THE EFFECT OF APPLICATIONS OF LIME AND FERTILIZER TO THE SOIL UPON THE COMPOSITION AND YIELD OF LEGUME HAYS

by

FLOYD EWING DAVIDSON

B. S., Kansas State College
of Agriculture and Applied Science, 1933

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1941

TABLE OF CONTENTS

INTRODUCTION

A large amount of investigation has been done in recent years to determine whether addition of lime and fertilizers to soils can be expected to result in increased percentages of calcium, phosphorus and, in some cases, other elements in crop plants. Only limited studies of this type have been made in Kansas and additional work, therefore, seemed to be justifiable. It has been proved beyond question that the use of lime and phosphatic fertilizers is essential for the economical production of certain legumes in many parts of eastern Kansas. This is especially true of alfalfa, red clover and sweet clover.

Since many of the soils in southeastern Kansas are quite deficient in available calcium and phosphorus, it appeared logical to assume that legume hay grown on these soils might be deficient in the elements mentioned. Numerous circumstances which have come to the writer's attention indicate this to be the case. Various malnutrition diseases among livestock in that section of the state have been reported by veterinarians to be caused either by lack of sufficient calcium or phosphorus, or, in some cases, both. These conditions have been corrected by the addition of calcium and phosphorus concentrates to the ration. On several occasions farmers have reported that livestock, especially cattle, have demonstrated ravenous appetites for corn or sorghum stalks grown on small areas popularly called "alkali spots." Such deficiency symptoms have been observed much more frequently in livestock grazed and fed with crops grown on sandy soils than on the heavier types of land.

With these problems in mind experiments were planned to study (1) the effect of plant environment, species and soil treatment upon the calcium, nitrogen and phosphorus in legume hays, and (2) the efficiency of various soil treatments in increasing yields of these hay crops and at the same time enriching them in calcium, nitrogen and phosphorus. From these studies it was hoped to ascertain whether deficiencies of calcium and phosphorus in legume hays could be partially or entirely corrected by the application of lime and fertilizers to the soil.

REVIEW OF LITERATURE

A review of the literature revealed that comparatively little information pertaining to the effect of lime and fertilizer applications upon plant composition was published before 1929. Since that time a large number of investigations have been conducted by workers all over the world to study the problem from many viewpoints. Studies of the effects of lime and fertilizer applications upon the composition of pasture herbage have commanded relatively more attention than those concerned with any other crops. However, since studies with pasture grasses are only indirectly related to the problem studied by the writer, only a few will be mentioned in this review.

Archibald and his associates (5, 7, 8), working with a tame grass mixture in Massachusetts, found that the application of a complete fertilizer slightly decreased the percentage of dry matter and crude fiber but increased most of the mineral nutrients in the plants. The acre yield of dry matter as well as that of protein, calcium and phosphorus was greatly increased. Although they used rather heavy applications of nitrogen in their fertilizer treatments, they reported that it was more efficient than phosphate and potash in increasing the mineral content of the herbage.

Beaumont (13) working on permanent pastures in the dairy section of Massachusetts, and Lush and Fletcher (37) studying the effect of fertilization upon the mineral composition of a tame pasture mixture in Louisiana reported similar results. On the contrary Brown (17, 18) found that larger increases in the protein content of Connecticut pasture herbage were produced by the application of phosphatic fertilizers than by nitrogen or lime.

Davies, working with Chippendale (24) and later with Milton (25) in Wales, reported that rather heavy applications of basic slag greatly increased the phosphorus content of the herbage. Similar results were obtained by Pierre and Robinson (42) in West Virginia.

On the other hand, Woodman and Underwood (52), in England, Grunder (33), in the state of Washington, and others, failed to find significant increases in the phosphorus content of pasture vegetation from the use of fertilizers.

It has been shown by many workers who have studied pasture herbages (13, 17, 25, 33, 42, 52) that the percentage of phosphorus, to some extent, and that of calcium to a very large extent, were affected by the relative abundance of certain types of plants in the vegetation. Since clover and weeds have much higher calcium contents than grasses, pasture herbages with a preponderance of either of the former types of plants have been found to have higher calcium contents than herbages in which grass species predominate. Also the treatments that favored or depressed legumes or weeds in relation to the amount of grass definitely affected the calcium content of the herbage. Most of the workers found that use of phosphatic fertilizers, and particularly lime and phosphate, was favorable for the increase of the relative number of clover plants, and consequently indirectly increased the calcium content of the herbage. However, use of nitrogen fertilizers resulted in a depressing effect upon the relative number of clover plants and a decrease in the percentage of calcium in the herbage.

Next to grasses, legume hay crops (particularly alfalfa) have been studied most in regard to the effect of lime and fertilizer applications upon their compositions. Since these studies are more closely related to the problem of the writer, the literature pertaining to them was reviewed more completely. Reference can be made only to those investigations that appear to be most nearly analogous to the present work.

Ames and Boltz (4), Eckles and associates (26), Sewell and Latshaw (46), Pittman (43), and Willis and Harrington (51), all using alfalfa as the test crop found definite increases in the phosphorus content of the plants where phosphatic fertilizers had been applied to the soil. Similar results were obtained by Alway and co-workers (3) studying both alfalfa and red clover, Snider and Hein (48) using sweet clover, Adams, et al. (1) investigating soybean hay, and Baker and Vandecaveye (10) working with oats and vetch.

On the contrary Grizzard (32), Millar (40), Austin (9), and Blair and Prince (15), all working with legume hays, failed to obtain any appreciable increases in the phosphorus content of plants when phosphatic fertilizers were applied at light or medium rates. They found that the type and structure of the soil had a much greater effect upon the phosphorus content of plants than soil treatment. Most of these workers agreed that very heavy applications of phosphatic fertilizers increased significantly the phosphorus content of the plants.

Mather (39) found that although applications of 200 pounds of treble phosphate (45 per cent) per acre produced maximum yields, applications of 1000 pounds per acre or more were necessary to materially increase the phosphorus content in the various crops. His work showed that, in those cases where the phosphorus content was definitely increased, the extra phosphorus in the plant was largely in the inorganic form.

Holtz (36) reported that the calcium and phosphorus contents of red clover hay were influenced by the amounts of these elements in the soil only when the total calcium and available phosphorus were quite low.

Sewell and Latshaw (46) and Millar (40) found that the phosphorus content of alfalfa hay varied inversely with applications of lime.

Sewell and associates (47) also showed that calcium content of alfalfa hay increased with increasing applications of hydrated lime up to 2000 pounds per acre.

Prigsley and McKibbin (44) reported that the calcium content of mixed red clover and timothy hay was directly proportional to the amount of total calcium in the soil, while Adams and his co-workers (1) found that the calcium in soybean hay varied directly with applications of superphosphate.

The calcium content of alfalfa hay increased with maturity, according to Fonder (27); and the percentage of calcium in hay produced on heavy soils was higher than in that produced on sandy types.

Many investigations have been conducted to study the effect of fertilization upon the qualities of cereal grains, potatoes, fruits, vegetables and their products, as well as that of many other types of plants.

Hartwell (34), in his comprehensive review of both American and foreign literature, concludes that use of phosphatic fertilizers generally increased the amount of protein, flavors, colors, and keeping qualities in many plants. Phosphate fertilization has also been observed to hasten maturity, strengthen stalks and increase the resistance of plants to both weather injury and diseases.

McAllister (38) found that the percentage of phosphorus in cereal grains was increased only when applications of fertilizers failed to increase the yields.

Bayfield (11, 12) reported that phosphates decreased the protein but increased the test weight in wheat, while lime had variable effects upon these factors. Also both lime and phosphates increased the ash in wheats, which was undesirable from the milling standpoint.

Although there appears to be some lack of agreement in the results of the various studies, much of it can be explained as being due to the different conditions under which the investigations were conducted. Generally lime and nitrogen fertilizer applications have caused definite increases in the protein content of plants. This has been especially true of crop plants that were used for forage or pasture. Usually the phosphorus contents have been materially increased only when the soil was very low in available phosphorus or when the fertilizers have been applied at rather high rates. In a few cases, workers have reported significant increases in the percentages of phosphorus in plants when, for some reason, the fertilizer failed to increase the yield of the crop. Ordinarily the phosphorus contents have been found to be higher in young plants than in those that had reached, or were nearing, maturity. The calcium contents of the plants were usually not affected materially by soil treatment except to the extent that such treatments altered the botanical composition of the plant cover.

