THE EFFECTS OF AMMONIUM PHOSPHATE AND BORON ON ALFALFA (MEDICAGO SATIVA L.) SEED PRODUCTION AND VEGETATIVE GROWTH

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THE EFFECTS OF AMMONIUM PHOSPHATE AND BORON ON ALFALFA (MEDICAGO SATIVA L.) SEED PRODUCTION AND VEGETATIVE GROWTH

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INTRODUCTION

Alfalfa seed production in the prairie provinces has always been very uncertain. The resulting scarcity of seed has, to a large extent, limited a more extensive use of alfalfa as a hay and pasture crop. The rapid expansion of mixed farming in the parkland area of Alberta has increased the demand for good legumes that produce a large amount of forage and, at the same time, are hardy enough to withstand the severe winters.

Alfalfa in the black soil region produces an abundance of vegetative growth and very little seed. The gray wooded soil zone offers the most satisfactory soil and climatic conditions for alfalfa seed production in Alberta. Up to the present, however, alfalfa seed yields on the gray wooded soils have been too low to make seed production economically possible.

Experimental results have shown that crops on the gray wooded soil make the most satisfactory growth when sulphur is applied to the soil (38).

In many districts in Canada and the United States the production of alfalfa hay and seed has been greatly increased and the possibility of a seed crop failure greatly reduced by the application of a small amount of boron to the soil.

It was thought that boron might possibly be a limiting factor in alfalfa production in Alberta and that, combined with an efficient fertilizer, it might increase the hay and seed yield of alfalfa on the gray wooded soil.

Experiments were conducted in the field on gray wooded soil and also in the greenhouse on both gray wooded soil and sand cultures. For this reason the paper is reported in two sections, Part I dealing with the field experiments and Part II with the greenhouse experiments.

PART I

FIELD EXPERIMENTS

Many aspects of seed setting in alfalfa have been studied in an effort to determine the factors responsible for the great variation in alfalfa seed production. These experiments were designed to study the application of various amounts of boron on alfalfa grown on gray wooded soil at two levels of fertility.

LITERATURE REVIEW

A review of literature dealing with factors other than nutrition that affect alfalfa seed setting in the prairie provinces is included here to give a better idea of the complexity of the problem.

R. P. Knowles (17), working at the University of Saskatchewan, found that in the White Fox area of Saskatchewan the leaf-cutter bee (Megachile spp.) was the most important alfalfa-tripping insect. He found a significant correlation between the prevalence of these bees and the amount of seed setting. High temperatures increased tripping. Most of the automatic tripping occurred from 8 a.m. to 4 p.m. Cross-pollination produced more seeds per flower tripped than self-

pollination. A great variation in seed setting among plants of the same strain was also evident.

Lejeune and Olson (18), Silversides and Olson (34), and Jones and Olson (15) studied many factors in an attempt to increase seed setting. They found that tripping was necessary for satisfactory seed production and that bumble-bees tripped practically all flowers visited, while honey bees tripped very few. Mechanical devices increased the number of flowers tripped but decreased seed setting owing to injury to flowers. Cross-pollination proved superior to self-pollination.

Sexsmith and Fryer (32) studied the effect of the seasonal age of the plant on the viability of pollen. They determined that temperature and humidity as well as the time of season had no significant effect on pollen viability. The same workers (33) reported a linear relationship between pollen-tube growth and temperature, the length increasing as the temperature increased from 70°F. to 100°F. Clarke and Fryer (4) found that artificial tripping increased seed setting, but that less than half of the flowers tripped set seed. Although the per cent of sterile pollen was the same for different flowers of the same plant, it varied greatly among different plants from the same strain, but not for the same plant from year to year.

Wyatt, Newton, and Ignatieff (38) applied different fertilizers to the gray wooded soils in Alberta. On a five-year average alfalfa hay increases from fertilizers not containing sulphur varied from 529 to 1054 pounds per acre, while increases

from fertilizers containing sulphur were from 3165 to 3681 pounds per acre. Another experiment with fertilizers applied to alfalfa on the gray wooded soils, reported by White (37), showed that ammonium phosphate which contained 14% sulphur was superior for alfalfa hay and seed production to other fertilizers not containing sulphur. The yield of alfalfa seed in this experiment was, however, too low to make seed production economical.

The application of sulphur to the soil has also produced increases in alfalfa in parts of the United States. Powers (27), at the Oregon Experiment Station, obtained striking increases in the yield of alfalfa by the application of sulphur. Soils of the northwestern states that responded best to sulphur were the residual, calcareous, and basaltic lands. Optimum growth of alfalfa was obtained when the concentration of sulphur in the soil solution was 15 to 30 p.p.m. during the first three weeks of growth and 8 to 15 p.p.m. during the next three weeks. Changing the reaction of arid soils from faint alkalinity to faint acidity by sulphur additions resulted in an increase in concentration of potassium, calcium, and magnesium bases in the soil solution. The application of sulphur increased the drought resistance of alfalfa. This was credited, in part, to a better floculated condition of the soil resulting from an increase in water-soluble calcium. The addition of sulphur to the soil also increased the chlorophyll content of alfalfa by 18%. Powers and Ruzik (28), in a later report from the Oregon station, advocated the application

of sulphur as phosphates containing sulphur. In 36 field trials, reported in the same paper, alfalfa hay production was increased as much as two tons per acre by the application of 30 pounds of borax per acre, and the sulphur and nitrogen content of the hay were also increased. Chapman (3), in greenhouse experiments with three calcareous soils relatively low in calcium carbonate (3.7% or less) and moderately well supplied with phosphates, found that physiologically acid nitrogen and sulphur fertilizers markedly increased the availability of the phosphates, being particularly effective on the soils lowest in carbonate and highest in phosphate.

Many workers in the United States have reported large increases in the hay and seed yield of alfalfa by small applications of boron to the soil. Boron becomes available very slowly and because of this the total boron content of the soil cannot be used as an indication of a need for boron.

Soil conditions that affect boron availability and the relation between boron and other plant nutrients have been studied in several districts in the United States. Cook and Millar (7), at the Michigan State College, reported that boron occurred most commonly on alkaline or overlimed soils but also found it occurring on acid soils. They found boron deficiency more often on hilltops and slopes than on low level land. Pervious subsoil layers usually occurred under areas where boron deficiency symptoms were most severe. The boron content of badly leached areas was not much less than that of surrounding areas leached to a lesser extent. They credited the boron

starvation of the leached areas to the removal by leaching of the boron as rapidly as it was made available. They determined that the availability of boron is not affected when the pH of the soil is raised with a salt that does not furnish a cation capable of forming an insoluble borate. However, calcium and magnesium fixed boron in the form of insoluble borates in soil with a basic reaction but not in a soil with an acid reaction.

