, made up more than 70 per cent of the total sulfur in the subsoils of the black prairie type of soil.

<u>Leaching and adsorption of sulfur by soils</u>:

The responses to applications of sulfur applied to tobacco, cotton, corn and soybeans growing on two soil types were studied in North Carolina (25). Sulfur deficiencies were observed early in the season on cotton and tobacco growing on Durham coarse sandy loam. The deficiency symptoms on tobacco disappeared as the season progressed, apparently because the roots were absorbing sulfur from the subsoil that had been leached down from the surface soil. No response to sulfur was noted with corn, cotton, and soybeans growing on Marlboro fine sandy loam soil even though only one ppm of SO_4-S was found in the 0-6 inch layer. The Durham soil had an accumulation of from 234 to 284 ppm of SO_4-S in the 18 to 30 inch depth as a result of leaching from the surface soil layer.

Ensminger (13) found alfalfa and sericea did not respond to sulfur in some Alabama soils because of an accumulation of subsoil sulfur. On light-textured surface soils, much of the sulfate leached to the heavier clay subsoils. The addition of superphosphate fertilizer reduced the adsorption of the sulfate in the surface soil. Lime also reduced sulfate retention. Kamprath, Nelson, and Fitts (26) found that 1:1 type clays adsorbed more sulfate than the 2:1 type clay minerals. Increasing the phospate concentration of the soil reduced the amount of sulfate adsorbed. Their data indicated that less sulfate was adsorbed in the presence of the phosphate ion, particularly if phosphate had been recently applied as fertilizer.

Sulfur in precipitation and in the atmosphere:

In addition to sulfur applied to the soil as fertilizers, manures, crop residues, and fungicides, appreciable amounts of sulfur reach the soil in precipitation in some areas. Leland (28) reported 48.67 lbs. of sulfur per acre per year was brought down in precipitation at Ithaca, New York, as measured over an 18 year period. He concluded that the possibilities of a sulfur deficiency for most crops grown there was slight. The amount of sulfur in the precipitation at 11 locations in Indiana ranged from 20 to 127 lbs. per acre per year with an average of about 27 lbs., when the figure of 127 lbs. for the industrial area aroung Gary was omitted (5, p. 28). This compared to a range of 5 lbs. to 100 lbs. of sulfur per acre per year in Minnesota. Higby (24) measured from 3 to 10 lbs. of sulfur per acre per year in precipitation in Western Oregon. Most investigators have found that local conditions such as kind of crop, length of the growing season, the level of soil fertility, extent of leaching, and the sulfur reserves in the soil, make it difficult to predict a sufficiency or deficiency of sulfur from that brought down in precipitation.

Fried (15) found that atmospheric sulfur in the form of sulfur dioxide could be absorbed directly by plant leaves and converted to organic form. Alfalfa growing in nutrient solution was able to absorb sulfur dioxide through its leaves when it was growing in an atmosphere containing 0.1 ppm SO_2. Cotton plants were found to use SO_2 from the atmosphere in an amount roughly proportional to the size of the plant or in relation to its leaf surface (37). Although the sulfur dioxide of the atmosphere was inadequate as the sole source of sulfur, it contributed over 50 per cent of the sulfur found in sulfur-deficient cotton plants as determined with radioactive sulfur.

Sulfur oxidation in the soil:

Several types of bacteria perform important functions in the oxidation of elemental sulfur and thiosulfate in the soil (46). The most important, Thiobacillus thiooxidans, can tolerate acidity as great as pH 2.2. Moses and Olson (34) found that the maximum sulfur oxidation occurred at a soil moisture tension of only 30 to 60 cm. of water in four soils. They concluded that lack of aeration limited the oxidation of sulfur at soil moisture tensions of less than 30 cm. They also concluded that sulfur oxidation can occur quite rapidly in irrigated soils or in dryland soils during the wet season.

Thirty-one surface soils of Kentucky were incubated at room temperatures for varying periods of time (45, p. 97-103). Sulfur was added to the soils at 250 ppm, and $CaCO_3$ was added at 4000 ppm at the start of the incubation periods. After 30 days of incubation, the sulfur oxidized in the unlimed soils ranged from 8.6 to 36 per cent of that applied and from 20.8 to 61.6 per cent of that applied after 120 days. Lime had no effect on the rates of sulfur oxidation. The investigator concluded that enough sulfur was oxidized in 30 days to supply most crop needs. Conrad (8, p. 47) found that elemental sulfur was as effective as gypsum as a source of sulfur in California except when the former was applied to the soil surface in the coldest months or in seasons of limited rainfall. Low rates of elemental sulfur applied with an 8-30-0 fertilizer mixture in greenhouse pots apparently increased the phosphate availability, but the oxidation of the sulfur was too slow under field conditions in Alberta, Canada to affect the availability of phosphorus (32).

Tisdale and Bertramson (49) found that the oxidation of sulfur resulted in an increase in the available manganese of the soil. The yield and oil content of soybeans and the amount of manganese absorbed by the plants were increased by the application of elemental sulfur to the soil. They postulated that sulfur may have a direct reducing action on MnO_2 in the soil exclusive of the acidity produced by the oxidation of sulfur. Garey and Barbur (17) found a correlation between manganese deficiency and sulfur content of certain Indiana soils. They found that elemental sulfur took part in oxidation-reduction reactions, increased the sulfate content of the soil, and caused a lowering of the soil pH. Soil treatments that included sulfur gave the highest yields of soybeans with the manganese content of the soybeans being higher on plots treated with sulfur. Treatments causing a lowering of soil pH benefited the crop in relation to the pH change. The benefits were greater with treatments that included sulfur oxidation than where sulfuric acid was added to lower the soil pH an equivalent amount. Vavra and Frederick (52) also studied the oxidation of elemental sulfur and sodium thiosulfate treatments applied to the soil and found that sulfur oxidation caused an increase in the available manganese and lowered the soil pH. Limestone added to the soil caused a decrease in the release of available manganese, but the amount of sulfate released was not decreased.

Other uses of sulfur applied to the soil:

Sulfur has several other important functions in agriculture besides its use as an essential element for plant growth. It has long been, and promises to continue as, an important fungicide in the deciduous fruit industry (20). It has been used in Florida to control brown rot of potatoes, *Pseudomonas solanocearum* (12). Summer applications of 800 lbs. of elemental sulfur per acre lowers the pH of the soil enough to be toxic to the pathogen. The application of limestone in the fall raises the soil pH to a high enough level for the satisfactory growth of potatoes. Single applications of sulfur control the disease for three to four years. Soil rot of sweet potatoes, *Actinomyces ipomoea*, has been controlled in Louisiana by the application of 500 to

800 lbs. of sulfur per acre. The soil pH can be lowered enough to kill the pathogen, and control has been obtained for periods of from four to six years (39, p. 6-10).

The reclamation of alkali soils in arid sections of the West has been materially assisted by the use of sulfur (23). Rates of sulfur from 1,000 to 4,000 lbs. per acre have been effective in lowering the soil pH and have caused sodium salts to be leached from the soil. A Malheur clay loam soil of very high alkalinity was improved enough by sulfur treatment and leaching that satisfactory crops of sweet clover, alfalfa, and cereal grains were grown.

EXPERIMENTAL METHODS

Selection of sites for field experiments:

Sulfur was used as a fertilizer variable in 24 field experiments during the five crop seasons from 1954 through 1958 on 21 farms in Jackson and Josephine Counties. The experimental sites were selected in several ways. Soil test results on samples submitted to the Soils Testing Laboratory by farmers were used to locate sites that might be expected to respond to applications of certain fertilizer elements. The results of the alfalfa survey conducted in 1953 were used to locate areas and specific sites where low levels of sulfur and other fertility elements were suspected. Personal observations of crops growing in the area were of value in locating problem sites upon which to conduct experiments. The probable good cooperation of the farmer upon whose land the experiment was to be conducted was also a consideration in the location of experimental sites.

Experiments on cereal grains:

Five fertilizer trials were conducted on cereal grains in 1954, three in 1955, and one each in 1956 and 1957. Sulfur was a variable at 0 and 60 lbs. per acre in the 1954 and 1955 seasons, at 0, 30, and 60 lbs. per acre in 1956, and at 0 and 30 lbs. in 1957. Elemental sulfur was used as the source of sulfur in 1954 and 1955, while gypsum was used in 1956 and 1957. Each sulfur treatment was a part of a series of from 10 to 16 treatments applied to the experimental areas in randomized block experiments with four replications. The plot size used was 7 feet wide by 40 feet long. The fertilizers were broadcast and mixed into the soil during seedbed preparation in all but two of the trials in which cases the fertilizers were applied after the grain had emerged. A plot combine was used to harvest a strip 44 inches by 38 feet through each plot for the determination of yield and test weights per bushel of the grain. Two of the 10 small grain experiments were on irrigated land.

Experiments on pasture crops:

Three pasture fertilizer trials were conducted in 1954 in Jackson County and one in Josephine County in 1955. Sulfur treatments of 0 and 60 lbs. per acre were part of a series of 14 fertilizer treatments involving N, P, K, S, and B plus minor elements, and in one case, a comparison of gypsum vs elemental sulfur. The plot sizes were 7 feet by 30 feet in 1954 and 6 feet by 25 feet in 1955. The fertilizers were broadcast on established pastures in replicated, randomized block experiments.

Fall application of fertilizer was made in one trial while spring applications were made in the other three. At each harvest, a plot mower was used to cut a strip 39 inches wide through the plots for the yield sample. The forage was weighed, and a subsample of approximately 500 grams was taken from each plot for moisture determination and chemical analysis.

Experiments on hay crops:

Fertilizers were applied to three alfalfa trials in the 1954 season, two in 1955, and one in 1956. The plot sizes were 7 feet by 30 feet or 7 feet by 40 feet. Sulfur variables, as elemental sulfur at 0 and 60 lbs. per acre, were applied as a part of a series of 18 to 20 treatments. Each treatment was replicated three times in randomized block designs. The harvest samples were obtained by mowing a 39 inch strip through the plots, weighing the green forage, and then taking a subsample of approximately 500 grams from each plot for moisture determination and chemical analysis. An unreplicated exploratory trial was placed on one farm in 1955 using sulfur at 0 and 60 lbs. per acre as both gypsum and elemental sulfur.

Four harvests were made with the alfalfa on a Kerby loam soil in 1955, three were made in 1956, and three were made in 1957. Harvest data on the other trials was taken only for one season except for one trial in which sulfur was applied at 0, 20, and 40 lbs. per acre on an annual basis for three years.

One trial was conducted on oats and vetch for hay in 1955 with sulfur as a variable at 0 and 60 lbs. per acre as part of a series of 18 treatments. The fertilizers were broadcast in the fall prior to the seeding of the crop. The plots were 7 feet by 30 feet. Harvesting was done with a 39 inch mower that cut a strip through the plots after which the forage was weighed and subsampled for moisture determination and chemical analysis.

Experiments on truck crops:

Sulfur in the form of gypsum was applied at 0 and 40 lbs. per acre to sweet corn and to tomatoes in 1958. The fertilizer treatments were applied in bands four inches deep and five inches from one side of the tomato and sweet corn rows. The tomato plots consisted of a single row of 10 plants with rows spaced 6 feet apart, while the sweet corn plots consisted of 4 rows by 25 feet. The tomatoes were harvested seven times, weighed, counted, and graded into market classes. The sweet corn was harvested once, and each ear was measured for length and circumference, and was graded into a market class.

Methods of soil analysis:

Soil samples were obtained from the 0-8 inch, 8-16 inch, and 16-24 inch depths of each replication of the experiments prior to the application of any fertilizers. The surface soil samples were analyzed by the O.S.C. Soils Testing Laboratory.[1] The pH of the soil was measured with the glass electrode on a 1:1 paste. The lime requirement was determined with the buffered solution and glass electrode method of Woodruff (55). Phosphorus was determined with the sodium bicarbonate method of Olsen et al (38, p. 1-17). Potassium, calcium, and magnesium were determined by the flame photometer method (1, p. 114). The method of Hatcher and Wilcox (22) was used to determine the boron content of the soils. Organic matter was measured by the chromic acid titration method of Walkley and Black (53). The cation exchange capacities of several of the soils were determined by the ammonium acetate method of Schollenberger and Simon (44).