MATERIALS AND METHODS

Samples of legume hays taken from various plots in the soil fertility experiments at the Columbus, Moran and Thayer experiment fields in southeast Kansas, were analyzed chemically for total calcium, nitrogen and phosphorus. The samples were taken during the summers of 1937 and 1938, and analyses were made during the following winters.

Columbus Experiment Field

At the Columbus experiment field, one mile west and three miles north of Columbus in Cherokee County, Kansas, soil fertility experiments have been conducted since 1924 on Cherokee silt loam soil. This soil is a Planosol developed under grass vegetation. The surface soil has an ashy-gray appearance and is rather extensively leached. The subsoil is a very dense, slowly pervious clay pan, and this together with nearly level topography often creates a serious drainage problem. This soil type is quite low in organic matter, nitrogen, calcium and available phosphorus. The surface soil has a pH value of 5.26. Applications of lime and phosphatic fertilizers have given very significant responses in yields of certain crops.

From 1924 to 1930, inclusive, the rotation used in the soil fertility experiments was as follows: (1) oats and sweet clover, (2) sweet clover plowed down in summer for green manure, (3) wheat, (4) wheat, (5) corn. Since 1931 it has been (1) oats and sweet clover, (2) sweet clover green manure plowed down in spring for corn, (3) soybeans, (4) flax, (5) wheat. With each rotation a sixth block was kept in alfalfa. Whenever the stand of alfalfa became thin it was plowed down and put into the rotation and one of the blocks originally in the rotation was taken out and seeded to alfalfa.

Soybean hay samples were taken from five plots in block A in

1937 and samples of alfalfa were collected from corresponding treatments in block B in 1938. A sample of redtop was also obtained from the non-legume plot in the alfalfa block. Plot treatments and rates of lime and fertilizer applications are shown in Table 1. No applications of fertilizer were made on block A in 1926 or on block B in 1927. Alfalfa has never been seeded on block A, but it occupied block B from 1935 to 1938, inclusive. Since much heavier applications of fertilizer have been made on alfalfa than on other crops, the average annual application of phosphate was considerably higher on block B than on block A.

Moran Experiment Field

Soil fertility studies were also begun in 1924 on the Moran experiment field, which is located on Woodson silt loam two miles west and two miles north of Moran in Allen County, Kansas. This is also a Planosol developed under grass cover. The surface soil has a dark brownish-gray color and has considerably more organic matter than Cherokee silt loam. The subsoil is a dense, slowly pervious clay pan, but since the topography is somewhat rolling, drainage usually is not a serious problem. The surface soil has a pH of about 5.28 and is quite deficient in lime and available phosphorus. There is apparently a fairly good supply of calcium in the subsoil because alfalfa plants that survive the first year and establish roots in the subsoil grow and produce about as well as those on the limed soil.

The crop rotation used in soil fertility studies from 1924

Table 1. Plot treatments and the rates of lime and fertilizer applications on plots at the Columbus experiment field.

Plot No.	Treatment	Block A - Soybeans: Total lime 1924-37 Tons	Block A - Soybeans: Av. annual application: Super-phosphate Lbs.	Block A - Soybeans: Av. annual application: KCl Lbs.	Block B - Alfalfa: Total lime 1924-38 Tons	Block B - Alfalfa: Av. annual application: Super-phosphate Lbs.	Block B - Alfalfa: Av. annual application: KCl Lbs.
1	Lime	3(1)	0	0	4.5(2)	0	0
2	Lime and superphosphate	3	50(3)	0	4.5	77.3(3)	0
3	Lime, superphos. and potash	3	50	6.7(4)	4.5	77.3	10.3(4)
10	Lime, superphos. - No legume	-	--	-	4.5	77.3	0
11	Lime and superphosphate	3	50	0	4.5	77.3	0
12	No treatment	0	0	0	0	0	0

(1) An initial application of 3 tons of limestone per acre was made in 1926.

(2) An initial application of limestone was made in 1926 and a supplementary application of 1½ tons per acre was made in 1934.

(3) Superphosphate (20%) was applied annually at the rate of 40 pounds per acre on corn, oats and soybeans, 80 pounds per acre on flax and wheat, and 120 pounds per acre on alfalfa.

(4) Potash (50% K_2O) was applied annually mixed with superphosphate in such amounts as to make an 0-16-5 1/3 fertilizer.

to 1930, inclusive, was as follows: (1) corn, (2) corn, (3) oats, (4) wheat and red clover, (5) red clover hay. Beginning with 1931, it was changed to (1) corn, (2) corn, (3) soybeans, (4) oats and red clover, (5) red clover hay. As at Columbus, a sixth block has been kept in alfalfa.

Soybean hay samples were taken from nine plots on block A in 1937 and samples of alfalfa hay were taken from corresponding treatments on blocks B and D in 1938. A sample of redtop hay was obtained from the non-legume plot in block B. Soil treatments and rates of lime and fertilizer applications are shown in Table 2.

No fertilizer was applied to block B in 1925 and 1930, or to block D in 1928 and 1933. Alfalfa had occupied the plots on block A from 1925 to 1929, inclusive. At the time the samples were taken in 1938, the alfalfa stand was four years old on block B and that on block D was one year old.

In addition to the samples taken from the plots discussed above, samples of alfalfa hay were obtained from the plots on block L, upon which the effects of varying amounts and combinations of lime and phosphatic fertilizer were being studied. From 1924 to 1928, inclusive, this block of plots was used for variety testing or was uniformly cropped without any fertility treatment. In the fall of 1928, following a uniform crop of oats, this block was prepared and seeded to alfalfa. Two tiers each of nine one-twentieth acre plots, were laid out and nine duplicated lime and fertilizer combination treatments were established. Soil treatments and rates of lime and fertilizer applications are presented

Table 2. Soil treatments and rates of lime and fertilizer applications at the Moran experiment field.

Plot No.	Treatment	Block A - Soybeans: Total lime per A. 1925-37 Tons	Block A - Soybeans: Av. ann. applic. superphos. per acre Lbs.	Block A - Soybeans: Total manure per A. 1925-37 Tons	Block A - Soybeans: Total rock phos. per A. 1925-37 Lbs.	Block B - Alfalfa: Total lime per A. 1924-38 Tons	Block B - Alfalfa: Av. ann. applic. superphos. per acre Lbs.	Block B - Alfalfa: Total manure per A. 1924-38 Tons	Block B - Alfalfa: Total rock phos. per A. 1924-38 Lbs.	Block D - Alfalfa: Total lime per A. 1924-38 Tons	Block D - Alfalfa: Av. ann. applic. superphos. per acre. Lbs.	Block D - Alfalfa: Total manure per A. 1924-38 Tons	Block D - Alfalfa: Total rock phos. per A. 1924-38 Lbs.
2	Lime	3[5]				4.5[5]				4.5[5]			
3	Lime & superphos.	3	78.5[6]			4.5	77.3[6]			4.5	60[6]		
5	Lime	3				4.5				4.5			
6	Lime, manure & super.	3	78.5	24[6]		4.5	77.3	24[7]		4.5	60	32[7]	
7	Lime, manure & r.phos.	3		24	2000[8]	4.5		24	3000[8]	4.5		32	3000[8]
8	Lime	3				4.5				4.5			
9	Manure			24				24				32	
10	No treatment												
11	Lime	3				4.5				4.5			
12	No treatment - No legume												

(5) An initial application of 3 tons per acre was made on block B in 1924, on block A in 1925 and on block D in 1927; also a supplementary application of $1\frac{1}{2}$ tons per acre was made on block B in 1935 and on block D in 1938.

(6) Superphosphate (20%) has been applied annually at the rate of 40 pounds per acre on corn and soybeans, 80 pounds per acre on oats and clover, and at the rate of 120 pounds per acre on alfalfa.

(7) Barnyard manure has been applied at the rate of 8 tons per acre on the second year of corn in the rotation and just before a stand of alfalfa was seeded.

(8) Rock phosphate was applied at the rate of 1000 pounds per acre on first year of corn in the rotation and just before a stand of alfalfa was seeded.

in Table 3.

Table 3. Soil treatments and rates of lime and phosphate fertilizer applications on alfalfa, Block L, Moran. 1929-1938.