Other workers observed the same relation. Midgley and Dunklee (21) reported that the ability of soils to fix boron depended on the degree of acidity and on the extent to which they had been subsequently limed. Peat moss from Maine, and Vermont A_1 podzol soil fixed very little boron in their acid state. Their ability to fix boric acid increased up to and slightly beyond neutrality when lime was applied in increased amounts. Most neutral soils tested were only slightly affected when similarly treated but, if acidified by leaching similar to podzolization, they fixed large amounts of boron when excessively limed.

Parks and Shaw (23) demonstrated a possible method of boron fixation in the soil by the use of mixtures of solutions of silicon, aluminum, iron, calcium, magnesium and phosphorus with boric acid titrated to reactions varying from a pH of 5.0 to a pH of 9.0. They found that boron fixation was favored by reactions above neutrality, by dehydration and retitration, and by the presence of calcium ions in the mixtures being titrated.

Colwell and Cummings (5) tested calcium, sodium, and potassium metaborates as compared with boric acid as sources of starvation of the legumes cause by the removal or leaching of the boron as rapidly as it was made available. They discovered that the availability of boron is not affected when the pH of the soil is raised with a salt that does not furnish a cation capable of forming an insoluble borate. However, calcium and magnesium fixed boron in the form of insoluble borates in soil with a basic reaction but not in a soil with an acid reaction.

Other workers observed the same behavior. Midgley and Dunklee (41) reported that the fixation of added or [illegible] boron depended on the degree of acidity and on the extent to which they had been subsequently limed. Test made from [illegible] and Vermont [illegible] soil fixed very slight [illegible] in [illegible] acid form. Their ability to fix boric acid increased [illegible] and alkalinity beyond neutrality when lime was applied in increased amounts. Most neutral soils tested were only slightly [illegible] when aluminium [illegible] to soils [illegible] by leaching similar to podsolization, each fixed large amounts of boron when excessively limed.

[illegible] and [illegible] ([illegible]) demonstrated a possible method of boron fixation in the soil by the use of mixtures of solutions of silicon, aluminum, iron, calcium, magnesium and [illegible] with boric acid [illegible] from a pH of 5.0 to a pH of 8.0. They found that boron [illegible] the [illegible] reactions [illegible], by [illegible], and by the presence of [illegible] in the [illegible].

[illegible] and [illegible] ([illegible]) [illegible], [illegible], and potassium [illegible] as compared with boric acid [illegible] boron in nutrient solutions. They found that, regardless of the source of boron, deficiency and toxicity symptoms appeared at the same time and at the same levels of concentration. Specific conductance tests on calcium, sodium, and potassium metaborates and sodium tetraborate showed that for solutions of all the salts except calcium metaborate the ionic conductance of the boron-carrying anion was the same and corresponded with the value for the H_2BO_3 anion. For the calcium metaborate this value was much lower and that the system was unstable was indicated by a gradual lowering, with aging, of the conductance values and of the pH.

Using Crosby silt loam Jones and Scarseth (16) grew alfalfa in the greenhouse with varying amounts of lime, fertilizers, and boron. The growth of alfalfa was not as good on the unlimed soil with a pH of 5.6 as on the limed soil with a pH of 6.6 and 7.6. Varying the borax application from 0 to 50 pounds per acre in the two series of limed pots produced no definite change in yield. The calcium-boron ratio, however, became lower as the applications of borax increased. This ratio was also consistently higher with the highest pH values resulting from the limed pots. The amount of boron taken up by the plants was in proportion to the amount of boron added to the soil. Less boron was taken up at the higher than at the lower pH values for each rate of borax application.

Marsh and Shive (19), working with corn in nutrient solutions with varying amounts of boron and calcium, found that

within certain limits the boron content of the substrate did not significantly affect the calcium absorption rates of the plants. The soluble calcium in the corn tissue was determined by the boron content of the plant which was in turn determined by the boron content of the substrate.

Investigations in many parts of the United States have shown that the available boron in soils, especially those heavily limed, is too low for satisfactory alfalfa production. Brown and King (2), in Connecticut, reported 75% more boron-deficient plants on soil which had received 9 tons of limestone per acre between 1914 and 1918 than on soil which had received 7.5 tons during the same time. On this land, 20 pounds of borax per acre increased the height of alfalfa by 15%, the yield by 16%, and the boron in the leaves from 21 to 62 p.p.m. Cook (6), in greenhouse experiments with Michigan soil, obtained increases in vegetative growth of alfalfa of 14.4% by the application of two pounds of borax per acre. In Alabama Naftel (22) obtained beneficial results from the application of borax to 15 out of 20 limed soils used. Piland and Ireland (24) obtained very good seed set on alfalfa by the application of 20 pounds per acre of borax, while the untreated plots yielded none.

Baur, Huber, and Wheeting (1), on western Washington soils, found that boron-deficiency characteristics were associated with a restricted supply of moisture. By the application of 60 pounds per acre of borax they obtained an increase of from 1457 to 2200 pounds of hay per acre. In Virginia, Gizzard and

Matthews (12) reported an increase of from 289 to 743 pounds of hay per acre by the application of 15 pounds of borax per acre, with a yield of from 82 to 184 pounds of seed per acre from the borax-treated plots and none for the untreated ones.

Dregne and Powers (9) reported that both borax and boric acid gave profitable increases in alfalfa hay on the major soil types of northwestern Oregon. The most profitable rate of application was 60 pounds per acre of boric acid. Powers (26) obtained an increase of 300% by the application of 30 pounds per acre of borax on an old stand of alfalfa on irrigated land. In three other fields an average increase of one ton per acre was realized by boron application. Growth response of alfalfa to one application of borax was maintained over a period of 2.5 years. The addition of boron to the soil increased the boron content of the plants grown in it and slightly increased the protein content. It also increased chlorophyll content 50% and vitamin A content 30%. Piland, Ireland, and Reisenauer (25) applied to 13 alfalfa fields in North Carolina sufficient borax to supply boron at the rates of 0.5, 1.0 and 1.5 p.p.m. They obtained, by the application of boron, hay increases as high as 27% over the check plots and seed increases of 460, 433, and 529 per cent respectively for the three boron applications.

Alfalfa has shown a response to fertilizers on many soils. Vandecaveye and Bond (36), in field trials in both eastern and western Washington, applied nitrogen, phosphorus, and potassium alone and in all possible combinations. Nitrogen

and phosphorus, when applied together, gave as large an increase as the complete fertilizer and larger than any one applied alone or in combination with any other. The increase over the check, obtained by the application of nitrogen and phosphorus, was 1.3 tons per acre in eastern Washington and 1 ton per acre in western Washington.