Methods of plant analysis:

The total sulfur contents of the second cuttings of alfalfa grown on the Kerby loam soil in 1955-56-57 were

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[1]Appreciation is expressed to Dr. L. A. Alban, under whose direction the soil analyses were performed.

analyzed using $Mg(NO_3)_2$ oxidation and the gravimetric determination of sulfur as barium sulfate (1, p. 114-115). Total nitrogen of the alfalfa was determined by Kjeldahl analysis (1, p. 12).

Pot trial on alfalfa with soils and sulfur rate variables:

Five agriculturally important soils, Climax clay adobe, Columbia fine sandy loam, Kerby clay loam, Medford fine sandy loam, and Sams loam were used to grow alfalfa in pots with sulfur rates as the variable. Each of the soils had been used as a site for a field experiment either in 1954 or 1955. Seven pounds of screened soil, oven-dry basis, were placed in number 10 cans that had been coated with clear lacquer to prevent corrosion. The soils were analyzed by the same methods used on the soils from the field experiments. Sulfur in the form of C.P. calcium sulfate was mixed with the soil at the rates of 0, 15, 30, 60, and 120 lbs. of S per acre,[2] prior to seeding the alfalfa. Elemental sulfur at 30 lbs. per acre was used as one treatment. The treatments were replicated four times. Extra cans were used as borders around the treated soils. Twelve seeds of Lahontan alfalfa, a variety recommended for Southern Oregon

[2]Empirical factor of 2,000,000 lbs. of soil equivalent to one acre, 6 inch depth.

conditions, were placed in each can November 5, 1955 and covered with one fourth inch of soil. Fertilizers in the form of KH_2PO_4, KCl, and HBO_3 to equal 200 lbs. of P_2O_5 per acre, 200 lbs. of K_2O per acre, and 5 lbs. of B per acre were added in nutrient solution November 7, and the cans were placed in an unheated greenhouse. Water, which had been passed through a Barnstead demineralizer, was added to the soils in the cans so that the minimum soil moisture tension was 0.1 atmosphere.[3] Water was added as necessary, and the cans were weighed on a solution balance at weekly intervals to assure that the correct amounts of water were being added. The number of alfalfa plants in each can was reduced to 5 on February 10, 1956, when the alfalfa was approximately 4 inches tall. The greenhouse was heated starting on February 16, and the cans were placed outside on March 12 where they remained until the termination of the experiment.

Four cuttings of alfalfa were harvested with harvest dates being May 30, July 4, August 7, and October 6, 1956. The samples were oven-dried at 65° C. for 24 hours and ground in a Wiley mill to pass a 100 mesh screen.

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[3]Appreciation is expressed to Dr. D. D. Evans, under whose direction the moisture tensions were determined.

Because of the large number of samples involved, only samples from replications two and four of the 0, 15, 30, 60, and 120 lbs. per acre S treatments were analyzed for total sulfur as barium sulfate by the gravimetric method (1, p. 114-115).

The method of Chesnin and Yien (7) was used to estimate the sulfate-sulfur in the 5 soils used in the pot trial before and after an incubation period of 22 days at 35° C. Estimates were made of the sulfate-sulfur in the soils of replications two and four at the conclusion of the trial.

Statistical analyses of data:

Statistical analyses of data were made with the assistance of the Oregon State College Statistical Service.[4]

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[4]Appreciation is expressed to Dr. R. G. Petersen, under whose direction the statistical analyses of data were performed.

DESCRIPTION AND CHARACTERIZATION OF SOILS

Soils of Jackson County:

The soils of Jackson County were classified and mapped in 1911 into 43 distinct soil types by the Bureau of Soils (48, p. 30-35). An area of 544 square miles was classified.

The parent materials of the soils include granite, greenstones, slate, limestone, sandstone, lava, basalt, and conglomerate. Several agriculturally important soils originated from alluvial fans, and they have textures ranging from fine sandy loams to clay adobe. A considerable acreage of soil on the main valley floor between Medford and Ashland is of the heavy clay adobe texture. It represents the Grumusol great soil group[5] which is best typified in the United States by the Houston black clay and in India by the Black Cotton soils.

The soils of the heaviest texture are well adapted to the production of pears, although some general farming is conducted on them. Farming operations of both general and specialized types including forages, grains, seed crops, and truck crops are carried on with the

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[5] Placement in the great soils groups was done by personal communication with Mr. Charles R. Buzzard, Soil Scientist, Soil Conservation Service, Grants Pass, Oregon.

other soil types in Jackson County. Approximately one-half of the agricultural land is now being irrigated. With an average rainfall of 18 inches at Medford, supplemental irrigation is necessary for maximum crop production.

Soils of Josephine County:

The soils of Josephine County were classified and mapped in 1919 by the Bureau of Soils into 20 soil types (27, p. 359-369). Several soil types are common to both Jackson and Josephine Counties, but none of the clay adobe types are found in Josephine County. General farming predominates with many small farming units being operated. The area west of Grants Pass along the Rogue River is a specialized crop area where hops, bulbs, and seed crops are extensively grown.

Soils used in the field trials:

The 24 field experiments conducted in the two counties represented 7 soil series and 14 soil types. Table 1 presents the experiment number and the cooperator's name, the soil type, and the soil test data for each of the soils used in the experiments.

Most of the soils were slightly acid, and approximately one-third of the soils were low in available

Table 1. Soil test data for fertilizer trials conducted on cooperating farms, 0-8 inch depth.

Exp.No. and co-operators name	Soil Type	pH	Lime req. tons/acre	P, ppm	Cations, m.e./100 gms. K	Ca	Mg	B, ppm	Organic matter %
1. Straus	Sams loam	6.2	1	21.0	0.316	10.48		0.77	4.06
2. McDonough	Sites sandy loam	5.5	1½	14.4	0.236	5.00	2.02	1.16	
3. Rapp	Medford gr. c. l.	6.1	1	12.6	0.421	11.65	6.31	1.05	
4. England	Kerby cl. loam	5.7	2	1.0	0.105	7.24	11.82	1.12	
5. Loosley	Kerby cl. loam	5.5	2	4.0	0.095	6.11	4.84	0.89	
6. Nichols	Climax cl. adobe	6.3	⅓	14.7	0.752	32.82	15.80	0.67	
7. Konschott	Sams loam	6.0	1½	20.3	0.446	13.05	12.74	0.88	
8. Thompson	Columbia f.s.l.	5.9	2	6.3	0.218	5.97	15.13	1.01	
9. Childreth	Medford cl. loam	6.6	0	4.0	0.231	24.00	11.32	2.40	
10. Abbott	Sams loam	6.4	0	52.1	1.379	14.29	4.16	0.67	
11. Nelson	Medford cl. adobe	6.2	1	3.9	0.324	11.85		0.95	4.88
12. Heffernan	Medford loam	6.1	1	9.0	0.326	10.37	5.90	1.89	
13. Cook	Meyer s.c.l.	7.2	0	16.7	0.570	12.15	13.60	3.17	
14. Scouten	Columbia loam	5.7	2	18.4	0.345	5.44	3.71	0.39	
15. Hamlin	Medford cl. adobe	6.7	0	4.2	0.324	16.23	18.72	1.60	
16. Hanley	Medford f.s.l.	5.9	1	3.5	0.136	10.37	4.94	1.14	
17. Smith	Kerby gr. loam	5.9	1½	3.6	0.151	5.48		0.63	3.87
18. Duggan	Sams loam	6.1	1	17.6	0.454	13.29	13.13	1.24	
19. Niedermeyer	Medford loam	5.7	1½	9.2	0.218	11.84	6.20	0.70	
20. Scouten	Columbia f.s.l.	6.2	1	14.0	0.210	9.15	8.34	0.73	
21. Sauer	Kerby loam	6.2	1½	4.0	0.180	4.86	16.44	0.35	
22. Sauer	Kerby loam	6.3	1	3.3	0.121	4.00	10.93	1.18	
23. Station	Medford loam	6.1	1¼	8.7	0.369	12.08	2.47		
24. Station	Medford loam	6.1	1	7.5	0.390	12.08	2.07		

phosphorus, according to present standards. One-fourth of the soils were low in potassium, and 7 of the soils had more magnesium than calcium, on a milli-equivalent basis. The relatively high magnesium contents of the 7 soils is probably related to parent material, which was composed of mixed rock, including serpentine. The boron contents of the soils ranged over a fairly wide scale. The organic matter content of three of the soils was determined.

Soils used in the pot trial with alfalfa:

Climax clay adobe

This is a residual soil consisting of from one to six feet of black clay with a pronounced adobe structure. It was formed from the weathering of lava. It is an agriculturally important soil even though much of it is non-irrigated, and it has poor internal drainage. It is classed in the Grumusol great soil group.

The soil of this type used in the pot trial was from the site of experiment 6 where a yield response to applied sulfur was obtained in 1955. The soil test data for the soil is shown in Table 2.

Table 2. Soil test data, 5 soils used in a pot trial with sulfur rates on alfalfa, 0-8 inch depth

Soil	pH	Lime req., Tons/Acre	P, ppm	Cations, m.e./100 gm.			B ppm	C.E.C., m.e./100 gm.	O.M., %	Moist.,%, .1 atmos
				K	Ca	Mg				
Climax	6.3	½	14.7	0.75	32.8	15.8	0.67	61.23	1.59	59.17
Columbia	6.2	1	14.0	0.21	9.6	4.1	0.73	17.51	1.95	42.46
Kerby	6.0	2	3.4	0.12	10.5	6.6	0.93	20.91	4.43	36.90
Medford	6.3	1	29.3	0.54	9.5	1.5	1.53	13.98	4.51	30.96
Sams	6.1	1	25.9	0.71	12.2	4.7	0.74	22.68	3.20	34.97

Columbia fine sandy loam

This soil has a depth of 6 feet or more, and it is a micaceous, friable, fine sandy loam, typically brown in color. No definite subsoil development has taken place since it is a recent alluvial soil. It is one of the most important soils in the specialized agricultural area west of Grants Pass.

The soil of this type used in the pot trial was obtained from the site of field experiment 20 where a marked response of alfalfa to sulfur was observed within three weeks after 60 lbs. of elemental S per acre had been broadcast on the plots. The soil test data for the soil is shown in Table 2.

Kerby clay loam

This soil type is a yellowish-brown clay loam of moderately compact structure to a depth of 12 to 15 inches underlain by a more compact clay subsoil. The parent material was of mixed rock, including serpentine. The soil bakes when dry and it is difficult to till. It is probably an intergrade between a reddish-brown latosol and a prairie soil.

The soil sample for the pot trial was obtained from the site of field experiment 4 where a sizeable response was obtained with N, P, and K on wheat in 1954. An early season sulfur response was noted, but it disappeared as the crop approached maturity.

Medford fine sandy loam

This is a light brown to medium brown alluvial soil formed by the deposition of weathered granitic materials by intermittent streams tributary to Jackson Creek. Both the surface soil and the slightly coarser subsoil contain an appreciable quantity of coarse particles of granitic material. It is one of the most important soils in Jackson County. It is probably an intergrade between an alluvial and a prairie soil.

Experiment 16 was conducted in 1954 near the location where the soil was obtained for the pot trial. No response to S was found at that time, but a thin stand of alfalfa coupled with a very dry season on unirrigated land probably restricted full expression of a growth response. Table 2 shows the soil test data for the soil.

Sams loam

This soil type consists of from 2 to 6 feet of dark, grayish-brown loam underlain by a dark brown, heavy loam or light clay loam. It is of alluvial origin, mostly from sandstone and greenstones, with some basalt. It is usually well-drained, and it is classed as an alluvial intergrade to the prairie great soils group.

The Sams soil for the pot trial was from the site of field experiment 7 where barley showed an early season response to S in 1955. Table 2 shows the soil test data for this soil.

RESULTS AND DISCUSSION

Field trials with sulfur:

Field responses to applied sulfur, in terms of increased yields, were great enough in 4 of 24 experiments to be significant at the 5 per cent level. Several other experiments gave strong indications of yield increases with sulfur application. Table 3 presents a summary of the results obtained over 5 seasons by crops, years, yield responses, and whether or not the crop was grown on irrigated or non-irrigated land.

Early season responses to applied S were noted in experiments 4, 5, 7, and 9 of the cereal grains and in experiment 11, which was a pasture mixture composed of perennial ryegrass and Ladino clover. It was reported by Kamprath, Nelson and Fitts (24), that early season responses to S were apparent on some soils in North Carolina with cotton, tobacco, and corn as the indicator crops. They found very little available S in the 0-6 inch soil layer, but rather large amounts at greater depths. As the roots of the plants extended downward, more S was absorbed with the result that the crops overcame the earlier deficiency. It is postulated that a similar phenomena may have occurred in the experiments reported here.

