A STUDY OF

THE RELATION OF CERTAIN MAJOR AND MINOR ELEMENTS TO THE PROBLEM OF SEED SETTING IN ALFALFA

by

Sidney Joshua Buckwold

A Thesis

Submitted to the Committee on Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree of

MASTER OF SCIENCE

THE UNIVERSITY OF MANITOBA
LIBRARY

THE UNIVERSITY OF MANITOBA

September 1944

TABLE OF CONTENTS

	Page
Acknowledgments	1
Introduction	2
Review of Literature	5
I. Major Elements	5
II. Minor Elements	6
Calcium	7
Sulphur	8
Boron	12
Manganese	14
Zinc	14
Copper	14
Molybdenum	15
Sodium and Chlorine	15
Iodine	16
Titanium	16
Thallium	16
Radioactive Elements	16
"A-Z" Solution	17
III. Burning	17
IV. Summary	18
Experimental Procedure and Results	20
I. The University Farm	23
Methods	23
(a) Experimental Field A	23
(b) Experimental Field B	24

	Page
(c) Experimental Field C	25
Results	26
II. Arborg	35
Methods	35
Results	36
III. Benito	36
Methods	36
Results	37
IV. South Junction	37
Agronomic Investigations	39
(a) Methods	39
(b) Results	41
Analyses of Plant Material and Seed ..	57
(a) Methods	57
(b) Results	58
Summary and Conclusions	67
Appendix	69
Methods of Soil Analysis	69
(a) Water-soluble Sulphate	69
(b) Total Sulphur	69
Literature Cited	71

LIST OF ILLUSTRATIONS

Figure		Page
1	Graph showing effect of soil treatments upon average yields of alfalfa seed at South Junction, Man.	45
2	Square yard samples of alfalfa plants (early bloom stage) from plots at South Junction receiving the following treatments: 1) no treatment; 2) potassium sulphate; 3) potassium chloride; 4) calcium sulphate.	53
3	Square yard samples of mature alfalfa plants from plots at South Junction treated with the following: no treatment, gypsum (calcium sulphate), potassium chloride, and potassium sulphate.	54
4	Square yard samples of alfalfa plants from the experimental plots at South Junction.	55
5	A close-up view of the alfalfa plants in Figure 4.	56

LIST OF TABLES

Number	Title	Page
1	Total sulphur and water-soluble sulphate and reactions of soil from the experimental field at South Junction.	21
2	Total sulphur and water-soluble sulphate content and reaction of soil at the University (Experimental Field B).	22
3	Average yields of alfalfa seed at the University (Experimental Field A), in pounds per acre.	28
4	Yields of alfalfa seed at the University (Experimental Field A), in pounds per acre.	29
5	Analysis of variance for yields in Table 4.	29
6	Yields of alfalfa seed at the University (Experimental Field A), in pounds per acre.	30
7	Analysis of variance for yields in Table 6.	30
8	Yields of alfalfa seed at the University (Experimental Field B), in pounds per acre.	31
9	Analysis of variance for yields in Table 8.	31
10	Alfalfa seed yields at the University (Experimental Field C), in pounds per acre.	32
11	Average number of seeds per pod from hand-tripped alfalfa flowers at the University (Experimental Field B).	33
12	Analysis of variance for data in Table 11.	33
13	Average number of seeds per pod from hand-tripped alfalfa flowers at the University (Experimental Field C).	34
14	Analysis of variance for data in Table 13.	34
15	Average yields of alfalfa seed at South Junction, Man., in pounds per acre.	44
16	Yields of alfalfa seed in pounds per acre from plots receiving different treatments at South Junction.	46

Number	Title	Page
17	Analysis of variance for "no treatment" cross-strip at South Junction.	47
18	Analysis of variance for borax cross-strip at South Junction, Man.	47
19	Analysis of variance for man. sulphate cross-strip at South Junction, Man.	48
20	Yields of alfalfa seed on the cross-strips at South Junction, Man., in pounds per acre.	49
21	Analysis of variance for alfalfa seed yields of cross-strips at South Junction, Man.	49
22	Effect of sulphate application at South Junction, Man., upon the seed set of alfalfa pods and upon the germination and viability of the seeds (averages for data in Tables 23 & 24).	50
23	Effect of sulphate application upon the seed set of alfalfa pods at South Junction, Man.	51
24	Effect of sulphate application upon the germination and viability of alfalfa seed at South Junction, Man.	52
25	Effect of sulphur fertilizers upon the sulphur content of alfalfa plants (early bloom stage) at South Junction, Man.	59
26	Analysis of variance for effect of sulphur fertilizers upon sulphur content of alfalfa plants at South Junction, Man.	59
27	Effect of sulphur fertilizers upon the nitrogen content of alfalfa plants (early bloom stage) at South Junction, Man.	60
28	Analysis of variance for effect of sulphur fertilizers upon nitrogen content of alfalfa plants at South Junction, Man.	60
29	Effect of different soil treatments upon the sulphur content of alfalfa seed at South Junction; and a comparison with the sulphur content of seed from other areas.	61

Number	Title	Page
30	Analysis of variance for sulphur content of alfalfa seed at South Junction and other areas (data in Table 29).	62
31	Analysis of variance for sulphur content of alfalfa seed at South Junction, Man.	63
32	Analysis of variance for sulphur content of alfalfa seed from plots at South Junction not receiving sulphur (No S) and from other areas (Norm).	64
33	Effect of soil treatments upon nitrogen content of alfalfa seed at South Junction, Man.	65
34	Analysis of variance for nitrogen content of alfalfa seed at South Junction, Man.	66

ACKNOWLEDGEMENTS

The author is indebted to Dr. P. J. Olson, Professor of Plant Science, under whose direction this research project was conducted, and to Prof. J. H. Ellis, Professor of Soils, for their valuable guidance, encouragement and advice. Dr. C. H. Goulden, Senior Agricultural Scientist, Dominion Rust Research Laboratory, Winnipeg, and Honorary Lecturer in Statistics, gave assistance and advice relative to the statistical analyses of the data. That help is hereby gratefully acknowledged.

The project was conducted under the Cora Hind Fellowship established by the United Grain Growers Limited. Financial assistance covering the expenses involved in the experiments was provided by the Manitoba Department of Agriculture and the Research Committee of The University of Manitoba. Grateful appreciation is extended to these organizations.

INTRODUCTION

The frequent failure of alfalfa to set seed adequately is a serious economic problem in Manitoba as well as in other areas. The problem may be, and has been, approached from different angles. Investigations have been conducted by various workers with respect to the following:

1) natural and artificial tripping and cross-pollination;
2) the effect of certain insects as tripping and cross-pollinating agents;
3) the breeding and selection of self-tripping and high seed-producing strains;
4) the effect of certain injurious insects;
5) the effect of applying nutrient elements to the soil;
6) sporogenesis and embryology.

Because little is known concerning the effect of applying nutrient elements upon the setting of alfalfa seed in Manitoba, and since certain elements such as boron were found to give beneficial results in certain areas elsewhere, it was considered advisable to pursue this phase of the problem.

In order to study what relation the application of certain major and minor elements to Manitoba souls might have to seed setting in alfalfa, the author conducted experiments on four different soil types located at 1) the University Farm (clay textured black earth soil), 2) Arborg (clay textured Rendzina soil), 3) Benito (clay textured

grey-wooded soil), and 4) South Junction (sandy podzolic soil over calcareous drift substrata). The term "major elements" is here used to designate the fertilizer elements, nitrogen, phosphorus and potassium; while the term "minor elements" is used to refer to all other elements, whether or not they are considered to be essential for normal plant growth and development.

In addition to applying certain elements to different soils to ascertain their effect on the production of alfalfa seed, the experiments included the application of soil amendments and the burning of applied straw. Three possible effects of the burning of straw on alfalfa in the early spring may be contemplated, namely, 1) the effect of the ingredients of the ash upon the growth and functioning of the plants affected, 2) the checking of the vegetative growth of alfalfa, and 3) the control of injurious insects by destroying overwintering eggs and adults. As far as these experiments were concerned, it was regarded as more or less doubtful that insect control would be a factor, because insects might readily migrate from untreated parts of the field to the experimental plots on which straw was burnt. Thus, the burning experiment was not designed primarily to check injurious insects, but rather to ~~see~~ ascertain what direct effect, if any, such treatment would have on the seed setting.

The burning experiment was included because of the results reported by one farmer, in particular. Mr. E. Hallberg of South Junction reported that in 1941 his alfalfa crop set very little seed. He cut a few swaths around one alfalfa field with a binder and left the rest uncut. The following spring he burnt the unharvested crop. The result was a 300 pound per acre seed crop on the burnt portion of the field and no flowers or seed on the unburnt portion (where the binder had passed) and on an unburnt adjoining field. This field of Mr. Hallberg's was consequently included in this project.

REVIEW OF LITERATURE

1. Major Elements

The elements, nitrogen, phosphorus and potassium have long been known to improve vegetative yields of alfalfa on certain soils, depending on the requirements of the particular soil. However, on reviewing the literature it appears that studies of the effects of the major elements on seed setting in alfalfa has been somewhat neglected. As pointed out by Blinn (8)[x] in 1920, this is "probably because of the many successful seed yields under conditions where no special fertility was provided."

Blinn (8) suggested that declining alfalfa seed yields may be partly due to an increase in the soil nitrates. Carlson and Stewart (13) in the Uintah Basin in Utah applied barnyard manure at the rates of 5 and 15 tons per acre. They report that the yields of alfalfa seed were highest for those plots receiving no manure and lowest for those receiving 15 tons of manure. In the Millard area in Utah, Whornham (61) applied nitrogen, phosphorus, and potassium. The alfalfa seed yields under these treatments were no different from those of the unfertilized plots. Westover and Noble (60) in California report that in preliminary

---

[x] Figures in parenthesis refer to "Literature Cited", p. 71.

tests alfalfa plots receiving phosphates yielded more seed than the accompanying checks. In Idaho, Toevs and Baker (58) observed that with phosphate applications there was a definite increase in alfalfa seed production in some instances, while in others there was no difference in the amount of seed set.

Stevenson and Mitchell (54) stated that in northern Saskatchewan on grey-wooded soils increased yields of seed have been obtained from the application of commercial fertilizers on alfalfa fields, and that responses are more likely to be obtained on older stands and on lighter soils. They stated that the elements, nitrogen, phosphorus, and sulphur all appear to be required. In 1943 the Dominion Forage Crops Laboratory (17) obtained significant increases in the yield of alfalfa seed on certain sandy soil types in northern Saskatchewan from the application of ammonium phosphates containing high percentages of sulphur. They concluded that the addition of sulphur, and possibly phosphorus and nitrogen, caused the increased yields.

11. Minor Elements

The essentiality of the elements, calcium, magnesium, sulphur and iron has long been recognized, but, in general, the question of the usefulness of their application to the soil as plant nutrients was not given the attention paid to the major elements. Although some of these occur in many

fertilizers in combined forms with the major elements and in soil amendments, their specific effects were seldom given much consideration. The essentiality of some of the other minor elements was not recognized until comparatively recent times. In view of the above, the author has deemed it advisable to include in the literature review not only the investigations dealing with the effects of the minor elements on alfalfa seed production, but also those concerned with their effects on alfalfa vegetation, as that might suggest their possible value for seed setting as well.

