Effect of Fertilization and Lime On Yields of Alfalfa and of Crops Grown With It In an Eight-year Rotation

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Alfalfa was grown in an eight-year rotation with four other crops from 1931 through 1955 on the Station's Perkins Farm nine miles south of Stillwater. This publication reports average yield data[1] and includes a brief economic analysis. Chemical data on 26 cuttings of alfalfa hay obtained from 1937 through 1946 and analyzed for nitrogen, phosphorus, calcium and potassium are reported in detail elsewhere.[2]

Experimental Procedure and Conditions

The experiment was laid out on an area 1,785 by 208 feet, as shown in Figure 1. Alfalfa was alternated at four-year intervals between Strips A and B, and a four-year rotation of other crops was grown on the strip not occupied by alfalfa.

Table I lists the crops grown each year on the strip not in alfalfa. The four-year rotation from 1931[3] through 1938 was Darso grain sor-

The research reported herein was conducted under Oklahoma Station Project 169.

[1]Annual yield data are reported in "Annual and Average Yields of Alfalfa and Other Crops in an Eight-year Rotation with 12 Different Fertilizer Treatments, With and Without Lime; 1931-1955." Okla. Agri. Exp. Sta. Processed Series P-359 (October, 1960).

[2] Horace J. Harper, "The Nitrogen, Phosphorus, Calcium and Potassium Content of Alfalfa Hay Grown on Variously Fertilized Plots, With and Without Lime; by Cuttings, 1937-1946." Okla. Agri. Exp. Sta. Processed Series P-360 (October, 1960).

[3]Throughout this publication, unless otherwise indicated, years refer to the year of crop harvest: e.g., "winter barley in 1939" refers to the crop planted in the fall of 1938 and harvested the following spring.

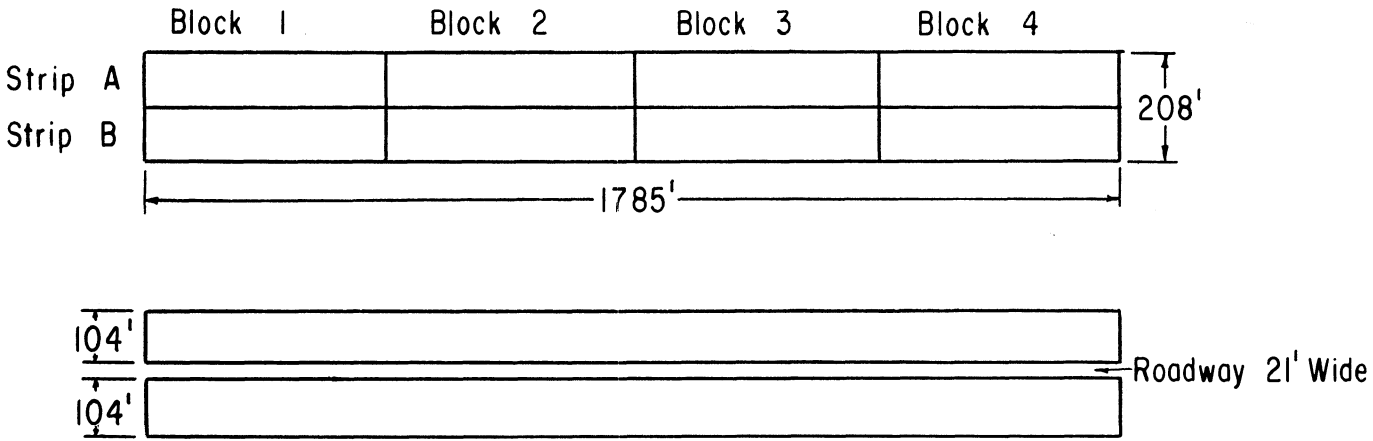


Figure 1.—Plat of the area used in the experiment, showing arrangement of blocks.

