THE RESPONSE OF ALFALFA AND SWEET CLOVER TO VARIOUS FERTILIZER TREATMENTS IN POT CULTURES OF SOILS OF THE CLAYPAN GROUP

by

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INTRODUCTION

The increased interest in the production of alfalfa and sweet clover on the claypan soils of southeastern Kansas prompted this greenhouse study of representative soils of that section. It is known that the larger the yields taken off the land in the form of hay crops, the more readily the nutrient elements of the soil are depleted. This brought up the question of what response could be realized from the addition of certain nutrient elements on these soils.

Field experiments at both the Thayer and Columbus experiment fields usually have shown that satisfactory yields of alfalfa can be obtained in this area from the use of large quantities of lime and phosphatic fertilizer. However, in recent years particularly, there have been strong indications that potassium may be quite deficient in the soils of this section. There also has been some indication that some of the nutrient elements other than these may play a limiting role in legume production.

Alfalfa in the rotation at the Columbus experiment field has been grown on each fertility series but once. It was believed that this initial crop, because of its deep roots, probably has been able to obtain a considerable portion of its nutrient supply from the subsoil. This supposition, however, had never been satisfactorily demonstrated. Sweet clover growth at the Thayer experiment field never has been particularly outstanding. The total growth of this crop, when used as a green manure crop has been much less than at Columbus. The question of whether or not raw rock phosphate can be used satisfactorily as a method of supplementing the native supply of phosphorus in the soil never has been intensely studied under these conditions.

To partially answer the above questions, a greenhouse study was set up with different kinds and amounts of the fertilizer elements. Also the nutrient elements, magnesium and boron, which may be depleted were included in the study. Soils were selected from each of the experiment fields, from a subsoil near the Columbus field and from a farm near the Thayer field. Phosphorus was studied in the form of both monocalcium phosphate and rock phosphate. The rock phosphate contained a total of 34.15 per cent P_2O_5.

METHOD OF CULTURE

The study was carried out in the greenhouse of the Agronomy Department of Kansas State College during the winter and spring of 1947-48. No attempt was made to control the photoperiod during the time the plants were grown. Just after the third cutting of alfalfa was taken on April 27, 1948, the glass on the greenhouse was covered with whitewash to eliminate the intense rays of the sun during the spring months.

The seeds were inoculated with a commercial inoculant at the time of planting in order to insure the presence of Rhizobia in the soil during the growth of the various crops of legumes.

There were 179 glazed earthenware jars of different volumes used with no outlets in the bottoms. The jars which were used were cleaned and the air dry soil was placed into the respective jars. To each one-half gallon jar were added 1800 grams of soil; to each one gallon jar were added 4000 grams of soil; to each two gallon jar were added 8000 grams of the top soil used and 7200 grams if subsoil were used; and to each four gallon jars were added 15,000 grams of soil.

The respective fertilizer treatments were added to the jars by thorough mixing. This was accomplished by placing the soil in an end-over-end churn and churning the soil for 20 turns in one direction and reversing the direction and churning for another 20 turns. This procedure was to insure equal distribution of the fertilizer materials throughout the entire soil medium.

After the soil had been mixed and replaced into its respective jar, enough distilled water was added to bring the soil in each jar up to 20 per cent moisture content. After this the surface of the soil was allowed to dry enough so that a seed bed could be prepared.

Seeds in excess were sown to a depth of one-half inch in a circular manner in the jars in order to insure a sufficient stand and an even distribution of plants. The plants were thinned to 8 in each one-half gallon jar; to 10 in each one gallon jar; to 12 in each two-gallon jar; and to 20 in each four-gallon jar. This was done two weeks after emergence. This was done because it was desired that complete and efficient utilization of the plant nutrients be accomplished and yet not have the plants too crowded.

The weeds were removed from the jars throughout the study at their seedling stage in order that they would not compete with the culture plants for the fertilizer elements. The plants were thoroughly sprayed with R.S. 380, manufactured by Rohn & Haas Company, Incorporated, Philadelphia, Pennsylvania, every week to 10 days to control the red spiders. The soil was kept at optimum moisture content throughout the study with the addition of distilled water to insure maximum growth and to eliminate the errors that would be introduced by using city supplied water. At regular intervals of time, the jars were rotated to allow all plants to receive the same amount of sunlight.

CULTURES AND SOILS USED

The soils used in this experiment included Parsons silt loam from the Thayer Experiment Field in Neosho County, Parsons silt loam from the F. E. Davidson farm also in Neosho County, Cherokee silt loam from the Columbus Experiment Field in Cherokee County, and Cherokee subsoil, taken from a road cut near the Columbus Experiment Field. Hereafter, these soils will be referred to as Thayer, Davidson, Cherokee and Cherokee subsoil, respectively, to permit identification.

Forty-eight of the one-half gallon jars, each containing 1800 g of soil from the Davidson farm, were used for sweet clover. Eight different treatments were studied on this soil with six replicates of each treatment and the results were obtained and reported as an average of the six jars. To the soil in each jar 6 g of $CaCO_3$ was added along with the treatment to insure optimum soil reaction. Table 1 shows the eight different treatments as to the elements and the amounts added. For convenience, the code used in the study will be used throughout this discussion to indicate the soil, the group of treatments and the number of the treatment.

From Table 1 it is noted that the Davidson farm soil on which sweet clover was grown in the one-half gallon jars was treated primarily with the fertilizer elements. Nitrogen was omitted from two of the treatments; potassium was omitted from four of the treatments, and almost four times as much rock phosphate replaced monocalcium phosphate in two of the treatments.

It was desired in this part of the study to determine whether a response in yield could be realized from the addition of monocalcium phosphate alone and how great an amount must be added to get the response. Also it was desired to find whether a response could be obtained from the addition of potassium and if doubling the fertilizer application would appreciably increase the yield. Due to the low and slow availability of the phosphorus from rock phosphate, this material was added in approximately four times the amount of monocalcium phosphate that was added in this group of treatments.

Sweet clover was also grown on the Thayer soil. There were 12 four-gallon jars each containing 15,000 grams of the soil. Three treatments with four replicates were used in this study and no lime was added to the soil since the soil had recently been limed.

From Table 1 it can be seen that the same amount of nitrogen

Table 1. Soil treatments and cultures grown for the greenhouse study.