Calcium

Shedd (52) in pot experiments on three Kentucky soils obtained increased vegetative yields of alfalfa with the addition of different calcium compounds, namely, calcium silicate, calcium citrate, and calcium oxalate. Larson (30) in water culture studies reports that the minimum concentration of calcium ion required by the alfalfa plant for growth appears to be about 16 p.p.m.[x], and that the most economical growth was produced with about 32 p.p.m. Excessive concentration of calcium did not seem to be toxic, in fact, Larson considered that increased growth may be produced thereby. Albrecht (2, 3) as a result of studies with soybean plants concludes that the beneficial results

---

[x] Parts per million.

obtained with legumes of liming on acid soils is due far more to the added calcium nutrient than to the reduction in the degree of acidity. Joret and Malterre (28) found that in two sandy loams of France the absorption complex of the soil should contain at least 45% of exchangeable CaO before a good stand of alfalfa could be obtained.

Sulphur

Reimer and Tartar (50) in field trials in Oregon found sulphur fertilizers increased the yield of alfalfa hay on many soils by 50% to 1000%. In field experiments by Olson and St. John (41) in the state of Washington, sulphur fertilization increased alfalfa yields two or more times. Later Neller (40) in the same state studied the effect of sulphur fertilizers on three soils under plant-house and field conditions. He obtained distinct increases in the yield of alfalfa on one of the three soils. In pot experiments with six Idaho soils Neidig, McDole and Magnuson (39) found that sulphur increased alfalfa yields on five of the soils. McDole and Christ (35) report increased alfalfa yields from the application of gypsum in northern Idaho. Erdman and Bollen (20) report that on some Iowa soils, gypsum gave increased yields of alfalfa. Field experiments with gypsum on alfalfa by Alway (4) at seven locations in Minnesota have shown that at five of these it does not affect the yields. At Backus and Bemidji it caused an

average increase of 19% and 70% respectively. In the Thunder Bay district of Ontario, Harrison (24) reports that in an experiment with the cooperation and guidance of Alway, gypsum increased the second crop of alfalfa four and a half times. Burke and Morris (12) state that gypsum greatly increases alfalfa yields on some soils in the western part of Montana. The University of Alberta Soils Department (1) obtained marked increases in the yield of alfalfa on grey-wooded soil from the application of sulphur compounds and fertilizers containing sulphur.

The failure of the application of sulphur or gypsum to improve the forage yields of alfalfa was reported by Stewart (55) in Illinois, Lomanitz (31) in Texas, Bruce (11) in Kansas, Westover and Noble (60) at the U.S. Yuma Field Station in California, McKibbin (36) in Maryland, and Toevs and Baker (58) at the Aberdeen Branch Experiment Station in Idaho.

A low sulphur content of the alfalfa plants grown on sulphur-deficient soils, and a decided increase with the application of sulphur fertilizers is reported by Miller (38), Reimer and Tartar (50), Neidig, McDole and Magnuson (39) (in the case of the three soils where sulphur caused the greatest increase in yield). After an investigation of the sulphur content of alfalfa in Minnesota, Alway (4) concludes that its determination "provides a means of detecting the locali-

ties and even the particular farms where sulfur fertilizers are most likely to prove valuable."

That sulphur fertilization of sulphur-deficient soils increases the nitrogen or protein content of alfalfa was demonstrated by Miller (38), Reimer and Tartar (50), Olson and St. John (41), Neller (40), Powers (48), and Burke and Morris (12).

That the application of sulphur fertilizers to responsive soils gave alfalfa plants a conspicuously darker green color as compared to untreated plants, was noted by Reimer and Tartar (50), Olson and St. John (41), Neller (40), and Alway (4). In pot trials with a sulphur-deficient soil, Powers (46) found that sulphur treated alfalfa plants contained 12% more chlorophyll than untreated. Alfalfa leaves collected from treated and check plots showed an increase of 18% in chlorophyll content with sulphur fertilization.

Powers (47, 48) found in water culture experiments that the sulphate concentration favorable for optimum growth of alfalfa was 15 to 30 p.p.m. during the first three weeks and 8 to 15 p.p.m. during the next three weeks of the growth period. He indicated that soils with a sulphate concentration in the soil solution as low as 13 to 17 p.p.m. were found. Thomas et al. (57) obtained definite evidence of sulphur deficiency in alfalfa plants grown in nutrient solutions with less than 1 p.p.m. sulphate sulphur. These

plants yielded appreciably less, and contained from 10% to 33% less chlorophyll, than those receiving adequate sulphur.

Very little is mentioned in the literature regarding the value of sulphur fertilization in relation to the production of alfalfa seed. To the author's knowledge, nothing other than the following has been reported up to the present time. Stevenson and Mitchell (54) speak of increased alfalfa seed yields having been obtained with commercial fertilizers in northern Saskatchewan on grey-wooded soils. They point out that the elements, nitrogen, phosphorus and sulphur all appear to be required. During the time of the investigations by the author, experiments were conducted by the Dominion Forage Crops Laboratory (17) in the northern alfalfa seed producing areas of Saskatchewan. They obtained pronounced and significant responses in the yield of alfalfa seed on sandy soils from the application of elemental sulphur and of fertilizers containing sulphur. Loam and clay loam soils did not respond to sulphur. Harrison (24), in reporting some work done with Dr. F. J. Alway in the Thunder Bay district in Ontario, mentions that on gypsum plots there was evidence of improved setting of alfalfa seed. In a recent personal note to the author Dr. F. J. Alway indicates that in the alfalfa seed area just south of Lake of the Woods and Rainy River he has found that on sulphur-deficient fields sulphur fertilizers greatly increase the yield of seed.

Boron

A boron deficiency in alfalfa plants is reported in a number of areas. Reviews of the literature on the effect of boron on alfalfa vegetation (42) have been made and need not be repeated here.

Investigators in Nova Scotia (6) found that alfalfa growing in parts of fields where boron had previously been applied to turnips developed more seed and seed pods than that in the rest of the field. Dijakova (14) in the U.S.S.R. reports that in field and pot experiments with alfalfa the application of boron-containing fertilizers speeded up growth and development and increased seed yield. The effect of boron was pronounced, however, only when an adequate amount of phosphates was supplied to the plants. In a later paper (15), he indicates that in a field experiment on podzolized soils, 3 kg. of boron per ha. (2.7 lbs. boron per acre, or the equivalent of 23.6 lbs. borax per acre) had little effect when applied alone, but with heavy applications of calcium carbonate it gave considerable increases in alfalfa seed yield as compared to no treatment, boron alone, or calcium carbonate alone. Without boron, the carbonate at the higher rates had apparently affected the seed yield detrimentally.

In Vermont the application of 30 pounds borax per acre increased alfalfa seed yields more than 35 times (Midgley,

37). Pods that formed on check plots were usually empty, such small seeds as developed were withered and of light weight, whereas those grown on borated plots contained many plump, healthy seed (Duncklee and Midgley, 19).

In North Carolina, Piland and Ireland (43) observed that alfalfa which received 20 pounds of borax per acre produced a good seed set, while that which received no borax set no seed. In a later paper, Piland, Ireland and Reisenhauer (44) report that check plots gave an average seed yield of 19.1 pounds per acre, and the addition of 0.5, 1, and 1.5 p.p.m. boron produced an average increase of 460, 433, and 529 per cent respectively.

In Virginia, Hutcheson and Cocke (27) observed that the application of 10 pounds of borax to the acre resulted in a good set of alfalfa seed while no seed had set on untreated plots. Grizzard and Matthews (23) found the application of borax at 15 pounds per acre resulted in the production of 82 to 184 pounds of alfalfa seed per acre; whereas, the plants on the plots receiving no borax failed to set any seed.

In some localities in Illinois, the application of boron fertilizer resulted in the production of large amounts of seed in alfalfa, whereas no seed was produced on the soils receiving no boron (Stinson and DeTurk, 56). In a wet season no seed was produced, regardless of whether or not boron was used.

The Dominion Forage Crops Laboratory (17) obtained no improvement in seed yields in the northern alfalfa seed producing areas of Saskatchewan from the applications of borax and boric acid, each at the rate of 15 pounds per acre.

Manganese

D'Ippolito (16) in Italy reports a marked increase in alfalfa yield from applications of 180 pounds per acre of a natural manganese carbonate (35% carbonate) and a natural phosphocarbonate (containing 35% carbonate and 11% phosphoric acid).

Zinc

Hoagland, Chandler and Hibbard (25) found that alfalfa was much less susceptible to injury from zinc deficiency than certain other plants (corn, tomato, and others). The Waite Research Institute of South Australia (59) reports that at Robe, where alfalfa gave satisfactory yields with the assistance of copper dressings, results were much improved by the addition of zinc.

Copper

Piper (45) grew alfalfa in nutrient solutions at three different copper levels: nil, 3, and 100 micrograms per litre. The yield of dry matter (straw plus roots) was in the follwoing ratio, 100:255:450. He gives a description of the main symptoms of the copper deficiency, namely, a

peculiar epinastic curvature of the petioles of the newly formed leaves, soon followed by the withering and death of these leaves and the cessation of growth of the stem tips. In the copper-free culture the symptoms appeared about two weeks after germination. The same symptoms developed in the culture receiving 3 micrograms of copper per litre when this supply of copper was exhausted. In the cultures receiving 100 micrograms of copper all the plants made normal growth.

Molybdenum

Bortels (9) reports having obtained small but probably significant increases in alfalfa yield after applications to field plots of sodium molybdate at 1 gm. per square metre (8.9 lbs. per acre) at various times. The effect was apparently enhanced by adding boron. Anderson (5) in pot tests with ironstone soil of the Meadows district of South Australia doubled the yield of alfalfa by the application of sodium molybdate at the rate of 2 pounds per acre. The leaves of the plants receiving molybdenum were a healthy dark green color in contrast to the yellowish to pale green color of the untreated plants.

Sodium and Chlorine

Lomanitz (32, 33) reports an increase in the yield of alfalfa grown in solution culture by the addition of sodium chloride.

Iodine

Powers (49) studied the influence of iodine in water and soil cultures. He reports that significant increases in yield were obtained with alfalfa.

Titanium

Konishi and Tsuge (29) report that when alfalfa without nodules was cultured in Crone's nutrient solution containing $NaNO_3$, the addition of titanium as K_2TiO_3 improved the plant growth remarkably.

Thallium

McCool (34) found that the addition of 1.7 p.p.m. of thallium sulphate to a sandy loam soil was slightly injurious to alfalfa, and 8.5 p.p.m. was much more so. The addition of 17.3 p.p.m. was very injurious. The alfalfa plants were about one-third as tall as the control plants, the leaves were yellow at their base, and root development was greatly retarded. The presence of 34.6 p.p.m. of thallium sulphate in the soil resulted in the death of the plants.

Borzini (10) in a study with alfalfa and other plants reports that thallium ions reduced both the germination and the growth rate, and inhibited the formation of chlorophyll.