Sewell and Latshaw (30) experimented in the greenhouse with different applications of lime, superphosphate, and potash on an acid silt loam soil to determine their effect on the growth and composition of alfalfa. They obtained the largest increase in yield by the application of 450 pounds of superphosphate per acre plus sufficient lime to bring the pH of the soil to the neutral point. Chemical analysis showed that the superphosphate treatments alone did not increase the phosphorus content of the hay but that the combined application of lime and superphosphate did.

MATERIAL AND METHODS

In the spring of 1943 two fields of one-year-old stands of alfalfa on gray wooded soil near Warburg were selected for the experiment.

One field was on the farm of Mr. J. Innes. It had been seeded at the rate of four pounds of seed per acre and, consequently, was a very thin but nevertheless very even stand.

The other field, on the farm of Mr. O. Anderson, had been seeded at the rate of 10 pounds of seed per acre. It was also a very even stand but much thicker than that on the former field.

The practice of light seeding is recommended for alfalfa seed production in Alberta (11). The choice of these two fields allowed a comparison between the light and heavy seeding.

One experiment was established on each field. Each experiment consisted of a 5 x 5 Latin square design with split plots. The five treatments varied only in the amount of borax applied, the rates being 0, 5, 15, 25, and 35 pounds per acre.

To half of each of the check plots and the borax-treated plots 16-20 ammonium phosphate was applied at the rate of 100 pounds per acre. The other half of each plot was left unfertilized. The fertilized and unfertilized parts were the smallest plot units in the experiment, each having an area of 200 square feet.

The ammonium phosphate (16-20) fertilizer used contained 15% sulphur which, as reported previously (38), is a necessary constituent of a fertilizer for the gray wooded soils.

The borax and fertilizer were applied on May 27, 1943. The amount to be applied to each plot was measured and placed in a container with a perforated bottom and shaken evenly over the prescribed area.

Samples from the plots were harvested on September 20th.

The sampler used was a half-inch steel rod bent in the form of a spiral with a diameter of 33 inches. Four samples were taken at random from each plot by placing the sampler on the foliage, turning it until it lay on the ground, and then cutting all the plants inside the circle. The four samples from each plot were bulked and weighed in the field to the nearest five grams. This weight was taken as the vegetative growth produced. The sample from each plot was wrapped in cloth to prevent loss of seed, tagged and allowed to dry.

Threshing was done with a rod-row thresher. The seed was cleaned with a Clipper seed cleaner and then hand-screened to remove any remaining foreign seeds. The samples of seed were then weighed to the nearest tenth of a gram.

To change the yield from grams per plot to pounds per acre the weights were multiplied by the conversion factor of 4.041.

The data obtained from these experiments were analysed according to the method described by Goulden (13).

EXPERIMENTAL RESULTS

The fields were inspected on July 26th. At this time it was quite evident, in both fields, that the application of fertilizer had increased the vegetative growth. The difference between the fertilized and unfertilized plots was, however,

noticeably greater for the thin stand of the Innes field than for the thick stand of the Anderson field. Besides being more abundant the foliage was a much darker green color on the fertilized than on the unfertilized plots.

Vegetative Yield

The vegetative yield in grams per sample for the different treatments on the Innes field, together with the mean yield in pounds per acre for the fertilized and unfertilized plots, is presented in Table I and the results of the analysis of variance of these data in Table II.

TABLE I

Vegetative yields for the Innes field

	Boron - pounds per acre					Mean yield	
Fertilizer 16-20	none	5	15	25	35	gm. per sample	pounds per acre
100 lb./acre	1594*	1746	1416	1668	1846	1654	6686
Unfertilized	175	225	197	188	199	197	795
Mean	884	985	806	928	1022	925	3740

* Each value is the mean of 5 replicates

TABLE II

Analysis of variance for vegetative yield
for the Innes field

Variance due to	D.F.	Mean squares	F
Boron	4	72143	1.72
Rows	4	199767	4.75*
Columns	4	34804	.83
Error (1)	12	42011	
Fertilizer	1	26542898	463.35**
Fertilizer x boron	4	61757	1.08
Error (2)	20	57408	
Total	49		

* Significant beyond the 5% point
** Significant beyond the 1% point

The application of fertilizer had a very pronounced effect on the vegetative growth of the alfalfa in this experiment, as is shown by the highly significant F value for fertilizer in the above table. The mean yield for the fertilized plots was 1654 grams as compared with a mean yield of 197 grams for the unfertilized plots (Table I), with a minimum significant difference of 135 grams. The increase due to the application of fertilizer on this field, converted to pounds per acre, represents a gain of 5891 pounds of vegetative growth per acre.

The alfalfa on this field showed no response whatsoever to the application of boron at any of the rates used. The significant F value for rows (Table II) is evidence that soil conditions were not uniform over the area occupied by this experiment.

The vegetative yield for the different treatments, and the mean yield in grams per plot and pounds per acre for the Anderson field are shown in Table III. The results of the analysis of variance of these data appear in Table IV.

TABLE III

Vegetative yield for the Anderson field

Fertilizer 16-20	Boron - pounds per acre: none	5	15	25	35	Mean yield: gm. per plot	pounds per acre
100 lb./acre	1042*	839	1036	1022	926	973	3932
Unfertilized	535	588	718	758	571	634	2562
Mean	788	713	877	890	748	803	3247

* Each value is the mean of 5 replicates

TABLE IV

Analysis of variance for vegetative yield for the Anderson field

Variance due to	D.F.	Mean squares	F
Boron	4	60586	1.03
Rows	4	14919	.25
Columns	4	50285	.86
Error (1)	12	58775	
Fertilizer	1	1436512	123.06**
Fertilizer x boron	4	26431	2.26
Error (2)	20	11673	
Total	49		

** Significant beyond the 1% point

The vegetative yields for the different treatments on this field followed the same trend as those on the Innes field. The mean vegetative yield of the fertilized plots was 973 grams compared with 634 grams for the unfertilized plots (Table III) with a minimum significant difference between the means of 61 grams.

The application of boron again produced no increase or decrease in the yield of vegetation.

Discussion

On both fields the application of 100 pounds of ammonium phosphate (16-20) per acre increased the vegetative growth of the alfalfa. The increase was, however, greater on the thin stand of the Innes field than on the thick stand of the Anderson field.

A combined analysis of variance of the vegetative yield for the two fields was attempted. The extremely low yield of the unfertilized plots and the relatively high yield of the fertilized plots on the Innes field in comparison with the intermediate yields for the corresponding plots on the Anderson field complicated the analysis. This resulted in the difference between the yield of the fertilized and the unfertilized plots appearing as interaction between fertilizer and field, thus masking the true effect of the fertilizer.

The increase in vegetative growth obtained in this

experiment by the application of fertilizer to alfalfa on the gray wooded soil agrees with the results reported by Wyatt, Newton, and Ignatieff (38) and by White (37).