Table 3. Summary of sulfur responses with field experiments conducted in the years 1954 to 1958

Exp. No. and Crop		Year	Yield No S	Yield S Applied	Response at P = 0.05	Irrigated
Cereal Crops			Bu./Acre			
1.	Barley	1954	40.1	37.0	not sig.	no
2.	Oats	1954	54.2	46.9	not sig.	no
3.	Wheat	1954	54.2	50.7	not sig.	yes
4.	Wheat	1954	59.3	64.3	not sig.; early season response noted	no
5.	Oats	1954	79.4	90.0	not sig.; early season response noted	yes
6.	Barley	1955	34.0	41.0	sig.; visible in field	no
7.	Barley	1955	37.2	38.3	not sig.; early season response visible	no
8.	Wheat	1955	10.6	12.8	not sig.	no
9.	Barley	1956	81.0	82.0	not sig.; possible early response	no
10.	Barley	1957	39.9	40.4	not sig.	no
Pasture Crops			Tons/Acre			
11.	Clover-grass	1954	2.320	2.780	not sig.; early response	no
12.	Clover-grass	1954	4.424	4.233	not sig.	yes
13.	Clover-grass	1954	3.522	3.478	not sig.	yes
14.	Clover-grass	1955	2.726	2.610	not sig.	yes

Table 3. Summary of sulfur responses with field experiments conducted in the years 1954 to 1958 (Continued)

Exp. No. and Crop	Year	Yield No S	 S Applied	Response at P = 0.05	Irrigated
Hay Crops		Tons/Acre			
15. Oats and Vetch	1955	2.544	2.499	not sig.	no
16. Alfalfa	1954	1.965	1.951	not sig.	no
17. Alfalfa	1954	1.803	1.890	not sig.	no
18. Alfalfa	1954	2.170	2.253	not sig.	no
19. Alfalfa	1956	1.173	1.068	not sig.	no
20. Alfalfa	1955	1.700	2.480	not replicated; response indicated	no
21. Alfalfa	1955	4.317	6.684	sig.	yes
	1956	3.311	5.099	sig.	yes
	1957	4.232	4.549	not sig.	yes
22. Alfalfa	1956	3.812	5.224	sig.	yes
	1957	4.695	5.850	sig.	yes
	1958	3.393	4.583	sig.	yes
Truck Crops					
23. Tomatoes (Tons/Acre)	1958	16.078	16.633	not sig.; resp. indicated	yes
24. Sweet Corn (Doz./Acre)	1958	1521	1568	not sig.	yes

The greatest yield increases from applied sulfur were obtained with alfalfa as shown in experiments 20, 21, and 22. Figure 1 shows the response to applied S obtained on alfalfa in experiment 20 on a Columbia fine sandy loam soil. Since experiments 21 and 22 were each continued for three years, they are discussed in greater detail later.

Figure 1. Alfalfa response to S, exp. 20, 8 weeks after the application of sulfur; left - 60 lbs. of elemental S per acre; center - 4 lbs. of B per acre; right - 60 lbs. of S per acre as gypsum; foreground - check plot.

There appeared to be no definite pattern between the field response to sulfur and the chemical analyses of the soil as shown in Table 1. The yield increases to S shown in Table 3 occurred on soils that ranged from a light-textured Columbia fine sandy loam to a very heavy

Climax clay adobe.

The amount of S applied as fertilizers in previous years was of great importance to succeeding crops. The cropping and sulfur fertilizer histories are shown in Table 4. Most of the trials where no yield responses to S were obtained had had some S applied within the previous one or two years. Experiments 6, 20, 21, and 22, each of which responded to S, had little or no sulfur applied in the two or three years previous to the fertilizer experiment.

While sulfur responses were obtained both with and without irrigation, the lack of irrigation water may have masked some S responses. The summer rainfall was very sparse during the years the experiments were conducted, and in non-irrigated pasture and alfalfa trials, the first crop was sometimes the only one of quantity from which yield data could be obtained.

Results obtained in experiment 21:

The yield responses to sulfur obtained in experiment 21 on a Kerby loam soil were of particular interest. The soil test data indicated the surface soil was quite low in phosphorus, potassium, calcium, and boron. Magnesium was in the high range, particularly in relation to calcium with a Ca/Mg ratio of 1:3.39 on a

Table 4. Cropping and sulfur fertilization history of field trial sites.

Exp.	Soil type	Cropping history*	S applied in fert. lbs./A**
1.	Sams loam	barley; wheat; o. & v.	36; 24; 24
2.	Sites sandy l.	alfalfa; same; same	30; 0; 30; 0; 30
3.	Medford g.c.l.	alfalfa; same; same	0; 30; 0; 36
4.	Kerby c.l.	pasture; same; same	0; 24; 24; 24; 24
5.	Kerby c.l.	pasture; same; same	12; 24; 24; 24; 24
6.	Climax c.a.	fallow; barley; barley	none in recent years
7.	Sams loam	fallow; barley; barley	0; not known
8.	Columbia f.s.l.	alfalfa; same; same	0; 0; not known
9.	Medford c.l.	barley; alfalfa; same	0; 18; 12
10.	Sams loam	barley; alfalfa; same	24; 18; 24
11.	Medford c.a.	pasture; same; same	0; 12; 18
12.	Medford loam	pasture; same; same	48; 48; 48; 48
13.	Meyer s.c.l.	pasture; same; same	0; 24; 24
14.	Columbia f.s.l.	pasture; same; same	48; 20; 30; 20
15.	Medford c.a.	o. & v.; corn; o. & v.	0; 0; 24; 0
16.	Medford f.s.l.	alfalfa; same; same	36; 36; 0; 36
17.	Kerby g.c.l.	alfalfa; same; same	none in recent years
18.	Sams loam	alfalfa; corn; wheat	36; 24; 0; 0
19.	Medford l.	alfalfa; oats; barley	48; 36; 0; 18
20.	Columbia f.s.l.	alfalfa; same; same	none in recent years
21.	Kerby l.	alfalfa; barley; wheat	0; 0; 18
22.	Kerby l.	alfalfa; same; barley	0; 0; 0; 18
23.	Medford l.	alfalfa; same; same	24; 36; 0; 36
24.	Medford l.	alfalfa; same; same	24; 36; 0; 36

* Most recent previous crop listed first.
** Most recent previous application listed first.

milli-equivalent basis. The parent material of the Kerby soil series was composed of mixed rocks, including serpentine, a magnesium bearing mineral. The soil pH of 6.2 was apparently being maintained at that fairly reasonable level by the magnesium in the cation exchange complex of the soil. The soil was permeable and well-drained, and it had 5 to 6 feet of soil above a layer of gravel. Table 4 indicates that very little sulfur was applied as fertilizer in recent years.

Outstanding yield increases were obtained in 1955 on plots receiving an application of 60 lbs. of elemental S per acre in March of that year. Table 5 shows the yield data from the trial as seasonal totals, while more detailed yields by cuttings are shown in the appendix (Table A-1). There was an indication of a response to elemental S at the time of the first cutting, while S applied as gypsum gave a slightly greater first cutting yield. Figure 2 shows the response to S on May 31, 1955 at the time of the first cutting. The yields of plots receiving elemental S and gypsum were essentially the same in succeeding cuttings. Conrad (8) reported that elemental S gave as great a yield response on alfalfa, bur clover, and vetch in California as gypsum except during the coldest months or during a dry period.

Figure 2. Alfalfa response to applied S, experiment 21, May 31, 1955. No S at left; 60 lbs. of S per acre applied March 5, 1955 at right.

Several sulfur comparisons were possible as shown in Table 5. In each case, the addition of S greatly increased the yields of alfalfa. Nutrient interactions with S were not evident in 1955, since the addition of P, K, or B did not change the crop response to sulfur.

Since the sulfur deficiency symptoms of the alfalfa, including a yellowing of the leaves and a stunting of the plants, resembled a nitrogen deficiency in a non-legume plant, an examination was made of the alfalfa roots from plots receiving S and compared with samples from plots receiving no S. The alfalfa on the S plots had more nodules on the roots than those not receiving S. Gaw and Soong (18) reported an increase in the dry

Table 5. Yield of alfalfa as affected by sulfur fertilization, exp. 21, Kerby loam, means of three replications.

Fertilizer treatment applied in 1955, lbs./A. N	P_2O_5	K_2O	S	B	Yield of alfalfa hay, tons/A. 1955*	1956	1957
0	0	0	0	0	4.32	3.31	4.23
0	0	0	60	0	6.68	5.10	4.55
0	0	0	0	4	4.32	3.13	4.03
0	0	0	60	4	6.19	4.41	4.25
0	120	120	0	0	5.34	3.36	4.59
0	120	120	60	0	6.86	4.49	4.01
0	0 (S as gypsum)	0	60	0	6.95	4.57	4.22
		LSD, (P=0.05)			1.05	0.90	-

* 4 cuttings taken in 1955; 3 cuttings taken in 1957 and 1957.

S was supplied as elemental sulfur except as noted.

weight of garden peas and an increase in the number of nodules on the roots where sulfur had been applied to the soil.

During the winter of 1955-56, the Illinois River flooded the alfalfa field with 4 to 5 feet of water on two occasions, and it was felt that much of the remaining sulfate may have been leached out. Such was not the case since sizeable responses were observed on S plots in the spring of 1956. Therefore, three harvests were made in 1956, with the application of no additional S. The yield increases due to S were again large, indicating that much of the S was retained by this soil.

There was an indication from the yield data that where phosphate was applied in 1955 to the S plots, the decline in yield in 1956 was more rapid than where no phosphate was used. Ensminger (13) found that the phosphate ion caused the release of adsorbed sulfate in some Alabama soils, while Kamprath, Nelson, and Fitts (26) found that less sulfate was adsorbed in the presence of the phosphate ion in some North Carolina soils. Since the phosphate level in the soil of experiment 21 was low, little loss of sulfate might be expected due to the action of phosphate.

Three more harvests were made during the 1957 season, again with no additional fertilizer being applied. The yields among treatments were closely grouped with no difference great enough to be significant at the 5 per cent level. There were further indications, that the phosphate ion caused a more rapid depletion of S than where no phosphate was added to the treatment. Where phosphate was applied with S in 1955, the yield of alfalfa in 1957 was 4.01 tons per acre, but where no phosphate was applied with S in 1955, the 1957 yield was 4.55 tons per acre. The alfalfa in all the plots displayed S-deficiency symptoms in 1957. The plants were stunted; they had yellow leaves, and the alfalfa was unable to compete satisfactorily with weeds.

There was a tendency for plots receiving no S to show decreasing yields from the first to the third cuttings in 1955 and 1956. Plots receiving S with or without P, K, or B maintained a more uniform level of production from the first through the third cutting during the same period.

Chemical analyses were made of alfalfa from the check plot, and from the S, PK, and PKS plots of the second cuttings for each of the three years of the trial. Table 6 shows the data from the analyses. The yields in 1955 and 1956 were increased by 60 lbs. of S per acre, applied in 1955, with only an indication of a positive yield response with S in 1957. The sulfur content of the alfalfa was closely related to S treatment in 1955 with the samples from no S plots containing 0.23 per cent S, while those from S plots contained 0.35 per cent, and those from the PKS plots contained 0.33 per cent. In 1956, the S content of the alfalfa grown in the check, PK, and PKS plots were nearly identical, while the straight S plot had alfalfa with the greatest S content. These

Table 6. Effect of sulfur on the yield, sulfur content, nitrogen content and the S:N ratio of second cutting alfalfa grown on a Kerby loam soil, exp. 21, means of three replications

Fertilizers applied in 1955, lbs./acre				1955				1956				1957			
N	P_2O_5	K_2O	S	Tons/A	% S	% N	S:N	Tons/A	% S	% N	S:N	Tons/A	% S	% N	S:N
0	0	0	0	0.97	0.23	2.77	1:11.8	0.91	0.25	2.60	1:10.4	1.25	0.20	2.42	1:11.9
0	0	0	60	1.74	0.35	3.20	1:9.4	1.72	0.31	2.99	1:9.6	1.60	0.22	2.49	1:11.5
0	120	120	0	1.51	0.23	2.72	1:12.0	1.12	0.24	2.61	1:11.0	1.40	0.20	2.30	1:11.4
0	120	120	60	1.89	0.33	3.14	1:9.6	1.49	0.26	2.72	1:10.6	1.26	0.18	2.39	1:13.0
LSD, (P = .05)				0.62	0.035	0.34	1:2.19	0.339		0.197					
Coeff. Var., %				18.1	8.5	5.8	10.2	12.9	9.6	3.6	9.1	10.3	8.7	5.1	8.3

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data support the belief that P increased the depletion of applied S. In 1957, the S contents of the alfalfa samples were nearly equal, with only the S treatment giving an indication of a slightly higher S content in the alfalfa.