Radioactive Elements

Drobkov (18) reports that the yields of alfalfa and other plants were considerably increased by the addition of small amounts of the radioactive elements, radium, uranium,

thorium, and actinium, to the nutrient solutions. The positive effects of these substances on the plants was evident chiefly in the production of more seed and an acceleration of the maturing process.

"A-Z" Solution

Schropp and Scharrer (51), in a water culture experiment, added small amounts of Hoagland's "A-Z" solution to a regular nutrient solution (containing N_2, P, K, Ca, Mg, S, and Fe). Hoagland's "A-Z" solution is a supplementary solution containing boron, manganese, copper, zinc, aluminum, nickel, cobalt, titanium, lithium, tin, iodine, and bromine. The dry weight of the shoots and roots of alfalfa was depressed by 29.84% and 16.67% respectively, as a result of the addition of the "A-Z" solution. At the same time, the length of shoot was increased by 7.7%.

111. Burning

Whornham (60) reports that the burning of alfalfa plots in the Millard area in Utah with a stubble burner gave a greater forage yield but usually a poor seed yield.

Hughes (26) in Minnesota has shown that thorough burning-over of alfalfa fields in the early spring effectively reduced the Adelphocoris lineolatus (Goeze) (alfalfa plant bug) population as well as the populations of Adelphocoris rapidus (Say) and Lygus spp. Cage and field studies demonstrated that A. lineolatus, A. rapidus, and Lygus spp. are responsible for

bud blast and flower fall in alfalfa. This damage is considered sufficient to account for the reduction of the alfalfa seed crop in that state.

IV. Summary

The major elements (nitrogen, phosphorus, and potassium) have long been known to improve vegetative yields of alfalfa on certain soils. Comparatively little appears to have been done in studying the effects of these elements upon seed setting in alfalfa. However, reports of beneficial results upon alfalfa seed production with the application of phosphorus have been made in California and Idaho. Ammonium phosphate fertilizers have increased alfalfa seed yields in northern Saskatchewan, but these responses appeared to be due primarily to the high percentage of sulphur in the fertilizers used.

On certain soils calcium has improved the vegetative growth of alfalfa. In certain areas sulphur fertilization has resulted in marked increases in the forage yields of alfalfa, and also increases in the chlorophyll, sulphur, and nitrogen and protein content of the plants. Sulphur fertilizers have improved the setting of alfalfa seed in the Thunder Bay district in Ontario, in the alfalfa seed area just south of Lake of the Woods and Rainy River, and in northern Saskatchewan. The application of boron has decidedly improved alfalfa growth and seed production in a number of areas. The elements, man-

ganese, zinc, copper, molybdenum, sodium with chlorine (NaCl), iodine, and titanium have been reported to have a beneficial effect upon alfalfa growth, in soil or nutrient solution experiments. The addition of small amounts of the radioactive elements, radium, uranium, thorium, and actium to nutrient solutions have improved alfalfa growth and seed production. Thallium has been found to be injurious to alfalfa plants. All of the above elements that were reported by someone to be beneficial to alfalfa have been included (except for titanium and the radioactive elements) in the investigations of the author herein reported.

Thorough burning-over of alfalfa fields have been shown to effectively reduce the population of certain insects which are responsible for bud blast and flower fall in alfalfa.

EXPERIMENTAL PROCEDURE AND RESULTS

In order to ascertain their effects upon seed setting in alfalfa, various major and minor elements were applied to four different soil types. The applications included the major elements, nitrogen, phosphorus, and potassium; and the minor elements, calcium, magnesium, sulphur, iron, boron, manganese, zinc, copper, molybdenum, sodium, chlorine, iodine, fluorine, aluminum, cobalt, and lithium. The soil amendments, calcium carbonate and calcium hydroxide were also used. In addition, straw was applied and burned on some plots.

The soil types involved were located at 1) the University Farm, 2) Arborg, 3) Benito, and 4) South Junction. Soil samples were obtained by horizons from the experimental field at South Junction (in the spring of 1943) and from Experimental Field A at the University Farm (in the fall of 1943). These were analyzed for total sulphur and water-soluble sulphates (see Appendix, page 69, for analytical methods used). The results of these analyses and the reaction of the samples analyzed are presented in Tables 1 and 2. The total sulphur and water-soluble sulphate content of the soil at the South Junction experimental field was much less than that of the soil at the University.

Table 1. - Total sulphur and water-soluble sulphate and reaction of soil from the experimental field at South Junction.

Depth ins.	Reaction of soil sample analyzed	Total S[x] %	Water-soluble SO_4[x] %
0-7	neutral	.009	.000
7-13	neutral	.002	.001
13-15	neutral	.002	.000
15-22	slightly alkaline	.008	.001
22-45	strongly alkaline	.012	.001
Weighted mean to 4 ft. depth		.009	.0008

[x] Moisture-free basis.

Table 2. - Total sulphur and water-soluble sulphate content and reaction of soil at the University (Experimental Field B).

Depth ins.	Reaction of soil sample analyzed	Total S[x] %	Water-soluble SO_4[x] %
Tongued profile:			
0-8	neutral	.029	.002
8-16	slightly alkaline	.014	.002
16-23	strongly alkaline	.011	.009
23-30	strongly alkaline	.015	.015
30-40	strongly alkaline	.017	.017
40-44	strongly alkaline	.017	not determined
Weighted mean to 4 ft. depth		.017	.011
"Normal" profile:			
0-8	neutral	.033	.002
8-12	neutral	.021	.002
12-21	strongly alkaline	.009	.008
21-30	strongly alkaline	.017	.011
30-40	strongly alkaline	.018	.016
40-44	strongly alkaline	.017	not determined
Weighted mean to 4 ft. depth		.019	.010

[x] Moisture-free basis.

Statistical analyses of the experimental data were made by the analysis of variance and t-test method as described by Fisher (21), Goulden (22), and Snedecor (53). In certain variance analyses the replicate variance, owing to its insignificance, was included with the error.

I. The University Farm

The soil on which the experiment at the University Farm was conducted is Fort Garry clay in the black earth soil.

Methods

All of the aforementioned treatments, except calcium hydroxide, were applied at the University Farm on three experimental fields, designated as A, B, and C respectively.

(a) Experimental Field A

Replicated plots receiving the treatments calcium hydroxide, phosphorus and no treatment were set alongside each other, while across these were strips receiving boron and no treatment, and border strips receiving potash in the chloride and sulphate forms. This field was laid out in 1940 by Mr. W. H. Silversides. On June 19, 1940 the plots were seeded down in six inch drill-rows to Macsel alfalfa. Applications to the soil were made by Mr. Silversides on June 18, 1940 and by the author on May 14, 1943, at the following rates per acre:

	1940	1943
Triple superphosphate (43% P_2O_5)	160 lb.	400 lb.
Calcium hydroxide ($Ca(OH)_2$)	10 tons	nil

	1940	1943
Borax	12 lb.	25 lb.
Potassium sulphate	100 lb.	200 lb.
Potassium chloride	nil	170 lb.

(b) Experimental Field B

A field with an established stand of Macsel alfalfa in six inch drill-rows (seeded in the fall of 1938) was divided into three replicates. Each replicate consisted of six randomized 1/240 acre plots receiving the treatments of (1) no treatment, (2) burning, (3) elemental sulphur, (4) manganese, (5) zinc, and (6) copper. For the burning treatments a mixed straw (oats, barley and some wheat) was applied at the rate of eight tons per acre. The chemicals were dissolved or dispersed in water and applied as a spray to the soil and new shoots, at the following rates:

Elemental sulphur - 150 lbs. per acre
Manganese sulphate - 50 " " "
Zinc sulphate - 25 " " "
Copper sulphate - 50 " " "

The treatments were applied on May 12, 1943.

The alfalfa flowers showed little evidence of tripping during the summer of this experiment. This lack of sufficient tripping by insects might have limited seed setting to such an extent as to conceal any beneficial effects resulting from the soil treatments. In order to

ascertain whether the treatments would have any effect on the seed set of alfalfa pods under conditions of artificial tripping, the author on August 16th selected at random ten racemes from each plot, tripped their flowers by hand, and allowed them to remain in the field uncovered under natural conditions until pods formed, at which time seed counts were made.

(c) Experimental Field C

An established stand of Macsel alfalfa in rows three feet apart (seeded in the spring of 1934) was divided into three replicates. In each replicate the following treatments were applied to randomized rows, each 32 feet in length; no treatment, nitrogen, sodium carbonate, and various minor elements. The treatments were made on June 12, 1943, as follows:

(1) Sodium carbonate-	1 ton per acre of	washing soda,
(2) Nitrogen	- 300 lbs. " " "	ammonium sulphate,
(3) Calcium	- 200 lbs. " " "	calcium chloride,
(4) Magnesium	- 100 lbs. " " "	magnesium chloride,
(5) Iron	- 80 lbs. " " "	ferrous sulphate (sprayed on plants 8% water-solution of ferrous sulphate, at rate of 100 gals. per acre),
(6) Cobalt	- 10 lbs. per acre of	cobalt chloride,
(7) Fluorine	- 10 lbs. " " "	sodium fluoride,
(8) Aluminum	- 8 lbs. " " "	aluminum sulphate,
(9) Lithium	- 2 lbs. " " "	lithium citrate,
(10) Molybdenum	- 1 lb. " " "	molybdic acid (min. 85% MoO_3),

(11) Iodine - 45 gms. per acre of potassium iodide,

(12) Boron (trace) - sprayed plants with 300 gals. per acre of water-solution of 2.5 p.p.m. boric acid,

(13) Calcium & Boron (trace) - (3) and (12) combined.

As in the case of Experimental Field B, ten racemes were selected at random from each plot on August 16th and their flowers were hand-tripped and left in the field uncovered until the pods formed. Counts of the number of seeds per pod were made.

Results

The average seed yields for Field A are given in Table 3, while the detailed yields appear in Tables 4 and 6. The yields for Fields B and C are presented in Tables 8 and 10. Statistical analysis of the data (Tables 5, 7, and 9) indicates that the seed set in the treated plots was not significantly different from that in the check plots. Due to a number of missing plots, an analysis of variance was not made on the yields of Field C where by examining the data it is obvious that there are no significant differences between the treatments. It will be noted that the boron plots in Experimental Field A (Table 4), in all cases except one, yielded more than the corresponding no treatment plots. However, the experimental design of this particular field was such that the difference between these two treatments was not measured with high statistical precision, there being only

two degrees of freedom for its error variance (see Table 5). Thus, the analysis of variance shows no significant difference between boron and no treatment. On account of the fact that these plots were not randomized the differences in yield noted above may have been due to a soil fertility gradient.

The number of seeds per pod from hand-tripped alfalfa flowers on Fields B and C is given in Tables 11 and 13 respectively. The analysis of variance (Tables 12 and 14) shows that there are no differences between the soil treatments as regards the number seeds per pod.

Table 3. - Average yields of alfalfa seed at the University (Experimental Field A), in pounds per acre.

