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THE USE OF RADIOACTIVE
SULPHUR IN A STUDY OF
FERTILIZER UPTAKE

D. V. Cormack,
University of Alberta.

April 1950.

Thesis
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THE USE OF RADIOACTIVE SULPHUR
IN A STUDY OF FERTILIZER UPTAKE.

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
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by

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EDMONTON, ALBERTA,

APRIL, 1950

Department of Agriculture

Ministry of Agriculture

Department of Agriculture and Forestry

The undersigned hereby certify that the
have been and continued to the end of the
year 1900. The undersigned hereby certify that the
of the undersigned is a true and correct
copy of the original of the undersigned.
in the year 1900.

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INTRODUCTION

The land surface of Alberta may be divided roughly into several major soil zones, each of which may be considered separately in relation to farming operations and soil fertility. The wooded or gray soil zone is the largest of these and covers about two thirds of the entire province. Gray soils, like these, which have developed for a long period of time under forest conditions have usually been subject to more severe leaching than soils which have developed under grass or prairie conditions. Because of their leached nature the gray wooded soils are generally rather low in natural fertility.

In order to investigate the fertilizer requirements of gray wooded soils experiments have been conducted by the Soils Department of the University of Alberta. These experiments come chiefly under two headings: (1) Those carried out on the Soils Department plots at Breton, and (2) Co-operative experiments with farmers. These experiments and others have clearly indicated that a large proportion of the gray wooded soils in Alberta have a serious sulphur deficiency for some crops. On sulphur deficient soils yields of legume crops are greatly increased (sometimes over 500%) by application of sulphate fertilizers. Direct application of sulphate fertilizers has very little, if any, beneficial effect on cereal crops or grasses, However, application of sulphate fertilizers to legume crops produces substantial increases in the yields of subsequent cereals.

All fertilizers containing a high percentage of sulphur have given these results when used on sulphur deficient gray soils. For example, mono-ammonium phosphate with added ammonium sulphate (16-20-0), ammonium sulphate (21-0-0), ammoniated superphosphate (2-20-0), sodium sulphate, potassium sulphate and gypsum have all given large increases in the yields of legumes such as altaswede clover and alfalfa. The yields of cereals following the legumes have been greatly improved. A beneficial residual effect lasting for several years has generally been obtained when sulphur fertilizers were applied to clover and alfalfa (13).

Analyses of crops from the Soils Department's plots at Breton have shown that sulphur fertilization has increased the sulphur content of crops there (15). However, the amount of the applied sulphur taken up by the crops and the proportion of sulphur in crops coming from the applied fertilizers could not be determined.

In order to obtain more direct information concerning these matters it was decided to carry out experiments using a sulphate fertilizer labelled with radioactive sulphur. The project, on which this report is being made, was conducted under the combined direction of the Department of Physics and the Department of Soils of the University of Alberta. The Physics Department was concerned with obtaining and measuring the activity of the radioactive sulphur while the Soils Department supervised the actual field work and the interpretation of the results obtained.

REVIEW OF LITERATURE

The normal isotopic composition of sulphur consists of S^{32} (95%), S^{33} (0.74%), S^{34} (4.2%), and S^{36} (0.016%) (18). Radioactive forms of sulphur of mass number 31, 35 and 37 have all been investigated. S^{31} is a positron emitter with a half life of 3.2 seconds. S^{35} is a negatron emitter ($T_{1/2} = 87.1$ days) having a maximum energy of 0.17 million electron volts (8,9,18). S^{37} , discovered more recently, is also a beta emitter and has a half life of 5.04 seconds (10). It is apparent that S^{35} is the only isotope of sulphur suitable for use as a radioactive tracer.

Of the several ways of producing S^{35} (9,10) the most common at the present time is by neutron irradiation of chlorine according to the reaction ${}_{17}\text{Cl}^{35}(n,p){}_{16}\text{S}^{35}$. The S^{35} decays, as mentioned before, by negatron emission with no appreciable gamma radiation. Measurement of the radiations of such radioactive isotopes has been discussed by many workers (4, 8, 12, 17), the method of Coryell (4) being the one most closely followed in the present work.

The long half life of S^{35} makes it especially suitable for use in such researches as the present one in which the experimental procedure is carried out over a comparatively long period of time. This was early recognized when S^{35} was used in the study of vitamin B and protein metabolism in animals (20). The first use of S^{35} in studies of plant metabolism and the fate of fertilizers was reported by Thomas in 1944 (21). Exten-

sive experiments were carried out on plots of grain treated both with $\text{Na}_2\text{S}^*\text{O}_4$ and S^*O_2 . In a previous paper (8) these workers describe their technique for measuring the activity of precipitated BaS^*O_4 samples. Radioautographs were also taken (7) to show the distribution of the S^{35} in the wheat kernels. The study of fertilizers using radiophosphorus has been quite extensive (2, 3, 19) and rather similar methods can be employed using S^{35} .

Although some experiments have been carried out in an attempt to define possible damage to plants by the more energetic beta emitters such as P^{32} (1, 16) no information was available on possible metabolic disturbances caused by the radiation from S^{35} . In this work it has been assumed, as is common in tracer experiments, that the concentrations of the radioactive isotope were so small that no significant changes would occur in the metabolism of the plants.