Plot No.	Treatment(9)	Total lime per acre, tons(10)	Superphosphate (16%) applied annually, per acre. Lbs.(11)
1 and 16	No lime - no phos.		
2 and 17	No lime - single phos.		150
3 and 18	No lime - double phos.		300
4 and 10	Single lime - no phos.	3	
5 and 11	Single lime - single phos.	3	150
6 and 12	Single lime - double phos.	3	300
7 and 13	Triple lime - no phos.	6	
8 and 14	Triple lime - single phos.	6	150
9 and 15	Triple lime - double phos.	6	300

(9) A single application of lime was 1 ton per acre and a single application of 16% superphosphate was 150 pounds per acre.

(10) One application of lime was made in fall of 1928 before the first stand was seeded and another in 1935 just before the second stand was seeded.

(11) Applications of superphosphate were made in the spring before growth began in those years when alfalfa was harvested, except that an additional application was made in the fall of 1935 before the second stand of alfalfa was seeded.

The stand of the first seeding of alfalfa had become rather thin by the fall of 1933, therefore it was plowed down and the ground fallowed through the summers of 1934 and 1935. In the fall of 1935, alfalfa was reseeded. Samples were taken from each of these treatments in the summer of 1938.

Thayer Experiment Field

Soil fertility studies were started in 1938 on the Thayer experiment field which is located four miles north of Thayer in Neosho County, Kansas. Previous to that time, the soil on this field has been uniformly cropped for several years. The soil is Bates-Parsons very fine sandy loam. This is a Prairie soil developed under grass vegetation. The surface soil is quite shallow, sandy, and of a light brownish-gray color. The subsoil is quite dense despite the presence of sand particles. Because of the rolling topography and sandy texture, drainage is not a serious problem except in extremely wet periods. The soil is very extensively leached and quite deficient in organic matter, nitrogen, calcium and phosphorus. The pH value of this soil is around 5.25.

Hay samples were taken from sweet clover plots representing three soil treatments, from lespedeza plots representing three soil treatments, and from a soybean plot with no treatment, in the summer of 1938. Lespedeza hay samples were also taken from three fertility treatments in 1939.

Although not all of these plots were in the same test, they were located very close together, and since in all cases they had been uniformly cropped previous to taking the samples, the results should be comparable. None of the soil included in the plots had received any lime, but all of it had been given a light application of superphosphate fertilizer on one or two wheat crops several years previous. Soil treatments and rates of lime and fertilizer applications are outlined in Table 4.

Table 4. Soil treatments and rates of lime and fertilizer applications at the Thayer experiment field.

Plot No.	Treatment	Total lime per acre, tons	Superphosphate (20%) applied annually per acre. Lbs.	Manure applied per acre, tons
		Sweet clover hay		
E-1	Lime	2		
E-2	Lime and superphos.	2	80	
E-3	No treatment			
		Soybean hay		
I-1	No treatment			
		Korean lespedeza hay - 1938		
I-2	No treatment			
I-3	Superphosphate		80	
I-4	Manure			8
		Korean lespedeza hay - 1939		
N-3	Lime	2		
N-5	Superphosphate		80	
N-6	No treatment			

Method of Sampling

The method of sampling employed in obtaining the hay samples was as outlined below. The plots were divided longitudinally into two equal portions. Eight stations evenly distributed along the longitudinal center of each portion were marked (16 in each plot). Then a composite sample was made by taking one plant from near each station and this was considered a representative sample for the plot. The samples were put into large paper bags and cured. Later they were transferred to smaller bags for storage.

Methods of Analysis

Each entire composite sample was ground in a Wiley mill until all passed through a 10-mesh screen. The sample was then thoroughly mixed and a portion (approximately 25 grams) was reground to pass a 100-mesh screen. Particular care was taken to get the entire 25-gram sample through the 100-mesh screen. After thoroughly mixing the sample again, portions of 1 gram each were weighed on analytical balances for chemical determinations.

Total phosphorus was determined by the standard volumetric procedure, after ashing according to the procedure outlined by Howk and DeTurk (35).

In the total calcium determinations, the plant material was moistened with distilled water and cautiously charred at low temperature over a bunsen burner, then heated more strongly until most of the carbon was removed. Finally, oxidation was completed in a muffle furnace. Total calcium was determined by the usual volumetric procedure, although it was precipitated in the presence of iron, aluminum, manganese and phosphorus as outlined by Chapman (19).

In determining total nitrogen, digestion was done according to the Gunning-Hibbard method. Then the ammonia was distilled into 4 per cent boric acid and titrated with N/7 H_2SO_4.

EXPERIMENTAL RESULTS

The soil fertility field experiments at the Columbus and Moran experiment fields were so arranged that every third plot was a check plot. The term "check plots" as here used refers to plots of standard treatment inserted at regular intervals in a block of plots for the purpose of determining the variation of native soil fertility from one end of the block to the other. The check plots were used as a basis for corrections for soil variation as it influenced yields and the percentages of the mineral constituents of the crop plants. Since there was more or less variation in the data from different check plots, it seemed advisable to correct the values for treatments where it was possible to do so. Although the methods of correcting these values were essentially the same for both fields, there were slight variations.

At the Columbus field, data were obtained from two groups of three plots each from each block. One group in each block was represented by plots 1, 2 and 3 and the other group by plots 10, 11 and 12. The middle plot of each group (plot 2 and plot 11, respectively) was a check plot. The method of calculating corrections for yields or plant composition values presumably due to soil variation was as follows. It was assumed that the soil variability and consequently the variability in yields or plant composition was uniformly progressive from one check plot to another. Therefore the values for the check plots were averaged. Next the actual experimental value for each treatment was compared to that of the adjoining check plot and the variation from the check plot value was added to or subtracted from the average of the check plots, depending upon whether the actual value for the treatment was above or below that of the adjoining check plot. The value thus obtained was recorded as the corrected value for the treatment. This method of calculating corrections makes possible the comparison of values for plots from one end of the block with those of plots from the opposite end, for example, values of plot 1 or plot 3 with those of plot 10 or plot 12.

Ten of the twelve plots in each series were studied at the Moran field. Hence values were obtained for check plots 2, 5, 8 and 11. These were averaged and corrections were then made for the treatments. For example, let it be assumed that plot 4 yielded 14, the average of the checks was 12, plot 5 (a check plot) yielded 10 and plot 2 (another check plot) yielded 12. A preliminary check yield for plot 4 was established by combining two-thirds of the actual value of plot 5 and one-third of the actual value of plot 2. The preliminary check yield thus obtained for plot 4 was compared to its actual yield to obtain the increase or decrease presumably attributable to the soil treatment of that plot. Finally the corrected value for the treatment on plot 4 was obtained by adding its increase (or subtracting its decrease) to the average of the check plots. In establishing preliminary check values for the plot on each end of the block, a value equal to the actual value of the adjoining check plot was used.

All of the data from the Columbus field and those from blocks A, B and D at the Moran field have been corrected according to the methods described above.

In studying the effects of lime and fertilizer applications upon the composition of legume hays, it was quite obvious that there were many factors which might have influenced the results. Therefore, in order to more exactly evaluate the influence of these factors, it seemed desirable to present the data of this problem from four general viewpoints. They are as follows: the effect upon the composition of legume hays, of (1) plant environment (location), (2) species, (3) soil treatment, and (4) the effect of soil treatment upon the yield of legume hays, upon the total removal of calcium and phosphorus from the soil by the crop and the percentage of applied phosphorus recovered in the hay.

The Effect of Plant Environment (Location) Upon the Composition of Legume Hays

Although this problem deals primarily with the effect of lime and fertilizer applications upon the composition of legume hays, it has been pointed out by several investigators (9, 10, 27, 32) that soil type, climate and other environmental conditions have marked influences upon the composition of crop plants. The influence of the environmental factors may be studied by comparing the composition of alfalfa and soybean hays taken from the no-treatment plots at the Columbus experiment field with those from the same soil treatment at the Moran experiment field. These data are presented in Table 5.

The percentages of the various mineral constituents are rather consistently higher in those hays grown on the Columbus field than in those grown at the Moran field. It should be pointed out that the alfalfa on block D at the Moran field was only one year old when the samples were taken, and therefore the data from this block are probably not strictly comparable with those from block B on the same field or those from the Columbus

Table 5. The effect of plant environment (location) upon the composition of alfalfa and soybean hays.