Treatment	None	Borax	Average
None	34.4	39.6	37.0
$CaCO_3$	28.8	42.3	35.5
P_2O_5	28.1	31.1	29.6
Average	30.4	37.7	34.0

Treatment	KCl	K_2SO_4	Average
None	23.2	22.1	22.6
$CaCO_3$	14.1	18.5	16.3
P_2O_5	17.1	9.6	13.4
Average	18.1	16.7	17.4

Table 4. - Yields of alfalfa seed at the University (Experimental Field A), in pounds per acre.

Basic treatment	Cross-strip treatment	Replicates 1	2	3	Total	
$CaCO_3$	None	34.0	28.6	23.7	86.3	213.2
	Borax	43.8	40.5	42.6	126.9	
None	None	28.5	35.9	38.7	103.1	221.8
	Borax	42.3	28.7	47.7	118.7	
P_2O_5	None	28.7	26.0	29.5	84.2	177.6
	Borax	31.4	29.6	32.4	93.4	
Total	None	91.2	90.5	91.9	273.6	612.6
	Borax	117.5	98.8	122.7	339.0	

Table 5. - Analysis of variance for yields in Table 4.

	SS	DF	MS	F	5% pt.
Replicates	58.403	2	29.202	1.02	6.94
P_2O_5, Chk, CaO	183.053	2	91.526	3.20	6.94
Error (a)	114.263	4	28.566		
Borax vs. None	237.620	1	237.620	10.06	18.51
Error (b)	47.250	2	23.625		
B x P, Ch, CaO	91.773	2	45.886	1.90	6.94
Error (c)	96.758	4	24.190		
Total	829.120	17			

Table 6. - Yields of alfalfa seed at the University (Experimental Field A), in pounds per acre.

Basic treatment	Cross-strip treatment	Replicates 1	2	3		Total
$CaCO_3$	KCl	10.7	11.8	19.8	42.3	97.7
	K_2SO_4	14.4	8.3	32.7	55.4	
None	KCl	15.7	22.7	31.2	69.6	135.8
	K_2SO_4	16.3	22.2	27.7	66.2	
P_2O_5	KCl	23.4	15.4	12.6	51.4	80.2
	K_2SO_4	11.9	9.3	7.6	28.8	
Total	KCl	49.8	49.9	63.6	163.3	313.7
	K_2SO_4	42.6	39.8	68.0	150.4	

Table 7. - Analysis of variance for yields in Table 6.

	SS	DF	MS	F	5% pt.
Replicates	183.308	2	91.654	1.01	6.94
P_2O_5, Chk, CaO	269.401	2	134.700	1.49	6.94
Error (a)	362.052	4	90.513		
KCl vs. K_2SO_4	9.245	1	9.245	0.94	18.51
Error (b)	19.623	2	9.812		
Cl, SO_4 x P, Ch, CaO	106.410	2	53.205	3.30	6.94
Error (c)	64.557	4	16.139		
Total	1,014.596	17			

Table 8. - Yields of alfalfa seed at the University (Experimental Field B), in pounds per acre.

Treatment	Replicates 1	2	3	Total	Average
Copper	40.1	34.0	39.8	113.9	38.0
Zinc	47.7	22.4	30.8	100.9	33.6
No treatment	26.2	41.8	21.0	89.0	29.7
Manganese	31.2	21.9	24.8	77.9	26.0
Sulphur	20.0	31.8	26.0	77.8	25.9
Straw burning	20.1	24.2	26.5	70.8	23.6
Total	185.3	176.1	168.9	530.3	29.5

Table 9. - Analysis of variance for yields in Table 8.

	SS	DF	MS	F	5% pt.
Treatments	446.41	5	89.282	1.48	3.11
Error	726.01	12	60.501		
Total	1172.42	17			

Table 10. - Alfalfa seed yields at the University (Experimental Field C), in pounds per acre.

Treatment	Replic.1	Replic.2	Replic.3	Average
Calcium	27.7	-	-	27.7
Calcium & Boron (trace)	23.8	-	17.4	20.6
Aluminum	20.2	-	15.5	17.8
Iodine	20.4	13.0	19.8	17.7
No treatment	20.7	17.8	14.4	17.6
Boron (trace)	19.2	15.8	-	17.5
Iron	22.6	11.7	-	17.2
Cobalt	-	18.2	16.0	17.1
Lithium	18.1	16.3	13.0	15.8
Molybdenum	11.7	14.4	21.2	15.8
Magnesium	15.5	12.4	15.7	14.5
Fluorine	15.8	14.3	10.4	13.5
Sod. Carbonate	18.4	-	7.0	12.7
Nitrogen	-	9.2	-	9.2

Table 11. - Average number of seeds per pod from hand-tripped alfalfa flowers at the University (Experimental Field B)

Treatment	Replic.1	Replic.2	Replic.3	Total	Average
No treatment	1.65	2.75	1.21	5.61	1.87
Copper	1.75	1.88	1.97	5.60	1.87
Sulphur	2.06	1.51	1.46	5.03	1.68
Zinc	1.90	1.57	1.52	4.99	1.66
Manganese	1.54	1.70	1.68	4.92	1.64
Straw burning	1.41	1.81	1.21	4.43	1.48
Total	10.31	11.22	9.05	30.58	1.70

Table 12. - Analysis of variance for data in Table 11.

	SS	DF	MS	F	5% pt.
Treatments	0.3361	5	.06722	0.45	3.11
Error	1.7917	12	.14931		
Total	2.1278	17			

Table 13. - Average number of seeds per pod from hand-tripped alfalfa flowers at the University (Experimental Field C).

Treatment	Replic.1	Replic.2	Replic.3	Total	Average
Iron	1.54	2.68	1.38	5.60	1.87
Sod. Carbonate	2.62	1.63	1.20	5.45	1.82
Calcium	1.76	1.08	2.27	5.11	1.70
No treatment	1.46	1.70	1.69	4.85	1.62
Fluorine	1.94	1.21	1.53	4.68	1.56
Molybdenum	1.47	1.67	1.54	4.68	1.56
Cobalt	1.44	1.23	1.96	4.63	1.54
Calcium & Boron (trace)	1.71	1.53	1.27	4.51	1.50
Magnesium	0.90	1.30	2.17	4.37	1.46
Nitrogen	1.49	1.50	1.18	4.17	1.39
Lithium	1.61	1.11	1.33	4.05	1.35
Iodine	1.85	0.91	0.96	3.72	1.24
Aluminum	1.07	1.07	1.30	3.44	1.15
Total	20.86	18.62	19.78	59.26	1.52

Table 14. - Analysis of variance for data in Table 13.

	SS	DF	MS	F	5% pt.
Treatments	1.5683	12	0.1307	0.66	2.15
Error	5.1137	26	0.1967		
Total	6.6820	38			

II. Arborg

The soil on which the experiment at Arborg was conducted is a Rendzina-like soil of clay texture developed on calcareous material of lacustrine origin. The experimental plots were located on the farm of Mr. Gunnar Simundson (S.W. 1/4 Sec. 5; Twp. 23; R 3 E).

Methods

An established stand of Grimm alfalfa (seeded in May, 1939) was divided into three replicates. Each replicate consisted of eight 1/90 acre plots receiving the following treatments, which were randomized among the eight plots of each replicate:

(1)	No treatment	
(2)	Ammonium sulphate	- 300 lbs. per acre
(3)	Triple superphosphate (43% P_2O_5)	- 400 lbs. " "
(4)	Potassium chloride	- 200 lbs. " "
(5)	(Triple superphosphate (& Potassium sulphate	- 200 lbs. " ") - 150 lbs. " ")
(6)	Elemental sulphur	- 200 lbs. " "
(7)	Borax	- 25 lbs. " "
(8)	Burning	- 2 tons of wild hay per acre.

At one end of the plots two strips were placed across the above treatments. In one strip manganese sulphate was added at the rate of 85 pounds per acre, and in the other borax at 15 pounds per acre. All the treatments were applied on May 21, 1943.

Results

Very little seed set on all the plots and no differences between the treatments were observed.

III. Benito

The soil on which the experiment near Benito was conducted is of the grey-wooded type. The experimental plots were located on the farm of Mr. J. H. Stenberg (S.E. Sec. 6; Twp. 33; R 29 W). The alfalfa stand was fairly poor; the field was weedy with Kentucky bluegrass and sow thistle.

Methods

On May 31, 1943, three replicates were laid out, each consisting of eight 1/90 acre plots receiving the following randomized treatments:

(1)	No treatment	
(2)	Ammonium sulphate	- 300 lbs. per acre
(3)	Triple superphosphate (43% P_2O_5)	- 400 lbs. " "
(4)	Potassium chloride	- 200 lbs. " "
(5)	(Triple superphosphate (& Potassium sulphate	- 200 lbs. " ") - 150 lbs. " ")
(6)	Elemental sulphur	- 100 lbs. " "
(7)	Borax	- 25 lbs. " "
(8)	Calcium hydroxide	- 5 tons " "

At one end of the plots two strips were placed across the above treatments. In one strip manganese sulphate was added at the rate of 45 pounds per acre, and in the other

borax at 13 pounds per acre.

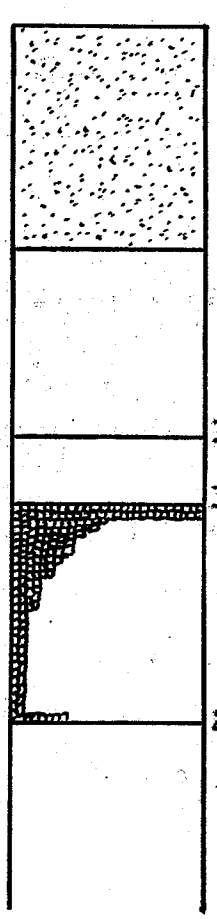
Results

There was a heavier growth and more blooming on all the plots treated with phosphate. The growth on the calcium hydroxide plots was better than that on the check plots but was not as good as on the plots receiving phosphate. There was very little seed setting on any plot and no differences between the treatments were observed.

IV. South Junction

The experimental plots at South Junction were located on the farm of Mr. E. Hallberg (N.W. 1/4 Sec. 1; Twp. 1; R 13 E). The alfalfa stand was a poor one and there was much Kentucky bluegrass present. The soil on which the experiment was conducted is of a local podzolic type and has been tentatively designated by Professor J. H. Ellis as Wampum loamy sand. The parent material is a sand deposit over calcareous till that has been subject to podzolic soil forming processes. A description of the profile of the soil on which the experiment was conducted is presented on the following page.