The high vegetative yield of 6686 pounds per acre for the fertilized plots of the thin stand as compared with the yield of 3932 pounds per acre for the corresponding plots of the thick stand may have been caused by other factors not considered in this experiment. One reason for the difference may be that the alfalfa seed sown at the rate of 10 pounds per acre produced a stand that, owing to crowding and competition between the plants, was too thick to produce maximum returns. Another possible reason for the increased growth on the thin stand may be the fact that each plant there received a larger proportion of the fertilizer than did those on the thick stand and that this added stimulus received by each plant produced more growth than could be realized by a greater number of plants. That the fertilizer produced nutrient conditions more nearly optimum for alfalfa growth on the one field than on the other offers another possible explanation for the difference between the growth response of the alfalfa on the two fields, since the fields were some six miles apart with different cropping histories and were conceivably quite different from each other nutritionally. The application of boron, as shown by Tables I and III, produced no significant effect on the vegetative growth on either of the fields. By examining the mean yields for the different boron treatments it becomes evident that there was no tendency toward

an increase or decrease in the vegetative yield as the rate of boron application was increased. This fact suggests that further experiments on these fields would fail to show any beneficial effect from the application of boron.

Seed Yield

The seed yield in grams per sample for the different treatments and the mean yield in pounds per acre for the fertilized and unfertilized plots on the Innes field are given in Table V. The results of the analysis of variance of these data are shown in Table VI.

TABLE V

Seed yield of the Innes field

	Boron - pounds per acre					Mean yield	
Fertilizer 16-20	none	5	15	25	35	gm. per sample	pounds per acre
100 lb./ac.	22.0*	23.1	15.9	22.0	24.0	21.4	86.4
Unfertilized	1.0	1.6	0.8	0.9	1.0	1.1	4.3
Mean	11.5	12.3	8.3	11.4	12.5	11.2	45.4

* Each value is the mean yield of 5 replicates

TABLE VI

Analysis of variance for seed yield
for Innes field

Variance due to	D.F.	Mean squares	F
Boron	4	28.37	2.57
Rows	4	32.24	2.93
Columns	4	7.01	.64
Error (1)	12	11.02	
Fertilizer	1	5169.41	306.46**
Fertilizer x boron	4	22.82	1.35
Error (2)	20	16.87	
Total	49		

** Significant beyond the 1% point

The seed yield of the fertilized plots on this field showed a remarkable increase over the seed yield of the unfertilized plots. The minimum significant difference between the mean seed yields for the fertilized and unfertilized plots is 2.3 grams, with an actual difference of 20.3 grams in favor of the fertilized plots (Table V). This difference represents an increase of 82.1 pounds of seed per acre.

The application of boron as shown by the analysis of variance (Table VI) had no effect on the amount of seed produced.

The seed yield in grams, obtained from the plots receiving the different treatments, and the mean yield in pounds of seed per acre for the fertilized and unfertilized plots on the Anderson field are shown in Table VII, and the analysis of variance of these results in Table VIII.

TABLE VII

Seed yield of the Anderson field

Fertilizer 16-20	Boron - pounds per acre: none	5	15	25	35	Mean yield: gm. per sample	pounds per acre
100 lb. /ac.	13.0*	9.4	13.9	9.4	10.5	11.2	45.5
Unfertilized	5.6	6.2	8.1	11.4	7.8	7.8	31.6
Mean	9.3	7.8	11.0	10.4	9.1	9.5	38.6

* Each value is the mean yield of 5 replicates

TABLE VIII

Analysis of variance for seed yield for Anderson field

Variance due to	D.F.	Mean squares	F
Boron	4	12.60	.89
Rows	4	24.70	1.74
Columns	4	13.88	.98
Error (1)	12	14.23	
Fertilizer	1	147.58	7.80*
Fertilizer x boron	4	34.23	1.81
Error (2)	20	18.91	
Total	49		

* Significant beyond the 5% point

As in the previous field, the yield of seed was increased by the application of fertilizers. The mean yield of seed for the fertilized plots was 3.4 grams per plot or 13.9 pounds per acre greater than that for the unfertilized plots

(Table VII), with a minimum significant difference of 2.5 grams. The seed yield on the plots in this field was neither increased nor decreased by the application of boron.

Discussion

Under the conditions of this experiment the application of 100 pounds of ammonium phosphate per acre increased the amount of seed produced by alfalfa on gray wooded soil. A similar increase was obtained by White (37) with the application of fertilizer to alfalfa on these same soils.

A comparison of Tables V and VII shows that the unfertilized plots on the thick stand yielded 31.6 pounds of seed per acre, an increase of 27.3 pounds per acre over the unfertilized plots on the thin stand. The application of fertilizer to these fields, however, reversed this order and the fertilized plots on the thin stand yielded 86.4 pounds of seed per acre as compared with 45.5 pounds per acre for the corresponding plots on the thick stand.

These results support the recommendation of a very light stand of alfalfa for seed production in Alberta (11). They also emphasize the importance of suitable fertilizers for satisfactory seed production.

There was no tendency for seed production to increase or decrease even below the level of significance as the rate of boron application was increased. This strongly indicates that

boron is not a limiting factor in alfalfa seed production on these soils.

A combined analysis of variance for the two fields was attempted but, as with the vegetative yield of the two fields, the extreme seed yields of the fertilized and unfertilized plots on the one field, when compared with the intermediate yields of the corresponding plots on the other, complicated the analysis.

In general, the results for the seed yield appeared to correspond very closely to the results obtained for the vegetative yield.

CORRELATION AND REGRESSION

The correlation and regression coefficients were calculated to determine the relationship between the seed yield and vegetative growth. These are given in Table IX.

TABLE IX

Relation between seed yield and vegetative growth

Field	r_{sh}	b_{sh}
Innes	.949**	.0135
Anderson	.617**	.0109
Combined	.908**	.0132

** Significant beyond the 1% point

The significance of the difference between the correlation coefficients and between the regression coefficients for the seed yield on vegetative yield for the two fields was calculated. The difference in both cases was found to be insignificant. This permitted the calculation of correlation and regression coefficients for the data for the two fields taken together.

The regression lines of the results for each field and for the two fields combined are shown in Figure 1.

To determine whether the seed yield had increased more than could be accounted for by the increase in vegetative growth the seed yield was adjusted, by means of covariance, for differences in yield of vegetative growth. The results of analysis of variance, using adjusted seed yields, are given for the Innes Field in Table IX A and for the Anderson field in Table IX B.