Soil	No. of treatment	Jar size	Crop*	Amount of fertilizer constituent added (grams) NH_4NO_3	$Ca(H_2PO_4)_2$	KCl	Raw rock phosphate	$MgCl_2$	$Na_2B_4O_7$
Davidson	1-1	½ gal.	S. Cl.	0.2250	0.5325				
	1-2	½ gal.	S. Cl.	0.2250	0.5325	2.2374			
	1-3	½ gal.	S. Cl.		0.5325				
	1-4	½ gal.	S. Cl.	0.2250		2.2374	5.0000		
	1-5	½ gal.	S. Cl.	0.4800	1.0680				
	1-6	½ gal.	S. Cl.	0.4800	1.0680	0.4748			
	1-7	½ gal.	S. Cl.		1.0680				
	1-8	½ gal.	S. Cl.	0.4800		0.4748	4.0000		
Thayer	III-1	4 gal.	S. Cl.	1.2000	4.2800				
	III-2	4 gal.	S. Cl.	1.0000	4.2000	1.0008			
	III-3	4 gal.	S. Cl.	1.2000		1.0008	16.0000		
Cherokee	II-1	2 gal.	Alfalfa	0.9000	2.1300				
	II-2	2 gal.	Alfalfa	0.9000	2.1300	0.9492			
Cherokee subsoil	II-1	2 gal.	Alfalfa	0.9000	2.1300				
	II-2	2 gal.	Alfalfa	0.9000	2.1300	0.9496			
Cherokee	II-1	1 gal.	Alfalfa	0.4800	1.0680				
	II-2	1 gal.	Alfalfa	2.4800	1.0680	0.4748			
	II-3	1 gal.	Alfalfa	0.4800	1.0680	0.4748		0.0800	
	II-4	1 gal.	Alfalfa	0.4800	1.0680	0.4748			0.0800
	II-5	1 gal.	Alfalfa	0.4800			4.0000		
	II-6	1 gal.	Alfalfa	0.4800		2.4748	4.0000		

	II-5	1 gal.	Alfalfa	0.4800			4.0000		
	II-6	1 gal.	Alfalfa	0.4800		0.4748	4.0000		
Thayer	III-2	1 gal.	Alfalfa	0.4800	1.0680	0.4748			
	III-3	1 gal.	Alfalfa	0.4800	1.0680	0.4748		0.8000	
	III-4	1 gal.	Alfalfa	0.4800	1.0680	0.4748			0.0600
Thayer	I-1	½ gal.	Alfalfa	0.4800	1.0680				
	I-2	½ gal.	Alfalfa	0.4800	1.0680	0.4748			
	I-3	¼ gal.	Alfalfa	0.2400	0.5340	0.2374			
Cherokee	I-1	½ gal.	Alfalfa	0.4800	1.0680				
	I-2	½ gal.	Alfalfa	0.4800	1.0680	0.4748			
	I-3	¼ gal.	Alfalfa	0.2400	0.5340	0.2374			
Cherokee subsoil	I-1	½ gal.	Alfalfa	0.4800	1.0680				
	I-2	½ gal.	Alfalfa	0.4800	1.0680	0.4748			
	I-3	¼ gal.	Alfalfa	0.2400	0.5340	0.2374			

* S. Cl. indicates sweet clover throughout the tables.

was added to the soil of each jar. The same amount of phosphorus in the form of monocalcium phosphate was added in the first two treatments and approximately four times this amount of rock phosphate was added in the third treatment. The potassium was omitted from the first treatment and the same amounts added to the second and third treatments.

It was desired in this study to ascertain the beneficial effect of the addition of potassium besides the addition of phosphorus. It was also desired to study the comparative effect of the addition of four times the amount of rock phosphate as there was monocalcium phosphate in the other treatments.

A group of 20 two-gallon jars was used to contain the Cherokee soil and the Cherokee subsoil. Ten of the jars were used for the top soil and 10 were used for the subsoil. In this group there were two treatments for each soil and each treatment was replicated five times. Twenty-four g of $CaCO_3$ was added to the soil of each jar to insure a desirable soil reaction.

A study of Table 1 will show that this group of treatments was designed to ascertain the effect of the addition of potassium where nitrogen and phosphorus had already been added. This group was designed also to study the difference in response of crops on the top soil and the subsoil where equal amounts of fertilizer treatment were added.

Thirty one-gallon jars were used for six treatments of Cherokee soil. No lime was added to this soil with the treatments because the soil recently had been limed before being brought to the greenhouse for study. Each treatment was replicated five times and the mean for the five replicates was reported. Alfalfa was the crop used for this investigation.

A study of Table 1 will show that the first two treatments were the same in composition and amount except that the second treatment contained potassium in addition to nitrogen and phosphorus. The third treatment contained magnesium in addition to the three fertilizer elements whereas the fourth treatment contained boron in addition to the three fertilizer elements. To compare the effects of monocalcium phosphate and rock phosphate applications, the fifth and sixth treatments were added. Both of these treatments had rock phosphate substituted for monocalcium phosphate in the same proportion as mentioned in previous discussions. The fifth treatment did not include the element potassium while the sixth did include this element.

Fifteen one-gallon jars were used to contain the Thayer soil in which alfalfa was grown. The three treatments were replicated five times and it may be seen from Table 1 that these treatments were the same as treatment two, three, and four as described for the Cherokee soil above. No lime was added to this soil since it recently had been limed. From Table 1 it may be seen that this group was designed to study the effect of the addition of magnesium and boron when sufficient amounts of the three fertilizer elements were already present. Also it was desired to see what effect, if any, magnesium had upon the uptake of phosphorus by the plant.

A group of 54 one-half gallon jars was used for additional studies with Thayer soil, Cherokee soil, and Cherokee subsoil.

Eighteen jars were used for each soil. Three different treatments were used and each was replicated six times. To insure a favorable soil reaction, six g of calcium carbonate was added to each jar of soil.

As seen in Table 1 each soil was treated alike insofar as the fertilizer treatments were concerned. The first treatment consisted of nitrogen and phosphorus only whereas the second treatment consisted of the same constituents as treatment one, but in addition, potassium was added. Treatment three consisted of the same fertilizer elements as treatment two; i.e., nitrogen, phosphorus, and potassium, but it contained only one-half the amount of each.

YIELD DATA

Yield of Sweet Clover

The sweet clover that was produced on the Davidson soil with the treatments as shown in Table 1 will be considered first. All yields are expressed on the air dry basis. A study of Table 2 showed that the yield from the addition of 0.5325 g of monocalcium phosphate gave a yield of 5.65 g. It was also noted that when the application of monocalcium phosphate was doubled, the yield was increased to 6.36 g of air dry alfalfa which is a 12.56 per cent increase.

In the treatment where 0.2250 g of NH_4NO_3 and 0.5325 g of monocalcium phosphate were added, the yield was 6.22 g which was a 10.09 per cent increase when compared with where the NH_4NO_3 was

Table 2. Yield of sweet clover on soil from the Davidson farm in the one-half gallon jars.

Treatment*	Yield of plant tissue** g
1/2 NP	6.22
1/2 NPK	6.73
1/2 N	5.65
1/2 N-RP-K	5.50
NP	5.59
NPK	6.07
P	6.36
N-RP-K	6.00

* Exact amounts for all the yield tables may be found in Table 1.

** Harvested 122 days after seeding; all reports are air dry weight.

not added. When the above treatment was doubled in amount, the yield was 6.59 g which was an increase of 5.95 per cent. The above results indicated that nitrogen also was a limiting factor for the production of the sweet clover on the Davidson soil.

In the treatment where 0.2250 g of NH_4NO_3, 0.5325 g of monocalcium phosphate, and 0.2374 g of KCl were added, the yield was 6.73 g which was the highest yield of any of the treatments. Where the treatment was doubled, it gave a yield of only 6.07 g which was a decrease of 9.80 per cent.

The indications thus far show that the Davidson soil was lacking in all three fertilizer elements since an addition gave an increase in yield. It was interesting to note that when potassium was added to the soil, it gave an increase in yield but when this amount was doubled, it decreased the yield. It would be interesting to study this further to see if the luxury absorption of potassium caused the decrease of yield or whether the extra amount of chlorine added to the soil in the KCl became toxic to sweet clover. It would be interesting to study the addition of K_2SO_4 to the soil to see if the same results would occur if the chlorine were not added but sulfur were present.