Description of Soil Profile of Experimental Field at South Junction



Cultivated layer, dark grey, fine sand, structureless, neutral in reaction.
(Moisture Equivalent = 6.86)

Brownish grey, fine sand, structureless when moist, weakly indurated when dry, neutral in reaction.
(Moisture Equivalent = 3.67)

Grey buff, loamy very fine sand, structureless, neutral in reaction.
(Moisture Equivalent = 6.60)

Chocolate brown, heavy clay loam to clay, with light grey mottling when dry, coarsely granular to small nutty structure, compact, slightly alkaline in reaction.
(Moisture Equivalent = 29.76)

Light grey, heavy clay loam calcareous till, strongly alkaline in reaction.
(Moisture Equivalent = 27.50)

Agronomic Investigations

(a) Methods

An established stand of Grimm alfalfa (seeded in 1940) was divided into three replicates. Each replicate consisted of ten longitudinal 1/90 acre plots receiving the following treatments:

(1) No treatment

(2) Early burn - applied alfalfa straw at 2½ tons per acre and burned

(3) Potassium sulphate - 200 lbs. per acre

(4) Triple superphosphate (43% P_2O_5) - 150 lbs. " "

(5) Potassium chloride - 150 lbs. " "

(6) Late burn - applied alfalfa straw at 2½ tons per acre and burned

(7) (Triple superphosphate - 150 lbs. per acre)
(& Potassium chloride - 150 lbs. " ")

(8) Calcium sulphate - 200 lbs. " "

(9) Calcium carbonate (powdered) - 5 tons " "

(10) No treatment

The plots were divided crosswise into three strips, with the following additional treatments:

(1) No treatment

(2) Borax - 25 lbs. per acre.

(3) Manganese sulphate - 50 lbs. " "

The dates on which the treatments were applied

were as follows:

April 28, 1943: potassium sulphate, calcium sulphate, triple superphosphate, potassium chloride, triple superphosphate & potassium chloride.

May 18, 1943: calcium carbonate, borax, manganese sulphate, and early burn.

May 28, 1943: late burn.

The seed yields were determined by harvesting and hand-threshing two square-yard samples from the plots of the no treatment cross-strip and one square-yard samples from the plots of the manganese sulphate and borax cross-strips.

In this experiment all sulphate treatments markedly increased the seed yield as well as the vegetative growth. This raised the question of whether the set of seed by the individual pods had been affected. In order to answer this, samples of 100 pods each were taken at random from mature alfalfa plants grown on four sulphate treated ($CaSO_4$ and K_2SO_4) and two untreated (no treatment and KCl) plots. The pods were weighed, and the seeds were carefully removed from the individual pods, counted and weighed. The seed from each of these hundred pod samples was then submitted to the Dominion Plant Products Division, Production Service, for a germination test. The combined percentage of normal seedlings and hard seeds was taken as a measure of the seed viability.

(b) Results

An outstanding improvement in the alfalfa stand was obtained on all plots receiving sulphur-containing compounds (calcium sulphate, potassium sulphate, and manganese sulphate). The alfalfa plants on the plots receiving sulphates were dark green in color and bloomed profusely, whereas the plants on the untreated plots were yellowish in color and showed little blooming. Kentucky bluegrass was crowding out the alfalfa on the untreated plots while on the sulphate treated plots the opposite was the case. Representative square yard samples of the alfalfa in the early bloom stage from plots receiving no treatment, potassium sulphate, potassium chloride, and calcium sulphate, are shown in Figure 2 (page 53). Square yard samples of mature plants are shown in Figures 3 to 5 (pages 54 to 56).

The average seed yields are presented in Table 15 (page 44), while the detailed yields appear in Table 16 (page 46). Sulphur increased the seed production more than ten times. Phosphorus also gave a significant increase in the seed set, but the response was not as great as in the case of sulphur. In field observations, the early burning of alfalfa straw appeared to give some improvement over no treatment, although the data do not indicate the improvement to be significant statistically. The failure to obtain significance here may be due to the small size of samples harvested which resulted in a high error variance. These

THE UNIVERSITY OF MANITOBA LIBRARY

treatment effects are shown graphically in Figure 1[x] (page 45). None of the other treatments gave a significant response.

In Table 20 (page 49) the cross-strip treatments are compared with each other by combining the yields of all plots within each cross-strip. The analysis of variance (Table 21, page 49) indicates no significant differences between the no treatment and borax cross-strips. When these two are compared with the manganese sulphate cross-strip the difference is highly significant. It will be noted in Table 16 (page 46) that twenty of the thirty boron plots yielded more than the corresponding plots of the no treatment cross-strip. The differences were small and such as might be expected to occur by chance in sampling, and consequently are not significant.

The data on the effect of the sulphate application upon the seed set of the pods is given in Table 23 (page 51), and the data on the effect upon the germination and viability

---

[x] In computing the averages for the graph in Figure 1, the yields from the boron strip were combined with those of the "no treatment" cross-strip, and the calcium carbonate and potassium chloride plots combined with the no treatment plots, since there were no significant differences in seed yield between these.

of the seed produced is presented in Table 24 (page 52). The averages for these two tables are presented in Table 22 (page 50). Analysis by the t-test indicates that the sulphate had significantly increased the pod weight, weight of the seed in each pod, the number of seed in each pod, and the percentage of viable seed produced. It had no effect upon the number of shrivelled seed in each pod or upon the percentage of normal seedlings.

Table 15. - Average yields of alfalfa seed at South Junction, Man., in pounds per acre.

Basic plot treatment	No treatment cross-strip	Borax cross-strip	Mang. sulphate[1] cross-strip
No treatment	6.7	14.2	109.5
No treatment	19.0	21.3	117.3
KCl	9.0	18.3	118.9
$CaCO_3$	12.7	14.5	132.1
Late burn[3]	21.7	22.1	77.4
Early burn[4]	37.9	49.9	198.0
P_2O_5 & KCl.	45.9	97.5	134.5
P_2O_5	87.6	124.1	220.4
$CaSO_4$ [2]	129.2	180.8	181.0
K_2SO_4 [2]	210.4	195.8	219.9
Necess. Diff.			
at 5% level	50.3	79.6	90.1
at 1% level	68.4	109.2	123.5

[1] At a rate equivalent to about 7 lbs. sulphur per acre.
[2] At a rate equivalent to about 34 lbs. sulphur per acre.
[3] On May 18th applied alfalfa straw and burned.
[4] On May 28th applied alfalfa straw and burned.

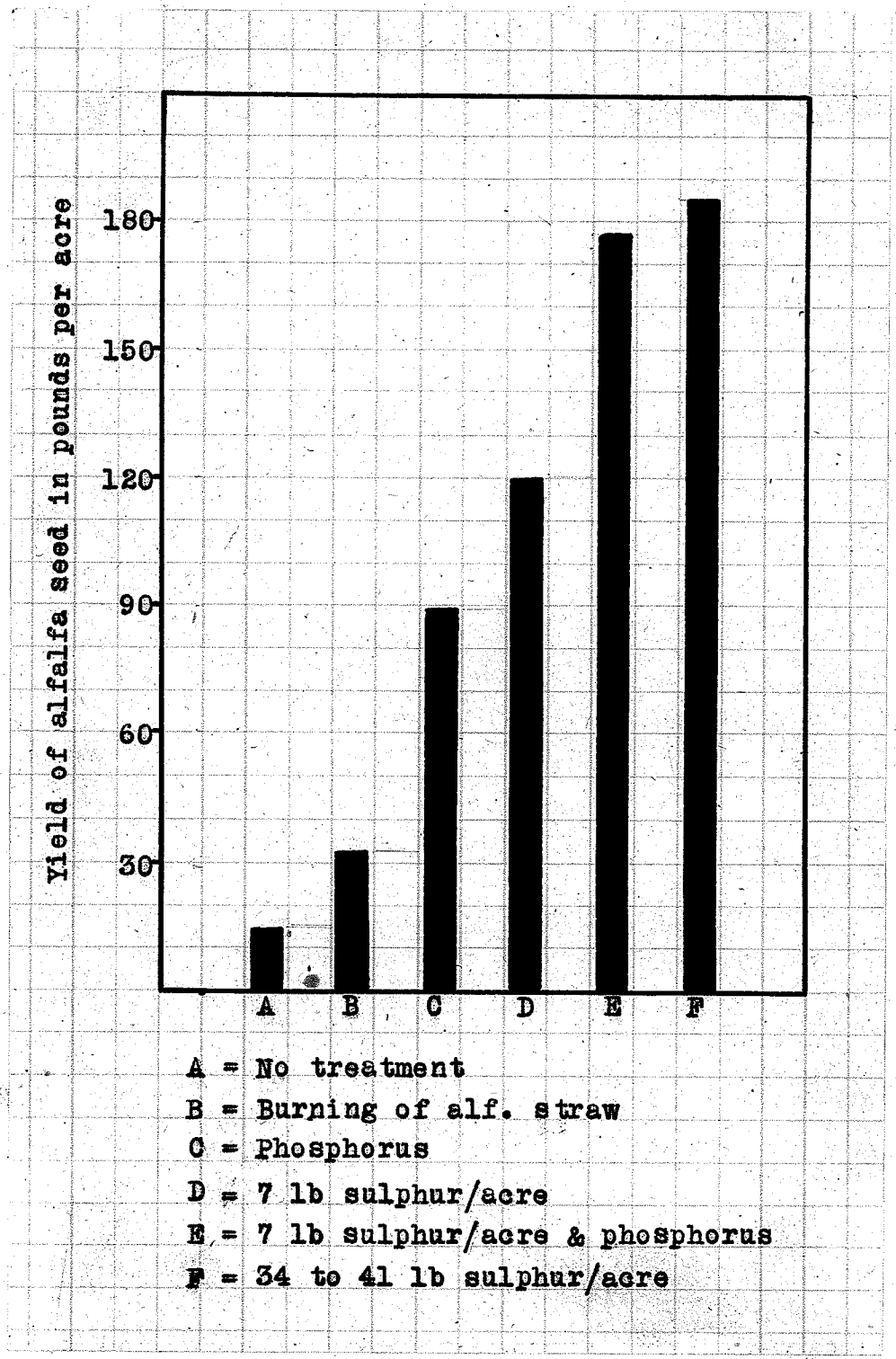


Figure 1. - Graph showing effect of soil treatments upon average yields of alfalfa seed at South Junction, Man.

Table 16. - Yields[X] of alfalfa seed in pounds per acre from plots receiving different treatments at South Junction.

	1 No Treatment	2 Early Burn	3 K_2SO_4	4 P_2O_5	5 KCl	6 Late Burn	7 P_2O_5 & KCl	8 $CaSO_4$	9 $CaCO_3$	10 No Treatment	Total
"No treatment" cross-strip:											
Replic. A	5.9	27.7	217.8	146.7	9.7	11.2	41.8	91.1	3.0	7.8	562.7
" B	10.7	58.5	163.2	57.1	6.5	33.7	32.8	190.5	5.3	9.0	567.3
" C	3.6	27.4	250.3	59.0	10.9	20.1	63.2	105.9	29.7	40.3	610.4
Total	20.2	113.6	631.3	262.8	27.1	65.0	137.8	387.5	38.0	57.1	1740.4
Borax cross-strip:											
Replic. A	6.6	34.7	236.2	55.0	24.0	11.5	41.8	203.2	11.8	12.6	637.4
" B	20.3	72.3	136.9	129.5	6.1	47.8	19.9	181.2	13.7	12.5	640.2
" C	15.8	42.6	214.4	187.7	24.9	7.0	230.9	158.1	18.1	38.9	938.4
Total	42.7	149.6	587.5	372.2	55.0	66.3	292.6	542.5	43.6	64.0	2216.0
Mang. sulphate cross-strip:											
Replic. A	127.5	254.6	168.9	290.1	226.6	89.4	169.2	249.1	171.5	135.9	1882.8
" B	137.2	206.6	277.8	232.3	48.2	93.6	111.1	159.8	36.6	90.7	1393.9
" C	63.7	132.7	213.1	138.8	81.8	49.2	123.2	134.1	188.1	125.4	1250.1
Total	328.4	593.9	659.8	661.2	356.6	232.2	403.5	543.0	396.2	352.0	4526.8

[X] Yields obtained from 2 sq.-yd. samples on plots of "no treatment" cross-strip and from 1 sq.-yd. samples on plots of borax and mang. sulphate cross-strips.