It appears from the data that the S content of the alfalfa from plots well supplied with sulfur, varied from 0.31 to 0.35 per cent. Morrison (33, p. 1154) reports the average S content of a large number of alfalfa samples as being 0.32 per cent, approximately the same as the best samples analyzed from the plots of experiment 21. Rendig and Weir (43) reported the total S content of alfalfa grown on a very sulfur deficient soil in California was 0.125 per cent and as high as 0.275 per cent when the soil was fertilized with 400 lbs. of gypsum per acre. It would appear that the S contents of deficient plants and of plants adequately supplied with S agree fairly well, in order of magnitude, with those reported in the literature.

While an increase in the N content of the alfalfa was found as a result of S applied in experiment 21, not all investigators have found an increase in the N content of alfalfa fertilized with S. Tisdale et al. (50) found the highest N content at the lowest level of S.

Nightingale, Schermerhorn, and Robbins (36, p. 592) found that tomatoes grown in a S-deficient medium, contained large amounts of nitrate-nitrogen with a slow rate of reduction to the amine form.

The S:N ratios of the alfalfa grown on the soil in experiment 21 were all narrower than 1:15 (Table 6). The S and PKS treatments in 1955 had S:N ratios of 1:9.4 and 1:9.6 respectively, as compared to 1:11.8 and 1:12.0 found in the check and PK treatments. These data indicate that the alfalfa grown on plots treated with S resulted in a greater proportional gain in S than in N content. Loosli (29) reported that a sulfur to nitrogen ratio, in livestock feeds, wider than 1:15 might be assumed to be low in S for ruminants while narrower ratios than 1:15 might indicate a surplus of S. Bardsley and Jordan (2) found S:N ratios averaging 1:24 with clover grown on sulfur deficient Southeastern soils and 1:17 on the same soils supplied with 47 lbs. of S per acre. The N contents of the clover averaged 2.42 and 3.25 per cent respectively.

In 1956, the S:N ratios were rather closely grouped except that the plots treated with S alone appeared to have the narrowest ratio. The 1957 S:N ratios were closely grouped except for the PKS treatment which appeared to have a slightly wider ratio than the other treatments. The relatively narrow S:N ratios, when compared to the results of other investigators, suggest that the ratios obtained in other areas, do not necessarily apply under Southern Oregon conditions.

The data in Table 6 which includes yields, S per cent, N per cent, and the S:N ratios indicate that the phosphate added in fertilizer did have an effect on the disappearance of sulfur from the soil when both P and S were added to the soil in the same treatment. The general leveling out of yields, S and N percentages, and of the S:N ratios in 1957 show that very little of the original 60 lbs. of S per acre applied in 1955 remained for the 1957 crop.

Results obtained in experiment 22:

This experiment was designed to gain information on S rates applied annually. Three years of yield data were obtained from the trial as shown in Table 7. The soil test data from Table 1 indicate the Kerby loam soil had a pH of 6.3, and that it was low in P, K, and Ca, and high in Mg and medium in B. Irrigation was by flooding.

Significant yield responses to S were observed. Gypsum as the source of S, produced the most rapid yield response at the time of the first cutting in the first

Table 7. Yield of alfalfa as affected by sulfur fertilization, exp. 22, Kerby loam soil, means of three replications

Fertilizers applied annually, lbs./acre[1] N - P_2O_5 - K_2O - S				Yield of alfalfa hay, tons per acre, total of three cuttings per year 1956	1957	1958	3-year ave.
0	60	80	0	3.81	4.69	3.39	3.97
0	60	80	20	4.22	5.20	4.14	4.52
0	60	80	40	5.22	5.84	4.58	5.22
0	60 (S as gypsum)	80	40	5.80	6.06	3.92	5.26
	LSD, (p = .05)			0.69	0.75	0.93	
	Coef. Variability			8.8%	8.1%	14.1%	

[1] S supplied as elemental sulfur except as noted

year as shown in Table 7. Elemental S at 40 lbs. per acre was equally responsive after the first cutting in 1956 and remained so until the termination of the trial in 1958. The 40 lb. S rate resulted in a somewhat higher yield than the 20 lb. rate, but not significantly so at the 5 per cent level of significance.

On the basis of the data from the trial, 20 lbs. of S per year was not enough for maximum alfalfa yields. The 40 lb. S rate also may not have been enough for a maximum yield since the yield was still increasing at that rate. If the S content of the alfalfa approximated the 0.31 to 0.35 per cent as shown by productive alfalfa in Table 6, it would contain from 6.2 to 7.0 lbs. of S per ton. With a yield of 6 tons of alfalfa per acre, the S required could be as high as 42 lbs. per acre per year. With alfalfa growing on a soil known to be low in available S, 40 lbs. of S per year would not then be adequate, in view of a less than 100 per cent recovery of applied S.

Results obtained from the pot experiment:

Yield data

Table 8 shows a summary of yield data for the four cuttings of alfalfa by soils and by S treatments. More detailed yield data are shown in the appendix, Table A-2. Figure 3 shows the yields of alfalfa by soils and by treatments for each of the four cuttings. Sizeable yield increases were obtained with S treatments in each of the soils except the Kerby clay loam. Differences were not independent of soil type, since response magnitudes and patterns varied among soils. The second cutting of alfalfa was the highest yielding for all soils except the Kerby in which the first crop had the highest yields. Figure 4 shows the alfalfa growing in the pots in one complete replication for each of the five soils on July 4, 1956, at the time of the second cutting. Third

Table 8. Yield of alfalfa, in grams per pot, as influenced by S treatments and soils, total of 4 cuttings, mean of 4 replications

Soil	Treatment, pounds of S applied per acre 0	15	30	60	120	Soil Mean
Climax	12.27	18.21	21.49	23.13	23.89	19.80
Columbia	7.19	13.08	15.03	15.21	14.49	13.00
Kerby	12.08	12.76	12.97	13.38	12.75	12.79
Medford	15.40	22.69	23.69	25.20	28.14	23.02
Sams	8.90	18.24	22.98	22.81	22.95	19.18
Treat. Mean	11.17	17.00	19.23	19.94	20.44	17.56

LSD	P = 0.05	P = 0.01
Treatments	0.771	1.026
Soils	1.492	2.092
Treat. x Soils	0.724	2.293

cutting yields were, in general, rather low because the extreme heat of July and early August hastened maturity at the expense of total growth.

Alfalfa growing on the Climax soil showed only a slight yield increase from applied S in the first cutting as shown in Figure 1. The alfalfa growing in the check pots was of a more yellow-green color than the alfalfa growing in pots treated with S. The second crop of alfalfa responded markedly up to the 30 lbs. of S per

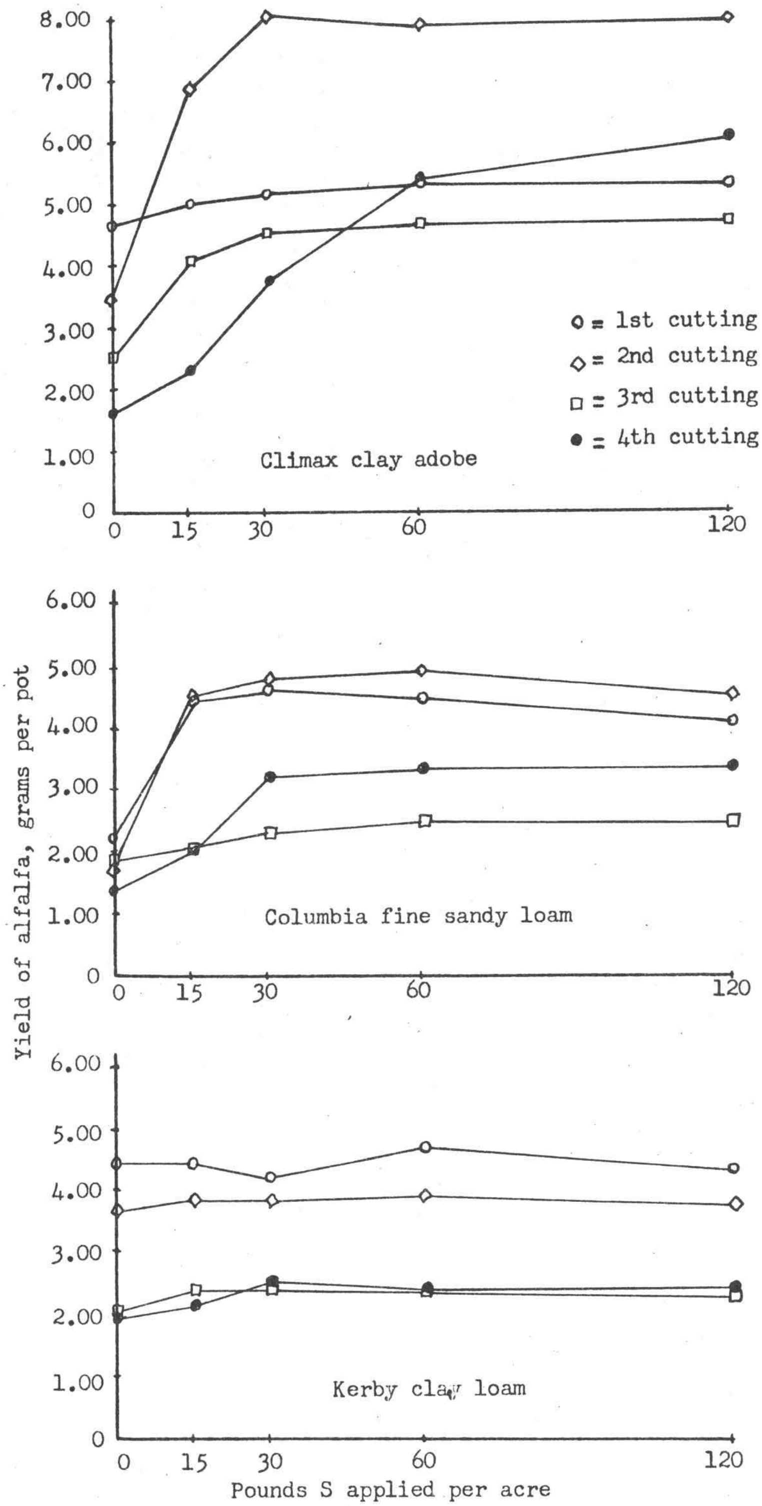


Figure 3. Yield of alfalfa as influenced by S treatment for five soils by cuttings