Type of hay, year, and soil treatment	Total phosphorus in hay produced at Columbus %	Total phosphorus in hay produced at Moran %		Total calcium in hay produced at Columbus %	Total calcium in hay produced at Moran %		Total nitrogen in hay produced at Columbus %	Total nitrogen in hay produced at Moran %	
	Block B	Block B	Block D	Block B	Block B	Block D	Block B	Block B	Block D
Alfalfa, 1938 (No treatment)	.395	.386	.369	1.81	1.76	2.29	3.21	2.91	2.23
	Block A	Block A		Block A	Block A		Block A	Block A	
Soybeans, 1937 (No treatment)	.434	.346		1.40	.99		2.71	3.12	

field, the stands of which were each four years old at the time of sampling. With this consideration in mind, the data appear to indicate that the percentages of calcium and phosphorus in alfalfa hay were at least as high or higher and those of nitrogen definitely higher in samples grown at the Columbus field than in those grown at the Moran field. The fact that the percentage of calcium in the alfalfa hay from block D at the Moran field was much higher than in that from the older stand on block B indicates that it takes at least one or two years of alfalfa production before the available calcium content of the soil becomes low enough to affect the calcium content of the alfalfa plant. The phosphorus and calcium contents of soybean hay were significantly higher at the Columbus field than at the Moran field, while that of nitrogen was slightly lower. In general, the environmental conditions which prevailed at the Columbus field seemed to result in a higher content of total phosphorus, calcium and nitrogen in alfalfa and soybean hays than at the Moran field.

The Effect of Species Upon the Composition of Legume Hays

The study of the composition of hays of various species was not included in the initial plan of the problem, consequently only limited incidental data were available relative to that question. However, the differences in composition of the hays of different species were so outstanding that it seemed desirable to consider them as far as possible. The data are presented in Table 6.

Table 6. The percentages of phosphorus, calcium and nitrogen in different legume hays and redtop grown on soils untreated, or similarly treated, and in the same season.

	Year	Soil treatment	Percentages of constituents in the plant tissue		
			Phosphorus %	Calcium %	Nitrogen %
At Columbus					
Redtop hay	1938	Lime & superphos.	.474	.50	1.53
Alfalfa hay	1938	" " "	.403	1.81	3.41
At Moran					
Redtop hay	1938	No treatment	.430	.33	1.66
Alfalfa hay	1938	" "	.386	1.76	2.91
At Thayer					
Sw. clover hay	1939	No treatment	.170	1.35	1.84
Lespedeza hay	1939	" "	.294	.85	2.20
Soybean hay	1939	" "	.340	.96	2.71

The greatest differences in the composition of hays occurred between samples of redtop hay, a non-legume, and samples of alfalfa, a legume hay which is considered to be relatively high in mineral constituents. There were two such comparisons; one at the Columbus field and one at the Moran field. In both cases the age of the redtop stand was the same as that of the alfalfa. At the Columbus field the two plots were adjacent to each other, while at the Moran field they were separated by a check plot. Both species were grown upon no-treatment plots at the Moran field, while equal applications of lime and superphosphate had been applied to both plots at the Columbus field. There was no indication that soil treatment had any effect upon the relative amount of mineral constituents in the two species of plants. The samples of redtop hay in both cases were definitely higher in phosphorus content than those of the alfalfa but very much lower in the percentage of calcium and nitrogen.

There was an opportunity to study the composition of different legume hays on no-treatment plots at the Thayer field in 1939. These legumes were grown upon plots located very close to each other and upon which uniform cropping and soil treatments had been practiced for several years previous to sampling. Although the phosphorus and nitrogen contents of the sweet clover hay were somewhat lower than those of either soybean or lespedeza hay, the percentage of calcium was definitely higher in the sweet clover. The sample of soybean hay was consistently higher in all constituents than was the sample of lespedeza hay.

These data are inadequate for the making of any generalizations, but they tend to substantiate the conclusion of many investigators that the calcium content of plants varies more widely between species than between plants of the same species grown on differently treated soil.

The Effect of Soil Treatment Upon the Composition of Legume Hays

Since it has been previously pointed out that plant environment has more or less influence upon the composition of plants and that plant composition also varies with species, it seemed desirable to consider the effect of soil treatments upon the composition of legume hays by fields and by species at each field. These data are presented in Tables 7, 8 and 9.

Table 7. The effect of soil treatments upon the composition of soybeans and alfalfa hays at the Columbus experiment field.

Treatment	Soybean hay - Block A			Alfalfa hay - Block B		
	Phosphorus %	Calcium %	Nitrogen %	Phosphorus %	Calcium %	Nitrogen %
No treatment	.435	1.40	2.71	.395	1.81	3.21
Lime	.367	1.40	3.11	.327	1.86	3.42
Lime + superphosphate	.424	1.32	2.98	.403	1.81	3.41
Lime + potash + superphos.	.449	1.35	2.75	.343	1.73	3.40

Table 8. The effect of soil treatments upon the composition of soybean and alfalfa hays at the Moran experiment field.

Treatment	Alfalfa hay - 1938						Soybean hay Block A - 1937		
	Block B			Block D					
	Phos. %	Cal. %	Nit. %	Phos. %	Cal. %	Nit. %	Phos. %	Cal. %	Nit. %
No treatment	.386	1.76	2.91	.369	2.29	2.23	.346	.99	3.12
Lime	.382	1.84	2.91	.324	2.17	3.21	.357	1.03	3.37
Manure	.384	1.77	2.81	.392	1.84	2.94	.362	1.09	3.26
Lime + superphosphate	.387	1.90	3.09	.347	2.50	2.51	.378	1.01	3.21
Lime + manure + superphos.	.406	1.73	3.01	.443	1.89	2.96	.386	1.20	3.41
Lime + manure + rock phos.	.425	1.66	2.89	.420	1.96	2.98	.390	1.18	3.43

Table 9. The effect of soil treatments upon the composition of sweet clover and Korean lespedeza hays at the Thayer experiment field.

Treatment	Sweet clover hay 1938			Korean lespedeza hay 1938			Korean lespedeza hay 1939		
	Phos. %	Cal. %	Nit. %	Phos. %	Cal. %	Nit. %	Phos. %	Cal. %	Nit. %
No treatment	.170	1.35	1.84	.294	.85	2.20	.383	1.09	1.48
Lime	.183	1.34	2.27				.370	1.06	1.83
Superphosphate				.288	.86	1.69	.392	1.04	1.40
Manure				.294	.91	1.37			
Lime + superphosphate	.159	1.45	2.38						

The effects of soil treatments upon the composition of soybean hay at the Columbus field were not as marked as in some of the other experiments. However, the phosphorus content of the soybean hay from plots receiving superphosphate (lime + superphosphate and lime + potash + superphosphate) was consistently higher than that of the hay from the lime treatment. Furthermore the data indicate that perhaps the addition of potash enabled the soybean plant to make more efficient use of the applied phosphorus in increasing the phosphorus content of the plant. The fact that the percentage of phosphorus in the hay from the no-treatment plot was higher than that of the hay from the lime plot was no doubt attributable to the higher yield of hay on the lime plot. Although the yield data for these plots have not been presented, the production was considerably more on the lime plot than on the no-treatment plot. Consequently the total removal of phosphorus in the crop on the lime plot may have been as much or more than on the no-treatment plot despite the higher percentage of phosphorus in the hay from the no-treatment plot.

The differences in the calcium content of soybean hay from different soil treatments at the Columbus field were so small that they may be considered to fall within the range of experimental error. Therefore it was assumed that the addition of lime or fertilizers had no effect upon the calcium content of soybean hay grown on this soil.

The effects of soil treatments upon the percentage of nitrogen in the soybean hay from the Columbus field were intermediate between the effects of soil treatments upon the phosphorus and calcium contents of the hay, but the increases were large enough to be considered significant. Each of the three treatments produced hay with higher nitrogen content than did the no-treatment plot. The percentage of nitrogen in the soybean hay from the lime + superphosphate plot was 10 per cent higher than that of the no-treatment plot and that of the lime plot was more than 14 per cent higher.

The effects of soil treatments upon the composition of alfalfa hay from the Columbus field were similar to those of the soybean hay. The only notable exception was that the phosphorus content of the hay from the lime + potash + superphosphate plot was decidedly lower than that from the lime + superphosphate plot. No explanation can be offered for this situation. While the calcium content of the hay was not increased by soil treatments, the percentage of nitrogen was consistently higher in the alfalfa hay from the treated plots than from the no-treatment plot.

The composition of soybean hay at the Moran field has been somewhat affected by soil treatments. There were progressive increases in the percentage of phosphorus in the soybean hay from the no-treatment plot through the lime, the manure, the lime + superphosphate, the lime + manure + superphosphate and the lime + manure + rock phosphate plots. The phosphorus content of the hays produced on plots receiving phosphorus applications were definitely and consistently higher than that from the no-treatment plot. Also there was a tendency for the phosphorus content of the plant to increase as the total amount of applied phosphorus increased.