TABLE IX A

Analysis of covariance between seed yield and vegetative growth (Innes field)

	D.F.	Mean squares	F	5%
Treatment + Error	40			
Error	31	11.0		
Treatment difference	9	10.5		
Treatment	8	6.5		
$b_e - b_t$	1	42.5	3.86	4.16

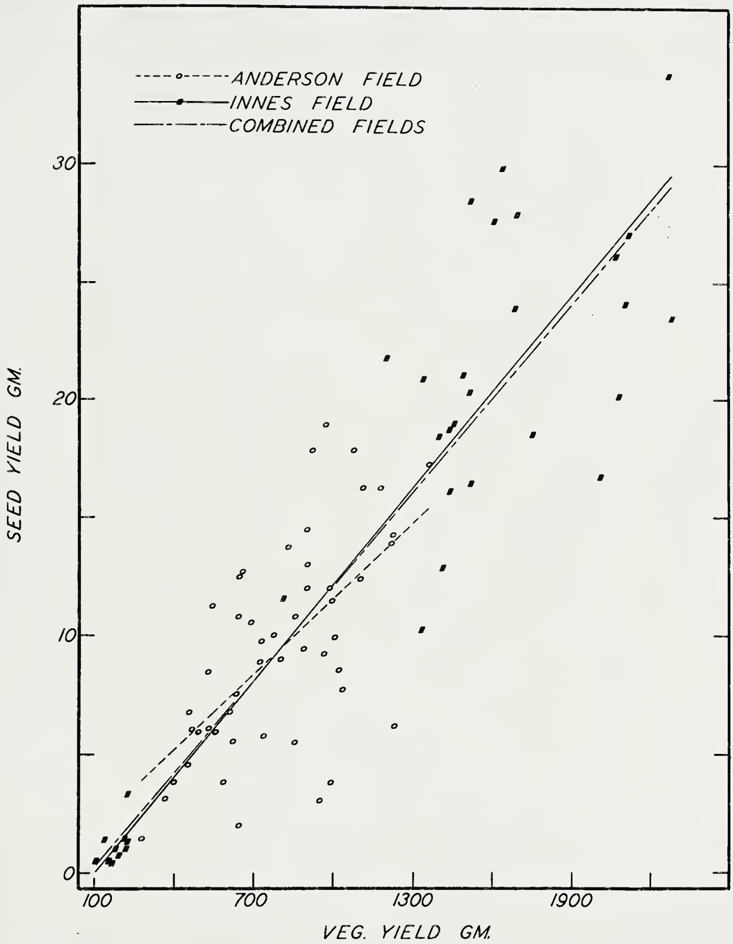

Figure 1

Relation between the seed yield and the vegetative yield

TABLE IX B

Analysis of covariance between seed yield and vegetative growth (Anderson field)

	D.F.	Mean squares
Treatment + Error	40	
Error	31	12.2
Treatment difference	9	10.3
Treatment	8	11.8
$b_e - b_t$	1	-1.2

Discussion

The positive relationship between seed yield and vegetative growth in this experiment (Table IX) agrees with the relationship found by White (37). The increase of 1.32 grams of seed per 100-gram increase in vegetative growth, obtained in this experiment, is however greater.

The correlation and regression coefficients for the seed yield on the vegetative growth for the combined fields (Table IX) and the regression line (Figure 1) give a more representative value of the relation between seed and vegetation than do the data for either field taken alone. The use of the data for the combined fields eliminates the very short range of values of the vegetative growth from the Anderson field and gives a more even distribution of the yields than was obtained in the Innes field where the yields were concentrated

at the extremes.

The analysis of variance of the adjusted seed yield for each of the fields (Tables IX A and IX B) shows that the increase in seed yield was a direct result of the increase in vegetative growth.

PART II

GREENHOUSE EXPERIMENTS

Since only one year's results could be obtained from the field experiments, it was thought that, though greenhouse experimental results are not always reliable when applied to field conditions, some additional data on the boron requirements of alfalfa on the gray wooded soil might be obtained from greenhouse experiments.

It was also desirable to secure more definite information on the boron requirements of alfalfa. For this purpose sand culture experiments were set up. Sand cultures were chosen for controlled nutrition studies to eliminate the difficulties encountered in aerating water culture media and to provide a better support for the plant than could be obtained in the latter type of controlled nutrient culture.

LITERATURE REVIEW

Thornton and Nicol (35) studied the reduction of nodule numbers and growth of alfalfa in sand cultures caused by the addition of sodium nitrate to a complete nutrient solution. The sodium nitrate was added at rates of from 0 to 10 grams per

[illegible]

[illegible]

Since only one year's results could be obtained from the field experiments, it was thought that, because greenhouse experimental results are not always reliable when applied to field conditions, some additional data on the boron requirements of alfalfa on the gray wooded soil might be obtained from greenhouse experiments.

It was also desirable to secure more definite information on the boron requirements of alfalfa. For this purpose sand culture experiments were set up. These cultures were chosen for controlled nutrition studies to eliminate the difficulties encountered in securing boron-free water and to provide a better support for the plant than could be obtained in the ordinary type of nutrient solution culture.

[illegible]

[illegible]

litre of nutrient solution. Increasing amounts of nitrate reduced both the number and the size of the nodules. The volume of bacterial tissue was, however, reduced to a greater extent than was the number of nodules. The mean root weights decreased with increasing doses of nitrate, but the ratio of roots to tops remained constant at all nitrate levels. The alfalfa was grown successfully in the sand culture solutions for 100 days.

Schroeder and Walker (31) grew garden peas in sand cultures with varying concentrations of a complete nutrient solution. The concentrations were 0.1, 1, 3, and 5 times the concentration which had proven to produce satisfactory growth. The nutrient solutions were added to the sand on alternate days and the excess drained off immediately. Plants grown in the nutrient solution of 5 times the strength of the check solution had smaller leaves and were shorter and a darker green in color than the plants grown in the check solution. The plants supplied with the solution of 0.1 times the concentration of the check solution were slightly lighter in color. All other characteristics of the plants grown in the solutions of 0.1, 1, and 3 times the concentration of the check solution were the same.

Eaton (10) grew alfalfa in sand cultures containing varying amounts of chloride and sulphate salts. The alfalfa grown in the control solution used in this experiment produced satisfactory growth during seven months of experimentation. Cook (6) prevented alfalfa yellows and obtained an increase in

growth of alfalfa in sand cultures of from 7.61 to 11.90 grams per plant by the addition of .003 grams of $Na_2B_4O_7$ to 5 kilograms of white quartz sand which had received an otherwise complete nutrient solution. White (37) grew alfalfa to maturity in the greenhouse using water cultures as the nutrient media. The plants grown in solutions containing half as much phosphorus or potassium as the check solution produced less vegetative growth and seed than did those grown in the complete nutrient solution. In this experiment daily aeration of the nutrient solutions was necessary for satisfactory growth.