The preferential uptake of radioactive isotopes because of a disturbance of the isotopic equilibrium has been described by Overstreet and Broyer (14). Although this may be an important consideration in the initial uptake of sulphur from the soil it becomes increasingly negligible as the total sulphur taken up becomes much larger than the quantity of sulphur originally present in the plant. The method of analysis used in the work here reported gives a direct measure of the fraction of the available sulphur in the soil which is attributable to the applied fertilizer. If we assume that no sulphur was initially present in the plant, this gives the fraction of the sulphur

in the plant which came from the fertilizer.

The effects of sulphur fertilizers on gray wooded soils in Alberta have been reviewed by Newton and co-workers (13), and Peters (15). Besides containing the results of experiments carried out in Alberta, Peters' ^{thesis} paper contains references to investigations on similar sulphur deficient soils in various parts of North America. It has frequently been observed that if wheat or another cereal follows a good crop of clover fertilized with ammonium sulphate or ammonium phosphate (containing sulphate) the grain yield is increased far more than is the case when the same fertilizers are applied directly to the cereal.

OUTLINE OF INVESTIGATION

The radioactive sulphur to be used as the tracer was obtained as carrier-free $\text{H}_2\text{S}^*\text{O}_4$ in separate one millicurie shipments from the Chalk River plant of the National Research Council. Handling the radioactive material with the approved precautions, each shipment of $\text{H}_2\text{S}^*\text{O}_4$ was mixed thoroughly with sufficient chemically pure Na_2SO_4 to fertilize ten square yards. In the field the various fertilizer solutions were applied by hand to 10 one square yard plots. Specific details concerning these applications follow:

<u>Shipment No.</u>	<u>Date of Application</u>	<u>Rate of Application</u>	<u>Crop</u>	<u>Plot No.</u>	<u>Previous history</u>
1	June 5, 1949	100 lbs. per acre	Alfalfa and clover	B-11 B- 5	No fertilizer since 1930
2	June 11, 1949	200 lbs. per acre	Barley	C-11 C- 5	No fertilizer since 1930
3	June 18, 1949	100 lbs. per acre	Alfalfa and clover	B-10	Fertilized with 16-20-0 since 1930
4	June 25, 1949	100 lbs. per acre	Barley	C-10	Fertilized with 16-20-0 since 1930

The first sampling of the plots was carried out on July 13-14, 1949. All the plant material from each square yard in the legume plots (SeriesB) was clipped off, the alfalfa and Altaswede clover being kept separate. A six inch strip was harvested from each barley plot. In each case all miscellaneous foreign plants were removed from the samples. Check samples

RESULTS OF INVESTIGATION

The qualitative analysis of the samples was carried out in the laboratory of the Department of Chemistry, University of California, Berkeley, California. The samples were analyzed for the presence of various elements and compounds. The results of the analysis are given in the following table. The first column gives the name of the sample, the second column gives the date of analysis, the third column gives the name of the analyst, the fourth column gives the name of the laboratory, the fifth column gives the name of the department, the sixth column gives the name of the university, the seventh column gives the name of the state, the eighth column gives the name of the country, the ninth column gives the name of the continent, the tenth column gives the name of the world.

Sample No.	Date of Analysis	Name of Analyst	Name of Laboratory	Name of Department	Name of University	Name of State	Name of Country	Name of Continent	Name of World
1	June 1, 1951	W. H. R. R.	Chemical	Chemistry	University of California	California	United States	North America	World
2	June 1, 1951	W. H. R. R.	Chemical	Chemistry	University of California	California	United States	North America	World
3	June 1, 1951	W. H. R. R.	Chemical	Chemistry	University of California	California	United States	North America	World
4	June 1, 1951	W. H. R. R.	Chemical	Chemistry	University of California	California	United States	North America	World

The first sample of the plate was analyzed on June 1, 1951. All the elements were found to be present in the sample. The second sample was analyzed on June 1, 1951. All the elements were found to be present in the sample. The third sample was analyzed on June 1, 1951. All the elements were found to be present in the sample. The fourth sample was analyzed on June 1, 1951. All the elements were found to be present in the sample.

were taken from square yards immediately adjacent to the fertilized plots in order to obtain a control for each fertilized plot. At the time of the first sampling there had been practically no rainfall in 1949 and the growth of crops, especially of the barley, was very poor. Yield data were obtained by taking the air dry weight of each sample.

The second collection of samples took place on August 24-25, 1949, under moisture conditions almost ^{the} opposite of those of the first sampling. A great deal of rain had fallen during the intervening time, especially in the period July 16-18. The samples were taken as before except the checks which were taken from square yards separated about a foot from the fertilized plots. Another six inch strip was harvested from each square yard of barley.