A further study of Table 2 indicated that once a soil was deficient in phosphorus it was not desirable to correct this deficiency with the addition of rock phosphate. In the treatment where 0.225 g of NH_4NO_3, 0.2374 g of KCl, and 2 g of rock phosphate were added, the yield was 5.50 g which was 18.28 per cent less than the treatment where 0.5325 g of monocalcium phosphate was added. This emphasized the low availability of phosphorus in rock phosphate because almost four times the amount of rock phosphate was added as monocalcium phosphate.

When the treatment was doubled in nitrogen, rock phosphate and potassium, the yield was 6.0 g which is 9.09 per cent more than for half the rate of this same treatment. It is probable that the small increase in yield from the increase in treatment was caused equally as much from the nitrogen and potassium as from the phosphorus contained in the rock phosphate.

Table 3. Yield of sweet clover on the Thayer soil in the four-gallon jars.

Treatment	Yield of plant tissue* g
NP	38.16
NPK	40.50
N-RP-K	34.91

* Harvested 120 days after seeding.

A study of the yields from the four-gallon jars on the Thayer soil as indicated in Table 3 showed an increase from the addition of potassium. In the treatment where 1.80 g of NH_4NO_3 and 4.26 g of monocalcium phosphate were added, the total yield was 38.16 g. In the treatment where 1.80 g of NH_4NO_3, 4.26 g of monocalcium phosphate, and 1.8992 g KCl were added, the total yield was 40.50 g or an increase of 3.51 per cent from the addition of potassium. The undesirability of rock phosphate as a source of phosphorus is again clearly indicated by the third treatment where 1.80 g of NH_4NO_3, 1.8992 g of KCl, and 16.0 g of rock phosphate yielded only 34.91 g. It was worthy of noting that the amount of rock phosphate was almost four times the amount as the monocalcium phosphate added; although the yield from rock phosphate was 13.79 per cent less than that of the monocalcium phosphate. Further it was noted that the yield from the treatment containing rock phosphate was even 8.51 per cent less than the yield obtained where no potassium was added. This study indicated that the Thayer soil had a deficiency of potassium since it responded to the addition of potassium but the soil had a greater deficiency of phosphorus. The latter was indicated by the fact that nitrogen and monocalcium phosphate without potassium gave a higher yield than that from nitrogen and potassium with the low available phosphorus in rock phosphate.

Yield of Alfalfa

The alfalfa grown in the one-half gallon jars was cut three times. The study was terminated on April 27, 1948 just after the third cutting because the plants at that time showed signs of plant nutrient exhaustion, and it was considered inadvisable to continue the study.

Table 4. Yield of alfalfa on the soil from three locations in one-half gallon jars.

Soil	Treatment	Yield in g			Total
		Date of cuttings			
		Feb.10	March 25	April 27	
Thayer	NP	2.39	2.42	2.64	7.45
	NPK	2.22	2.43	2.78	7.43
	1/2 NPK	2.25	2.33	2.76	7.34
Cherokee	NP	1.82	2.46	2.53	6.81
	NPK	2.40	2.99	3.24	8.63
	1/2 NPK	2.21	2.51	2.92	7.64
Subsoil	NP	2.14	1.90	2.42	6.46
	NPK	2.22	2.20	2.84	7.26
	1/2 NPK	1.71	1.86	2.66	6.23
Days lapsed since seeded or last cut		79	45	32	

A study of Table 4 showed that the first cutting from the Thayer soil yielded 2.39 g where nitrogen and phosphorus had been added. There was a decrease of 7.11 per cent where potash was added. When the treatment was added which contained one-half the amount of the complete fertilizer, the yield was 2.25 g or an increase of 1.35 per cent above the full treatment. On the other hand, the one-half treatment is 5.86 per cent less than that of the treatment with only nitrogen and phosphorus.

In the second cutting from the Thayer soil, the yield was larger than from the first cutting in every case. In the second cutting the greatest increase in yield was realized from the full treatment where potash had been added.

The third cutting from the Thayer soil showed again the greatest yield from the addition of the fertilizer treatment which included potash. The second highest yield and the one with the greatest increase in the last cutting was where the one-half treatment was added. The treatment in which potash was omitted gave the lowest yield which was 5.39 per cent lower than the full treatment and 4.35 per cent lower than the one-half treatment of a complete fertilizer.

This study indicated that the Thayer soil was deficient in available potassium to the extent that it was unable to continue a large production of alfalfa over a long period of time. Although the total yields for this study show that there was no increase in yield from the addition of potash, it is believed that if succeeding crops had been taken that the relative yield would have been in favor of the potash addition. This was indicated by the fact that in the second and third cuttings, the yields were higher where only half the treatment was added than where no potash was added.

Where the above group of treatments were used on the Cherokee soil in the one-half gallon jars, a different trend was noted. A study of Table 4 showed that starting with the first cutting, an increase in yield was realized from the addition of potash. The lowest yield of 1.82 g was obtained from the treatment where only nitrogen and phosphorus were added. The yield was increased 31.89 per cent by the addition of potash. In the one-half treatment of a complete fertilizer, there was an increase of 21.41 per cent over the nitrogen and phosphorus treatment which indicates that the Cherokee soil is definitely deficient in available potassium.

The existence of the potash deficiency was also indicated by the results of the second and third cuttings where the yields were higher where potash had been added and lowest where no potash had been added. These data did not indicate whether a greater yield could be obtained from a further increase in potash or not, but the trend seemed to indicate that a larger yield could be expected from a greater addition of potash.

The total yields from the treatments indicated that the potash was a limiting factor in the production of alfalfa on the Cherokee soil. The total yield for the treatment containing only nitrogen and phosphorus gave a yield of 6.81 g whereas where potash was included in the treatment, there was an increase of 26.75 per cent. Also where the one-half treatment was used, it showed an increase of 12.20 per cent over the treatment where a full treatment of nitrogen and phosphorus was used. This indicated again that potassium was deficient in this particular soil.

The yield from the Cherokee subsoil indicated a deficiency of available potassium. The first cutting yielded 2.14 g where the treatment contained nitrogen and phosphorus. In the treatment where potassium was also included there was an increase in yield of 3.74 per cent and where the complete fertilizer treatment was added in one-half amount, there was 22.95 per cent less than the complete fertilizer and 20.10 per cent less than where the full amount of nitrogen and phosphorus was added. These results indicated that the Cherokee subsoil has a deficiency of potassium but that it is also deficient in available nitrogen and phosphorus.

This fact also was indicated by the yield of the second cutting, but the third cutting gave the highest yield from the treatment where a full amount of the complete fertilizer was added and the smallest yield was where potash was omitted.

The fact that the one-half treatment of a complete fertilizer gave a yield greater than the full amount of nitrogen and phosphorus indicated that the available potassium in the soil had been taken up by the plant and the added potassium caused an increase in yield. The higher yield from the full amount of the complete fertilizer than the one-half complete fertilizer indicated that a portion of the available supply of the fertilizer elements was being obtained by the plants from that which had been added.

The total yields also indicated that the Cherokee subsoil was deficient in available potassium. This was indicated by the fact that a 12.39 per cent increase was realized just from the addition of potash. When the one-half complete fertilizer was added, the yield was 3.56 per cent less than that where the full amount of nitrogen and phosphorus was added. This indicated that the Cherokee subsoil was not deficient in potassium alone but that a decrease in the supply of nitrogen and phosphorus had a negative effect on the yield also.