The effects of soil treatments upon the calcium and nitrogen contents of soybean hay at the Moran field were not marked but appreciable, in some cases at least. The application of manure increased the calcium content of the soybean hay about 10 per cent, while the calcium content of the hay from the lime + manure + superphosphate plot and the lime + manure + rock phosphate plot was about 20 per cent higher than in the hay from the no-treatment plot. All soil treatments increased the percentage of nitrogen in the soybean hay. The increases in the nitrogen content of hay from the lime, the lime + manure + superphosphate and the lime + manure + rock phosphate treatments amounted to about 9 per cent of the total nitrogen in the hay from the no-treatment plot.

The data representing the effect of soil treatments upon the composition of alfalfa hay at the Moran field indicate that certain soil treatments definitely increase the phosphorus content but the indications are not so definite for the calcium content. The percentages of nitrogen were not appreciably affected by soil treatments on block B, the older stand of alfalfa, but on the younger stand, block D, consistent increases were recorded. There were very small differences between the phosphorus content of the hay produced on the no-treatment, the lime, the manure or the lime + superphosphate plots but definite increases were obtained in the phosphorus content of the hays grown on the lime + manure + superphosphate and the lime + manure + rock phosphate treatments. This was generally true of the hay from both block B and block D. The phosphorus content of the hay on the lime plot of block D was exceptionally low and no attempt has been made to account for it.

Likewise the percentage of phosphorus in the hay from the manure plot on block D was relatively higher than on block B, but that condition was probably attributable to the fact that the manure on block D had been applied only the fall previous to sampling. The phosphorus supply from the manure on block D was therefore adequate to produce a relatively high percentage of phosphorus in the alfalfa hay, whereas, on block B, the manure had been applied four years previous and most of its phosphorus supply had been removed by subsequent alfalfa production. Also, on block B the content of phosphorus in the alfalfa hay from the rock phosphate plot was higher than that from the superphosphate plot. The reverse was true on block D. This condition may be explained as being due to the slow availability of the rock phosphate, since it will be remembered that the rock phosphate application on block B had been made four years prior, and that on block D had been made in the fall immediately preceding sampling. The data would seem to indicate that the phosphorus carried by either the manure or superphosphate applications was sufficient to supply the alfalfa plants with enough phosphorus to maintain the percentage of that element in spite of the increased production under these applications. When manure and phosphates were applied in combination, phosphorus ceased to be a limiting factor and the excess was used to enrich the alfalfa hay by increasing the percentage of that constituent in the plants.

The effects of soil treatments upon the calcium content of alfalfa at the Moran field were somewhat inconsistent. However, the lime + superphosphate treatments appeared to have definitely increased the calcium in the alfalfa hay and all manure treatments tended to produce a depressing effect. These data have been presented graphically in Fig. 1.

As has been stated above, soil treatments had little or no influence upon the nitrogen content of the hay produced by the old stand of alfalfa on block B, but very definite and significant differences in the percentage of nitrogen were obtained in the hay produced on the various plots of block D, a new stand of alfalfa. The lime + superphosphate treatment produced alfalfa hay with 12 per cent more nitrogen than the hay on the no-treatment plot. Each of the other treatments increased the nitrogen content in the hay by 32 per cent or more. The vast difference in the effect of soil treatments upon the nitrogen content of hay produced by new and old stands of alfalfa may perhaps be explained in that the subsoil at the Moran field is apparently fairly well supplied with calcium while the surface soil has become quite deficient in this element. Many of the plants on the no-treatment plot perish during the first summer, but those plants which do survive evidently establish their roots in the subsoil where there is a more nearly adequate supply of calcium since they appear to produce about normally after the first year. Therefore, it follows that the plants present in an older stand of alfalfa on the no-treatment plot would have available to them a more nearly adequate supply of calcium than those plants on the no-treatment plot of a new stand. There seems to be a tendency for lime to increase the nitrogen content of alfalfa hay more than any other of the soil treatments studied. Consequently, the nitrogen content of the alfalfa

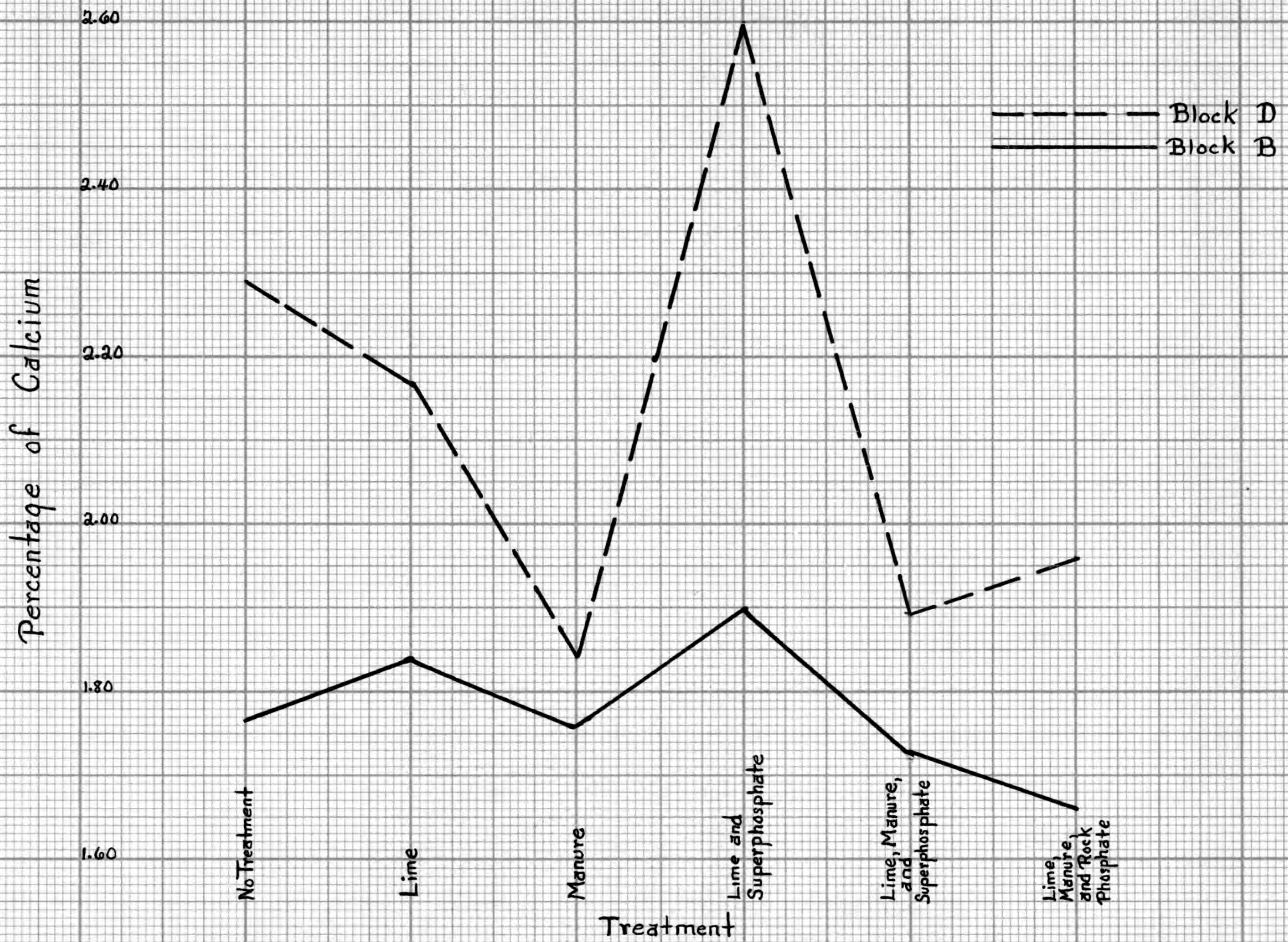

Fig. 1. The effect of soil treatment upon the percentage of calcium in alfalfa hay at the Moran experiment field.

plants on the no-treatment plot of an old stand might be higher than that of plants on the same treatment in a new stand.

The data obtained from the Thayer field were very limited and the values were quite low. Since most of the data were more or less inconsistent it was difficult to arrive at any definite conclusions. Apparently soil treatments failed to alter the phosphorus and calcium contents of either sweet clover or Korean lespedeza hay on the Thayer field. This may be accounted for in that the samples were taken from the first crop grown on these plots after soil fertility treatments were begun. Since the applications of the lime and superphosphate were moderately light it may be that much if not all of the phosphorus and calcium added to the soil was fixed in a form not available to the plants.