Table 17. - Analysis of variance for "no treatment" cross-strip at South Junction.

	SS	DF	MS	F	1% pt.
Treatments	118,942.07	9	13,215.79	15.19[xx]	3.45
Error	17,404.54	20	870.227		
Total	136,346.61	29			

[xx]Highly significant.

Table 18. - Analysis of variance for borax cross-strip at South Junction, Man.

	SS	DF	MS	F	1% pt.
Treatments	136,721.87	9	15,191.32	7.04[xx]	3.60
Replicates	5,984.40	2	2,992.20	1.39	6.01
Error	38,842.00	18	2,157.89		
Total	181,548.27	29			

[xx]Highly significant

Table 19. - Analysis of variance for man. sulphate cross-strip at South Junction, Man.

	SS	DF	MS	F	5% pt.	1% pt.
Treatments	67,837.84	9	7,537.54	2.73[x]	2.46	3.60
Replics.	22,000.36	2	11,000.18	3.99[x]	3.55	6.01
Error	49,657.68	18	2,758.76			
Total	139,495.88	29				

[x]Significant

Table 20. - Yields of alfalfa seed on the cross-strips at South Junction, Man., in pounds per acre.

Application	Replic.A	Replic.B	Replic.C	Total
$MnSO_4$ [x]	188.28	139.39	125.01	452.68
Borax [x]	63.74	64.02	93.84	221.60
No treatment [x]	56.27	56.73	61.04	174.04
Total	308.29	260.14	279.89	848.32

[x] Average yield of all plots in the cross-strip.

Table 21. - Analysis of variance for alfalfa seed yields of cross-strips at South Junction, Man.

	SS	DF	MS	F	1% pt.
No treatment vs Borax	376.992	1	376.992	0.80	13.74
No treatment & Borax vs $MnSO_4$	14,434.138	1	14,434.138	30.79 [xx]	13.74
Error	2,812.324	6	468.721		
Total	17,623.454	8			

[xx] Highly significant

Table 22. - Effect of sulphate application at South Junction, Man., upon the seed set of alfalfa pods and upon the germination and viability of the seeds (averages for data in Tables 23 & 24).

	Application		Increase with Sulphate Application		t-value[1]
	No sulphate	Sulphate	Absolute	Relative %	
Wt. of 100 pods, gm.	1.115	1.305	0.19	17.0	7.58[x]
Wt. of seed in 100 pods, gm.	0.466	0.663	0.197	42.3	10.42[x]
No. of seed in 100 pods.	410	499	89	21.7	4.14[x]
No. of non-shrivelled seed in 100 pods.	263.5	355.5	92	34.9	4.75[x]
No. of shrivelled seed in 100 pods.	146.5	143.5	-3	-2.0	0.09
Wt. per 1000 seed, gm.	1.135	1.335	0.20	17.6	2.36
Germination results:					
Normal seedlings, %	24.00	25.38	1.38	5.8	0.34
Abnormal seedlings, %	8.00	5.62	-2.38	-29.8	1.36
Hard seed, %	34.25	50.88	16.63	48.6	2.20
Viable seed[2], %	58.25	76.25	18.00	30.9	3.59[x]
Dead Seed, %	33.75	18.12	-15.63	-46.3	4.57[x]

[1] t-value necessary for significance:
5% pt. - 2.78
2% pt. - 3.75
1% pt. - 4.60

[2] Normal seedlings plus hard seed.

[x] Significant.

Table 23. - Effect of sulphate application upon the seed set of alfalfa pods at South Junction, Man.

	Wt. of 100 pods, gm.		Wt. of seed in 100 pods, gm.		No. of seed in 100 pods		No. of non-shrivelled seed in 100 pods		No. of shrivelled seed in 100 pods		Wt. per 1000 seed, gm.	
	O[1]	S[2]	O	S	O	S	O	S	O	S	O	S
	1.11	1.27	0.481	0.650	418	512	277	351	141	161	1.15	1.27
	1.12	1.35	0.451	0.695	402	473	250	389	152	84	1.12	1.47
		1.30		0.660		479		335		144		1.38
		1.30		0.647		532		347		185		1.22
Average	1.115	1.305	0.466	0.663	410	499	263.5	355.5	146.5	143.5	1.135	1.335
Av. increase with S application												
Absolute	0.19		0.197		89		92		-3		0.20	
Relative,%	17.0		42.3		21.7		34.9		-2.0		17.6	
t-value[3]	7.58		10.42		4.14		4.75		0.09		2.36	

[1] No sulphate applied (Check).

[2] Sulphate applied to soil.

[3] t-value necessary for significance: 5% pt. - 2.78, 2% pt. - 3.75, 1% pt. - 4.60

Table 24. - Effect of sulphate application upon the germination and viability of alfalfa seed at South Junction, Man.

	% normal seedlings		% abnormal seedlings		% hard seed		% viable seed (normal & hard)		% dead seed	
	0[1]	S[2]	0	S	0	S	0	S	0	S
	25.0	31.0	10.0	4.5	28.0	46.5	53.0	77.5	37.0	18.0
	23.0	19.5	6.0	4.0	40.5	63.5	63.5	83.0	30.5	13.0
		28.5		7.5		44.0		72.5		20.0
		22.5		6.5		49.5		72.0		21.5
Average	24.00	25.38	8.00	5.62	34.25	50.88	58.25	76.25	33.75	18.12
Av. increase with S application										
Absolute		1.38		-2.38		16.63		18.00		-15.63
Relative,%		5.8		-29.8		48.6		30.9		-46.3
t-value[3]		0.34		1.36		2.20		3.59		4.57

[1] No sulphate applied (Check).

[2] Sulphate applied to soil.

[3] t-value necessary for significance: 5% pt. - 2.78, 2% pt. - 3.75, 1% pt. - 4.60

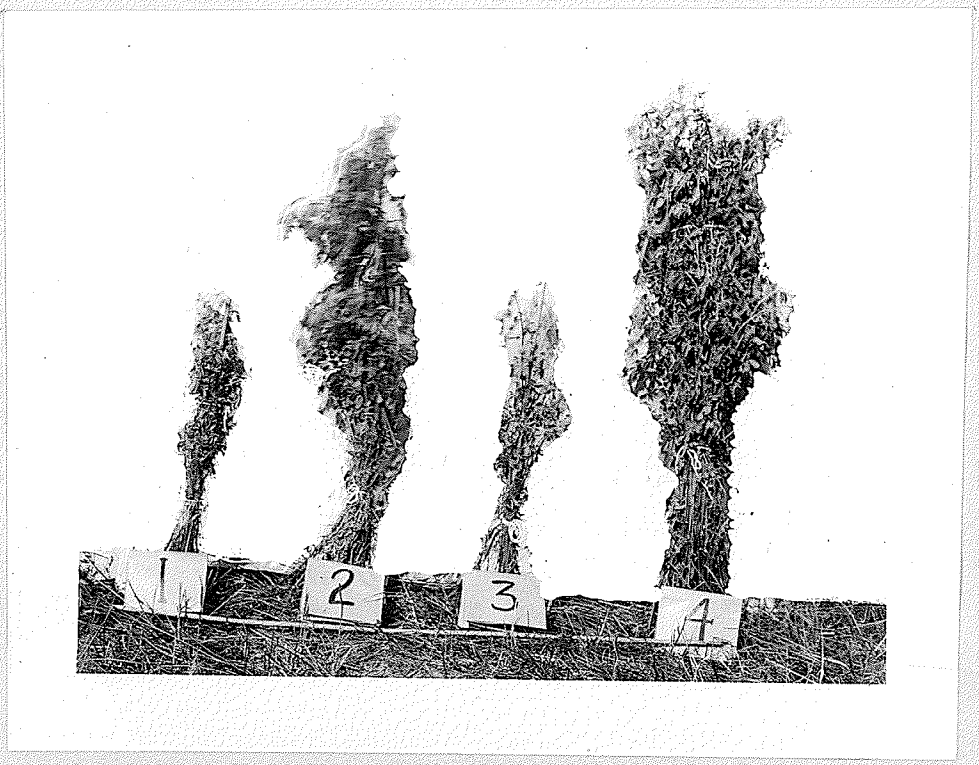


Figure 2. - Square yard samples of alfalfa plants (early bloom stage) from plots at South Junction receiving the following treatments:

1. No treatment,
2. Potassium sulphate,
3. Potassium chloride,
4. Calcium sulphate.

(Photographed by J. H. Ellis).



Figure 3. - Square yard samples of mature alfalfa plants from plots at South Junction treated with the following: no treatment, gypsum (calcium sulphate), potassium chloride, and potassium sulphate. A marked increase in seed set from the application of sulphates to the soil is apparent. (Photographed by A. M. Brown).

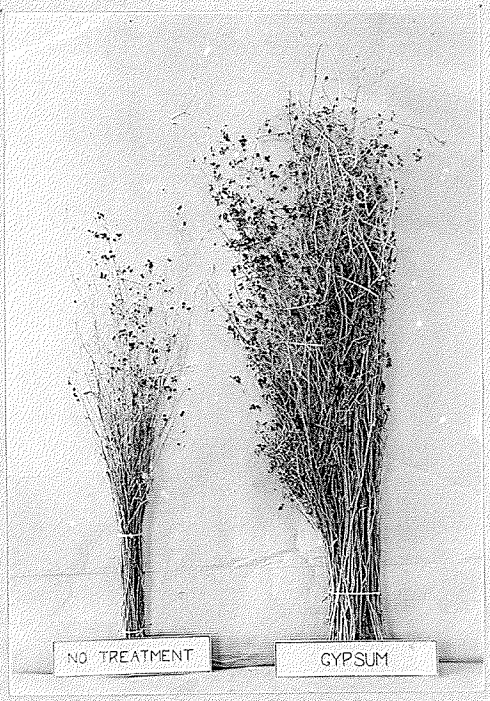


Figure 4. - Square yard samples of alfalfa plants from the experimental plots at South Junction. A close-up view of these plants is given in Figure 5.

(Photographed by A. M. Brown).



No treatment Gypsum

Figure 5. - A close-up view of the alfalfa plants in Figure 4. (Photographed by A. M. Brown).

Analyses of Plant Material and Seed

Samples of alfalfa plants in the early bloom stage were obtained from three sulphate treated plots, and from three plots receiving no sulphate treatment. These were analyzed for sulphur and nitrogen. Seed samples from the plots receiving the treatments, no treatment, early burn, triple superphosphate, calcium sulphate, and potassium sulphate, were also analyzed for sulphur and nitrogen.