By comparing the radioactivity of the field samples with those of samples from the original fertilizer material, it is possible to determine the fraction of the sulphur in the plant which came from the fertilizer. Suppose a quantity of S^{35} having an activity of "a" counts per minute is combined with "b" gm. of ordinary sulphur which is to be applied to the soil. The ratio $\frac{a}{b}$ is called the specific activity of the mixture. If the plant, in taking up sulphur from the soil, takes "b" gm. from the fertilizer for every "c" gm. originally present in the soil, the specific activity will be reduced to $\frac{a}{b+c}$. The specific activities $\frac{a}{b}$ and $\frac{a}{b+c}$ may be determined analytically and by division the fraction of sulphur coming from the fertilizer

may be found:

$$\frac{\frac{a}{b+c}}{\frac{a}{b}} = \frac{b}{b+c} = \frac{\text{Fertilizer sulphur}}{\text{Total sulphur}}$$

METHODS OF ANALYSIS

1. The Counting Apparatus

In order to determine specific activity, samples containing S^{35} were precipitated in the form of $BaSO_4$ and were then transferred to nickel-plated steel dishes, or planchets. These planchets were placed in the recess of a 1/8 in. aluminum plate which was slid beneath the thin (1.8 mg. per cm.²) window of a Tracerlab TGC-2 G.M. counter tube shielded by a lead castle. Regulated voltage was applied to the counter by means of a power supply and voltage stabilizer. After amplification by an N.R.C. type pre-amplifier the pulses were recorded using a conventional scale-of-64 scaler and mechanical register. Reproducible geometry of the planchet with respect to the window of the G.M. counter was achieved by the use of guides for the aluminum plate at various distances from the window. The shielding by the lead and aluminum of the castle cut down the background count to about 30 counts per minute. The resolving time of the tube was determined by the method described by Lapp and Andrews (12) to be 5×10^{-6} minutes.

Fig.1. THE G.M.TUBE,CASTLE, AND ARRANGEMENT FOR REPRODUCIBLE GEOMETRY OF SAMPLES.

2. Self Absorption

One of the most important factors to be considered in the use of such low energy beta emitters as S^{35} is the absorption of radiation by the carrier precipitate. The first attempt to correct for this was made by precipitating various amounts of a homogeneous solution of S^{35} in Na_2SO_4 carrier. The $Na_2S^{35}O_4$ solution used was, in this case, some of the stock solution from one of the applications of fertilizer. Expressing the specific activity as counts per minute per milligram of $BaSO_4$ precipitate and plotting this figure against weight of $BaSO_4$ the graph shown in Fig. 2 was obtained. This curve was used to prepare a correction curve for self absorption (Fig. 3). However, using samples of this size (10-30 mg.), it was very difficult to obtain reproducible results, and when duplicate determinations were made on certain of the field samples considerable variation was found. This is illustrated by the following data for % fertilizer sulphur in a set of samples.

<u>Sq. yd. no.</u>	<u>BaSO₄ in mg.</u>		<u>% fertilizer S</u>	
	<u>I</u>	<u>II</u>	<u>I</u>	<u>II</u>
1	14.6	12.2	55.0	64.6
2	21.9	18.7	60.2	70.5
3	19.1	17.8	64.6	69.8
4	19.6	17.1	54.8	66.7
5	14.5	14.0	59.2	59.3

This variability is probably due to failure to obtain layers of $BaSO_4$ of uniform thickness. This would result in differences in self absorption properties. The differences in the weights of precipitates are believed due to the difficulty in handling such minute quantities of precipitate. However, the variability might also be due to inaccuracies of the correction curve. In any case, the results obtained were unsatisfactory.

Fig. 2. Self absorption in thin samples.

Fig. 3. Correction curve calculated from Fig. 2

In view of this difficulty it was decided to use samples such that radiation from the lower layers of precipitate were completely absorbed by the upper layers. This is achieved by increasing the amount of precipitate until a maximum counting rate for a given material is obtained (Fig. 5). Such samples are generally referred to as thick samples and were determined to have a minimum thickness of 16 mg. per sq. cm. for the BaSO_4 precipitates. Surface irregularities of the precipitate in the planchets are much less important in these samples. A series of samples was made up to check the relation between the thick sample counting rate and the specific activity (Fig. 4). Since this relation is linear the calculations using the thick sample method are very simple. The fraction of the sulphur coming from the fertilizer may be found by a direct comparison of the thick sample counting rates for field samples with the counting rates of the corresponding standards.

3. Preparation of Samples for Counting

For analysis approximately 11 gm. of air dry plant material from each plot was oven dried in a weighed aluminum container. The dried samples were weighed and then ashed with HNO_3 and HClO_4 following the method of Giesekeing (6). The ashed material was treated with HCl to destroy chlorates (11) and was finally taken up in HCl approximately 0.3N. After filtering, the solutions were stored in 500 ml. volumetric flasks.

For the preliminary analysis of the field samples, 50 or 100 ml. aliquots were removed from these solutions and pre-

is also of this division it was located to see some
and that resulting from the same source of radiation was
completely absorbed at the upper levels. This is evident in
interesting the present of "experiments" with a similar
case for a given material in solution (H₂O, NaCl, Na₂SO₄,
and potassium nitrate) as in solid samples and were determined
to have a similar behavior of 10 to 15 per cent. for the same
phenomena. Further investigation of the behavior of the
absorption was now less important in some samples. A series
of samples was made up to show the variation between the two
single counting rate and the specific activity of the sample.
This relation is linear and demonstrates that the same
method is very simple. The position of the curve is
the position and the form of a linear relation as the
single counting rate for solid samples with the same
of the corresponding elements.