Reeve and Shive (29) used sand culture experiments to determine the potassium-boron and calcium-boron relationships in plant nutrition. When the nutrient solution contained 0.5 p.p.m. of boron, tomato plants produced satisfactory growth at all concentrations of potassium and calcium used in this experiment. No symptoms of boron deficiency or toxicity were evident in the plants grown in the solutions containing 0.1 to 0.5 p.p.m. of boron with concentrations of potassium from 10 to 500 p.p.m. The plants grown in the solution containing 0.001 and 5.0 p.p.m. of boron, however, showed boron deficiency and toxicity symptoms respectively and in increasing intensity as the amount of potassium in the solutions was increased. Plants grown in solutions containing varying amounts of boron and calcium showed no boron symptoms when the solutions contained 0.5 p.p.m. of boron with calcium concentrations of between 5 and 500 p.p.m. Boron deficiency symptoms were increased as the calcium content of the solutions containing 0.001 and 0.01 p.p.m. of boron was increased.

The boron toxicity symptoms were, however, decreased as the concentration of calcium in the solutions containing 5 and 10 p.p.m. of boron was increased.

EXPERIMENT I

During the winter of 1942-43 an experiment was set up in the greenhouse to test the suitability of local and purified silica sand as media for the growing alfalfa under controlled nutrient conditions.

Material and Methods

Purified silica sand was obtained from the Dominion Glass Company, Medicine Hat, Alberta.

Two-gallon, glazed crocks, with drainage holes, were used for the experiment. Fifteen crocks were filled to within an inch of the top with each of the two sands. This made thirty crocks in all for the experiment.

Four alfalfa plants were dug from the field after growth had ceased in the fall, and were stored in the root cellar until three weeks before cuttings were required. On December 1st stem cuttings were made from the plants. The top portion of each stem was discarded to eliminate some of the variability among the cuttings. For each cutting the basal cut was made through a

node and the terminal cut about one inch above the next node, thus leaving one complete node on each cutting. The cuttings from each plant were kept separate. The basal ends of the cuttings were immersed for 24 hours in a solution of Hormodin A, a liquid root-stimulating substance manufactured by Merck and Co., Rahway, N.J. The strength of the solution used was 1.25 cc. of Hormodin A in 250 cc. of distilled water. White (37) found this strength to give satisfactory results.

One cutting from each of the four plants was transferred from the Hormodin A solution to each crock. Extra cuttings, to be used if any failed to form roots, were transferred to a flat containing local sand.

The nutrient solutions applied to the sand in this experiment were based on solutions advocated by Hoagland and Arnon (14) for water culture experiments. Three different solutions were used: a complete solution containing all the essential elements, one containing all the elements except nitrogen, and one containing all the elements except calcium.

The constituents used to make up one litre of each of the nutrient solutions are given in Table X. Distilled water was used in all cases.

TABLE X

Constituents of one litre of the plant nutrient solutions

Salt	Concentration of stock solution	cc. of stock solution Complete	Nitrogen-deficient	Calcium-deficient
KNO_3	1M	2.5	--	2.5
$Ca(NO_3)_2$	1M	2.5	--	-
$Mg(NO_3)_2$	1M	-	--	2.5
$MgSO_4$	1M	1.0	1	1.0
KH_2PO_4	1M	0.5	3	0.5
$Ca(H_2PO_4)_2$	.0625M	-	40	-
Ferric tartrate	0.5%	1.0	1	1.0
A-Z*	-	1.0	1	1.0

* A-Z solution consists of the required amounts of the trace elements.

For the pots containing each of the sands, the experiment was of a randomized block design as described by Goulden (13). Each solution was applied to ten crocks, five containing silica sand, and five containing local sand. Thus the experiment with each sand consisted of three treatments with five replicates of each.

Every second day for the first two months of the experiment, and twice every three days for the remainder of the time sufficient nutrient solution was added to each crock to permit 200 cc. to drain out. This helped to prevent the accumulation

of unused salts. As a further precaution against the accumulation of salts each of the pots was flushed with two litres of distilled water every two weeks.

Artificial light to supplement the short winter days was found to be necessary to prevent excessive vegetative growth and to provide conditions under which the plants would produce seed. Artificial light was supplied from 4:30 p.m. to 1:30 a.m.

To prevent algae from growing on the surface of the sand it was necessary to cover the tops of the crocks, leaving openings for the plants.

The flowers on each plant were artificially tripped every second day and the number for each plant recorded. The pods were picked on June 15th, counted, and those from each plant put in separate paper sacks to dry. When they were dry enough to thresh readily, the pods from each plant were threshed by hand and the seeds counted.

The vegetative growth was removed at the same time as the pods and allowed to dry. The weight of the air-dried material from each crock was taken as the vegetative growth produced.

Experimental Results

The vegetative growth and the number of flowers tripped, pods set, and seeds produced for the alfalfa grown in of unused salts. As a further precaution against the accumulation of which each of the pots was flushed with two liters of distilled water every two weeks.

Artificial light to supplement the short winter days was found to be necessary to prevent abnormal vegetative growth and to provide conditions under which the flowers would produce seed. Artificial light was supplied from 4:30 p.m. to 11:30 p.m.

To prevent flies from spreading pollen from one plant to another it was necessary to cover the tops of the plants, leaving openings for the plants.

The flowers on each plant were artificially selfed every second day and the number for each plant recorded. The pods were picked on June 15th, recorded, and those from each plant put in envelopes until ready to dry. When they were dry enough to thresh readily, the seeds from each plant were threshed by hand and the seeds weighed.

The vegetative plants were harvested at the same time as the pods and allowed to dry. The weight of the air-dried material from each plant was taken as the vegetative growth produced.

Experimental Results

The vegetative growth and the number of flowers produced, pods set, and seeds produced by the plants grown in the three solutions in the local and silica sandsare given in Table XI. The results of the analysis of variance of these results for the local sand are shown in Table XII.

TABLE XI

Alfalfa yields for Experiment I

Solution	Vegetation (grams)	Number of Flowers tripped	Pods	Seeds
Local sand				
Complete	32.8*	881	203	710
Nitrogen deficient	29.5	910	435	1591
Calcium deficient	29.0	887	252	919
Minimum significant difference			123	463
Silica sand				
Complete	35.9*	1269	499	1654
Nitrogen deficient	0	0	0	0
Calcium deficient	5.8	276	77	164

* Each value is the mean of 5 replicates.

TABLE XII

Analysis of variance of the alfalfa yield results for local sand, Experiment I

Variance due to	D.F.	Mean squares Vegetation	Flowers	Pods	Seeds
Replicates	4	34.68	51265	10885	230302
Solution	2	21.22	3536	75336*	1060867*
Error	8	15.72	145319	9509	133994
Total	14				

* Significant beyond the 5% point

The cuttings in the silica sand to which the nitrogen-deficient solution was applied produced very little growth and died before the completion of the experiment. The yields, for all factors studied, produced by the complete and calcium-deficient solution on the silica sand (Table XI) were sufficiently different that statistical analysis of the results was considered unnecessary.