It was deemed advisable to compare the sulphur content of the South Junction seed with that of seed produced by alfalfa plants grown at other points. Samples were obtained from three different locations, namely, 1) Lenswood (near Bowsman), Man., 2) Teulon, Man., and 3) Red River Valley of North Dakota[x], and analyzed for sulphur.

(a) Methods

The nitrogen and sulphur content of the plant material and seed samples were determined by the official methods of the Association of Official Agricultural Chemists (7), nitrogen by the Kjeldahl-Gunning-Arnold method and the sulphur by the magnesium nitrate method.

In the statistical analyses of the data on the nitrogen and sulphur content of the seed samples, the treatment sums of squares were separated into orthogonal components representing individual degrees of freedom, in order that logical comparisons may be more clearly demonstrated.

[x] Exact location unknown.

(b) Results

Sulphate application increased the sulphur and nitrogen (and protein) content of the alfalfa plants and of the seed (Tables 25, 27, 29, and 33, pages 59, 60, 61 and 65, respectively). In the case of the sulphur content of the seed, there was a relative increase of 45%. These increases were all highly significant (Tables 26, 28, 31, and 34, pages 59, 60, 63 and 66, respectively). There was no statistically significant differences in the sulphur and nitrogen content between the seed samples from the no treatment, early burn and triple superphosphate plots (Tables 29, 31, 33, and 34, pages 61, 63, 65 and 66, respectively).

The sulphur content of the seed samples obtained from the three other locations were distinctly higher than that of the seed produced on South Junction plots not treated with sulphur, and was about the same as that of the sulphur treated South Junction plots (Table 29, page 61). By considering the areas outside South Junction as another treatment (designated in the Tables as "Norm"), with samples from three different stations to offset station effect, the analysis of variance indicates that in sulphur content of seed there is a highly significant difference between them and the South Junction plots not receiving sulphur (Table 32, page 64), and no significant differences between them and the sulphur treated South Junction plots (Table 30, page 62).

Table 25. - Effect of sulphur fertilizers upon the sulphur content of alfalfa plants (early bloom stage) at South Junction, Man.

Application	% S[x]	Application	% S[x]
No treatment	.13	$CaSO_4$	.22
No treatment	.12	$CaSO_4$	.22
KCl	.12	K_2SO_4	.23
Average	.12	Average	.22

[x]Moisture-free basis

Table 26. - Analysis of variance for effect of sulphur fertilizers upon sulphur content of alfalfa plants at South Junction, Man.

	SS	DF	MS	F	1% pt.
S applied vs no S applied	.015000	1	.015000	454.5[xx]	21.20
Error	.000133	4	.000033		
Total	.015133	5			

[xx]Highly significant

Table 27. - Effect of sulphur fertilizers upon the nitrogen content of alfalfa plants (early bloom stage) at South Junction, Man.

Application	% N_2 [x]	Application	% N_2 [x]
No treatment	2.36	$CaSO_4$	2.78
No treatment	2.40	$CaSO_4$	2.78
KCl	2.54	K_2SO_4	2.92
Average	2.43	Average	2.83

[x] Moisture-free basis

Table 28. - Analysis of variance for effect of sulphur fertilizers upon nitrogen content of alfalfa plants at South Junction, Man.

	SS	DF	MS	F	1% Pt.
S applied vs no S applied	.232067	1	.232067	746.2[XX]	34.12
K applied vs no K applied	.030000	1	.030000	96.46[XX]	34.12
Error	.000933	3	.000311		
Total	.263000	5			

[XX] Highly significant

Table 29. - Effect of different soil treatments upon the sulphur content of alfalfa seed at South Junction; and a comparison with the sulphur content of seed from other areas.

	Treatment	% sulphur (H_2O-free basis) in seed				
		Samples from field replicates			Total	Average
No S	Check	.21	.20	.19	.60	.20
	Burn[4]	.21	.19	.19	.59	.20
	P_2O_5	.20	.21	.19	.60	.20
S	$CaSO_4$	.26	.32	.30	.88	.29
	K_2SO_4	.30	.29	.27	.86	.29
Norm	Other areas	.26[1]	.32[2]	.25[3]	.83	.28

[1]Sample of alfalfa seed produced at Lenswood, Man.
[2]Sample of alfalfa seed produced at Teulon, Man.
[3]Sample of alfalfa seed produced in the Red River Valley of North Dakota.
[4]Early burning of applied alfalfa straw.

Table 30. - Analysis of variance for sulphur content of alfalfa seed at South Junction and other areas (data in Table 29).

	DF	SS	DF	MS	F	1% pt.
Treatments	5	.03424				
No S vs S & Norm			1	.03380	69.1XX	9.33
S vs Norm			1	.00035	0.72	9.33
Within S						
$CaSO_4$ vs K_2SO_4			1	.00007	0.14	9.33
Within No S						
Chk vs P_2O_5			1	.00000	0.00	9.33
Chk & P_2O_5 vs Burn			1	.00002	0.04	9.33
Error	12	.00587		.000489		
Total	17	.04011				

XX Highly significant

Table 31. - Analysis of variance for sulphur content of alfalfa seed at South Junction, Manitoba.

	DF	SS	DF	MS	F	1% pt.
Treatments	4	.02997				
No S vs S			1	.02988	99.6^{xx}	10.04
Within S						
$CaSO_4$ vs K_2SO_4			1	.00007	0.23	10.04
Within No S						
Chk vs P_2O_5			1	.00000	0.00	10.04
Chk & P_2O_5 vs Burn			1	.00002	0.07	10.04
Error	10	.00300		.00030		
Total	14	.03297				

^{xx}Highly significant

Table 32. - Analysis of variance for sulphur content of alfalfa seed from plots at South Junction not receiving sulphur (No S) and from other areas (Norm).

	DF	SS	DF	MS	F	1% pt.
Treatments	3	.01363				
No S vs Norm			1	.01361	30.8^{xx}	11.26
Within No S						
Check vs P_2O_5			1	.00000	0.00	11.26
Check & P_2O_5 vs Burn			1	.00002	0.05	11.26
Error	8	.00354		.000442		
Total	11	.01717				

^{xx} Highly significant

Table 33. - Effect of soil treatments upon nitrogen content of alfalfa seed at South Junction, Man.

Application		Per cent nitrogen (H_2O-free basis) in seed.					
		Samples from field replics.			Total	Average	
No S	Check	5.81	5.81	5.83	17.45	5.82	5.84
	Burn[1]	5.86	5.88	5.93	17.67	5.89	
	P_2O_5	5.81	5.73	5.86	17.40	5.80	
S	$CaSO_4$	6.14	6.01	5.90	18.05	6.02	6.00
	K_2SO_4	5.94	5.93	6.09	17.96	5.99	
Total		29.56	29.36	29.61	88.53	5.90	

[1] Early burning of applied alfalfa straw

Table 34. - Analysis of variance for nitrogen content of alfalfa seed at South Junction, Man.

	DF	SS	DF	MS	F	5% pt.	1% pt.
Treatments	4	0.11444					
No S vs S			1	.09933	17.61^{xx}	4.96	10.04
Within S							
$CaSO_4$ vs K_2SO_4			1	.00135	.24	4.96	
Within No S							
Check vs P_2O_5			1	.00042	.07	4.96	
Check & P_2O_5 vs Burn			1	.01334	2.36	4.96	
Error	10	0.05640					
Total	14	0.17084					

^{xx} Highly significant

SUMMARY AND CONCLUSIONS

Investigations in the relation of certain major and minor elements to the problem of seed setting in alfalfa were conducted.

Various elements were applied to alfalfa plots on four different Manitoba soils. In addition soil amendments were applied and straw was burned in the early spring on a number of plots. No improvement in seed setting resulted from any of the treatments on a black earth soil at the University, a Rendzina soil at Arborg, or a grey-wooded soil south of Benito. At the University the treatments had no effect upon the seed set of the pods of hand-tripped flowers.

On the podzolic soil at South Junction significant increases in seed yield were obtained with sulphur-containing compounds (potassium sulphate, calcium sulphate, and manganese sulphate) and with triple superphosphate. The increase in seed production with triple superphosphate was not as great as in the case of the sulphur compounds. The early burning of alfalfa straw appeared to give a slight improvement, while the application of borax, potassium chloride, and calcium carbonate had no effect. The responses obtained with the application of the sulphur compounds were very striking, the following effects being noted:

1) outstanding improvement in the alfalfa stand;

2) restoration of normal dark green color of the plants;

3) significant increase in the sulphur and nitrogen (and protein) content of the plants;

4) more than tenfold increase in the yield of seed;

5) significant increase in the seed set per pod and in the percentage viable seed, (no effect upon the number of shrivelled seed set per pod).

The application of sulphur compounds significantly increased the weight of seed per pod and the number of plump seed per pod by 42 and 35 per cent respectively, and significantly decreased the percentage dead seed by 46 per cent (relative). The sulphur content of the seed produced on plots not receiving sulphates was significantly less than that of seed samples obtained from three other points. The application of sulphur compounds increased the sulphur content of the seed by 45 per cent (relative), making it equal to that of the seed from the other points.

The average sulphur content of the soil of the experimental field at South Junction to the four foot depth was 0.009%, while that of an experimental field at the University was twice that amount. The water-soluble sulphate content at South Junction was less than 0.001% to the four foot depth, while that at the University was over ten times as great.

There is a definite sulphur deficiency in the soil at South Junction, on which the experiments were conducted, with respect to the nutritional requirements of alfalfa for growth and seed production.

APPENDIX

Methods of Soil Analysis

(a) Water-Soluble Sulphate

The water-soluble sulphate content of soil samples was determined as follows: Shook 60 gm. of air-dry soil with 300 cc. of distilled water (1:5 soil:water ratio) for one hour. Allowed to stand for several days. Siphoned off the supernatant liquid and filtered (No. 42 Whatman filter paper). Pipetted off a 100 to 200 cc. aliquot. If the extract was not clear it was evaporated to dryness and the residue dissolved in water, as was suggested by Dr. F. A. Wyatt, Professor of Soils at the University of Alberta. Acidified the extract aliquot with 0.5 cc. HCl, brought to a boil, and precipitated the sulphates as $BaSO_4$ by adding drop by drop 5 cc. of a 10% solution of $BaCl_2$. Heated below the boiling point for about an hour. Allowed to stand overnight. Filtered, ignited, and weighed as $BaSO_4$. The water-soluble sulphate content of the soil was calculated on the moisture-free basis.

(b) Total Sulphur

The total sulphur content of soil samples was determined by the following method suggested by Dr. F. A. Wyatt: Moisten 5 gm. of soil with a little alcohol in a porcelain dish and add 10 cc. of $Mg(NO_3)_2$ solution. Mix well, evaporate to dryness and char on an electric hotplate

until no further action takes place. Place a watch glass over the dish just as charring commences. Ignite in a muffle furnace at 600°C. until the charge is thoroughly oxidized. No black particles should remain. Add enough water to moisten. Add 10 cc. of concentrated HCl and evaporate to dryness. Moisten with water and add 10 cc. of concentrated HCl, heat to boiling, filter and wash on Buchner funnel into a filter flask, using medium suction. Transfer the filtrate into a 250 cc. beaker. Heat to the boiling point and add drop by drop 5 cc. of a 10% solution of $BaCl_2$. Digest for one to two hours on a low-heat hot-plate. Allow to stand overnight or an equivalent length of time. Filter, ignite, and weigh as $BaSO_4$. Blank determinations must be made on all reagents used. Analysis is carried out on air-dry soil. However, the sulphur content was calculated by the author on a moisture-free basis by determining the moisture content of the air-dry soil and calculating the results accordingly.