The study of the yield of alfalfa grown in the one-half gallon jars indicated that the Thayer soil had no marked deficiency in potassium because the total yield from the full amount of nitrogen and phosphorus was 0.027 per cent larger than the yield where potash was added. A slight deficiency of nitrogen or phosphorus was indicated by the fact that a decrease of 1.21 per cent was obtained where the one-half complete fertilizer was used.

In contrast to the above, the Cherokee soil showed a definite deficiency in potassium. The fact that the potassium was the most deficient fertilizer element was indicated by the increase in yield of the one-half complete fertilizer treatment over the full amount of just nitrogen and phosphorus.

The total yield data indicated that the Cherokee subsoil was deficient in potassium to a lesser degree than the top soil because the increase in yield from the addition of potash in the top soil was 26.75 per cent whereas the increase in yield on the subsoil from the addition of potash was 12.39 per cent. It was interesting to note, however, that the yield of alfalfa from the subsoil compared favorably with that of the normal surface soil when comparable fertilizer treatments were applied. It must, therefore, be concluded that the subsoil is capable of supplying considerable plant nutrients under normal field conditions.

Table 5 shows the yield data of alfalfa grown in the one-gallon jars on the Cherokee and Thayer soils.

Table 5. Yield of alfalfa on Cherokee and Thayer soils in the one-gallon jars.

Soil	Treatment	Yield in g			
		Date of cutting			
		Feb. 10	March 25	April 27	May 22
Cherokee	NP	3.45	4.87	4.12	3.06
	NPK	4.13	5.84	5.21	3.92
	NPK+Mg	4.01	5.15	4.65	3.97
	NPK+B	4.02	5.84	4.95	4.46
	N-RP	2.51	3.89	3.92	3.00
	N-RP-K	3.00	5.11	5.14	4.45
Thayer	NPK	3.69	5.59	5.55	4.70
	NPK+Mg	3.67	6.78	5.89	4.81
	NPK+B	4.34	5.88	5.80	4.79
Days lapsed since seeding or last cut		79	45	32	25

The Cherokee soil showed a response to the addition of potash in every cutting by an increase in yield. The addition of potash gave a 19.7 per cent increase in the first cutting over that treatment where potash was not added. The second cutting showed a 20.4 per cent, the third a 26.5 per cent, and the fourth a 28.1 per cent increase just from the addition of potash.

The above data showed that the Cherokee soil is strikingly deficient in potassium and that a continued increase can be expected even to the fourth cutting from the addition of potash.

In the treatment where magnesium was added, the data showed no increase in yield except in the fourth cutting where a 1.41 per cent increase was noted. These data not only failed to show an increase from the addition of magnesium, but a decrease of 2.9

per cent in comparison to the treatment where magnesium was omitted was obtained for the first cutting. Similar decreases were noted for the second and third cuttings. It was indicated here that the Cherokee soil was not deficient in magnesium and it was therefore, not advisable to make additions to the soil in the form of $MgCl_2$.

The addition of boron did not increase the yield in either the first, second, or third cuttings, but there was a 13.8 per cent increase in the fourth cutting which indicated that the available boron content of the Cherokee soil was becoming somewhat depleted.

In the treatment of nitrogen and phosphorus where the phosphorus was added in the form of rock phosphate, there was a 27.2 per cent decrease in the first cutting when compared with where the phosphorus was added as monocalcium phosphate. The second, third, and fourth cuttings gave decreases of 22.2 per cent, 4.85 per cent, and 1.96 per cent, respectively. The decreases in yield in comparison to monocalcium phosphate clearly showed the slow and low availability of the phosphorus in the rock phosphate.

The study of the Thayer soil showed a deficiency of both magnesium and boron. From Table 5 it can be seen that the addition of magnesium gave about the same yield in the first cutting, but increases were obtained from the second, third, and fourth cuttings of 21.3 per cent, 6.13 per cent, and 2.34 per cent, respectively. These data indicated that the Thayer soil was deficient in magnesium and that a continued percentage increase in yield could possibly be realized from a greater addition of magnesium.

The Thayer soil gave an increase in yield from the addition of boron in every cutting. The first cutting gave a 17.2 per cent increase and the second, third, and fourth cuttings gave increases of 5.2 per cent, 4.5 per cent, and 1.91 per cent, respectively. These data indicated that the Thayer soil was deficient in boron and that a prolonged increase in yield could have been obtained if more boron had been added.

The study of the Cherokee and Thayer soils in the one-gallon jars indicated that the Cherokee soil was deficient in potassium to a marked degree but it was not deficient to any extent in magnesium. However, there was indication that boron might eventually be deficient in this soil. The study also indicated the undesirability of rock phosphate as a source of phosphorus on the Cherokee soil. On the other hand, the Thayer soil showed a deficiency of both magnesium and boron. The data indicated that both elements could be added to the Thayer soil for even greater yields.

The study of the Cherokee soil and Cherokee subsoil yield in the two-gallon jars from Table 6 indicated a potassium deficiency of both soils. In the case of the topsoil, the increase in yield from the addition of potash in the first cutting was 30.9 per cent. The second and third cuttings showed increases of 11.1 per cent and 11.4 per cent whereas the fourth cutting showed an increase of 36.8 per cent which exceeded the increase of the first cutting.

Table 6. Yield of alfalfa from the Cherokee and Cherokee subsoils in the two-gallon jars.

Soil	Treatment	Yield in g, Date of cutting: Feb. 10	March 25	April 27	May 22
Cherokee	NP	3.43	10.67	12.88	8.62
	NPK	4.49	11.85	14.35	11.79
Subsoil	NP	2.72	6.35	8.43	6.01
	NPK	4.14	8.34	11.77	9.48
Days lapsed since seeding or last cutting		79	45	32	25

The data from the yield of the subsoil showed an increase of 52.2 per cent from the increase of potash at the first cutting. The second and third cuttings showed increases of 31.4 per cent and 39.6 per cent and the fourth cutting showed a 57.8 per cent increase.

This study of the Cherokee topsoil and Cherokee subsoil showed that the topsoil was deficient in potassium, but that the subsoil was much more deficient in potassium than the topsoil. This was somewhat contrary to the results reported in Table 4 from the use of smaller jars. This difference must be attributed to the difference in the mass of soil used as otherwise the common treatments are comparable.

CHEMICAL ANALYSES OF THE SOILS

Total Phosphorus

Total phosphorus determinations were made on the Thayer soil, Davidson soil, Cherokee subsoil, and Cherokee soil by the magnesium nitrate method as outlined in A.O.A.C., 1935 (2). Five gram samples were used in duplicates and the average results were reported in percentage P_2O_5 of the air dry soil as shown in Table 7. The Cherokee topsoil proved to be more deficient in total phosphorus than any of the other soils. The Thayer soil contained the greatest percentage of phosphorus, the Cherokee subsoil was next in percentage and the Davidson soil was third.

Table 7. Soil reaction and nutrient content of the soils studied.

Soil	pH	Total P_2O_5	Total K_2O	Available P_2O_5	Available K_2O
		Per cent			
Thayer	6.85	0.0895	0.934	0.0053	0.0082
Davidson	5.13	0.0772	0.848	0.0025	0.0109
Cherokee	5.74	0.0542	0.817	0.0016	0.0072
Cherokee subsoil	4.75	0.0808	0.872	0.0021	0.0109

These data agree closely with the yield data in Table 5 where an increase in yield was obtained where monocalcium phosphate was the source of phosphorus in comparison with where the phosphorus was added in the form of rock phosphate. Also in Table 2, a 1.15 per cent decrease in yield was a result of the addition of rock phosphate. This small yield indicated that a greater amount of monocalcium phosphate could have resulted in a greater increase in yield.