Table I.—Pattern of the four-year rotation grown on strip not occupied by alfalfa.*

	Block 1	Block 2	Block 3	Block 4
1931-4 (Strip A)				
1931	Darso	Cotton	Oats	Corn
1932	Cotton	Oats	Corn	Darso
1933	Oats	Corn	Darso	Cotton
1934	Corn	Darso	Cotton	Oats
1935-8 (Strip B)				
Same as Strip A in 1931-4, except that barley replaced corn in 1938.				
1939-42 (Strip A)				
1939	Darso	Cotton	Oats	Barley-lesp.
1940	Cotton	Oats	Barley-lesp.	Darso
1941	Oats	Barley-lesp.	Darso	Cotton
1942	Barley-lesp.	Darso	Cotton	Oats
1943-46 (Strip B)				
Same as 1939-42.				
1947-50 (Strip A)				
Same as 1939-42.				
1951-54 (Strip B)				
Same as 1939-42 except that lespedeza failed in 1954.				
1955-end (Strip A)				
1955	Barley**	Cotton	Oats	Darso
1956	Cotton	Oats	†	Barley**
1957	††	††	Barley	††

*Years listed are year of harvest; e.g. "barley in 1938" indicates the winter barley crop planted in the fall of 1937 and harvested in 1938.

**Lespedeza failed because of severe summer drought.

†Darso Sorghum lodged badly and was not harvested.

††No Spring-planted crops grown in 1957.

hum, cotton, spring oats, and corn (except that winter barley replaced corn in 1938). In 1939 and thereafter, the rotation was Darso, cotton, spring oats, and winter barley. The barley was used as a nurse crop for Korean lespedeza and was also harvested for grain.

Soil

The soil was a gently sloping Norge loam with a profile approximately seven feet deep. The surface soil when the experiment was started was low in easily soluble phosphorus and contained an average of 1.8 percent organic matter, 0.87 percent total nitrogen, and 8.1 milli equivalents of exchangeable bases per 100 grams of soil. The distribution of exchangeable bases was calcium 64 percent, potassium 15 percent, and magnesium 20 percent, a ratio favorable for alfalfa.[4] The

[4]Hunter, Albert S., Stephen J. Toth, and Firman E. Bear, "Calcium-Potassium Ratios for Alfalfa." *Soil Science*, 55:61-72 (1943).

exchangeable potassium in the surface soil on different plots varied from 200 pounds to more than 300 pounds per acre. Both surface and subsoil were slightly acid (pH about 6.0).

Boron deficiency symptoms were observed during some seasons on an occasional alfalfa plant prior to the second and third cuttings on plots fertilized with 0-20-0 and potash. This effect was not observed in the first cutting.

Fertilizer Treatments

Fertilizer treatments extended across Strips A and B in each block, as shown in Figure 2. The treatments were:

1. No fertilizer
2. 0-20-0—200 pounds per acre annually.
3. 0-45-0—89 pounds per acre annually.
4. Rock phosphate at the rate of 160 pounds of P_2O_5 per acre applied every four years when alfalfa seedbed was being prepared.
5. No fertilizer.
6. 4-8-4—200 pounds per acre annually.
7. 12-24-12—67 pounds per acre annually.
8. 4-12-4—134 pounds per acre annually.
9. No fertilizer.
10. 10-30-10—80 pounds per acre annually.
11. Barnyard manure at the rate of 80 pounds of nitrogen per acre every four years when alfalfa seedbed was being prepared.
12. Barnyard manure and rock phosphate at same rates as Treatments 4 and 11.
13. No fertilizer.
14. Barnyard manure as in Treatment 11, and 0-20-0 as in Treatment 2.
15. Barnyard manure as in Treatment 11, 0-20-0 as in Treatment 2, and muriate of potash at the rate of 50 pounds per acre annually.

16. 0-20-0 as in Treatment 2, and muriate of potash as in Treatment 15.

17. No fertilizer.

From 1931 through 1938, the foregoing treatments were applied to the entire area. Thereafter they were applied only to the strip currently in alfalfa.

The rates at which mixed fertilizers were applied were chosen to make the cost per acre similar to that of 200 pounds of 0-20-0. The 10-30-10 contained 50% more phosphorus than the other three mixed fertilizers.