LITERATURE CITED

1. Alberta, University of. Experimental results. Breton experimental field. mimeo. cir. for field day at Breton. 1943.

2. Albrecht, Wm. A. Calcium and hydrogen-ion concentration in the growth and inoculation of soybeans. Jour. Amer. Soc. Agron., 24:793-806. 1932.

3. ----------. Physiology of root nodule bacteria in relation to fertility levels of the soil. Soil Sci. Soc. Am., Proc., 2:315-327. 1937.

4. Alway, F. J. Detection of sulfur-deficiency of soils by means of plants. Proc. Pap. First Int. Cong. Soil Sci., 3:2-31. 1927.

5. Anderson, A. J. Molybdenum deficiency on a South Australian ironstone soil. Jour. Australian Inst. Agr. Sci., 8:73-75. 1942.

6. Anonymous. Boron and seed production. Nova Scotia Dept. Agric. Ext. News Serv. 1936.

7. Association of Official Agricultural Chemists. Official and tentative methods of analysis. 5th ed. Washington, D. C. 1940.

8. Blinn, P. K. Factors that affect alfalfa seed yields.

Colorado Agr. Exp. Sta. Bul. 257. 1920.

9. Bortels, H. Supplementary communication on the effects of applying molybdenum to field plots of lucerne. Zbl. Bakt. II, 103:129-133. 1941. Original not seen. Abstracted in Imp. Bur. Soil Sci. 4:202.

10. Borzini, G. The influence of thallium ions on the germination of several seeds, and on the initial growth of the young plants. Boll. staz. patol. vegetale (N. S.) 15:200-31. 1935. Original not seen. Abstracted in Chem. Abs. 29:5476. 1935.

11. Bruce, O. C. The relation of sulphur to alfalfa production. Jour. Agric. Res. 30:937-947. 1925.

12. Burke, E., and Morris, H. E. Some causes of infertility in Montana soils. Montana Agr. Exp. Sta. Cir. 164. 1941.

13. Carlson, J. W. and Stewart, G. Alfalfa seed production. Utah Agr. Exp. Sta. Bull. 226. 1931.

14. Dijakova, E. V. The effect of boric fertilizers on development and seed yield of lucerne. Doklady Vsesojuz. Akad. Seljskohoz. Nauk., No. 22 (31):12-17. 1938. Original not seen. Abstracted in Imp. Bur. Pl. Gen. Herb. Abs. 9:296. 1939.

15. ----------. The effect of boron in increasing the

yield of lucerne seed on limed podzolized soils. Chemisation Socialistic Agr. (U.S.S.R.), No. 2-3, 70-73. 1940; Khim. Referat. Zhur. 8:52. 1940. Original not seen. Abstracted in Chem. Abs. 36:6291. 1942.

16. D'Ippolito, G. Manuring experiments with magnesium carbonate in Italy. Agr. Mod. (Milan), 20:259-260. 1914. Original not seen. Abstracted in Exp. Sta. Rec. 33:326. 1915.

17. Dominion Forage Crops Laboratory. Alfalfa investigations 1943. Northern seed production area. mimeo. rpt. by Dom. Forage Crops Lab., Saskatoon, Sask.

18. Drobkov, A. A. The influence of radioactive elements on the yields of plants. Bull. acad. sci. U.R.S.S., Ser. Biol. 783-801, 1940; Chem. Zentr. I, 1819. 1941. Original not seen. Abstracted in Chem. Abs. 37:2776. 1943.

19. Dunckles, D.E., and Midgley, A.R. Need and use of boron for alfalfa. Vt. Agric. Exp. Sta. Bul. 501. 1943.

20. Erdman, L.W., and Bollen, W.B. Field experiments with gypsum in Iowa. Iowa Agric. Exp. Sta. Bul. 232. 1925.

21. Fisher, R. A. Statistical methods for research workers. 5 th ed. Oliver and Boyd, Edinburgh and London. 1934.

22. Goulden, C. H. Methods of statistical analysis. John Wiley and Sons, New York. 1939.

23. Grizzard, A. L., and Matthews, E.M. The effect of boron on the seed production of alfalfa. Jour. Amer. Soc. Agron., 34:365-368. 1942.

24. Harrison, N. W. Report of Thunder Bay Crop Improvement Association. 1940-1941. mimeo. Port Arthur, Ont.

25. Hoagland, D. R., Chandler, W. H., and Hibbard, P. L. Little-leaf or rosette of fruit trees. V. Effect of Zinc on the growth of plants of various types in controlled soil and water culture experiments. Proc. Amer. Soc. Hort. Sci. 1935. 33:131-141. 1936.

26. Hughes, J. H. The alfalfa plant bug. Adelphocoris lineolatus (Goeze) and other Miridae (Hemiptera) in relation to alfalfa seed production in Minnesota. Minn. Agric. Exp. Sta. Tech. Bul. 161. 1943.

27. Hutcheson, T. B., and Cocke, R. P. Effects of boron on yield and duration of alfalfa. Va. Agric. Exp.

Sta. Bul. 336. 1941.

28. Joret, G. and Malterre, H. Importance of the calcic state of the soil in the cultivation of forage legumes. Compt. rend. acad. agr. France 26:500-507. 1940. Original not seen. Abstracted in Chem. Abst. 34:6747. 1940.

29. Konishi, Kametaro and Toshihisa Tsuge. Inorganic constituents of green-manure crops. II. Jour. Agr. Chem. Soc. Japan 12:916-930. 1936 Original not seen. Abstracted in Chem. Abst. 31:2339. 1937.

30. Larson, H. W. E. The relation of the concentration of calcium ion required by alfalfa to the amount present in soil solution. Soil Sci., 25:399-408. 1928.

31. Lomanitz, S. The needs of the soils of Brazos and Jefferson counties for sulphur. Texas Agric. Exp. Sta. Bul. 302. 1922.

32. ----------. A preliminary study of the effects of sodium chloride upon alfalfa grown in solution cultures. Soil Sci., 16:183-193. 1923.

33. ----------. The influence of sodium chloride upon alfalfa grown in solution cultures. Soil Sci., 18:353-369. 1924.

34. McCool, M. M. Effect of thallium sulphate on the growth of several plants and on nitrification in the soil. Contrib. Boyce Thompson Inst. 5:289-296. 1933.

35. McDole, G. R., and Christ, J. H. Farming practices for the cut-over lands of Northern Idaho. Idaho Agric. Exp. Sta. Bul. 136. 1925.

36. McKibbin, R. R. The effect of sulphur on soils and crop yields. Md. Agric. Exp. Sta. Bul. 296. 1928.

37. Midgley, A. R. Fifty fourth annual report. Vt. Agric. Exp. Sta., Bul 475:20-22. 1941.

38. Miller, H. G. Relation of sulphates to plant growth and composition. Jour. Agric. Res., 17:87-102. 1919.

39. Neidig, R. E., McDole, G. R., and Magnuson, H. P. Effect of sulfur, calcium and phosphorus on the yield and composition of alfalfa on six types of Idaho soils. Soil Sci., 16:127-136. 1923.

40. Neller, J. R. The influence of sulfur and gypsum upon the composition and yield of legumes. Wash. Agric. Exp. Sta. Bul. 190. 1925.

41. Olson, G. A., and St. John, J. L. An investigation of sulfur as a plant food. Wash. Agric. Exp. Sta. Bul. 165. 1921.

42. Pacific Coast Borax Company. Boron in agriculture. rev. ed. pages 30-35. 1944.

43. Piland, J. R., and Ireland, C. F. Application of borax produces seed set in alfalfa. Jour. Amer. Soc. Agron., 33:938-939. 1941.

44. ----------, and Reisenhauer, H. M. The importance of borax in legume seed production in the South. Soil Sci., 57:75-84. 1944.

45. Piper, C. S. Investigations on copper deficiency in plants. Jour. Agr. Sci., 32:143-178. 1942.

46. Powers, W. L. Studies of sulfur in relation to the soil solution. Univ. Calif. Pub. Agric. Sci. 5:119-166. 1927.

47. ----------. The role of sulfur in plant nutrition. Jour. Amer. Soc. Agron. 22:371-373. 1930.

48. ----------. The role of sulfur in plant nutrition. Proc. Pap. Second Int. Cong. Soil Sci., 4:46-53. 1932.

49. ----------. Will iodine come to be considered an

essential plant nutrient? Science 89:434-5. 1939.

50. Reimer, F. C., and Tartar, H. V. Sulfur as a fertilizer for alfalfa in southern Oregon. Oregon Agric. Coll. Exp. Sta. Bul. 163. 1919.

51. Schropp, W. and Scharrer, K. Wasserkulturversuche mit der "A-Z-Lösung" nach Hoagland. Jahrb. Wiss. Bot. 78:544-563. 1933.

52. Shedd, O. M. Effect of certain calcium compounds and other substances on the yield and calcium content of some crops. Soil Sci., 14:233-246. 1922.

53. Snedecor, G. W. Statistical methods. 3rd ed. Collegiate Press Inc., Ames, Iowa. 1940.

54. Stevenson, T. M., and Mitchell, J. Alfalfa seed production on the grey wooded soils of northern Saskatchewan. Univ. Sask. Agric. Ext. Bul. 78. rev. ed. 1939.

55. Stewart, R. Sulfur in relation to soil fertility. Ill. Agric. Exp. Sta. Bul. 227. 1920.

56. Stinson, C. H., and DeTurk, E.E. The boron problem in Illinois. mimeo. cir., Dept. Agron., Ill. Agric. Exp. Sta. 1943.

57. Thomas, M. D., Hendricks, R. H., Collier, T. R., and Hill, G. R. The utilization of sulphate and sulphur dioxide for the sulphur nutrition of alfalfa. Pl. Phys., 18:345-371. 1943.

58. Toevs, J. L., and Baker, G. O. Progress report of phosphate and other fertilizer investigations at the Aberdeen Branch Experiment Station, University of Idaho. Univ. Idaho Agric. Exp. Sta. Bul. 230. 1939.

59. Waite Research Institute. Report of the Waite Research Institute, South Australia, 1939-1940. 1941. Original not seen. Abstracted in Rev. Applied Mycol. 21:124-125. 1942.

60. Westover, H. L., and Noble, E. G. Fertilizer experiments with alfalfa conducted at the United States Yuma Field Station, Bard, Calif. 1919 to 1925. U. S. Dept. Agr., Dept. Bul. 1418. 1926.

61. Whornham, G. Alfalfa seed investigations and other crop varietal studies. Utah Agric. Exp. Sta. Bul. 268. 1936