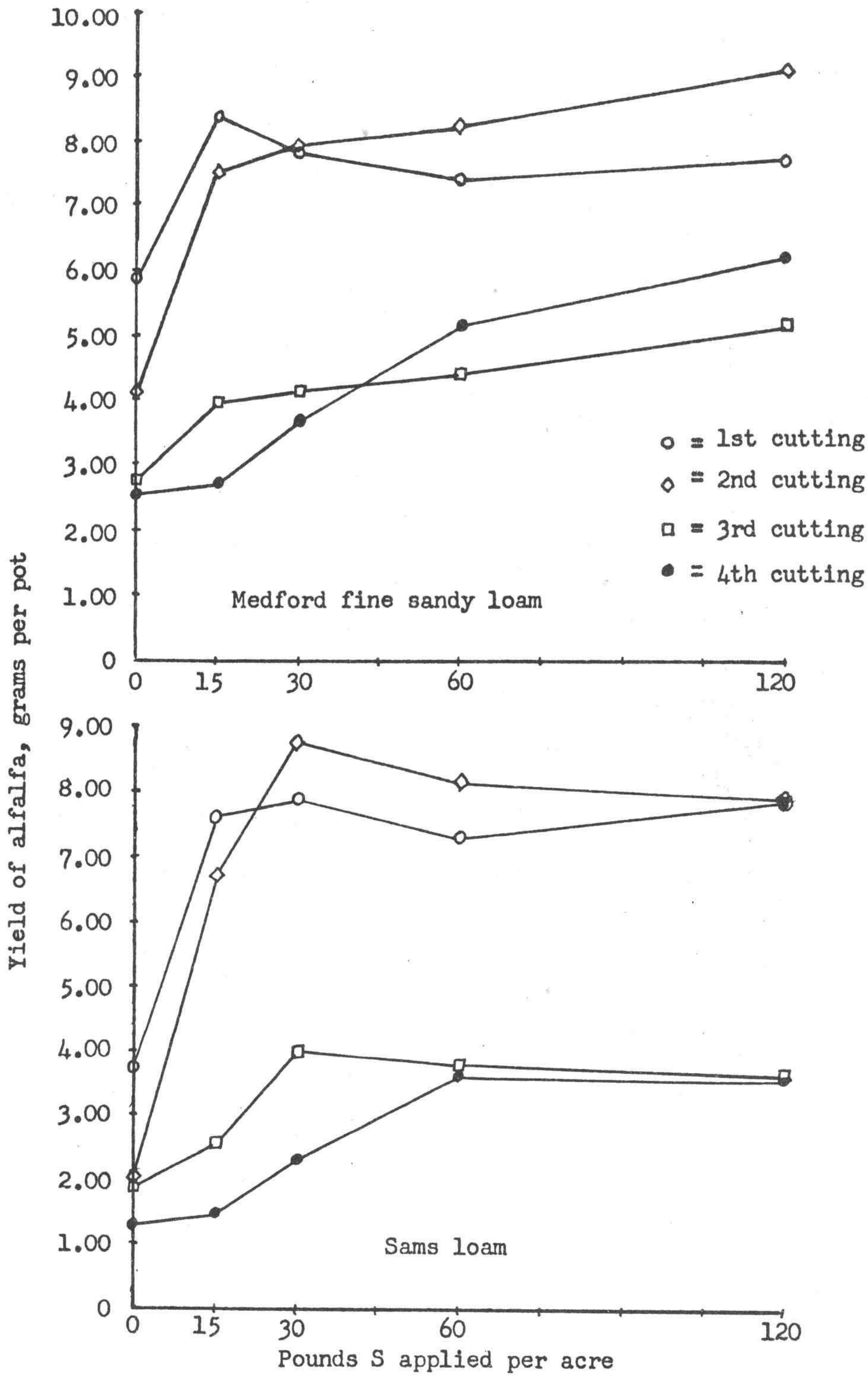


Figure 3, continued. Yield of alfalfa as influenced by S treatments for five soils by cuttings

Climax soil

Columbia soil

Figure 4. Second crop alfalfa, pot trial, July 4, 1956.

Kerby soil

Medford soil

Figure 4. Second crop alfalfa, pot trial, July 4, 1956.

Sams soil

Figure 4. Second crop alfalfa, pot trial, July 4, 1956. (Continued)

acre rate after which the yields leveled off at a relatively high level. The third cutting yields of alfalfa again responded to the 30 lb. S rate that had been applied at the start of the experiment. The data suggest that by the time of the fourth cutting, much of the S applied at the start of the experiment had been used by the alfalfa, especially at the lower rates. In this cutting, yields continued to increase, at a decreasing rate, up to the 120 lbs. per acre rate of S. The possibility existed that a higher yield would have been reached with a rate of S greater than 120 lbs. per acre.

S deficiency symptoms, in the form of stunted growth and yellowing of the alfalfa leaves, were apparent up to the 60 lbs. S rate at the time of the fourth harvest. Considering the total yields shown in Table 8, and the mean square values shown in the appendix, Table A-3, significant yield increases at the 1 per cent level of significance were found between the 0 and 15 lbs. of S rate and between the 15 and 30 lb. S rates in the Climax soil. The fertilizer history of the field from which the soil was obtained showed no S was applied as fertilizer in recent years.

The first and second cuttings of alfalfa gave marked yield responses from the application of the 15 lbs. rate of S to the Columbia soil. These two cuttings produced yield patterns that were very similar as shown in Figure 3. Yields tended to level off near the 15 lbs. of S rate. Yields in the third cutting were influenced to a lesser degree by S rates than any of the other cuttings. Hot weather hastened the maturity of the third cutting. Markedly increased yields up to the 30 lbs. rate of S were noted in the fourth cutting. S-deficiency symptoms were pronounced in the check pots in all four cuttings, and in the fourth cutting, from pots receiving the equivalent of 15 lbs. of S. The general yield level of the alfalfa grown on the Columbia soil was not high when compared to the Climax, Medford, and Sam soils. Considering the total yields for all cuttings as shown in Table 8, significant yield increases were found only between the 0 and 15 lb. rates of S. No S had been applied to the soil for several years prior to obtaining the soil sample for the pot trial.

The only soil among the five not showing pronounced S responses yieldwise was the Kerby. It was the only soil on which the highest yield of alfalfa was obtained in the first cutting. As indicated in the fertilizer history for experiment 4 of Table 4, considerable amounts of S were applied to the soil in several previous years. Since the soil test data of Table 2 indicated a low level of P, losses of S as a result of the phosphate ion causing its release probably were small. The second cutting was nearly equal in quantity to the first with only a very slight indication of a yield increase due to the S application. The third and fourth cuttings of alfalfa were quite similar in their yield patterns except that the fourth cutting gave more of an indication of a yield response where 30 lbs. of S per acre had been applied at the start of the experiment. Considering the total yields as shown in Table 8, the differences in yields of alfalfa among the sulfur rates were not significant at the 5 per cent level.

A large yield increase in the alfalfa harvested in the first cutting on the Medford soil was obtained on pots that had received 15 lbs. of S per acre at the start of the experiment. The yields of alfalfa with higher rates of S were slightly lower than the yield obtained with 15 lbs. of S per acre as shown in Figure 3. In the second cutting, approximately 83 per cent more alfalfa was produced in pots receiving the 15 lbs. rate of S per acre than was produced in the check pots. The yields continued to increase at the 30, 60, and 120 lbs. of S per acre rates. The third cutting yield response was sharply upward to 15 lbs. of S and upward at a lesser, but almost linear rate, to the 120 lbs. of S rate per acre. The 15 lbs. rate of S failed to increase the fourth cutting yield significantly, but the higher rates resulted in yield increases. Rates of S higher than 120 lbs. per acre applied at the start of the experiment might have resulted in even higher yields of alfalfa. Considering the total yields, each increment of added S increased the yield significantly at the 1 per cent level of significance.

In the first cutting on the Sams soil, the yields of alfalfa grown on pots that had received the 15 lbs. rate of S per acre yielded over 100 per cent more than the yields from the check pots, while higher rates of S did not increase the yields further. At the time of the second and third cuttings, alfalfa grown on pots that had received 30 lbs. of S per acre produced the greatest yields. The 15 lb. of S rate per acre had a very small effect at the fourth cutting; the 30 lb. rate of S resulted in a moderate yield increase, while the 60 and 120 lb. rates of S gave higher, but nearly equal yield increases. The total yields showed significant yield increases over the check treatment with 15 lbs. of S per acre, and alfalfa grown on pots treated with 30 lbs. of S per acre yielded significantly more than the alfalfa grown on the 15 lbs. of S treatment at the 1 per cent level of significance.

Considering the soil means in Table 8, the alfalfa grown on the Medford soil produced the highest yields, followed by the alfalfa grown on the Climax and Sams soils, which were very similar in total yields, while the Kerby and the Columbia soils produced the least alfalfa.

Elemental S, applied at the rate of 30 lbs. per acre, resulted in yield increases in the four responsive soils, that were approximately equal to the 30 lbs. of S per acre rate supplied as gypsum. The yields from the elemental S treatment are shown in the appendix. The rate of S oxidation in each of the soils apparently was rapid enough to supply the plants with enough sulfate-sulfur to equal the gypsum treatment.

<u>SO_4-S content of the five soils:</u>

Table 9 presents data on the SO_4-S content of the soils. In order to relate the SO_4-S content of the soils used in the pot trial to their responses to applied S, and to estimate the relative rates of S release among the soils, the SO_4-S contents of the soils were determined. The Climax, Columbia, and Medford soils contained nearly equal amounts of SO_4-S in their original state. The Sams contained less and the Kerby contained more than the first three soils. Following a 22 day incubation period, the SO_4-S content of each soil increased with the Kerby soil showing the greatest increase on a ppm basis. After four cuttings of alfalfa had been removed from the pots, there were few differences in the SO_4-S contents of the pots among the S treatments within the Climax, Columbia, and Medford soils.

In the Sams soil, there were slightly greater amounts of SO_4-S remaining in the 30, 60, and 120 lbs. of S per acre pots than in the check and 15 lbs. of S per acre pots. The fourth cutting yields of alfalfa were higher in the 60 and 120 lbs. of S per acre than in the 0 and 15 lbs. S per acre rates, while the yield of alfalfa in the 30

Table 9. SO_4-S content, ppm, of 5 soils before and after an incubation period of 22 days and after the removal of 4 cuttings of alfalfa, means of two replications.

Soil	Original Soil	Incubated Soil	Pounds per acre of S applied as gypsum 0	15	30	60	120	As elemental S 30
Climax	5	10	4	5	4	4	5	4
Columbia	6	9	6	6	4	6	7	5
Kerby	8	13	7	9	9	9	10	7
Medford	5	9	8	9	6	7	10	9
Sams	3	6	4	4	7	6	7	6

lb. rate of S treatment was of an intermediate amount.

The Kerby soil had the greatest amount of SO_4-S remaining after the removal of four cuttings of alfalfa. It was the one soil that did not respond yieldwise to applied S. In contrast to the Kerby soil, the Medford soil did respond to S treatment very markedly, while at the same time, it also contained a relatively high amount of sulfate at the termination of the experiment.

The data of Table 9 would seem to indicate that the SO_4-S content of the incubated soils might be of some value in predicting crop response to S. The Kerby soil with 13 ppm of SO_4-S did not respond at the time of the first cutting; the Climax with 10 ppm of SO_4-S showed only a small response in the first cutting, while the Columbia soil with 9 ppm of SO_4-S responded well as did the Medford soil with 9 ppm. The Sams soil, with only 6 ppm of SO_4-S, was the most responsive soil, yieldwise, to 15 lbs. of S per acre in the first cutting. Under the conditions found in the experiment, soils with less than 10 ppm of SO_4-S, after an incubation period of 22 days, could be expected to respond to applied S with an increased growth of alfalfa by the time of the first harvest.

The SO_4-S contents of the original soils also gave an indication of the yield responses obtained with applied S. The Kerby soil again had the highest SO_4-S content, while the Climax, Columbia, and Medford soils were closely grouped at a lower SO_4-S content. The Sams soil had the lowest SO_4-S content, and it was also the most responsive soil to S treatment at the time of the first harvest.

Sulfur content of the alfalfa:

Alfalfa grown in each of the five soils showed an increase in S content as a result of S treatments applied to the soils. Tables 10, 11, 12, and 13 present the analytical data by cuttings for the five soils and five S treatments. Figure 5 shows the graphic representation of the S contents of the alfalfa by soils and by cuttings.