Table XII shows that the three solutions when applied to the local sand caused a significant difference in the numbers of pods and seeds produced by the alfalfa. The alfalfa grown in the nitrogen-deficient solution, as shown by Table XI, produced more pods and seeds than the alfalfa grown in either of the other solutions.

Discussion

The fact that the elimination of nitrogen or calcium from the nutrient solution applied to the local sand had no effect on the amount of vegetation or the number of flowers produced was sufficient to show that the local sand contained plant nutrients that rendered it useless for controlled nutrient studies.

As shown by Tables XI and XII the number of pods and seeds produced by the alfalfa grown on the different solutions on the local sand do not correspond with the number of flowers tripped. The greater number of pods and seeds produced by the alfalfa on the nitrogen-deficient solution agrees with field

observations. Soils high in nitrogen, as in the black soil area of Alberta, are not as satisfactory for alfalfa seed as are the gray wooded soils which are low in nitrogen. The difference in seed production is, however, usually associated with excessive vegetation on the soils with a high nitrogen content. Since vegetative growth was the same regardless of the solution applied, this experiment would appear to indicate that excessive amounts of nitrogen exert a depressive effect on alfalfa seed setting quite independent of the amount of vegetation produced. Although these results are in no way conclusive they do suggest another approach to this problem.

On the silica sand the failure of the alfalfa plants to grow in the nitrogen-deficient solution and the very limited growth produced by the calcium-deficient solution, when compared with the growth produced by the complete solution, were considered sufficient evidence of the suitability of this sand for controlled nutrient studies.

In this experiment there was a great deal of variation between crocks that could not be accounted for by treatments or replicates. This is shown by the large experimental error in Table XII.

EXPERIMENT II

During the summer of 1943 an experiment was conducted in the greenhouse to determine the effect on the growth and seed

production of alfalfa of different concentrations of boron and other plant nutrients in the nutrient solution.

Material and Methods

Purified silica sand for this experiment was obtained from the same source as that used in Experiment I.

Alfalfa plants to be used in this experiment were dug from the field in the spring of 1943 as soon as the ground had thawed. They were stored in the root cellar in moist earth until June 11th when they were taken to the greenhouse. Each plant was divided into four parts by splitting the root and crown with a sharp knife.

Glazed, two-gallon, earthenware crocks, with drainage holes, were used in this experiment. Each crock, containing one section of an alfalfa plant, was filled with sand to within one inch of the top.

The standard solution in this experiment was the same as the complete nutrient solution used in Experiment I. The solutions varied in both the concentration of boron and the concentration of all other nutrients taken together. The concentrations of boron were 0.2, 0.6, and 1.8 p.p.m. of the nutrient solution. Concentrations of all other nutrients were 0.5, 1, and 3 times the concentration used for the complete nutrient solution in Experiment I. The different concentrations of boron and of the other nutrients were applied in all possible combinations.

This made nine treatments in all.

The experiment was of a randomized block design with three replicates of each treatment. In the statistical analysis the variance due to treatments was divided into the variance due to: (1) the concentrations of boron, (2) the concentrations of all other nutrients, and (3) the interaction between boron and the other nutrients.

The other details for the experiment were the same as those for Experiment I except that no artificial light was necessary during the summer. Boron deficiency symptoms are described and illustrated by deTurk (8). This report was used as a basis for recognizing boron deficiency symptoms in the alfalfa in the greenhouse experiments.

Experimental Results

It was found that although the flowers were tripped every second day some self-tripping took place, possibly owing to the high temperatures. As a result of this the data on the number of flowers tripped were discarded.

The vegetative growth and the numbers of pods and seeds produced by the alfalfa in the experiment are given in Table XIII and the results of the analysis of variance of these data appear in Table XIV.

TABLE XIII

Alfalfa yields for Experiment II

	Boron in p.p.m.			
Nutrient solution concentration	0.2	0.6	1.8	Mean
Vegetative yield (grams)				
Low	39.2*	27.9	32.3	33.1
Medium	26.5	25.7	29.0	27.0
High	26.7	20.4	20.2	22.4
Mean	30.8	24.7	27.1	
Number of pods				
Low	843*	438	528	603
Medium	422	285	348	352
High	528	508	459	502
Mean	601	410	445	
Number of seeds				
Low	2715*	1248	1820	1928
Medium	1495	1076	1300	1290
High	2236	1833	1997	2022
Mean	2149	1386	1706	

* Each value is the mean of 3 replicates.

TABLE XIV

Analysis of variance of the alfalfa yields for Experiment II

		Mean squares		
Variance due to	D.F.	Vegetation	Pods	Seeds
Replicates	2	16.99	20003	565678
Solution	2	259.05	144023	1425738
Boron	2	86.38	92763	1320465
Solution x boron	4	33.20	30931	286848
Error	16	110.77	88310	1416552
Total	26			

The different concentrations of boron or of the other nutrients used in this experiment had no effect on any of the factors of alfalfa growth or on seed production studied in this experiment.

Discussion

In this experiment, as in the previous one, relatively large variations between crocks caused the error in the analysis of variance to be very large. For this reason it was necessary that there be great differences between treatments before any significance could be realized.

The results of this experiment demonstrate the very small amounts of boron necessary for satisfactory growth of alfalfa. They also indicate that the availability of boron was not adversely affected when the concentration of all the other

salts in the solution was varied within the limits of the experiment.

EXPERIMENT III

As mentioned previously in this paper, only one year's results on the effect of borax and ammonium phosphate on alfalfa vegetative growth and seed production were available. In an effort to obtain further evidence on the effect of these plant nutrients on alfalfa grown on gray wooded soil, this experiment was conducted in the greenhouse during the summer of 1943.

Material and Methods

The plants for this experiment were treated in the same manner as were those used in Experiment II. One section of each plant was placed in a two-gallon, glazed crock filled to within an inch of the top with gray wooded soil. The drainage holes in the crocks were stoppered to prevent the loss of nutrients.

This experiment consisted of twenty-seven crocks. Ammonium phosphate was applied at the rates of 0, 50, and 100 pounds per acre, and borax at the rates of 0, 10, and 30 pounds per acre. The experimental design was the same as for Experiment II. The borax and fertilizer were applied in all possible

combinations, making a total of nine treatments with three replicates of each. In the analysis of variance of the results, the variance due to treatments in general was divided into its component parts: the variance due to rate of application of fertilizer, that due to the rate of application of boron, and that due to the interaction between the two.

The amount of borax and fertilizer to be applied to each crock was determined by the area of the surface of the soil. The correct amount was weighed on a precision balance, dissolved in distilled water, and the solution applied to the soil.

Distilled water was supplied to the soil as required.