Lime applications increased the nitrogen content of both the sweet clover and lespedeza. The soil of this field, which is quite acid, was rendered more favorable for the activities of symbiotic nitrogen-fixing organisms by the neutralizing action of lime applications and the increased supply of the nutrient element, calcium. It is realized that in many cases the data herein presented are inadequate to establish beyond doubt the conclusions which have been drawn. In a few cases, the writer has been unable to offer adequate explanations of the results. The data have not been given statistical treatment because the field experiments were not so arranged as to make this possible. However, careful study of the data revealed certain relationships from which apparently justifiable conclusions could be drawn.

In general the data indicate that the phosphorus contents of legume hays are increased by applications of phosphates and manure, alone or in combinations. Except for the depressing influence of manure treatments in the case of alfalfa hay and the increases produced by lime + superphosphate, soil treatments failed to affect the percentage of calcium in legume hays. The nitrogen content of legume hays was increased by practically all soil treatments containing lime or manure, or both, but applications of superphosphate alone tended to depress the nitrogen content of the plants.

The Effect of Soil Treatment on Removal of Phosphorus and Calcium in the Crop and the Percentage of Applied Phosphorus Recovered in the Plants

Block L at the Moran experiment field has been devoted to a study of rates of lime and superphosphate applications. At the time of sampling these plots had been in alfalfa continuously for 10 years except for the sixth year when they were fallowed prior to the second seeding. The relative yields have been exceptionally consistent throughout the nine years of almost continuous alfalfa production. Because of these facts and because the lime and superphosphate had been applied at different rates, it seemed desirable to study not only the composition of the hay but also the yields, the total removal of phosphorus and calcium in the plants and the percentage of applied phosphorus recovered in the alfalfa hay from each treatment. These data are presented in Table 10.

Table 10. The influence of lime and superphosphate treatments on alfalfa hay yields, phosphorus, calcium and nitrogen contents of the hay, the removal of phosphorus and calcium from the soil and the percentage of applied phosphorus recovered in the hay.

Treatment	Superphos. applied per acre in 1938 Lbs.	Total elemental phosphorus applied per acre in 1938 Lbs.	Yield of hay per acre 1st cutting 1938 Tons	Constituents in plant tissue Phos. %	Constituents in plant tissue Cal. %	Constituents in plant tissue Nit. %	Total removal per acre Phos. Lbs.	Total removal per acre Cal. Lbs.	Phosphorus recovered %
No lime - No phos.	0	0	.77	.279	1.94	3.00	4.30	29.88	---
No lime - Single phos.(12)	150	24	.93	.413	1.88	3.11	7.68	34.97	14.1
No lime - Double phos.(13)	300	48	.95	.459	1.89	3.23	8.72	35.91	9.2
Single lime(14) - No phos.	0	0	.98	.359	2.06	3.18	7.04	40.37	---
Single lime - Single phos.	150	24	1.69	.449	2.01	3.24	15.18	67.94	32.3
Single lime - Double phos.	300	48	1.68	.485	1.64	3.00	16.30	55.10	19.3
Triple lime(15) - No phos.	0	0	1.37	.393	2.21	3.21	10.77	60.55	---
Triple lime - Single phos.	150	24	1.66	.444	2.04	3.39	14.74	67.73	16.5
Triple lime - Double phos.	300	48	1.74	.484	1.98	3.34	16.84	68.90	12.6

(12) Annual application of 150 pounds of 16% superphosphate.

(13) Annual application of 300 pounds of 16% superphosphate.

(14) Initial application of 1 ton of ground limestone.

(15) Initial application of 3 tons of ground limestone.

The results are in agreement with previous interpretations and conclusions in that moderate applications of superphosphate increased the phosphorus content of alfalfa hay. In all comparisons, the percentage of phosphorus was definitely higher in the hay produced on plots receiving applications of superphosphate than on those plots which received no such treatment. Furthermore, in all cases, plots receiving double applications of superphosphate produced alfalfa hay with higher phosphorus content than those plots receiving single applications. These data were so conclusive that they have been presented graphically in Fig. 2. The data also indicate that applications of limestone tend to increase the phosphorus content of alfalfa. These increases were greater between plots with no limestone applications and those with single applications than between the latter and those receiving triple applications of limestone. That is, the single applications exerted more influence upon the phosphorus content of the hay per unit of lime applied than the triple applications. However, the effect of limestone applications upon the phosphorus content of alfalfa was relatively small as compared to that of superphosphate applications.

There was a tendency for lime, especially the triple applications, to increase the calcium content of the hay, while superphosphate, particularly the heavier applications, tended to depress it slightly.

With but one exception, both lime and superphosphate applications increased the percentage of nitrogen in the alfalfa hay. Triple applications of limestone had somewhat greater influences

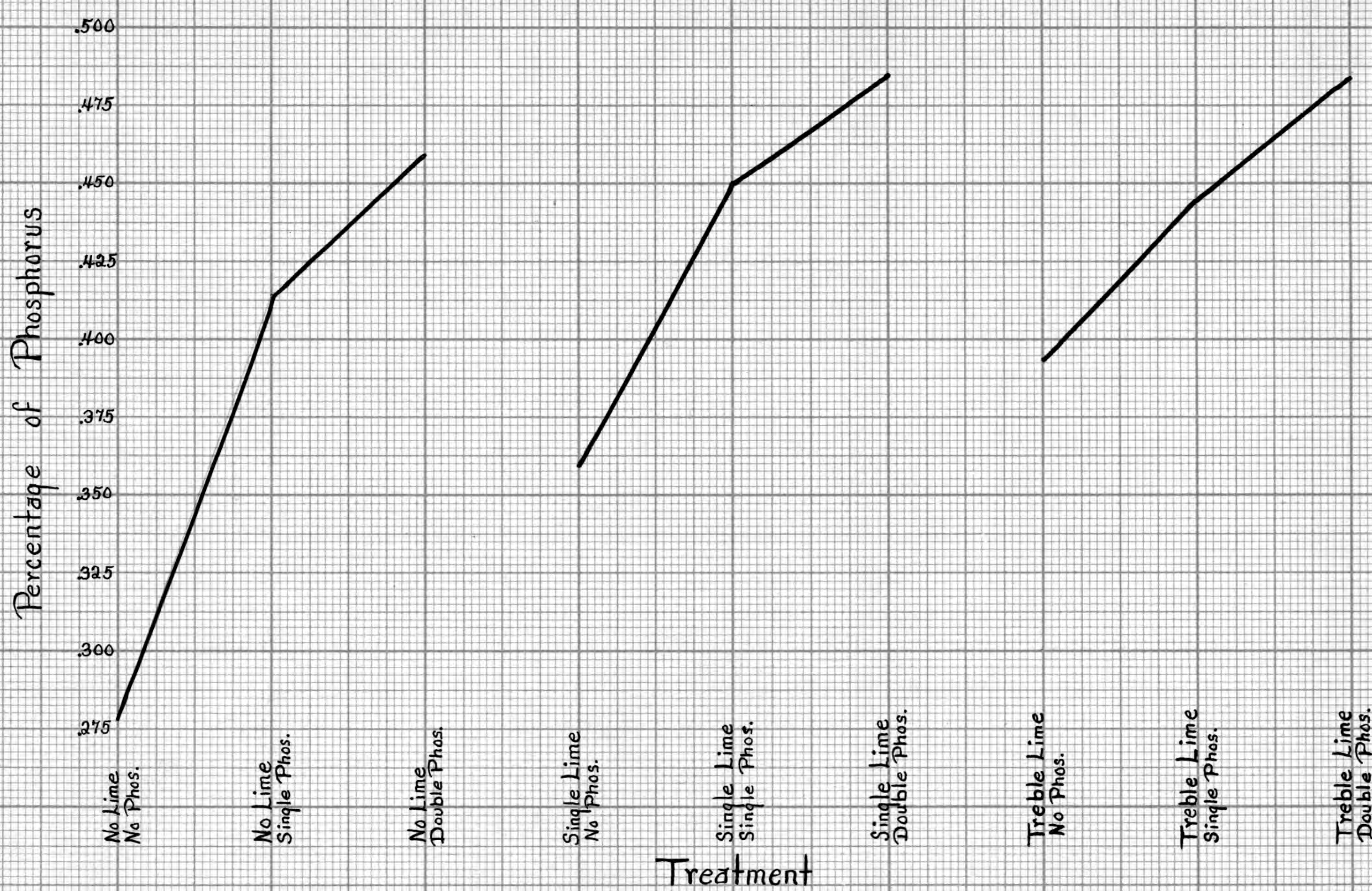

Fig. 2. Effect of superphosphate applications upon percentage of phosphorus in alfalfa hay.

upon the nitrogen content than did the single applications. On the other hand, the percentage of nitrogen in the alfalfa hay was generally higher from those plots which received single applications of superphosphate than from those which received double applications.