Alfalfa grown on the Climax soil increased in S content from 0.28 per cent for the check treatment to 0.43 per cent at the 120 lbs. of S per acre rate in very nearly a linear fashion in the first cutting (Figure 5). The S contents found in the second cutting of alfalfa were lower than in the first, particularly at the 0 and 15 lbs. of S per acre rates. In the third cutting, the S contents of alfalfa grown with the 0 and 15 lbs. of S rates were nearly equal, but increases were noted at the higher rates. Indications were that by the fourth cutting, most of the S that was applied at the start of the

Table 10. Sulfur content, per cent, of alfalfa grown in pot trial, as influenced by treatments and soils, means of two replications, first cutting

Soil	Pounds S applied per acre					Soil Mean
	0	15	30	60	120	
Climax	0.28	0.31	0.32	0.39	0.43	0.35
Columbia	0.23	0.28	0.32	0.38	0.42	0.32
Kerby	0.27	0.32	0.35	0.37	0.37	0.34
Medford	0.22	0.24	0.33	0.34	0.41	0.31
Sams	0.23	0.26	0.30	0.32	0.36	0.29
Treat. mean	0.25	0.28	0.32	0.36	0.40	0.32

LSD, Treatments, (P = 0.05), 0.034
(P = 0.01), 0.047

Table 11. Sulfur content, per cent, of alfalfa grown in pot trial, as influenced by treatments and soils, means of two replications, second cutting

Soil	Pounds S applied per acre					Soil Mean
	0	15	30	60	120	
Climax	0.18	0.22	0.27	0.34	0.39	0.28
Columbia	0.20	0.22	0.30	0.33	0.44	0.30
Kerby	0.27	0.33	0.36	0.38	0.53	0.37
Medford	0.21	0.23	0.33	0.35	0.54	0.33
Sams	0.25	0.21	0.26	0.32	0.43	0.29
Treat. mean	0.22	0.24	0.30	0.34	0.47	0.32

LSD	P = 0.05	P = 0.01
Soil	0.018	0.029
Treatment	0.023	0.031

Table 12. Sulfur content, per cent, of alfalfa grown in pot trial, as influenced by treatments and soils, means of two replications, third cutting

Soil	Pounds of S applied per acre 0	15	30	60	120	Soil Mean
Climax	0.25	0.24	0.28	0.38	0.41	0.31
Columbia	0.21	0.27	0.35	0.35	0.38	0.31
Kerby	0.25	0.33	0.36	0.43	0.47	0.37
Medford	0.26	0.31	0.32	0.36	0.38	0.32
Sams	0.22	0.22	0.26	0.35	0.41	0.29
Treat. Mean	0.24	0.28	0.31	0.37	0.41	0.32

LSD	P =0.05	P =0.01
Treatments	0.028	0.038
Soils	-	-

Table 13. Sulfur content, per cent, of alfalfa grown in pot trial, as influenced by treatments and soils, means of two replications, fourth cutting

Soil	Pounds of S applied per acre 0	15	30	60	120	Soil Mean
Climax	0.22	0.17	0.19	0.25	0.26	0.22
Columbia	0.20	0.20	0.23	0.29	0.27	0.24
Kerby	0.22	0.28	0.28	0.39	0.47	0.33
Medford	0.18	0.19	0.21	0.27	0.30	0.23
Sams	0.18	0.20	0.18	0.28	0.29	0.23
Treat. Mean	0.20	0.21	0.22	0.30	0.32	0.25

LSD	P =0.05	P =0.01
Soils	0.022	0.037
Treatments	0.034	0.046

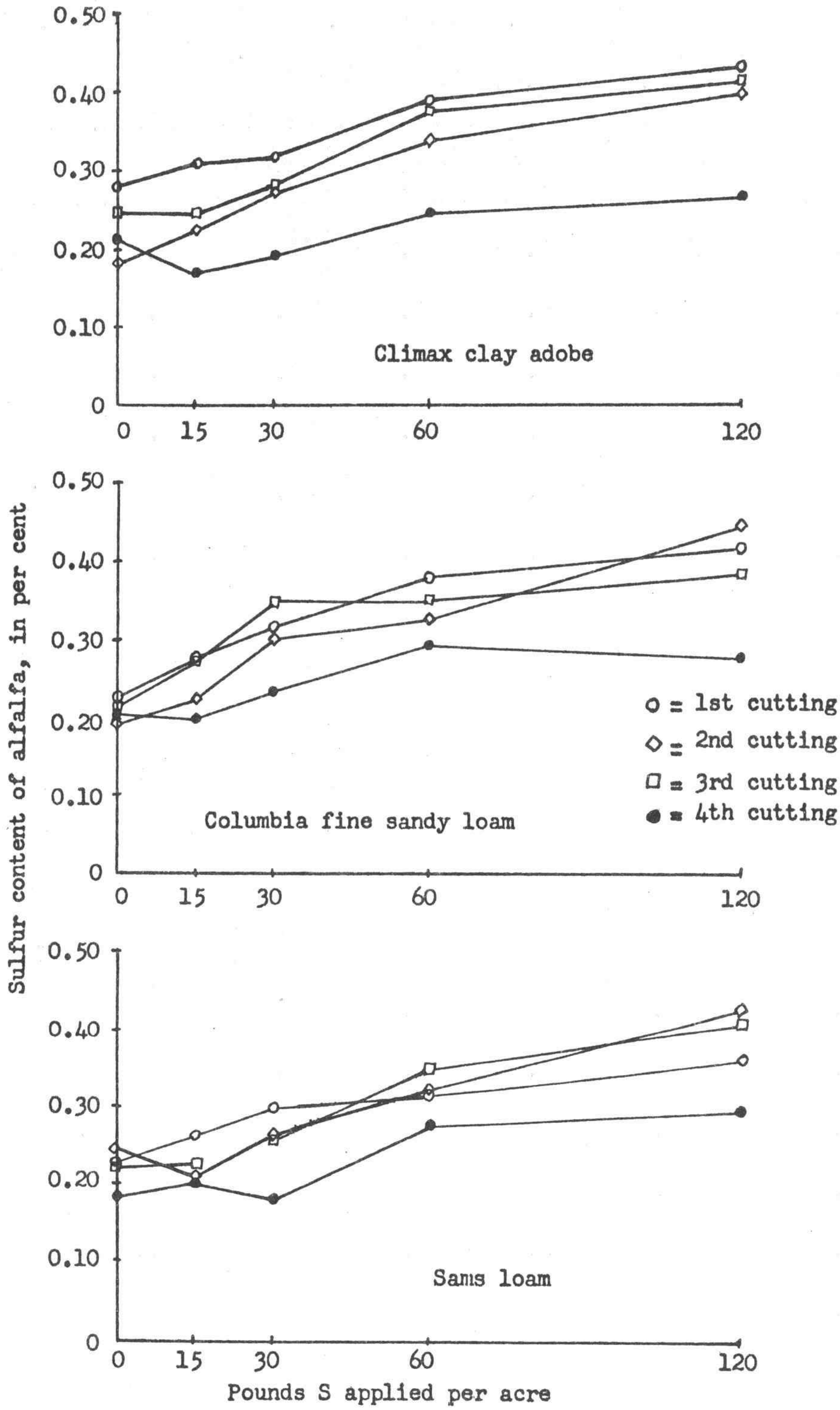


Figure 5. S content of alfalfa, in per cent, as influenced by cuttings and by S treatments on five soils

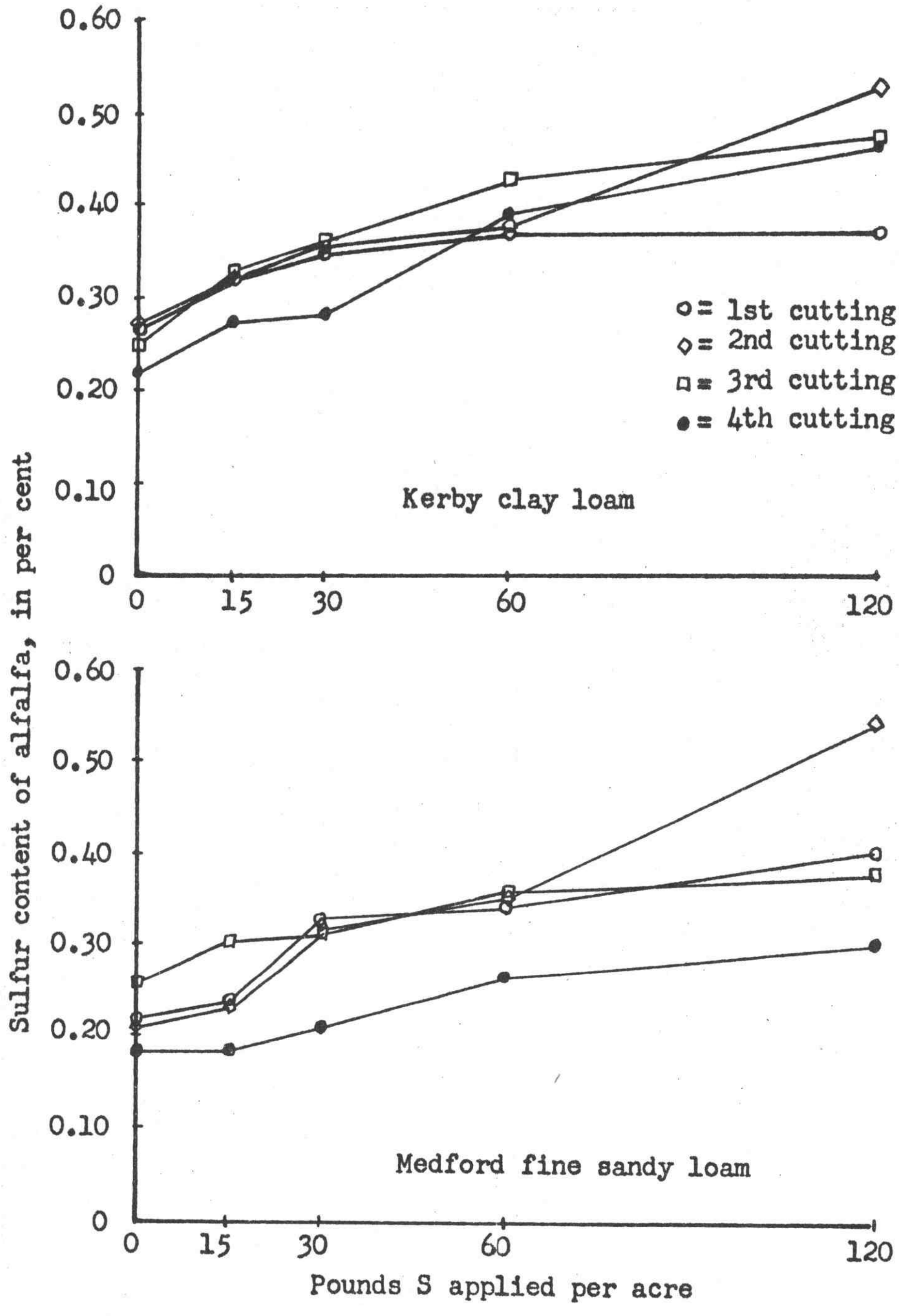


Figure 5, continued. S content of alfalfa, in per cent, as influenced by cuttings and by S treatments on five soils experiment in the 0, 15, and 30 lbs. of S rates per acre had been used by the alfalfa, and that much of the S of the 60 and 120 lbs. rates had been taken up by the alfalfa.

Alfalfa grown on the check treatment of the Columbia soil showed a remarkable uniformity in its S content through all four cuttings as shown in Figure 5. Severe S deficiency symptoms were also shown by the alfalfa growing in the check pots. Marked increases in the S contents of the alfalfa grown on the 15 and 30 lbs. of S per acre treatments over that of the check treatments were found in the first three cuttings. At the fourth cutting, the data indicated that much of the S of the 30 lbs. of S per acre rate was used up, and that a sizeable fraction of the S of the 60 and 120 lbs. of S per acre rates had been taken up also.

The S content of the alfalfa grown on the Kerby soil generally was higher than for the other soils, particularly with the check treatments. The yields, as previously discussed, were low as compared with the Medford, Climax, and Sams soils. Each added increment of S increased the S content of the alfalfa over the preceding rate (Figure 5), except for the 120 lbs. of S per acre rate in the first cutting and the 30 lbs. of S per acre rate in the fourth cutting. It was only at the last harvest that alfalfa growing in the check treatment showed sulfur deficiency symptoms. There was apparently a sizeable quantity of S left in the 120 lbs. of S per acre rate at the time of the final harvest as indicated by the S content of the alfalfa of 0.47 per cent.

On the Medford soil, 15 lbs. of S per acre applied at the start of the experiment, resulted in only small increases in the S content of the alfalfa in the first, second, and fourth cuttings. Sizeable increases in the S content of the alfalfa were obtained over that of the check treatment with the 30 lbs. of S treatment in the first three cuttings. The data indicates that most of the S of the first three rates was used up by the fourth cutting, with only moderate amounts of S left in the soils of the 60 and 120 lbs. of S per acre treatments.

Alfalfa grown on the Sams soil generally was quite low in S even when 15 and 30 lbs. of S per acre were applied (Figure 5). In the fourth cutting, no increases in the S content of the alfalfa were noted except at the 60 and 120 lb. rates of S. The Sams soil also contained the least amount of SO_4-S as shown in Table 9.

Tables 10, 11, 12, and 13 show the statistical analyses of the data. Least significant differences are shown for the soil means and for the treatment means.