The flowers were tripped every second day and the number recorded. When the pods were ripe the plants were treated as in Experiment I.

Experimental Results

As in Experiment II, self-tripping took place and the data on the number of flowers tripped had to be discarded.

The vegetative yield and the number of pods and seeds produced by the alfalfa on the gray wooded soil in the greenhouse are shown in Table XV. The results of the analysis of variance of these data are given in Table XVI.

TABLE XV

Alfalfa yields for Experiment III
on gray wooded soil

Fertilizer (16-20)	Borax, pounds per acre			
	none	10	30	Mean
Vegetative yield (gm. per plant)				
No fertilizer	13.5*	13.5	12.7	13.2
50 lb./acre	12.5	12.4	11.3	12.1
100 lb./acre	14.9	13.3	16.4	14.9
Mean	13.6	13.1	13.5	
Minimum significant difference				1.6
Number of pods per plant				
No fertilizer	365*	397	377	397
50 lb./acre	358	310	300	329
100 lb./acre	371	249	155	258
Mean	365	319	277	
Number of seeds per plant				
No fertilizer	1516*	1578	1455	1517
50 lb./acre	1309	1313	1050	1224
100 lb./acre	1356	737	363	819
Mean	1394	1209	956	

* Each value is the mean of 3 replicates

TABLE XVI

Analysis of variance of the alfalfa yields for Experiment III with gray wooded soil

		Mean squares		
Variance due to	D.F.	Vegetation	Pods	Seeds
Replicates	2	8.04	28165	530838
Fertilizer	2	17.79*	33172	1105324
Boron	2	.80	17216	435001
Fertilizer x boron	4	4.10	10752	202450
Error	16	3.17	19915	367836
Total	26			

* Significant beyond the 5% point

The amount of vegetation produced by the alfalfa on the gray wooded soil was the only factor studied that was affected significantly by the application of fertilizer. (Table XVI). The application of ammonium phosphate at the rate of 100 pounds per acre, as shown by Table XV, significantly increased the vegetative growth above that produced by the alfalfa on the soil which had received no fertilizer or only 50 pounds per acre.

The application of borax to the soil had no significant effect on either the vegetative growth or the seed yield.

Discussion

In this experiment, the increase in vegetative growth resulting from the application of ammonium phosphate (16-20)

to gray wooded soil is in direct agreement with the results obtained from the field experiment reported in this paper and also with the results obtained by other workers (38 and 39).

Although the fertilizer had no significant effect on seed production in this experiment, there was a definite trend toward a reduction in the amount of seed produced as the rate of fertilizer application was increased (Table XV). If the experiment had contained more replicates this difference would no doubt have been significant.

Although the vegetative growth and seed yield of the plants receiving the different applications of borax did not differ significnatly, there was a definite trend, as shown in Table XV, toward a reduction in seed yield as the rate of application of borax was increased.

GENERAL DISCUSSION

The large increase in both seed and hay production resulting from the application of ammonium phosphate (16-20) containing 15% sulphur to two fields of alfalfa on gray wooded soil is a good indication of the necessity of fertilizers for satisfactory crop production on this type of soil. Only one year's results are reported here, but they are substantiated by results reported by other workers. Over a five-year period Wyatt et al (38) obtained an increase of 3165 pounds of alfalfa

hay per acre by the application of ammonium phosphate (16-20) to gray wooded soil. White (37) reported increases in both hay and seed production by the application of fertilizers to alfalfa on the same farms on which the field experiments reported in this paper were conducted. The seed yields obtained by White were, however, much lower than those obtained in this experiment. This indicates that other factors besides nutrition play an important part in the failure of alfalfa to produce a satisfactory yield of seed and that economic increases in seed production can be realized by the application of fertilizers only if the other environmental conditions are favorable. This fact is demonstrated in the greenhouse experiment with alfalfa on gray wooded soil. The application of ammonium phosphate at the rate of 100 pounds per acre increased the vegetative growth but showed a tendency to decrease the seed yield.

In the field experiment, increased vegetative growth was accompanied by an increase in seed production. This relationship is the same as that found by White (37) and indicates that, within the limits of these experiments, nutritional conditions favoring vegetative growth also favor seed production.

The increase in seed production on the Anderson field was directly due to the increase in vegetative growth. This relationship, also held for the Innes field. The very low seed yield from the unfertilized plots on this field indicates that one or more nutrients were sufficiently low to prevent satisfactory seed formation. The lack of sulphur in the soil has a detrimental effect on seed formation and, since, as

shown by Wyatt et al (38), the gray wooded soils of Alberta are in general very low in sulphur, it is quite probable that sulphur was the limiting factor in seed production on the unfertilized plots.

The comparatively high yield of seed from the fertilized plots on the thin stand over that produced by the thick stand is in accordance with practices recommended by Fryer (11) for alfalfa seed production in Alberta.

The apparent depressive effect of an excessive amount of nitrogen on seed production, obtained in the sand culture experiment with local sand, agrees very well with general field observations in Alberta. Soils high in nitrogen do not lend themselves to satisfactory seed production. Contrary to field observations, however, low seed production was not accompanied by excessive vegetative growth.

The boron requirement of alfalfa, as shown by the controlled nutrient studies, is very small since 0.2 p.p.m. of boron was as effective for vegetative growth and seed production as were concentrations of 0.6 and 1.8 p.p.m. Under the conditions of this experiment the availability of boron was not greatly affected by the concentration of the other salts in the nutrient solution, since no symptom of boron deficiency was evident on the alfalfa receiving 0.2 p.p.m. boron regardless of the concentration of the other salts.

SUMMARY

1. The application of ammonium phosphate (16-20) to alfalfa on gray wooded soil at the rate of 100 pounds per acre increased both the vegetative growth and the seed production.

2. Alfalfa seeded at the rate of 4 pounds per acre, and fertilized at the above rate produced more hay and seed than alfalfa seeded at the rate of 10 pounds per acre and receiving the same treatment.

3. On the thick stand the increase in seed production was due to the increase in vegetative growth, while on the thin stand the increase in seed production was not greater than could be accounted for by the increase in vegetation.

4. The application of borax, at the rates of 5, 15, 25, and 35 pounds per acre, to alfalfa on gray wooded soil had no effect on either the vegetative growth or the seed production over that produced by the plots receiving no boron.

5. Local sand contained enough plant nutrients to render it useless for controlled nutrient experiments.

6. Alfalfa growing in local sand in the greenhouse produced less seed when nitrogen was included in the nutrient solution added to the sand than did alfalfa grown in sand to which solutions containing no nitrogen were added.

7. Alfalfa grown in silica sand to which nutrient solutions were added showed no signs of boron deficiency or toxicity with concentrations of boron of 0.2, 0.6, and 1.8 p.p.m.

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