Lime Treatment

No lime was applied at the time the experiment was started. The plan was to determine if high yields of alfalfa could be produced without liming, thereby reducing the cost. However, field observations and laboratory tests between 1931 and 1936 indicated that liming would be necessary for optimum production of this crop. Consequently, agricultural limestone was applied during the summer of 1936 at the rate of two tons per acre on one half of each of the plots, as shown in Figure 2. Data were taken separately on the limed and unlimed areas in 1938 and following years.

Soil samples collected in December, 1950, showed a pH of 5.4 on unlimed plots and 5.5 where lime had been applied in 1936. Consequently, the limed portion of each of the plots was given a second application of limestone at the rate of two tons per acre in February, 1952. This application should have been applied at an earlier date.

Methods of Planting and Harvesting

The first planting of alfalfa was made in March, 1931. Thereafter, at the end of each four-year period, the alfalfa was planted in March where it followed cotton, corn or darso, and in late September where it followed oats or barley-lespedeza. After oats were harvested in June, the land usually was plowed in early July. Following cotton, corn, or darso the land was plowed or disked during the winter. When alfalfa followed barley-lespedeza, the plots were plowed in mid-August.

Inoculated alfalfa seed was drilled in 7-inch rows at the rate of 12 to 15 pounds per acre. A corrugated roller was used to firm the seed bed immediately after drilling the alfalfa.