The S content of the alfalfa by soils and cuttings for the five sulfur rates, and the S contents of the alfalfa by cuttings and by S rates are summarized in the appendix, Tables A-4 and A-5.

It is of interest to note that the S content of the alfalfa grown in the second cutting of the pot trial with the 60 lbs. of S per acre rate averaged 0.34 per cent for the five soils. The average S content of the alfalfa grown in experiment 21 (Table 6) with 60 lbs. of S applied per acre also averaged 0.34 per cent S in the second cutting in 1955.

Yield of sulfur curves:

The amount of sulfur taken up by the alfalfa tops was calculated from the second cutting data, and it is shown in Table 14. Alfalfa grown on the Kerby soil took up the most S from the check treatments, probably because the Kerby soil had the highest content of SO_4-S. Alfalfa grown on the Medford soil took up more S than the alfalfa grown on the S treated pots of the remaining soils. Alfalfa grown on the Climax and Sams soils took up approximately equal amounts of S from the soils. Except for the check treatment, as previously noted, alfalfa grown on the Kerby soil and alfalfa grown on the Columbia soils took up nearly equal amounts of S.

Table 14. Sulfur taken up by alfalfa grown on five soils, mgms per pot, second cutting, means of two replications

Pounds S Applied per acre	Climax	Columbia	Kerby	Medford	Sams
			Soil		
0	5.2	3.4	10.7	8.5	4.4
15	15.5	10.7	12.5	17.9	14.0
30	22.3	14.3	14.0	28.1	23.0
60	26.8	15.0	16.0	34.4	25.0
120	30.7	21.6	21.2	52.6	32.7

Fried and Dean (16) have described a method of estimating the amount of a given nutrient in the soil that is available when a known amount of the nutrient is applied to the soil as fertilizer. They used labeled isotopes to calculate the uptake of nutrient from the applied fertilizer as a fraction of the nutrient content of the plant. The calculated "A" value or the amount of the available nutrient in the soil is used as a basis of evaluating factors affecting nutrient availability.

A method of extrapolating the yield of nutrient curve to obtain a sulfur "a" value, without the use of labeled isotopes, was used with the second cutting data from the pot trial. The curves are shown in Figure 6 for each of the five soils. The actual "yields of sulfur"

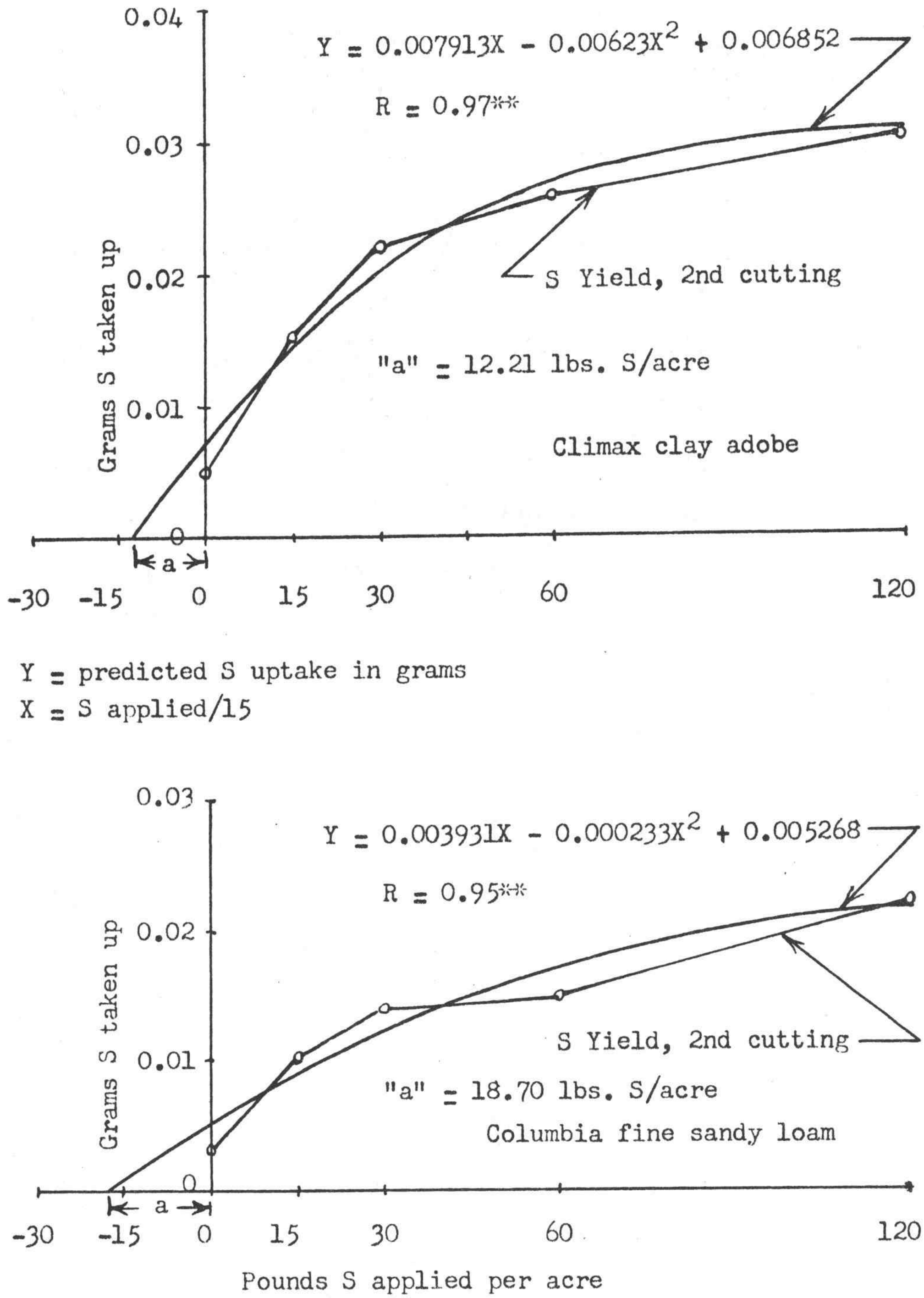
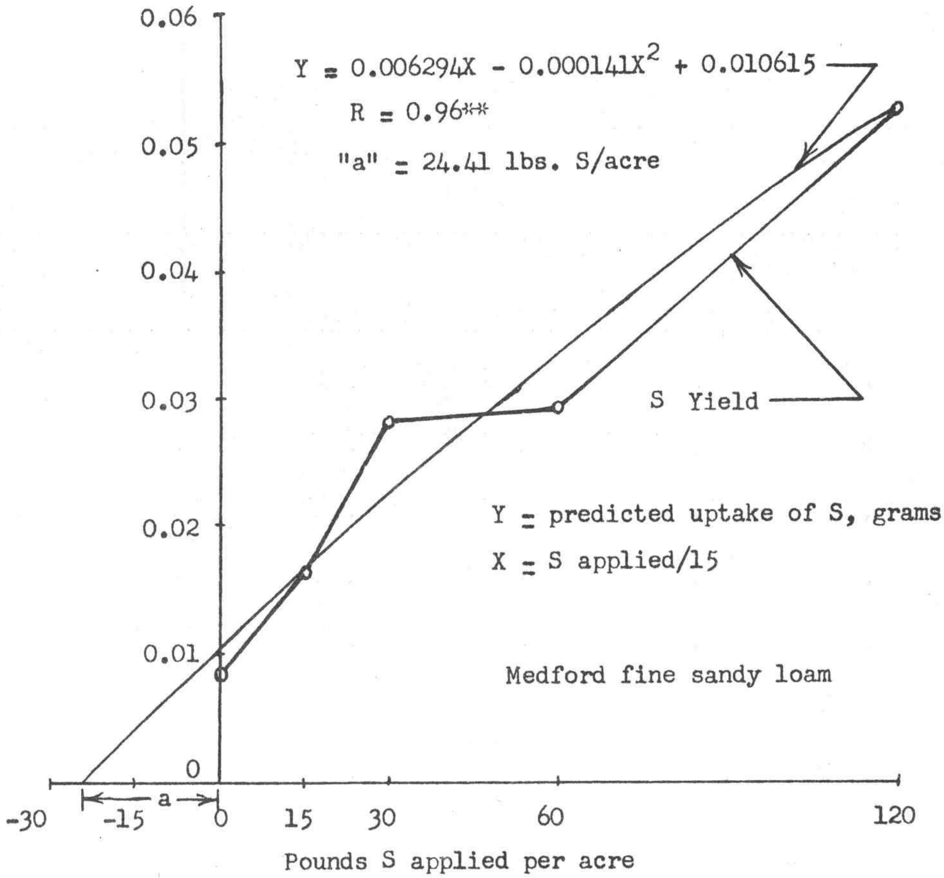


Figure 6. Sulfur taken up by alfalfa, grams per pot, and the sulfur "a" values of the soils as influenced by the sulfur treatment, second cutting.



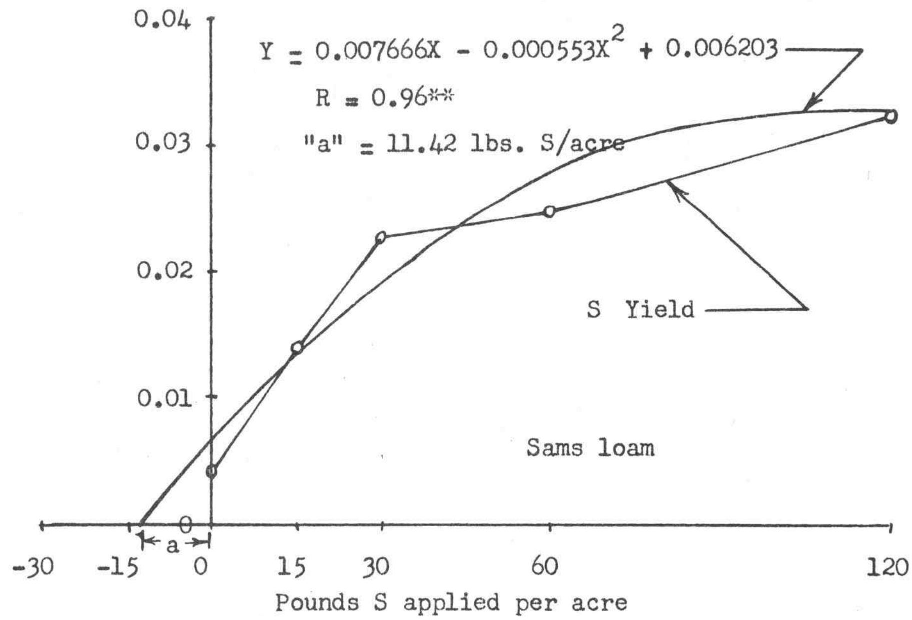


Figure 6, continued. Sulfur taken up by alfalfa, second cutting, in grams, and the S "a" values of the soils