Even though the Thayer soil had the highest percentage of total P_2O_5, Table 3 shows that it gave an 8.15 per cent increase in yield where readily available phosphorus was added in the form of monocalcium phosphate.

Total Potassium

Total potassium was determined for the four soils that were studied. The one-half g samples were fused according to the method described by W. O. Robinson (5). After the reprecipitation of the calcium, filtering and washing, the total filtrates were evaporated to dryness. The residue was then taken up with hot water, transferred to 100 ml volumetric flasks, allowed to cool to room temperature, and filled to volume. An aliquot of 50 ml of this solution was taken and 5 ml of Li_2SO_4 (1100 p.p.m. of Li.) was added. The Li_2SO_4 was used as an internal standard. The solution was passed through a Perkin Elmer flame photometer and the relation of the potassium to the lithum was recorded. The parts per million for the recorded data were interpolated from a standard curve run by single known standard solutions.

All the soils studied showed a low percentage of total potassium. These data agree well with the yield data where all the soils showed an increase in yield from the addition of potash. All the other soils, namely Cherokee topsoil, Cherokee subsoil, and Davidson soil showed increases in yield on the first cutting from the addition of potash.

Available Phosphorus

Available phosphorus determinations were made on the Thayer soil, Davidson soil, Cherokee soil, and Cherokee subsoil by the procedure outlined by Arnold and Kurtz (1). The determinations were made in duplicate and the average results were reported in percentage P_2O_5 as shown in Table 7. The Thayer soil contained the highest percentage of available phosphorus and the Cherokee topsoil contained the least amount. The fact that the Cherokee subsoil contained a greater amount of available phosphorus than the Cherokee soil was explained by the crop removal of the phosphorus in the top soil in large quantities by more shallow rooted crops.

Available Potassium

The available potassium was determined by first extracting the potassium with a normal solution of ammonium acetate. A 25g sample of soil was placed in a 300 ml flask, 50 ml of ammonium acetate was added, the mixture was shaken 15 minutes on a mechanical shaker, and filtered. A 20 ml aliquot was taken and to it 2 ml of Li_2SO_4 (1100 p.p.m. Li.) was added as an internal standard. The solution was then passed through the flame photometer in like manner as described under total potassium determination. Table 7 showed that the Davidson soil and Cherokee subsoil contained the greatest amount of available potassium. It was interesting to note that the Thayer soil contained the greatest amount of total potassium, but it contained less available than either the Davidson or the Cherokee subsoil. Also it was interesting to note that the Cherokee topsoil contained the least amount of both total and available phosphorus and potassium when compared with the other soils.

Soil Reaction

The soil reaction of the soils studied was determined with a Leeds-Northrup glass electrode. A 25 g sample of each soil was taken and a 25 ml portion of distilled water was added. This mixture was allowed to stand for one hour with frequent stirring. The pH was then determined by means of the glass electrode. Table 7 indicated that the Thayer soil had the highest pH. The Cherokee, Davidson, and Cherokee subsoil showed lower pH values in that order of decreasing pH. The addition of lime, as mentioned previously, had not been made on any of the samples used in the laboratory for pH measurements.

CHEMICAL ANALYSES OF PLANT MATERIAL

The uptake of phosphorus, potassium, and boron by the plants was studied. This was accomplished by determining the content of each of the elements for each cutting from each of the different treatments used. The replicates were composited for each treatment and a sample was taken from the separate composites for analysis.

Phosphorus Content

The phosphorus extraction from the plant material was made by the wet digestion method with perchloric, nitric, and sulfuric acids as described by Piper (4). The determination for the first two cuttings of the amount of phosphorus was gravimetric as described by Piper (4). A comparison was made in order to determine the feasibility of converting the procedure to a volumetric one. The results from the two methods checked so closely that to speed up the determinations, the precipitates in the crucibles were washed four times with 2.5 per cent ammonium nitrate, washed with cool water, titrated with standard NaOH, and then back titrated with standard HNO_3 as described in A.O.A.C. (2).

Table 8. Phosphorus content of the sweet clover produced on soil from the Davidson farm in the one-half gallon jars.

Treatment	P_2O_5 Per cent*
1/2 NP	0.531
1/2 NPK	0.527
1/2 P	0.596
1/2 N-RP-K	0.422
NP	0.649
NPK	0.647
P	0.804
N-RP-K	0.466

* Expressed upon percentage of air dry plant material throughout the paper.

A study of Table 8 showed that where monocalcium phosphate alone was added to the soil, the percentage phosphorus content in the sweet clover was higher than where combinations of nitrogen and phosphorus were added or where such combinations also included potassium.

The greatest percentage content was evident in the plants that produced the smallest yield. The lowest percentage content occurred in the plants where the highest yield was realized. This was explained by the extra carbohydrates formed due to the addition of nitrogen and potassium. The possible increase in the uptake of potassium and nitrogen and the increased formation of carbohydrates was the reason for the comparative decrease in the uptake of phosphorus.

The undesirability of the use of rock phosphate was again brought out in this investigation. From Table 8 it was noted that the use of rock phosphate in the one-half treatment decreased the yield 19.95 per cent and in the full treatment there was a decrease of 27.98 per cent, when compared with the treatments containing monocalcium phosphate. The low availability of phosphorus in rock phosphate was readily emphasized when it was remembered that almost four times as much rock phosphate was added in comparison to monocalcium phosphate.

The study of the Thayer soil in the four-gallon jars as denoted in Table 9 showed that when potash was added to the soil, the percentage phosphorus content was decreased. Again this was attributed to the increase in carbohydrate formation and greater uptake of other nutrients.

Table 9. Phosphorus content of the sweet clover produced on the Thayer soil in the four-gallon jars.

Treatment	P_2O_5 Per cent
NP	0.731
NPK	0.702
N-RP-K	0.489

This study also showed a decrease in phosphorus uptake by the sweet clover when rock phosphate was applied as a source of phosphorus. The application of rock phosphate showed a relative decrease of 29.99 per cent when compared with the application of monocalcium phosphate.

The above studies with the sweet clover cultures showed that each time potash was added, the per cent phosphorus content in the sweet clover decreased. The studies also showed, in a striking manner, the undesirability of the use of rock phosphate as a source of phosphorus because not only was the per cent phosphorus less in the plant material, but a study of Tables 2 and 3 showed that the yield also was smaller.

A study of Table 10 showed in each of the Thayer, Cherokee, and Cherokee subsoil that the percentage phosphorus in the alfalfa decreased with the addition of potash. It was also noted that for each soil the content of phosphorus in the alfalfa increased in each succeeding crop. This fact indicated that phosphorus was not the limiting factor which was causing the plants to show severe nutrient deficiencies at the time of the third cutting.

Table 10. Phosphorus content of the alfalfa produced on soil from three locations in the one-half gallon jars.