2. Properties of the samples

For accurate measurements of the activity of the
samples these must be made under the same conditions
conditions. The first sample was weighed and then placed in
the same container as the other samples. The
samples were sealed with a lead container (10 cm x 10 cm x 10 cm)
which served as in the experiments (10 cm x 10 cm x 10 cm).
For accurate measurements of the activity of the
samples the same conditions must be maintained and the
same conditions must be maintained.

Fig. 4 Relation between thick sample counting rate and specific activity

Fig. 5. Thick sample condition for S^{35}

Fig. 6. Correction curve calculated from Fig. 5.

precipitated with 10% BaCl_2 to give a fine precipitate of BaSO_4 . The precipitates were transferred quantitatively to centrifuge tubes, centrifuged, washed with water and finally washed with ethyl alcohol to remove the water. Nearly all the final alcohol wash was drawn off before the suspended precipitate was transferred as quantitatively as possible to weighed planchets by use of special "dropper" tubes. In the planchet a uniform suspension of precipitate in the alcohol was obtained by churning the material with the "dropper". This produced an even distribution of precipitate on the bottom of the planchet. The alcohol was evaporated under a heat lamp.

When analyses were being made by correcting for self absorption the following procedure was used. Standard samples from the stock solutions of applied fertilizers were precipitated and transferred in a similar way to give precipitates of about the same weight as those from the field samples. After weighing, the field samples were counted against the standards. A count on a standard was made at the beginning and at the end of each set of five field samples. After correcting for resolving time, background and self absorption, the specific activities of the field samples and of the standards were calculated and the fraction of the sulphur coming from the fertilizer was determined.

When it was decided to adopt the thick sample method of determining specific activity, the entire remaining solution of ashed material was precipitated and counted against thick samples from the standard stock solutions. The plot of counts per minute for thick samples of various specific activities showed a linear

relationship so, after correction for background, the fraction of sulphur from fertilizer was found directly by division. However, there were insufficient amounts of precipitate from some samples to be considered as "thick" samples and in such cases an appropriate correction was applied (Fig. 6). In order to obtain a more reliable determination of the total sulphur content the BaSO_4 precipitate was weighed in the centrifuge tubes before transferring to planchets.

EXPERIMENTAL RESULTS

Since the time available for analysis was somewhat limited only 5 of the 10 field samples from each of the various treatments were analysed for S^{35} . Results were obtained for 12 sets of samples from plots fertilized with $\text{Na}_2\text{S}^*\text{O}_4$ and from 12 sets of corresponding check samples. Each of these samples was analyzed by the methods described and typical values of a set of samples from one treatment are shown in Table I. The yields are given in gm. of air dry material per square yard while the percent sulphur figures are reported on the basis of the oven dry weight of the sample analyzed. The activities of samples and standards are the observed counting rates for thick samples of BaSO_4 corrected for background and self absorption where necessary using the correction curve of Fig. 6.

Tables II and III report only average values for each set of 5 samples from a particular treatment. At the time of writing the analysis of the barley collected at harvest time had

not been completed. However, yield data for this sampling of barley are shown in Table IV. Table V shows the amount of sulphur which the various plants obtained from the soil. This was found by subtracting the fertilizer sulphur uptake from the total sulphur uptake.

It will be seen from these tables that some of the check or control plots show appreciable uptake of fertilizer. This effect is generally more pronounced for the second sampling than for the first in spite of the stricter precautions which were taken at that time to guard against it. It is believed that the unusually heavy rainfall between the two sampling dates caused the unexpected lateral movement of fertilizer.

The amounts of sulphur taken up from the fertilizer on each square yard was found from the yield data and from the figures for percentage of fertilizer sulphur. As the sulphur had been applied at the rate of 22.6 lb. per acre or 2.12 gm. per sq. yd. (except for the second application) it was possible to determine the fraction of the applied sulphur which was recovered in the crop. The recovery data are as follows:

<u>Plot</u>	<u>Crop</u>	<u>Previous fertilizer history</u>	<u>% fertilizer S recovered</u>
B-11	Alfalfa and clover	None	11%
B-10	Alfalfa and clover	16-20-0	10%
C-11	Barley	None	8%
C-10	Barley	16-20-0	7%

The recovery figures for barley are based on the results from the second sampling. The maximum removal of fertilizer was

about 2.5 lb. per acre. The more typical figures reported by Peters show an average yearly uptake of 7.5 lbs. per acre on Plot 10 by clovers.

Using the percentage of sulphur for the unfertilized legumes on Plot 10 as determined in this study, and applying that figure to hay yields reported by Newton et al. (13) for the period 1940-46 the average hay crop would remove about 5.7 lbs. of sulphur per acre. Annual applications of 75 lbs. per acre of 16-20-0 (10.5 lbs. of sulphur per acre) would supply more than this amount of sulphur. However, semi annual applications as now applied to the Breton plots would hardly supply the sulphur needs of the legume hay crop. Inadequate data do not permit similar calculations for other crops. Peters' figures indicate a sulphur removal considerably in excess of this application.

In order to show some of this information more clearly the % S, yield and uptake data are presented graphically in Figs. 7-12.

The accuracy in determining the percent fertilizer sulphur in any one of the field samples was estimated from the results from various standards using thick samples. The maximum variation between duplicate standards was 2% so the accuracy in the reported values of specific activity for field samples may also be taken as being at least within 2%. In view of the biological fluctuations between square yard plots of the same treatment, it was not thought necessary to try to attain any greater degree of accuracy.