The alfalfa yields presented in Table 10 were the production of the cutting from which the samples for chemical analyses were taken and they are quite representative of the relative yields of the plots, in previous years, except that the yield of the single lime-single phosphate treatment is slightly higher than usual. These yield data were presented (1) to give an indication of relative production as influenced by different treatments, and (2) to be used as a basis for calculating the removal of phosphorus and calcium in the plants. These calculations were made by multiplying the yield of hay (pounds) by the percentage of the constituent in the hay. Therefore, the values for phosphorus and calcium removals in the plants are the results of the combined effects of yield and composition and provide a means of comparing the relative extent to which applied phosphorus entered the plants on plots having different treatments.

Comparisons of the total removals of phosphorus for the various treatments indicate that those plots receiving superphosphate applications had from 50 to 100 per cent more phosphorus removed in the hay per acre than the plots which received no superphosphate. These differences tended to be greatest on the treatments where single applications of limestone had been made and smallest on the plots receiving triple applications of limestone. The removals of phosphorus from plots with double applications of superphosphate were consistently but not greatly larger than those from plots which received single applications. The greater phosphorus removals in the latter case were largely attributable to higher percentages of phosphorus in the hay. The total removals of calcium for the various treatments were quite similar to those of phosphorus except that they were several times as large and the differences were much smaller on a percentage basis. The differences in calcium removal on different treatments were due largely to differences in yield as the variations in the calcium content of the alfalfa hay from the different treatments were small.

The percentage of applied phosphorus recovered in the hay was calculated as indicated in the following statements. The difference in the tótal removal of phosphorus on the plot receiving no superphosphate from that of each plot receiving superphosphate application was obtained and divided by the amount of elemental phosphorus applied. The quotient was then multiplied by 100 to convert it to percentage. The values thus obtained for the various treatments in which superphosphate applications had been made were assumed to be an indication of the relative uptake of the applied phosphorus by the alfalfa hay. On this basis it appeared obvious that the single applications of superphosphate were considerably more efficient per unit of phosphorus applied than the double applications. Furthermore, superphosphate was more efficient in increasing the phosphorus uptake by alfalfa hay when it was applied in combination with either single or triple applications of limestone than when it was applied alone. However, the efficiency of the applied phosphorus was greater in combination with single applications of limestone than in combination with triple applications.

SUMMARY

1. The object of the studies here reported was to ascertain what effect lime, manure and fertilizer applications exert upon the composition of legume hays as grown under conditions prevailing in southeast Kansas.

2. Numerous samples of legume hays, principally alfalfa and soybean, were collected from some of the soil fertility plots at the Columbus, Moran and Thayer experiment fields located in southeast Kansas. Chemical analyses were made for total phosphorus, total calcium and total nitrogen.

3. The limited data available from the problem bearing on the question of effect of environment (location) indicate that the composition of legume hays was not affected greatly, although, in general, hays produced on the Columbus field were richer in phosphorus, calcium and nitrogen than those produced at Moran. These same data showed that the phosphorus contents of hays varied to only a moderate extent with species, but the percentages of calcium were much smaller in soybeans than in alfalfa and still smaller in the non-legume, redtop. Nitrogen percentages were highest in alfalfa, intermediate in lespedeza and soybeans and lowest in redtop.

4. It was concluded from the data obtained at the Columbus field that superphosphate applications definitely increased the phosphorus content of alfalfa and soybean hays. Due to the higher production of hay on the lime plot than on the no-treatment plot, the phosphorus content of hay from the former was somewhat lower than that of the hay from the latter. The calcium contents of the hays were unaltered by soil treatment. The percentages of nitrogen in the hays were significantly increased by lime and lime + superphosphate treatments at the Columbus field.

5. Each of the soil treatments at the Moran field increased the percentage of phosphorus in soybean hay over that from the no-treatment plot. The largest increases were obtained from those plots where manure and phosphates were applied in combination. The phosphorus content of alfalfa hay was not greatly affected except by the lime + manure + superphosphate and the lime + manure + rock phosphate treatments. However, there was some indication that manure alone increased the phosphorus content in alfalfa for a year or two immediately following application.

6. All manure treatments and particularly those in combination with lime and phosphates increased the calcium content of soybean hay at the Moran field. In the alfalfa hay, manure had a depressing effect upon the percentage of calcium, while the lime + superphosphate treatment tended to increase it.

7. All soil treatments increased the percentage of nitrogen in the soybean hay at the Moran field but the lime treatments and the combinations of lime, manure and superphosphates were most

effective. The effects of soil treatments upon the nitrogen content of the hay grown in the old stand of alfalfa were small but very large increases due to soil treatments were obtained in the hay produced in the new stand of alfalfa.

8. The limited data from the Thayer field indicated that soil treatment had little effect upon the phosphorus content of sweet clover and Korean lespedeza. It appeared that where the native supply of available phosphorus in the soil was sufficient for fairly good crop production, applications of superphosphate, unless heavy, did not increase the percentage of phosphorus in the legume hays. The percentage of calcium in these plants was not greatly affected by soil treatment but that of nitrogen was materially increased by the lime and the lime + superphosphate treatments.

9. Additional data from the Moran field showed that applications of superphosphate and limestone not only increased the phosphorus content of alfalfa hay, but also the yield of hay and consequently the total removal of phosphorus and calcium from the soil by the plants. Double applications of superphosphate resulted in higher total removals of phosphorus than single applications but thedifferences were not great. These small increases were largely due to the increase in the phosphorus content of the plants rather than increased crop yields. The differences in the total removals of calcium were principally due to differences in yield, although the percentages of calcium were affected to some extent by the heavier applications of limestone.

10. The percentages of applied phosphorus recovered in the alfalfa hay were calculated for those treatments in which superphosphate applications were included. These values indicate the relative efficiency of the superphosphate applications in increasing the uptake of phosphorus by the alfalfa plants. On this basis annual applications of 150 pounds of 20 per cent superphosphate per acre were more efficient than applications of twice that amount. The efficiency of superphosphate in increasing the phosphorus uptake was considerably higher when applied in combination with limestone than when used alone.

ACKNOWLEDGMENT

Indebtedness is acknowledged to Dr. W. H. Metzger, the major instructor, for helpful suggestions in regard to outlining the problem, collecting and analyzing the samples, interpreting the results and clarifying difficult explanations.

REFERENCES

1. Adams, J. E., Boggs, H. M. and Roller, E. M.
Effect of fertilizers on composition of soybean hay and seed and of crop management on carbon, nitrogen and reaction of Norfolk sand. U.S. Dept. Agr. Tech. Bul. 586. 34 p. 1937.

2. Aldous, A. E.
Pasture improvement investigations. Effect of fertilizers on the yield, quality and succession of pasture grasses. Kans. Agr. Expt. Sta. Bien. Rpt. 1932-1934. 147 p. 1934.

3. Alway, F. J., Shaw, W. M. and Methley, W. J.
Phosphoric acid content of crops grown on peat soils as an index of the fertilizers received or required. Jour. Agr. Res. 33:701-740. 1926.

4. Ames, J. W. and Boltz, G. E.
Nitrogen and mineral constituents of the alfalfa plant. Ohio Agr. Expt. Sta. Bul. 247. 19 p. 1912.

5. Archibald, J. G.
The chemical composition of grass from plots fertilized and grazed intensively in 1929. Jour. Agr. Res. 41:491-501. 1930.

6. Archibald, J. G. and Bennett, E.
Chemical composition of herbage from Massachusetts pastures. Mass. Agr. Expt. Sta. Bul. 300. 7 p. 1933.

7. Archibald, J. G. and Nelson, P. R.
The chemical composition of grass from plots fertilized and grazed intensively. Amer. Soc. Agron., Jour. 21:686-699. 1929.

8. Archibald, J. G., Nelson, P. R. and Bennett, E.
A three-year study of the chemical composition of grass from plots fertilized and grazed intensively. Jour. Agr. Res. 45:627-640. 1932.