Soil	Treatment	P_2O_5 content by cutting (per cent)		
		First	Second	Third
Thayer	NP	0.867	1.020	1.269
	NPK	0.760	0.906	1.062
	1/2NPK	0.751	0.769	1.045
Cherokee	NP	0.743	0.880	1.660
	NPK	0.669	0.801	0.989
	1/2NPK	0.672	0.844	0.928
Subsoil	NP	0.681	0.763	0.950
	NPK	0.649	0.698	0.839
	1/2NPK	0.680	0.662	0.816

A comparison of the data in Table 10 indicated that the Thayer soil originally had the largest amount of available phosphorus, the Cherokee had the next highest amount and the Cherokee subsoil had the least amount. The Thayer soil had the largest content of phosphorus by the plants. The Cherokee soil had a smaller content of phosphorus and a study of the total yields from these jars showed that the Cherokee soil had also the smaller yield. These facts indicated that possibly an additional increase in yield could have been realized from the addition of larger amounts of phosphorus to the Cherokee soil. Likewise the indications were that a larger yield could have been obtained by a larger addition of monocalcium phosphate to the Cherokee subsoil.

Table 11. Phosphorus content of the alfalfa produced on Cherokee and Thayer soils in the one-gallon jars.

Soil	Treatment	P_2O_5 content by cutting (per cent)			
		First	Second	Third	Fourth
Cherokee	NP	0.676	0.799	0.923	0.939
	NPK	0.643	0.786	0.861	0.937
	NPK+Mg	0.611	0.751	0.819	0.916
	NPK+B	0.637	0.779	0.906	0.926
	N-RP	0.603	0.686	0.751	0.881
	N-RP-K	0.544	0.597	0.600	0.691
Thayer	NPK	0.681	0.837	0.795	0.876
	NPK+Mg	0.764	0.793	0.751	0.874
	NPK+B	0.674	0.824	0.786	0.867

A study of Table 11 showed that the percentage content of phosphorus was greatest where only nitrogen and phosphorus had been added to the soil when compared with the other treatments added to the Cherokee soil. Where potash had been added to the soil, there was a decrease in the uptake of phosphorus which may be explained by the increased formation of carbohydrates as discussed previously. In the fourth cutting the uptake of phosphorus was only 0.21 per cent lower from the addition of potash in comparison with the larger increases in the preceding cuttings. This was explained by the possibility that the potassium was available in smaller quantities so as to have resulted in smaller yields. Also the available phosphorus was taken up by the heavier yields of the preceding cuttings in the treatment where potash was added.

In the treatment where magnesium was added, there was a decrease in each cutting in the uptake of phosphorus by the plants grown on the Cherokee soil. This decrease was not explained by an increase in carbohydrate formation because in Table 5 it was noted that there was a decrease in yield for this treatment.

The study of Table 11 also showed a decrease of phosphorus uptake by the Cherokee soil when rock phosphate was used. This again was explained by the low availability of phosphorus in rock phosphate.

The data from the plant material grown on the Cherokee soil showed that the percentage uptake of phosphorus was decreased with the addition of potash, boron, magnesium, and rock phosphate in that order.

The plant material grown on the Thayer soil showed an increase in the uptake of phosphorus due to the addition of $MgCl_2$ on the first cutting but the succeeding cuttings showed a decrease in the uptake of phosphorus where $MgCl_2$ was added. These data were explained by referring to Table 5 and noting that where there was an increase in yield, there was a decrease in phosphorus uptake where magnesium had been added. On the other hand, where there was a decrease in yield, there was an increase in phosphorus uptake. The latter occurred only in the case of the first cutting. The explanation again may be due to the increase in carbohydrate formation which in turn decreased the percentage phosphorus.

Where boron was added to the Thayer soil in addition to the complete fertilizer, the percentage phosphorus uptake showed a decrease in each cutting. Again this fact was explained by the increased formation of carbohydrates because a study of Table 5 showed that in each case the yield was higher where boron was added to the Thayer soil. The study of the Thayer soil in the one-gallon jars showed no definite indication that either magnesium or boron were carriers of phosphorus. In this same study of treatments, the Cherokee subsoil indicated a decrease of phosphorus uptake in each cutting from the addition of potash.

The Cherokee subsoil gave a higher percentage of phosphorus uptake than did the Cherokee topsoil for the first two cuttings but a larger uptake on the third and fourth cuttings. This was explained by the fact that the subsoil initially had a greater percentage of total phosphorus as shown in Table 7. This, however, does not explain why the Cherokee topsoil gave a higher yield than the subsoil. This possibly could be partially explained by the lack of organic matter and low nitrogen content of the subsoil. There is also considerable likelihood that an insufficient supply of some minor nutrient element served also to limit the growth of alfalfa on the Cherokee subsoil. Severe boron deficiency symptoms were noted on the plants growing on this particular soil following the fourth cutting on those cultures where the combination of the three fertilizer elements had been furnished.

The study of phosphorus uptake by alfalfa in the two-gallon jars showed a decrease in phosphorus where potash was added to the Cherokee soil and Cherokee subsoil. The data also showed that the uptake of phosphorus was in smaller amounts from the topsoil the first two cuttings and in larger amounts the third and fourth cuttings when compared with the subsoil. In the case of each soil, the phosphorus uptake kept increasing with each succeeding cutting.

Table 12. Phosphorus content of the alfalfa produced on Cherokee subsoil in the two-gallon jars.

Soil	Treatment	P_2O_5 content by cutting (per cent)			
		First	Second	Third	Fourth
Cherokee	NP	0.720	0.726	0.874	1.045
Cherokee	NPK	0.711	0.785	0.796	0.876
Subsoil	NP	0.748	0.769	0.869	0.958
Subsoil	NPK	0.738	0.659	0.706	0.796

The study of the phosphorus uptake by the plants grown on the Cherokee soil in the two-gallon jars showed a decrease in phosphorus content where potash was added in each cutting except the second one which showed a slight increase as shown in Table 12.

Potassium Content

A study of the uptake of potassium was made by determining the potassium content of the plant material from each separate treatment for each cutting. The plant material from each replicate of each treatment was composited and a sample was taken for analysis. The potassium was reported in percentage K_2O on the air dry basis of the plant material.

The potassium extraction was made with a 1 normal solution of ammonium acetate which had been adjusted to a neutral pH. One-half g samples were determined in duplicate. The plant material was ground to pass a sieve with a 1 mm opening. The one-half g sample of plant material was placed in a 500 ml flask and the 100 ml or 150 ml of extracting solution added as suggested by Dr. O. J. Attoe.[1] The amount of extracting solution was determined by the p.p.m. of potassium expected in the plant material. After the flask had been shaken on a mechanical shaker for one hour and filtered through Watman No. 2 filter paper, a 50 ml aliquot was taken. A 5 ml portion of Li_2SO_4 was added. This combination made the concentration of lithium, the internal standard, to be 100 p.p.m.

The above solution was run through a Perkin Elmer flame photometer and the relation of potassium to lithium was recorded. The parts per million for the recorded data were interpolated from a standard curve determined by a single known standard solutions.

Table 13. Potassium content of the sweet clover produced on the soil from the Davidson farm in the one-gallon jars.

Treatment	K_2O Per cent
1/2 NP	2.02
1/2 NPK	2.29
1/2 P	1.86
1/2 N-RP-K	2.53
NP	1.85
NPK	2.80
P	1.87
N-RP-K	2.53

[1] Dr. O. J. Attoe, University of Wisconsin. Unpublished data.