TABLE I
DATA FROM S³⁵ TREATED PLOTS AT BRETON, 1949
Complete results for second sampling of barley
Series C, Plot 10, showing typical fluctuations
in % S and in fraction of S from fertilizer

<u>Sq. yd. no.</u>	<u>Yield in gm.</u>	<u>% S</u>	<u>Activity of sample c.p.m.</u>	<u>Activity of standard c.p.m.</u>	<u>Fraction of S from fertilizer</u>
(a) Unfertilized or Check Samples					
1	15.6	0.115	14	8000	0.000
2	41.0	0.119	18		0.000
3	51.6	0.116	5		0.000
4	64.0	0.106	0		0.000
5	25.5	0.149	10		0.000
Average	39.5	0.121			0.000
(b) Fertilized or Active Samples					
1	32.9	0.130	3370	8000	0.425
2	41.7	0.157	3610		0.451
3	42.0	0.175	3080		0.385
4	43.9	0.130	3240		0.405
5	48.2	0.188	3620		0.453
Average	41.7	0.156			0.424

TABLE II
AVERAGE DATA FROM PLOTS NOT PREVIOUSLY FERTILIZED
Data obtained by averaging results from five square yards
in Plot 11 which had received no previous fertilizer
since 1930
(1, 2 refer to first and second samplings)

	<u>Yield in gm. per sq. yd.</u>	<u>% S</u>	<u>Fraction of S from fertilizer</u>	<u>Fertilizer S per sq. yd.</u>
(a) Clover grown on Series B, Plot 11				
Check-1	14.2	0.132	0.085	
Fertilized-1	11.8	0.231	0.719	20 mg.
Check-2	19.2	0.079	0.013	
Fertilized-2	34.6	0.148	0.732	38 mg.
(b) Alfalfa grown on Series B, Plot 11				
Check-1	16.0	0.103	0.020	
Fertilized-1	25.0	0.184	0.544	24 mg.
Check-2	31.3	0.077	0.199	
Fertilized-2	149	0.124	0.793	148 mg.
(c) Barley grown on Series C, Plot 11				
Check-1	78	0.135	0.012	
Fertilized-1	66	0.248	0.559	93 mg.
Check-2	126	0.126	0.309	
Fertilized-2	162	0.163	0.643	170 mg.

TABLE III
AVERAGE DATA FROM PREVIOUSLY FERTILIZED PLOTS
Data obtained by averaging results from 5 sq. yds.
in Plot 10 which had been fertilized with
16-20-0 since 1930
(1, 2 refer to first and second samplings)

	<u>Yield in gm. per sq. yd.</u>	<u>% S</u>	<u>Fraction of S from fertilizer</u>	<u>Fertilizer S per sq. yd.</u>
(a) Clover grown on Series B, Plot 10				
Check-1	19.0	0.087	0.008	
Fertilized-1	34.7	0.100	0.382	14 mg.
Check-2	54.7	0.085	0.009	
Fertilized-2	74.9	0.173	0.602	78 mg.
(b) Alfalfa grown on Series B, Plot 10				
Check-1	17.0	0.103	0.005	
Fertilized-1	23.4	0.118	0.311	8 mg.
Check-2	47.8	0.105	0.008	
Fertilized-2	82.1	0.189	0.633	109 mg.
(c) Barley grown on Series C, Plot 10				
Check-1	72	0.192	0.012	
Fertilized-1	78	0.199	0.423	66 mg.
Check-2	234	0.121	0.000	
Fertilized-2	252	0.156	0.424	166 mg.

TABLE IV
BARLEY YIELDS AT THIRD SAMPLING - Sept. 17

<u>Plot</u>	<u>Treatment</u>	<u>Total yield in gm. per sq. yd.</u>	<u>Grain yield in gm. per sq. yd.</u>	<u>Grain yield in bus. per acre</u>
C-11	Check	291	53	12
	Fertilized	347**	43	10
C-10	Check	450	75	17
	Fertilized	480	77	17

**Highly significant yield increase.

TABLE 1
 SUMMARY OF DATA FOR THE
 STUDY OF THE EFFECTS OF
 THE 1960-1961 DROUGHT
 ON THE GROWTH OF
 THE 1961-1962 CROP
 IN THE SOUTHERN
 PLAINS