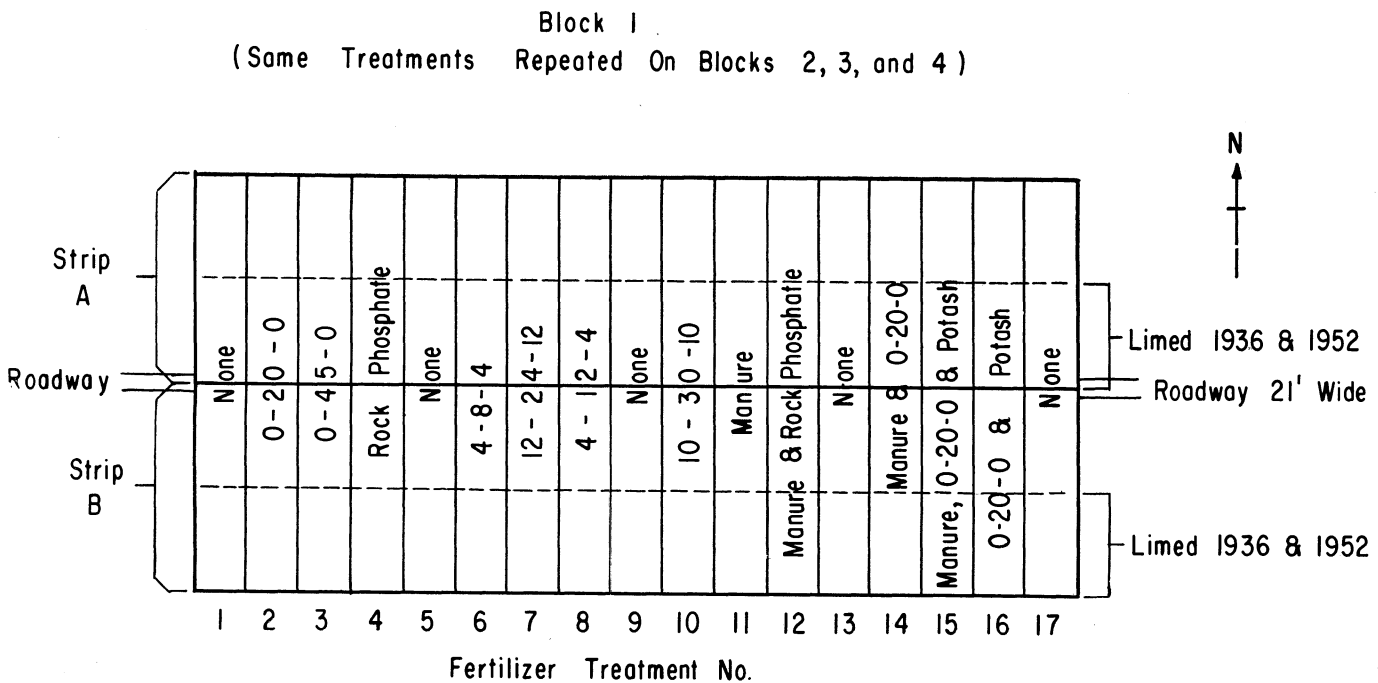


Figure 2.—Plat of one of the blocks, showing locations of the various fertilizer treatments. The treatments were applied to both strips from 1931 through 1938. Thereafter they were applied only on the strip currently in alfalfa. The plots were separated by guard strips and included 1/20th acre before liming and only 1/40th acre after liming.

The first cutting of alfalfa was made in late April or early May, whenever a few days of favorable curing weather occurred. Second and third cuttings usually were obtained at intervals of three to five weeks when rainfall was average or above average in May and June. When the first cutting was delayed for 10 days by unfavorable weather or for other reasons, very often a third cutting was not obtained in years when rainfall was low in late spring and early summer. The first cutting was delayed in some years to permit "Agronomy Day" visitors to observe forage differences in the plots in mid-May.

Lespedeza hay was usually harvested in late August or early September. In years when alfalfa was to be planted, or when summer drought was severe, forage yields from the lespedeza plots were obtained by cutting 9 or 16 square feet from each plot in mid-August.

Seasonal Variations

Yields of alfalfa on fertilized plots were closely related to the January-June rainfall. Distribution of rainfall was often more important than quantity. Average hay yields on plots fertilized with manure, lime and superphosphate varied from a minimum of 2,547 pounds per acre in 1954 when January-June rainfall was only 9.79 inches to a maximum of 12,105 pounds in 1942 when January-June rainfall was 25.08 inches.

An interesting exception to the usual pattern occurred at the beginning of the 1939-1942 period. A thick stand of young alfalfa plants was not thinned by competition, and the roots did not penetrate into the deep subsoil where an abundant supply of moisture had collected as a result of early spring rains. Consequently, hay yields were low during the earlier life of this planting.

Young alfalfa plants were destroyed by severe wind erosion in late winter and early spring in 1935. No hay yields were obtained from fall- or spring-planted plots that season.

Spring-planted alfalfa which followed cotton was retarded by severe competition from crabgrass in three of the four years when new stands were being established during the second phase of the experiment (1939-1954). In one of the four years, volunteer sorghum plants reduced the growth of spring-planted alfalfa on plots where Darso sorghum was grown the previous year.

Alfalfa yields were never seriously reduced by insect damage, although greenbugs were numerous during early spring in some seasons.

The experiment was concluded before the spotted alfalfa aphid caused severe damage to alfalfa crops in this part of Oklahoma.

Grain sorghum production was reduced occasionally on a few plots by chinch bugs that migrated from barley planted on adjacent land.

Cotton yields were limited by unfavorable weather or by boll weevil and/or leafhopper injury from 1934 through 1937, and in 1943, 1946, 1950, and 1956.

Results and Discussion

Relation of Alfalfa Yields to Fertilizer Treatment

Prior to Liming (1932-1937)

Average annual yields of alfalfa hay during the period before lime was applied to any of the plots are shown in Table II. These include the yields for 1937, since data were not taken separately from the limed and unlimed areas the first year after lime was applied.

Phosphorus fertilization during this period nearly doubled the yield of alfalfa, as indicated by comparing yields obtained from check plots with those where 0-45-0 or 0-20-0 was applied.

After Liming (1938-1954)

Average annual yields of alfalfa hay for the various fertilizer treatments with and without lime from 1938 through 1954 are shown in Table II. Table III presents results of a multiple range test for significance.

Effect of Liming

Table IV shows the increased yield on the limed plots, as compared to unlimed plots, for each of the fertilizer treatments. On the check plots, lime alone increased the average yield of hay 936 pounds per acre. Average increase on the 12 variously fertilized plots was 1,694 pounds per acre. Figure 3 includes a comparison of the average yields from limed and unlimed plots.