A study of Table 13 showed a marked increase in the uptake of potassium by the sweet clover plants where potash was added to the Davidson soil. In the case of the one-half treatments, the largest uptake was indicated where rock phosphate was used as the source of phosphorus in the complete fertilizer. The decrease in the uptake of phosphorus as shown in Table 8 and the decrease in the formation of carbohydrates as shown by the decreased yield in Table 2 was the explanation for the relatively high percentage of potassium where rock phosphate was added.

The one-half treatments otherwise showed the same relationship of potassium uptake as was shown by yield; i.e., the addition of potash showed the highest uptake of potassium from the addition of potash, the nitrogen and phosphorus treatment was next and the monocalcium phosphate treatment was the lowest. This was explained by the fact that the phosphorus uptake was greater where monocalcium phosphate was added as shown in Table 7 and this appeared to lower the potassium percentage.

Where full treatments were added to the Davidson soil, the highest uptake of potassium by the sweet clover was where rock phosphate was added. This percentage uptake was the same as where the one-half treatment was added. The same explanation as above was offered for this high percentage.

Where potash was added, the uptake of potassium was greater than the other treatments which showed practically the same percentage uptake of potassium.

Table 14. Potassium content of the sweet clover produced on the Thayer soil in the four-gallon jars.

Treatment	K_2O Per cent
NP	1.58
NPK	2.28
N-RP-K	2.58

A study of Table 14 showed similar results concerning the potassium uptake by the sweet clover grown on the Thayer soil in the four-gallon jars as shown in Table 13. The uptake of potassium was greatest where rock phosphate had been added. This fact was explained by the same reasoning as for the Davidson soil. The uptake of potassium was greater by 0.70 per cent K_2O where potash had been added than where it had been omitted.

Table 15. Potassium content of the alfalfa produced on soil from three locations in the one-half gallon jars.

Soil	Treatment	K_2O content by cutting (per cent) First	Second	Third
Thayer	NP	2.02	1.27	1.30
	NPK	4.26	3.47	2.62
	1/2 NPK	3.50	2.08	1.83
Cherokee	NP	1.16	0.76	0.83
	NPK	4.01	2.89	2.05
	1/2 NPK	3.36	2.51	1.55
Cherokee subsoil	NP	2.03	1.30	1.12
	NPK	3.58	3.30	2.58
	1/2 NPK	3.29	2.62	1.99

The plants grown on Thayer soil in the one-half gallon jars showed a marked increase in the uptake of potassium for each cutting where potash was added. Table 15 showed that at the first cutting the uptake of potassium was more than doubled where the full amount of complete fertilizer was added and about one and one-half times more where the one-half amount of the complete fertilizer was added.

The second and third cutting plants showed a decrease in potassium for each succeeding cutting. When the yield in Table 4 was compared with the phosphorus uptake in Table 15, it was noted that the yield increased with decreased potassium uptake for the three cuttings. This indicated that there was possibly a potassium toxicity where potash was added in a full amount at the first cutting. This indicated that potassium was not deficient in the Thayer soil especially for the first few cuttings.

The plants from the Cherokee soil in the one-half gallon jars showed a marked increase in the uptake of potassium where potash was added. The uptake of potassium decreased at each succeeding cutting. From comparing Table 15 and Table 4 it was noted that on the Cherokee soil, the yields increased as the percentage uptake of potassium decreased.

The plants from the Cherokee subsoil showed an increase in potassium uptake where potash was added and the uptake decreased with each succeeding crop.

In the study of the soils in the one-half gallon jars, the Thayer soil appeared to be the least deficient soil in potassium. This was shown where the uptake of potassium by the plants was less on this soil when compared with the other two soils where no potash was added. The yield from the Cherokee soil also showed an increase on all cuttings where potash was added to the soil. The Cherokee subsoil also showed an increase in yield from the addition of potash but the increase was not so pronounced as that shown from the Cherokee topsoil. The maturity of the plants and the depletion of potassium from the soil partially explained the decrease in the potassium in the plants on the succeeding cuttings.

Table 16. Potassium content of the alfalfa produced on Cherokee and Thayer soils in the one-gallon jars.

Soil	Treatment	K_2O content by cutting (per cent)			
		First	Second	Third	Fourth
Cherokee	NP	1.67	1.17	0.86	1.08
	NPK	3.36	2.30	1.58	1.61
	NPK + Mg	3.40	2.36	1.48	1.83
	NPK + B	3.40	2.20	1.58	1.56
	N-RP	1.87	1.48	1.02	1.17
	N-RP-K	3.59	2.78	1.88	1.79
Thayer	NPK	3.48	2.42	1.58	1.58
	NPK + Mg	3.54	2.40	1.59	1.71
	NPK + B	3.44	3.12	1.58	1.60

The data in Table 16 showed that the plants from the Cherokee soil grown in the one-gallon jars were doubled in the content of potassium in the first cutting where potash was added to the soil. The uptake decreased with each succeeding cutting.

Where magnesium was added to the soil, the percentage uptake of potassium was greater except in the third cutting.

Where boron was added to the soil, the percentage uptake of potassium changed very little from the complete fertilizer treatment with boron omitted.

Where rock phosphate was the source of phosphorus, the percentage uptake of potassium increased when compared with where monocalcium phosphate was used. This may be explained by the increased formation of carbohydrates where monocalcium phosphate was added as shown by yields in Table 5.

The plants from the Thayer soil showed an increase in the uptake of potassium the first cutting where potash was added, but thereafter the differences in uptake between the treatments were slight. Where boron was added in addition to a complete fertilizer, there was a decrease the first cutting, an increase the second cutting, and practically no difference thereafter.

The study of the Cherokee and Thayer soils in the one-gallon jars showed an increase in potassium uptake where potash was added. This uptake was greater from the Thayer soil than from the Cherokee soil which indicated that the Cherokee was the most deficient in potassium. The addition of magnesium or boron to the soil gave no marked indication of affecting the uptake of potassium.

The plants on Cherokee soil and subsoil in the two-gallon jars showed an increase in the uptake of potassium where potash had been added as indicated in Table 17. The uptake was greater from the subsoil for each cutting where no potash had been added which indicated that the Cherokee soil is more deficient in potassium than the subsoil.

Table 17. Potassium content of the alfalfa produced on Cherokee and Cherokee subsoil in the two-gallon jars.

Soil	Treatment	K_2O content by cutting (per cent) First	Second	Third	Fourth
Cherokee	NP	1.63	1.35	0.93	0.98
	NPK	3.58	3.26	1.52	1.33
Subsoil	NP	1.60	1.42	1.19	1.29
	NPK	4.87	3.34	2.26	2.17

These data of the potassium uptake from the respective soils agree very well with the available potassium data as shown in Table 7 for the soils which were used in this investigation.

Boron Content

The boron content of the plant material was determined as outlined by Berger and Truog (3) and was expressed in parts per million.

Table 18. Boron content of the sweet clover produced on the Davidson soil in the one-half gallon jars.

Treatment	Boron content p.p.m.
1/2 NP	24.5
1/2 NPK	22.5
1/2 P	22.5
1/2 N-RP-K	20.5
NP	20.0
NPK	17.5
P	18.5
N-RP-K	19.5

A study of Table 18 showed the greatest amount of boron was taken up by the sweet clover on the Davidson soil where the one-half treatment of nitrogen and monocalcium phosphate was added. All the one-half treatments showed a greater uptake of boron than the full treatments. It was noted that the addition of potash and the elimination of nitrogen seemingly decreased the uptake of boron. The decrease where the potash was added was explained by the increased formation of carbohydrates as shown in Table 2, the one-half application of a complete fertilizer. An increase in the uptake of potassium and the increase in carbohydrates tended to decrease the relative uptake of boron. When this same reasoning was used for the one-half phosphorus treatment, it was seen that the yield there was even lower than the complete fertilizer and the boron content was just the same.