Year	Area (Acres)	Yield (Bushels/Acre)	Total Yield (Bushels)
1960-1961	10,000	10.0	100,000
1961-1962	10,000	12.0	120,000
1962-1963	10,000	14.0	140,000
1963-1964	10,000	16.0	160,000
1964-1965	10,000	18.0	180,000
1965-1966	10,000	20.0	200,000
1966-1967	10,000	22.0	220,000
1967-1968	10,000	24.0	240,000
1968-1969	10,000	26.0	260,000
1969-1970	10,000	28.0	280,000
1970-1971	10,000	30.0	300,000
1971-1972	10,000	32.0	320,000
1972-1973	10,000	34.0	340,000
1973-1974	10,000	36.0	360,000
1974-1975	10,000	38.0	380,000
1975-1976	10,000	40.0	400,000
1976-1977	10,000	42.0	420,000
1977-1978	10,000	44.0	440,000
1978-1979	10,000	46.0	460,000
1979-1980	10,000	48.0	480,000
1980-1981	10,000	50.0	500,000
1981-1982	10,000	52.0	520,000
1982-1983	10,000	54.0	540,000
1983-1984	10,000	56.0	560,000
1984-1985	10,000	58.0	580,000
1985-1986	10,000	60.0	600,000
1986-1987	10,000	62.0	620,000
1987-1988	10,000	64.0	640,000
1988-1989	10,000	66.0	660,000
1989-1990	10,000	68.0	680,000
1990-1991	10,000	70.0	700,000
1991-1992	10,000	72.0	720,000
1992-1993	10,000	74.0	740,000
1993-1994	10,000	76.0	760,000
1994-1995	10,000	78.0	780,000
1995-1996	10,000	80.0	800,000
1996-1997	10,000	82.0	820,000
1997-1998	10,000	84.0	840,000
1998-1999	10,000	86.0	860,000
1999-2000	10,000	88.0	880,000
2000-2001	10,000	90.0	900,000
2001-2002	10,000	92.0	920,000
2002-2003	10,000	94.0	940,000
2003-2004	10,000	96.0	960,000
2004-2005	10,000	98.0	980,000
2005-2006	10,000	100.0	1,000,000

TABLE 2
 SUMMARY OF DATA FOR THE
 STUDY OF THE EFFECTS OF
 THE 1960-1961 DROUGHT
 ON THE GROWTH OF
 THE 1961-1962 CROP
 IN THE SOUTHERN
 PLAINS

Year	Area (Acres)	Yield (Bushels/Acre)	Total Yield (Bushels)
1960-1961	10,000	10.0	100,000
1961-1962	10,000	12.0	120,000
1962-1963	10,000	14.0	140,000
1963-1964	10,000	16.0	160,000
1964-1965	10,000	18.0	180,000
1965-1966	10,000	20.0	200,000
1966-1967	10,000	22.0	220,000
1967-1968	10,000	24.0	240,000
1968-1969	10,000	26.0	260,000
1969-1970	10,000	28.0	280,000
1970-1971	10,000	30.0	300,000
1971-1972	10,000	32.0	320,000
1972-1973	10,000	34.0	340,000
1973-1974	10,000	36.0	360,000
1974-1975	10,000	38.0	380,000
1975-1976	10,000	40.0	400,000
1976-1977	10,000	42.0	420,000
1977-1978	10,000	44.0	440,000
1978-1979	10,000	46.0	460,000
1979-1980	10,000	48.0	480,000
1980-1981	10,000	50.0	500,000
1981-1982	10,000	52.0	520,000
1982-1983	10,000	54.0	540,000
1983-1984	10,000	56.0	560,000
1984-1985	10,000	58.0	580,000
1985-1986	10,000	60.0	600,000
1986-1987	10,000	62.0	620,000
1987-1988	10,000	64.0	640,000
1988-1989	10,000	66.0	660,000
1989-1990	10,000	68.0	680,000
1990-1991	10,000	70.0	700,000
1991-1992	10,000	72.0	720,000
1992-1993	10,000	74.0	740,000
1993-1994	10,000	76.0	760,000
1994-1995	10,000	78.0	780,000
1995-1996	10,000	80.0	800,000
1996-1997	10,000	82.0	820,000
1997-1998	10,000	84.0	840,000
1998-1999	10,000	86.0	860,000
1999-2000	10,000	88.0	880,000
2000-2001	10,000	90.0	900,000
2001-2002	10,000	92.0	920,000
2002-2003	10,000	94.0	940,000
2003-2004	10,000	96.0	960,000
2004-2005	10,000	98.0	980,000
2005-2006	10,000	100.0	1,000,000

Source: U.S. Department of Agriculture, National Agricultural Statistics Service, 2006.

TABLE V
UPTAKE OF SULPHUR FROM THE SOIL

C - check plots; F - fertilized plots
1, 2 refer to first and second samplings

Plot		Soil sulphur uptake in mg. per sq. yd.					
		Clover		Alfalfa		Total	
		C	F	C	F	C	F
B-11	1.	17	8	16	21	33	29
	2.	15	14	19	38	34	52
	Total	32	22	35	59	67	81
B-10	1.	16	21	17	19	33	40
	2.	46	39	50	57	96	96
	Total	62	60	67	76	129	136
		<hr/>					
		Barley					
C-11	1.	100	72				
	2.	110	94				
C-10	1.	137	89				
	2.	284	226				