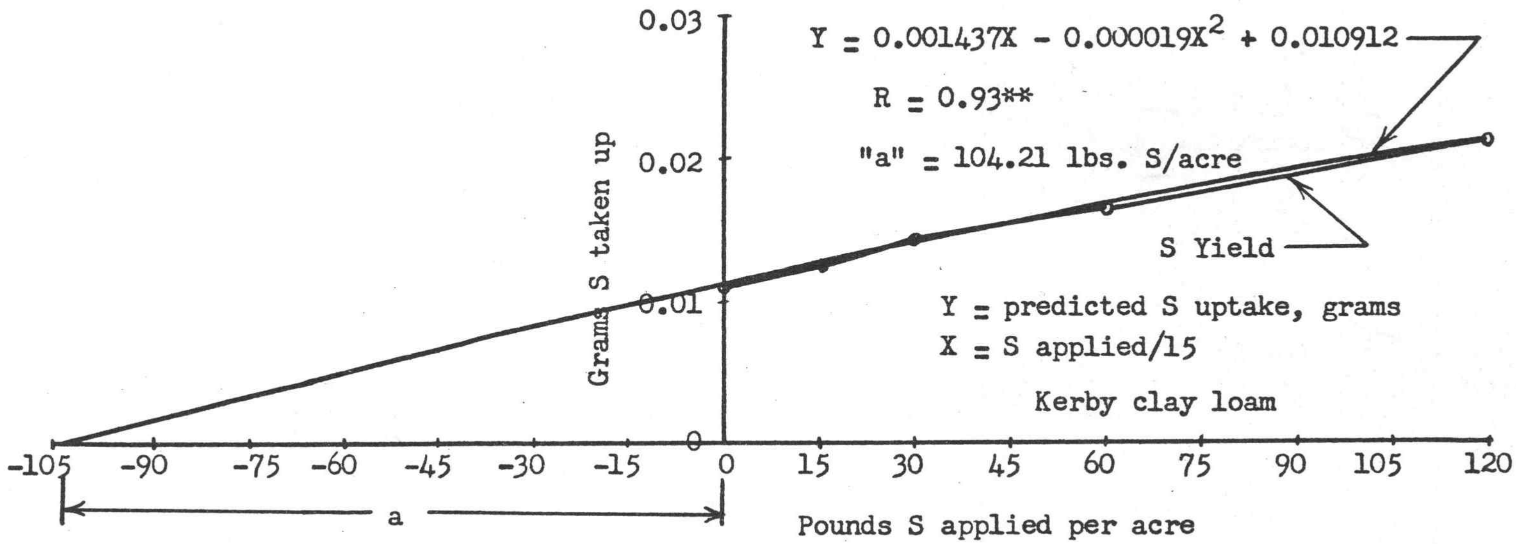


Figure 6, continued. Sulfur taken up by alfalfa, second cutting, in grams, and the sulfur "a" value of the soils as influenced by S treatment were plotted, and quadratic equations were fitted to the data from which the extrapolations were made to the X-axes. The "a" value for each of the soils was calculated, and multiple correlation coefficients were used to measure the goodness of fit of the quadratic function to the actual yield data. The multiple correlation coefficients for the curves range from 0.93 for the Kerby soil to 0.97 for the Climax soil, indicating that good fits were obtained in all five soils. The calculated sulfur "a" values were 12.21 lbs. of S per acre for the Climax soil, 18.70 lbs. of S for the Columbia soil, 104.21 lbs. of S for the Kerby soil, 24.41 lbs. of S for the Medford soil, and 11.42 lbs. of S per acre for the Sams soil.

Steenbjerg (47, p. 101) has shown that, in many instances, "yield of nutrient curves" can be represented as a straight line. In soils that have a large amount of the nutrient being studied, the ascending straight line tends to become curvilinear and eventually flattens out. Flattening out of the curves of the Climax, Columbia, and Sams soils were noted (Figure 6).

Dean (11) pointed out that the extrapolation of P curves from a low-slope curve may lead to rather wide errors. The Kerby soil had a curve with a relatively low slope, resulting in a sulfur "a" value that could be too high or too low by a considerable margin if Dean's observation applied in the case of the Kerby soil. It appears that the values obtained for the five soils did give a reasonable estimate of the sulfur in the soil that was as available as an equivalent amount of SO_4-S applied as gypsum. The one soil that did not respond yieldwise was shown to have a much higher sulfur "a" value than the four soils that did respond to sulfur applications. It does not appear possible from these limited data to establish a critical limit for the sulfur "a" value of the soils below which a response to applied S could be expected. The number of soils analyzed is too small, and the spread between the highest "a" value of the responsive soils, 24.41 lbs. of S per acre, and the "a" value of the Kerby soil of 104.21 lbs. of S per acre is too great to interpolate a critical sulfur "a" value.

SUMMARY AND CONCLUSIONS

Twenty-four fertilizer experiments in which sulfur was a variable were conducted in the fields of cooperating farmers in Jackson and Josephine Counties of Southern Oregon. Seven soil series and 14 soil types were represented in the field trials. The crops included cereal grains, clover and grass pastures, alfalfa and oats and vetch for hay, fresh market tomatoes, and market sweet corn. Both irrigated and non-irrigated sites were utilized in the experiments.

Sulfur rates of 0 and 60 lbs. of S per acre, as elemental sulfur, were used in combination with other fertilizers in most of the trials. Rates of 0, 20, and 40 lbs. of S per acre were used in two trials. Gypsum was also included as a source of S in several experiments.

Statistically significant yield increases at the 5 per cent level of significance were obtained in four of the 24 field trials (including one experiment on barley and three on alfalfa). Several other experiments gave indications of S responses, including some early-season responses that were not apparent as the crops approached maturity. The responses were related to the type of crop (legumes were the most responsive), and to previous fertilizer history. Responses were obtained at locations where S had not been applied in the past few years.

In several trials in which comparisons were made, elemental S was as effective as gypsum in producing yield responses to applied S, although, in some instances, the response to S supplied as gypsum appeared more quickly. It appears that many of the soils of Southern Oregon have the ability to oxidize elemental S rapidly enough for most field crops.

The S content of alfalfa was increased by sulfur fertilization. It appears, from a limited number of observations, that an S content in alfalfa, of less than 0.28 per cent might indicate a deficiency of available sulfur in the soil. The application of S to alfalfa growing on a sulfur-deficient soil caused an increase in the nitrogen content of the alfalfa. The S:N ratio of the alfalfa was narrowed by S fertilization to as low as 1:9.4, well under the upper limit of 1:15 thought by some investigators to indicate an undersupply of S in relation to N.

There was some indication from the yield data, from the S content, from the N content, and from the S:N ratio of the alfalfa that phosphate added as fertilizer accelerated the loss of S by leaching. It was found that 20 lbs. of S per acre applied annually to alfalfa growing on a S-deficient soil was not enough for maximum production, and that 40 lbs. of S per acre per year may not have been sufficient for maximum yields of alfalfa. In one experiment, 60 lbs. of S per acre continued to give yield responses on alfalfa for two seasons when it was applied to a sulfur deficient soil.

Four of five soils used in a pot trial responded to S application by the increased yields of alfalfa grown as the indicator crop. The sulfur content of alfalfa grown on the five soils was increased by S fertilization, although there were differences among the soils. The SO_4-S content of the soils, following an incubation period of 22 days, appeared to be of some significance in predicting the alfalfa response to S on soils under pot conditions.

The uptake of sulfur by alfalfa was calculated for the second cutting of the five soils used in the pot trial, and the "yield of nutrient" curves were plotted. Quadratic equations fitted to the yield data were found to fit the actual yield curves very closely, and the "yield of S" curves were extrapolated to the X-axes to obtain sulfur "a" values for each of the soils. The spread between the "a" values obtained for the responsive soils and the non-responsive soil was too great to interpolate a critical level of "a" value, although the data did indicate a relationship.

The data from the field trials and the pot trial indicate that some of the agricultually important soils of Southern Oregon are low in available sulfur, particularly when no sulfur has been applied in the fertilizer program in recent years.

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A P P E N D I X

Table A-1. Effect of sulfur treatment on the yield of alfalfa hay grown on a Kerby loam soil, exp. no. 21.

Fertilizer Treatment, applied in 1955 only, lbs./acre N	P_2O_5	K_2O	S	B	Year	Yield of alfalfa hay, tons per acre, by cuttings First	Second	Third	Fourth	Seasonal Total
0	0	0	0	0	1955	1.50	1.18	1.06	0.57	4.31
					1956	0.97	1.24	1.60		3.31
					1957	1.48	1.38	1.37		4.23
0	0	0	60	0	1955	1.87	1.74	1.90	1.18	6.69
					1956	1.64	1.72	1.73		5.09
					1957	1.56	1.60	1.39		4.55
0	0	0	0	4	1955	1.41	1.20	1.10	0.61	4.32
					1956	0.84	1.08	1.20		3.12
					1957	1.52	1.36	1.15		4.03
0	0	0	60	4	1955	1.61	1.74	1.88	0.96	6.19
					1956	1.47	1.42	1.52		4.41
					1957	1.48	1.44	1.33		4.25
0	120	120	0	0	1955	1.83	1.51	1.39	0.60	5.33
					1956	0.97	1.12	1.26		3.35
					1957	1.71	1.40	1.48		4.59

Table A-1. Effect of sulfur treatment on the yield of alfalfa hay grown on a Kerby loam soil, exp. no. 21. (Continued)

Fertilizer Treatment, applied in 1955 only, lbs./acre						Yield of alfalfa hay, tons per acre, by cuttings				
N	*P_2O_5 -	K_2O -	S -	B	Year	First	Second	Third	Fourth	Seasonal Total
0	120	120	60	0	1955	1.80	1.89	2.13	1.04	6.86
					1956	1.58	1.49	1.42		4.49
					1957	1.32	1.26	1.42		4.00
0	0	0	60	0	1955	1.97	1.79	2.00	1.19	6.95
	(S as gypsum)				1956	1.54	1.44	1.59		4.57
					1957	1.51	1.37	1.35		4.23

LSD, (P = .05), Seasonal totals: 1955 - 1.05 T./A.
1956 - 0.90 T./A.
1957 - N.S. at the 5 per cent level

Table A-2. Yield of alfalfa, grams per pot, as affected by sulfur treatment, mean of 4 replications.

Soil	Cutting	Pounds S per acre as gypsum					S as elemental sulfur
		0	15	30	60	120	30
Climax	1	4.65	4.99	5.14	5.31	5.26	5.25
	2	3.47	6.85	8.06	7.83	7.93	7.53
	3	2.52	4.06	4.54	4.65	4.68	4.78
	4	1.63	2.31	3.75	5.34	6.02	3.10
	total	12.27	18.21	21.49	23.13	23.89	20.66
Columbia	1	2.22	4.47	4.66	4.47	4.12	4.75
	2	1.71	4.51	4.80	4.93	4.54	5.07
	3	1.87	2.06	2.34	2.47	2.46	2.50
	4	1.39	2.04	3.24	3.34	3.37	2.85
	total	7.19	13.08	15.03	15.21	14.49	15.17
Kerby	1	4.46	4.45	4.21	4.70	4.34	4.39
	2	3.68	3.83	3.83	3.93	3.75	3.48
	3	2.03	2.36	2.40	2.37	2.26	2.19
	4	1.91	2.12	2.53	2.38	2.40	2.33
	total	12.08	12.76	12.97	13.38	12.75	12.39

Table A-2. Yield of alfalfa, grams per pot, as affected by sulfur treatment, mean of 4 replications. (Continued)

Soil	Cutting	Pounds S per acre as gypsum 0	15	30	60	120	S as elemental sulfur 30
Medford	1	5.92	8.39	7.84	7.40	7.68	7.71
	2	4.16	7.60	7.99	8.21	9.03	8.20
	3	2.76	3.96	4.15	4.41	5.22	4.82
	4	2.56	2.74	3.71	5.18	6.21	4.51
	total	15.40	22.69	23.69	25.20	28.14	25.24
Sams	1	3.74	7.51	7.92	7.30	7.85	7.63
	2	2.04	6.74	8.76	8.14	7.92	7.23
	3	1.85	2.52	3.99	3.75	3.64	3.40
	4	1.29	1.47	2.31	3.62	3.54	2.70
	total	8.92	18.24	22.98	22.81	22.95	20.96

Table A-3. Analysis of variance mean square values, alfalfa pot trial, among soils and sulfur treatments, totals for 4 cuttings, mean of 4 replications

	Soil				
Comparison	Climax	Columbia	Kerby	Medford	Sams
Among S treatments	6.3629**	0.9306	0.0868	5.6572*	5.4584*
S vs check	70.7632**	42.1661**	0.6266	72.5805**	131.7384**
15 S vs 30, 60, and 120 S	16.1008**	-	-	-	16.3567**

* Significant at P = 0.05

** Significant at P = 0.01

Table A-4. Sulfur content of alfalfa hay by soils and cuttings, per cent, means of 5 sulfur rates and two replications

Cutting	Soils Series Climax	Columbia	Kerby	Medford	Sams	Average 5 soils
First	0.35	0.32	0.34	0.31	0.29	0.32
Second	0.28	0.30	0.37	0.33	0.29	0.32
Third	0.31	0.31	0.37	0.32	0.29	0.32
Fourth	0.22	0.24	0.33	0.23	0.23	0.25
Average	0.29	0.29	0.35	0.30	0.28	

Table A-5. Sulfur content of alfalfa hay by cuttings and S treatments, per cent, means of 5 soils and two replications

Lbs. S applied per acre	Cutting First	Second	Third	Fourth	Average, 4 cuttings
0	0.25	0.22	0.24	0.20	0.23
15	0.28	0.24	0.28	0.21	0.25
30	0.32	0.31	0.31	0.22	0.29
60	0.36	0.34	0.37	0.30	0.34
120	0.40	0.37	0.41	0.32	0.40
Average	0.32	0.32	0.32	0.25	