9. Austin, R. H.
Effect of soil type and fertilizer treatment on the composition of the soybean plant. Amer. Soc. Agron., Jour. 22:136-156. 1930.

10. Baker, G. O. and Vandecaveye, S. C.
Effect of fertilizers, soil type and certain climatic factors on the yield and composition of oats and vetch. Jour. Agr. Res. 50:961-974. 1935.

11. Bayfield, E. G.
Influence of soil and fertilizers on quality of soft winter wheat. Ohio Agr. Expt. Sta. Bul. 563. 77 p. 1936.

12. ----------
Effect of fertilizers on the ash of wheat. Ohio Agr. Expt. Sta. Bul. 579. (55th Ann. Rpt.) 140 p. 1937.

13. Beaumont, A. B.
Experiments with permanent pastures. Mass. Agr. Expt. Sta. Bul. 281. 36 p. 1932.

14. Bender, C. B.
Protein in pasture grasses. N.J. Agr. 15(6):3-4. 1933.

15. Blair, A. W. and Prince, A. L.
The influence of phosphates on the phosphoric acid content of the plant. Jour. Agr. Res. 44:579-590. 1932.

16. ----------
Studies on the nitrogen, phosphorus and mineral requirements of alfalfa. Soil Sci. 47:459-466. 1939.

17. Brown, B. A.
The effects of fertilization on the chemical composition of vegetation in pastures. Amer. Soc. Agron., Jour. 24:129-145. 1932.

18. ----------
Effects of fertilizers on the botanical and chemical composition of the vegetation in permanent pastures. Conn. (Storrs) Agr. Expt. Sta. Bul. 187. 54 p. 1933.

19. Chapman, H. D.
Precipitation of CaC_2O_4 in the presence of iron, aluminum, titanium, manganese, magnesium and phosphorus, with special reference to the determination of total soil calcium. Soil Sci. 26:479-486. 1926.

20. Crampton, E. W. and Finlayson, D. A.
Pasture studies. VII. The effect of fertilization on the nutritive value of pasture grass. Empire Jour. Expt. Agr. 3:331-345. 1935.

21. Daniel, H. A.
A study of certain factors which affect the calcium, phosphorus and nitrogen contents of prairie grass. Okla. Acad. Sci., Proc. 12:42-45. 1932.

22. Daniel, H. A. and Harper, H. J.
The relation between total calcium and phosphorus in mature prairie grass and available plant food in the soil. Amer. Soc. Agron., Jour. 26:986-992. 1934.

23. Davidson, J.
The possible effect of hydrogen-ion concentration on the absorption of potassium and phosphorus by wheat plants under field conditions. Jour. Agr. Res. 46:449-453. 1933.

24. Davies, R. O. and Chippendale, H. G.
The response of grasses and clover to treatment on acidic upland soils and the effect of herbage plants on the reaction of acidic soils. I. The response of herbage plants to treatment on Molinia soil. Empire Jour. Expt. Agr. 2:324-336. 1934.

25. Davies, R. O. and Milton, W. E. J.
The response of grasses and clover to treatment on acidic upland soils and the effect of herbage plants on the reaction of acidic soils. III. A comparison of the produce of Molinia and fescue soils. Empire Jour. Expt. Agr. 5:48-62. 1937.

26. Eckles, C. H., Becker, R. B. and Palmer, L. S.
A mineral deficiency in the ration of cattle. Minn. Agr. Expt. Sta. Bul. 229. 49 p. 1936.

27. Fonder, J. F.
A critical study of the influence of soil type on the calcium and magnesium content and other physiological characters of the alfalfa plant. Soil Sci. 27:205-232. 1929.

28. Fraps, G. S., Fudge, J. F. and Reynolds, E. B.
Effect of fertilization on the composition of a Lufkin fine sandy loam and of oats grown on it. Amer. Soc. Agron., Jour. 29:990-996. 1938.

29. Fudge, J. F. and Fraps, G. S.
The relation of nitrogen, phosphoric acid and lime in the soils of East Texas to those constituents in Bermuda and Little Bluestem grasses. Soil Sci. Soc. Amer., Proc. 3:189-194. 1938.

30. Gainey, P. L. and Sewell, M. C.
The role of nitrogen in the production of spots in wheat fields. Jour. Agr. Res. 45:129-148. 1932.

31. Geddes. W. F., Winkler, C. A. and Roberts, J.
Influence of nitrogenous, phosphatic and potassic fertilizers on the chemical composition and blending value of western Canadian wheat. Sci. Agr. 19:380-388. 1939.

32. Grizzard, A. L.
Effect of soil type and soil treatments on the chemical composition of alfalfa plants. Amer. Soc. Agron., Jour. 27:81-99. 1935.

33. Grunder, Maynard S.
Yield and chemical composition of certain pasture crops, fertilized and unfertilized. Jour. Agr. Res. 46:375-386. 1933.

34. Hartwell, B. L.
The influence of fertilizers on crop quality. Natl. Fert. Assoc., Proc. 2:5-60. 1932.

35. Howk, B. W. and DeTurk, E. E.
Ashing plant materials to determine total phosphorus. Indus. and Engin. Chem., Analyt. Ed. 4:11-112. 1932.

36. Holtz, H. F.
Effect of calcium and phosphorus content of various soil series in Western Washington upon the calcium and phosphorus composition of oats, red clover and white clover. Wash. Agr. Expt. Sta. Bul. 243. 45 p. 1930.

37. Lush, R. H. and Fletcher, J. L.
Pasture fertilization at Lafayette, Louisiana. La. Agr. Expt. Sta. Bul. 304. 21 p. 1939.

38. McAllister, R. E.
Effect of fertilizers on the yield and composition of crops from wooded soils of Alberta. Sci. Agr. 14:249-256. 1934.

39. Mather, T. H.
The effect of fertilizers upon the forms of phosphorus and the amounts of phosphorus, nitrogen, and silica in hays. Sci. Agr. 10:35-63. 1929.

40. Millar, C. E.
Quantity and relationships of certain elements in Michigan legume hays. Amer. Soc. Agron., Jour. 30:507-513. 1938.

41. Moon, F. E.
The influence of fertilizer treatment on the carotene content of poor pasture grass, and on the relation of this constituent to the ash and organic fractions. Jour. Agr. Sci. 29:524-543. 1939.

42. Pierre, W. H. and Robinson, R. R.
The calcium and phosphorus contents of pasture herbage and of various pasture species as affected by fertilization and liming. Amer. Soc. Agron., Jour. 29:477-497. 1937.

43. Pittman, D. W.
Effect of manure and fertilizer on the yield and composition of alfalfa hay. Utah Agr. Expt. Sta. Bul. 247. 12 p. 1934.

44. Prigsley, L. I. and McKibbin, R. R.
Calcium relationships of forage crops. Canad. Jour. Res. 4:39-51. 1931.

45. Sayre, J. O. and Morris, V. H.
Concentrations of mineral nutrients in the corn plant as affected by fertilizer treatment. Ohio Agr. Expt. Sta. Bul. 548. (53rd Ann. Rpt.) 128 p. 1935.

46. Sewell, M. C. and Latshaw, W. L.
The effect of lime, superphosphate and potash on reaction of soil, and growth and composition of alfalfa. Amer. Soc. Agron., Jour. 23:799-814. 1931.

47. Sewell, M. C., Latshaw, W. L. and Tague, E. L.
Effect of acid phosphate on soil reaction and growth of alfalfa. Intern. Congr. Soil Sci., Comm. 2, Proc. 2:439-455. 1927.

48. Snider, A. M. and Hein, M. A.
The influence of soil treatment upon the composition of sweet clover. Amer. Soc. Agron., Jour. 26:740-745. 1934.

49. Thomas, B. and Moon, F. E.
A preliminary study of the effects of fertilizing treatment and of age on the carotene content of grass. Empire Jour. Expt. Agr. 6:235-245. 1938.

50. Weidemann, A. G.
Available phosphorus in soil and the phosphorus content of grain as influenced by phosphorus applications to soil. Amer. Soc. Agron., Jour. 26:170-178. 1934.

51. Willis, Jr., W. P. and Harrington, F. M.
Phosphate investigations in Montana, 1938. Mont. Agr. Expt. Sta. Bul. 369. 30 p. 1939.

52. Woodman, H. E. and Underwood, E. J.
Nutritive value of pastures. VIII. The influence of intensive fertilizing on the yield and composition of good permanent pasture (seasons 1 and 2). Jour. Agr. Sci. 22:26-71. 1932.