From the same study there was no indication that any of the fertilizer elements directly affected the boron uptake by the plant except to the extent of increasing yield and in turn resulting in an apparent reduction of boron.

Table 19. Boron content of the sweet clover produced on the Thayer soil in the four-gallon jars.

Treatment	Boron content p.p.m.
NP	28.5
NPK	26.5
N-RP-K	24.0

The plants on the Thayer soil in the four-gallon jars, as shown in Table 19, showed the highest boron uptake where the ammonium nitrate and monocalcium phosphate were added. A decrease was shown in boron uptake where a complete fertilizer was used and an even greater decrease was noted where rock phosphate was used as a source of phosphorus in the complete fertilizer.

Table 20. Boron content of the alfalfa produced on soil from three locations in the one-half gallon jars.

Soil	Treatment	Boron content by cutting (p.p.m.) First	Second	Third
Thayer	NP	27.5	23.5	17.5
	NPK	26.0	27.0	13.5
	1/2 NPK	27.5	40.5	12.5
Cherokee	NP	37.5	38.0	33.5
	NPK	40.0	40.5	24.5
	1/2 NPK	37.0	24.5	26.5
Cherokee subsoil	NP	14.5	12.5	6.5
	NPK	14.5	12.5	6.0
	1/2 NPK	16.0	13.5	6.0

A study of Table 20 showed no consistent effect upon the uptake of boron by the alfalfa plants by different kinds nor amounts of the fertilizer elements. The overall trend of boron uptake seemed to be a decrease with each succeeding cutting; although this did not hold true in every case.

The data in Table 20 suggested that the Cherokee soil was capable of furnishing the greatest amount of boron, the Thayer soil was next in amount, and the subsoil was the most deficient in boron. This was seen by the relative uptake of boron by the plants.

Table 21. Boron content of the alfalfa produced on Cherokee and Thayer soils in the one-gallon jars.

Soil	Treatment	Boron content by cutting (p.p.m.)			
		First	Second	Third	Fourth
Cherokee	NP	59.0	54.5	70.0	62.0
	NPK	55.0	49.5	58.5	56.0
	NPK + Mg	59.0	50.5	63.0	51.0
	NPK + B	75.0	80.0	100.0	100.0
	N-RP	56.0	55.0	69.5	58.5
	N-RP-K	70.0	53.0	64.0	51.0
Thayer	NPK	46.0	25.5	26.5	19.5
	NPK + Mg	35.5	23.0	27.5	20.5
	NPK + B	67.5	60.0	70.0	56.5

The data in Table 21 showed again that the Thayer soil was more deficient in boron than the Cherokee soil which is brought out by the relative uptake of boron from the two soils. The uptake of boron was very irregular in each soil for each successive cutting.

The most outstanding portion of these data is where the addition of boron to the soil increased the uptake of boron to a marked degree. This high uptake of boron by the plants continued throughout four cuttings from the Cherokee soil, but in the case of the Thayer soil, the uptake showed a decrease on the fourth cutting. This fact and the fact that the uptake was less than that from the Cherokee soil clearly showed the boron deficiency of the Thayer soil.

Table 22. Boron content of the alfalfa produced on Cherokee and Cherokee subsoil from the two-gallon jars.

Soil	Treatment	Boron content by cutting (p.p.m.)			
		First	Second	Third	Fourth
Cherokee	NP	31.0	32.0	42.0	39.5
	NPK	43.0	31.5	39.0	27.5
Subsoil	NP	8.0	5.5	13.0	10.0
	NPK	10.5	10.5	14.5	12.5

The boron deficiency of the Cherokee subsoil was clearly shown by the data in Table 22. The uptake of boron was higher in every case from the topsoil when compared to the uptake from the subsoil. These data showed no consistency in boron uptake when the treatments were compared.

The study of the boron uptake showed a marked increase in boron uptake when boron was added to the soil. Definite boron deficiencies were indicated by the data for the Thayer soil and the Cherokee subsoil. The data were limited to the extent that they did not show whether or not an increased amount of boron added to the soil would increase the boron uptake by the plants.

SUMMARY

The object of this greenhouse study was to determine whether an increased yield could be realized from the addition of incomplete and complete fertilizers added and how the various applications affected the uptake of various nutrients by the plants grown on the soil. Soils from the two southeastern Kansas experiment fields at Thayer and Columbus were used because of previous knowledge relative to the behavior of these areas. Additionally a Cherokee subsoil was used because of special problems believed to exist with regard to it. A soil was also selected from the F. E. Davidson farm as representative of the private farms in the southeastern Kansas area. Sweet clover and alfalfa were the crops grown on the soils.

Various amounts of the complete and incomplete fertilizer were added to the soil. In addition to the above, some of the treatments on the Thayer and Cherokee soils included boron and magnesium as separate treatments. Nitrogen was applied as ammonium nitrate, phosphorus as monocalcium phosphate and rock phosphate, potassium as potassium chloride, magnesium as magnesium chloride, and boron as sodium tetraborate.

One cutting of sweet clover was taken from the Davidson soil and the Thayer soil in the one-half gallon and four-gallon jars respectively. Three cuttings were taken from the Thayer soil, Cherokee soil, and the Cherokee subsoil in the one-half gallon jars. Four cuttings were reported from the Cherokee soil and

Thayer soil in the one-gallon jars and the Cherokee soil and Cherokee subsoil in the two-gallon jars. The mean yield for each respective treatment was reported.

The amount of phosphorus and potassium in the soils was determined both in total and available amounts. The soil reaction was determined for each soil before any treatment was applied.

A study of the nutrient uptake was made by determining the amount of phosphorus, potassium, and boron in the plant material.

There was an overall increase in yield from the addition of phosphorus to the Davidson soil. An increase was realized in yield from this soil when potash was added at the rate of 0.2374 g per 1800 g of soil but when this application was doubled, there was no increase in yield.

The Thayer soil showed a deficiency in phosphorus, potassium, magnesium, and boron from the yield data. The Cherokee soil showed phosphorus, potassium, and mild boron deficiencies, but there was no marked indication of magnesium deficiency through the fourth cutting.

The Cherokee subsoil showed a deficiency of potassium and the low uptake of boron from the subsoil indicated a marked deficiency of boron; although no boron treatment was used on this soil.

Each time phosphorus was added in the form of monocalcium phosphate, the yield was increased and the uptake of phosphorus by the plants was increased. Where rock phosphate was added, the yield decreased in comparison with monocalcium phosphate and the relative uptake of phosphorus by the plants was lowered.

Where potash was added to the soil, the yield increased for all soils except the Thayer soil which was studied in the one-half gallon jars where alfalfa was grown. In addition, the relative uptake of phosphorus decreased and the relative uptake of potassium increased.

The addition of magnesium showed no indication of increasing the uptake of phosphorus and it increased the yield only on the Thayer soil. Boron addition greatly increased the uptake of boron by the plants and increased the yield in the Cherokee and Thayer soils.

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