Field observations and laboratory tests indicated that lime should be applied on this soil at 10-year intervals. The prorated cost of liming on this basis was about 65 cents per acre per year. Higher costs prevail at the present time.

Table II.—Average annual yields of alfalfa hay in relation to 12 different fertilizer treatments, with and without lime; 1932 through 1954.

(Pounds of hay per acre)

Treatment No.	Fertilizer*	On Unlimed Soil		On Limed Soil
		1932-1937**	1938-1954	1938-1954
1	None	1055	1114	2142
2	0-20-0	2530	3553	5376
3	0-45-0	2538	3813	5723
4	Rock phosphate	2413	3943	5543
5	None	1593	1475	2390
6	4-8-4	2105	2569	4123
7	12-24-12	2050	2645	4260
8	4-12-4	2060	2387	3965
9	None	1304	1175	2062
10	10-30-10	2300	3064	4927
11	Manure	2557	3889	4925
12	Manure and rock phosphate	3261	4958	6776
13	None	1348	1800	2651
14	Manure and 0-20-0	3205	4833	6749
15	Manure, 0-20-0, and Potash	3151	4893	6634
16	0-20-0 and Potash	2696	3297	5174
17	None	1291	1239	2241
Average of five check plots		1318	1361	2298
Average of treatments 2 and 4			3748	5460
Average of Treatments 12 and 14			4896	6762

*Applied on all plots 1932-38, and on alfalfa plots only from 1938 through 1954.
**Lime applied in summer of 1936; Limed and unlimed plots were not harvested separately in 1937. Averages do not include 1935, when young alfalfa plants were severely damaged by wind erosion.

Effect of Phosphorus

On plots which had been limed, phosphate fertilization more than doubled the yield of hay. The average of the 0-45-0 and rock phosphate treatments on the limed plots was 5,633 pounds per acre as compared to an average of 2,298 pounds on five plots that received only lime. Figure 4 shows the average yield of alfalfa produced on plots fertilized with rock phosphate, 0-20-0, and 0-45-0.

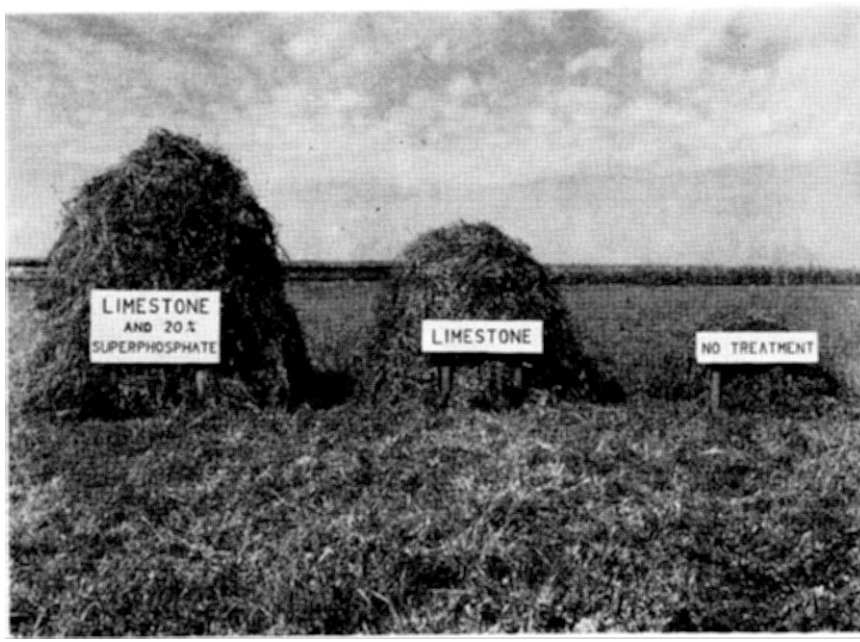
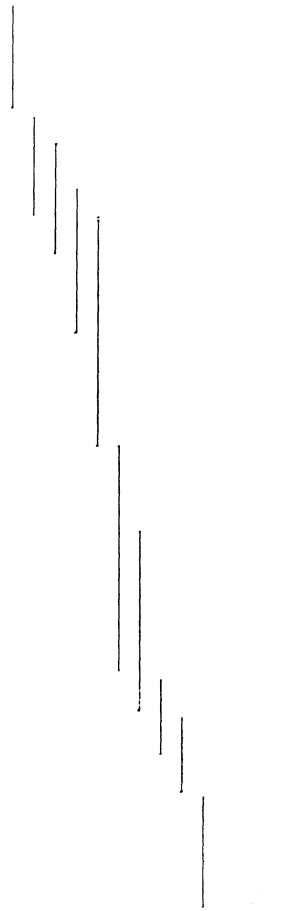