Table 1
Summary of Results

1. 3 values for (1) and (2) are given
 2. 3 values for (3) and (4) are given

Type	Total Results (1) and (2)					
	1	2	3	4	5	6
1-1	14	14	14	14	14	14
2-1	14	14	14	14	14	14
3-1	14	14	14	14	14	14
4-1	14	14	14	14	14	14
5-1	14	14	14	14	14	14
6-1	14	14	14	14	14	14
7-1	14	14	14	14	14	14
8-1	14	14	14	14	14	14
9-1	14	14	14	14	14	14
10-1	14	14	14	14	14	14
11-1	14	14	14	14	14	14
12-1	14	14	14	14	14	14
13-1	14	14	14	14	14	14
14-1	14	14	14	14	14	14
15-1	14	14	14	14	14	14
16-1	14	14	14	14	14	14
17-1	14	14	14	14	14	14
18-1	14	14	14	14	14	14
19-1	14	14	14	14	14	14
20-1	14	14	14	14	14	14
21-1	14	14	14	14	14	14
22-1	14	14	14	14	14	14
23-1	14	14	14	14	14	14
24-1	14	14	14	14	14	14
25-1	14	14	14	14	14	14
26-1	14	14	14	14	14	14
27-1	14	14	14	14	14	14
28-1	14	14	14	14	14	14
29-1	14	14	14	14	14	14
30-1	14	14	14	14	14	14
31-1	14	14	14	14	14	14
32-1	14	14	14	14	14	14
33-1	14	14	14	14	14	14
34-1	14	14	14	14	14	14
35-1	14	14	14	14	14	14
36-1	14	14	14	14	14	14
37-1	14	14	14	14	14	14
38-1	14	14	14	14	14	14
39-1	14	14	14	14	14	14
40-1	14	14	14	14	14	14
41-1	14	14	14	14	14	14
42-1	14	14	14	14	14	14
43-1	14	14	14	14	14	14
44-1	14	14	14	14	14	14
45-1	14	14	14	14	14	14
46-1	14	14	14	14	14	14
47-1	14	14	14	14	14	14
48-1	14	14	14	14	14	14
49-1	14	14	14	14	14	14
50-1	14	14	14	14	14	14
51-1	14	14	14	14	14	14
52-1	14	14	14	14	14	14
53-1	14	14	14	14	14	14
54-1	14	14	14	14	14	14
55-1	14	14	14	14	14	14
56-1	14	14	14	14	14	14
57-1	14	14	14	14	14	14
58-1	14	14	14	14	14	14
59-1	14	14	14	14	14	14
60-1	14	14	14	14	14	14
61-1	14	14	14	14	14	14
62-1	14	14	14	14	14	14
63-1	14	14	14	14	14	14
64-1	14	14	14	14	14	14
65-1	14	14	14	14	14	14
66-1	14	14	14	14	14	14
67-1	14	14	14	14	14	14
68-1	14	14	14	14	14	14
69-1	14	14	14	14	14	14
70-1	14	14	14	14	14	14
71-1	14	14	14	14	14	14
72-1	14	14	14	14	14	14
73-1	14	14	14	14	14	14
74-1	14	14	14	14	14	14
75-1	14	14	14	14	14	14
76-1	14	14	14	14	14	14
77-1	14	14	14	14	14	14
78-1	14	14	14	14	14	14
79-1	14	14	14	14	14	14
80-1	14	14	14	14	14	14
81-1	14	14	14	14	14	14
82-1	14	14	14	14	14	14
83-1	14	14	14	14	14	14
84-1	14	14	14	14	14	14
85-1	14	14	14	14	14	14
86-1	14	14	14	14	14	14
87-1	14	14	14	14	14	14
88-1	14	14	14	14	14	14
89-1	14	14	14	14	14	14
90-1	14	14	14	14	14	14
91-1	14	14	14	14	14	14
92-1	14	14	14	14	14	14
93-1	14	14	14	14	14	14
94-1	14	14	14	14	14	14
95-1	14	14	14	14	14	14
96-1	14	14	14	14	14	14
97-1	14	14	14	14	14	14
98-1	14	14	14	14	14	14
99-1	14	14	14	14	14	14
100-1	14	14	14	14	14	14

1 - 1st Sampling ; 2 - 2nd Sampling

Fertilized - F , Check - C

Fig.7. Sulphur content of atlaswede clover.

Fig.8. Yield and fertilizer uptake of atlaswede clover.

Fig.9. Sulphur content of alfalfa.

Fig.10. Yield and fertilizer uptake of alfalfa.

Fig.11. Sulphur content of barley.

Fig.12. Yield and fertilizer uptake of barley.

Fig. 13. Uptake of soil sulphur

DISCUSSION OF RESULTS

The results reported in this paper were obtained from the analysis of crops grown during a single season, 1949. Since the seasonal fluctuations in yields and sulphur percentages are rather large, it might well be expected that other similar determinations would also vary considerably from season to season. This limitation of the value of the results obtained must be kept in mind in drawing any conclusions from them. The season, itself, was rather an unusual one, being made up of a prolonged period of drought followed by one of extremely heavy rains.

From a consideration of the total sulphur content of the plant material from the various plots certain general conclusions can be drawn. The values found for percent sulphur were generally considerably lower than corresponding figures reported by Peters (15) for 1940 and 1941. However, Peters' results may possibly have been affected by the presence of weeds and other miscellaneous plant material not included in the materials analyzed in this study. No comparison has been made of relative accuracies of the magnesium nitrate method as used by Peters and the nitric-perchloric method used in the present investigation.

On Plot 10, alfalfa was found to be consistently higher in sulphur content than Altaswede clover, while on Plot 11, not previously fertilized, the clover contained a higher percentage of sulphur than did the alfalfa. This was found in plant

material taken at both sampling dates. These differences, however, were rather small and most of them were not statistically significant. In nearly all cases barley on Plot 11 contained a higher percentage of sulphur than did barley on Plot 10 for both check and fertilized plots. Again the differences are not generally statistically significant but they are nevertheless rather surprising since Plot 10 had received previous sulphur fertilizer.

The sulphur content of alfalfa and clover grown on Plot 11, and of all barley samples was lower at the time of the second sampling than it was when the first samples were taken. This might have been expected since in the period of rapid growth following the heavy July rains the general level of mineral content would tend to be lower than it would during a drought period such as the one preceding the first sampling. However, the percentage of sulphur in both alfalfa and clover on Plot 10 increased during the period between the samplings. This might possibly be due to the plants being more vigorous and deeply rooted as a result of previous fertilization of this plot.

Much information can be obtained by a study of the results of the radioactivity measurements. This was the main purpose of the present investigations since all the foregoing results could have been obtained by purely chemical methods.

Of the total sulphur taken up by the plants, a large proportion was found to come from the applied fertilizer. This fraction varied from 30% to 80% in the samples analyzed. It is

interesting to note that the highest percent of sulphur coming from the fertilizer (79.3%) corresponds to the greatest increase in yield (400%).

In all plots the fraction of sulphur from fertilizer was greater in Plot 11 than in Plot 10. This was to be expected since the previous fertilization of Plot 10 had presumably left a residual quantity of available sulphur in the soil which, by the method of analysis used, would appear as sulphur from the soil rather than sulphur from fertilizer.

Perhaps the most surprising result was the amount of fertilizer sulphur taken up by the barley. Previous work, described earlier in this report, indicated that direct application of sulphur fertilizers did not produce important or very significant increases in the yield of cereals and it might have been supposed that barley would not take up much sulphur from the applied fertilizer. However, the results indicate that the uptake of fertilizer by the barley compared favorably with the uptake by the legumes both in percent of sulphur from fertilizer and in total uptake. Effects of the sulphur fertilization on barley yields were somewhat variable. At the time of the first sampling, there were slight decreases in the yield on the fertilized plots of both Plot 11 and Plot 10, but these differences were not statistically significant. Yields at the second sampling showed slight, non-significant increases. The larger increase was on Plot 11 which had received no previous fertilizer since 1930. Yields at harvest time showed increases on both plots, the large increase on Plot 11 being highly significant whereas

the increase on Plot 10 was not significant. However, these increases did not affect the grain yield (see Table IV) and in terms of crop production were unimportant.

Figure 13 shows that the amount of sulphur taken from the soil by the legumes is about the same for the fertilized plots as it is for the corresponding checks. In the barley plots, however, the amount of soil sulphur in the plants seems to be definitely lower in the fertilized plots. This may have been due to fertilizer sulphur having been more readily available to barley than was the soil sulphur.

The graphs of Figures 8, 10 and 12 show the amount of fertilizer taken up per square yard by each of the various crops. The alfalfa and Altaswede clover took up a great deal more sulphur from the fertilizer in the period between samplings than they had before the first cutting. This was to be expected for a number of reasons. In all cases the length of time between cuttings was greater than that between the application of fertilizer and the first sampling. The rapid growth of the plants and the increase in soil moisture would both tend to increase the uptake of the fertilizer. In the chart for the barley plots the amount of fertilizer sulphur taken up between samplings is represented by the difference between the values for the first and second samplings. These graphs indicate that more than half the total uptake occurred before the first sampling. This is particularly noteworthy for Plot 10 since the fertilizer was applied less than three weeks before the first collection of samples. The graphs also show that the uptake of fertilizer sulphur by clover was greater on the previously

fertilized B-10 plots while the uptake by alfalfa was greater on the B-11 plots.

In nearly all cases, the application of Na_2SO_4 fertilizer resulted in increases in the yields of legumes. For the samples taken at the second cutting these increases are large and statistically highly significant. The percentage increases, however, are generally considerably lower than the average figures reported by Peters (15). This is probably due to the unusual nature of the 1949 growing season.

SUMMARY

Sodium sulphate was labelled with radioactive sulphur, S^{35} , in order to trace the uptake of fertilizer by plants growing on a sulphur deficient soil. Harvested plant materials were ashed and dissolved before precipitating the sulphur as BaSO_4 and measuring its activity with a G.M. counter. This enabled the determination of the fraction of sulphur coming from the fertilizer and the total fertilizer sulphur taken by the plants.

Results show that for alfalfa, Altaswede clover and barley the amount of sulphur taken up from the fertilizer accounted for a large proportion of the total sulphur found in the plant material. On plots which had received no previous sulphur fertilizer this proportion was more than 50%, while on plots previously fertilized with 16-20-0 the percentage was somewhat lower. The application of fertilizer produced

considerable increases in the legume yields but rather small increases in the yields of barley, although the amount of fertilizer sulphur taken up was about the same in both cases.

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considerable interest in the subject of the
importance in the field of work, although the subject of
direct control over the work was not in the case.

CONCLUSIONS

The writer finds it difficult to state
to Dr. J. H. Smith in his report of 1911, that it is
a. a study of the importance of the subject, for the purpose
of the study and for the purpose of the study, it is
found that it is not possible to state the importance of the
subject in the field of work, and it is not possible to state
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It is found that it is not possible to state the importance of the
subject in the field of work, and it is not possible to state
it at all.

The writer finds it difficult to state the importance of the
subject in the field of work, and it is not possible to state
it at all.

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