Figure 3.—Average annual yields of alfalfa hay during the period 1939 through 1954 were 1,380 pounds per acre on untreated plots, 2,397 pounds per acre on plots treated with limestone only, and 5,376 pounds per acre on plots treated with both limestone and 0-20-0.

Figure 4.—There was no statistically significant difference among the average annual yields of alfalfa hay from Treatments 2, 3 and 4 on limed plots during the period 1939 through 1954.

Table III.—Relation of alfalfa hay yields to lime and fertilizer treatment, 1938-1954.*

Treatment No.	Fertilizer	Lime	Alfalfa Yield (lbs./A.)
12	Manure and rock phosphate	yes	6,776
14	Manure and 0-20-0	yes	6,749
15	Manure, 0-20-0, and potash	yes	6,634
3	0-45-0	yes	5,723
4	Rock phosphate	yes	5,543
2	0-20-0	yes	5,376
16	0-20-0 and potash	yes	5,174
12	Manure and rock phosphate	no	4,958
10	10-30-10	yes	4,927
11	Manure	yes	4,925
15	Manure, 0-20-0 and potash	no	4,893
14	Manure and 0-20-0	no	4,883
7	12-24-12	yes	4,260
6	4-8-4	yes	4,123
8	4-12-4	yes	3,965
4	Rock phosphate	no	3,943
11	Manure	no	3,889
3	0-45-0	no	3,813
2	0-20-0	no	3,553
16	0-20-0 and potash	no	3,297
10	10-30-10	no	3,064
7	12-24-12	no	2,645
6	4-8-4	no	2,569
8	4-12-4	no	2,387
	None (avg. of 1, 5, 9, 13 and 17)	yes	2,297
	None "	no	1,361



*No statistically significant difference at the 5 percent level between treatments within a bracket or covered by overlapping brackets.

At least 40 pounds of phosphoric acid per acre was required to produce a maximum yield of alfalfa on this soil. The mixed fertilizers supplied either 16 or 24 pounds of phosphoric acid per acre.

There was no significant difference in yield between rock phosphate and superphosphate treatments, whether applied alone or with manure and/or lime (Table III). Cost of application was lower for the rock phosphate, since it was applied only once in four years. The average annual cost of material and application from 1941 through 1955 was about $1.60 per acre for rock phosphate and $3.00 per acre for 0-45-0.

Effect of Manure

Use of manure with either rock phosphate or superphosphate increased the hay yield about one-half ton per acre on both limed and unlimed soil, as compared to either phosphate applied alone (Table II). Yield increase from manure alone (Treatment 11) was about the same as that from a mixed fertilizer containing the equivalent of 16 pounds of P_2O_5 per acre (Treatments 6, 7 and 8). The manure supplied less than one-fourth as much phosphorus as did the 0-20-0 or the rock phosphate.

Table IV.—Increased Yield of Alfalfa Hay on Limed Plots as Compared to Unlimed Plots, 1938-1954.

Treatment No.	Fertilizer	Increase in Yield Due to Liming	
		Lbs. per acre	Percent
1	None	1028	93
2	0-20-0	1823	51
3	0-45-0	1910	50
4	Rock phosphate	1600	41
5	None	915	62
6	4-8-4	1554	60
7	12-24-12	1615	61
8	4-12-4	1578	66
9	None	887	75
10	10-30-10	1863	61
11	Manure	1036	27
12	Manure and rock phosphate	1818	37
13	None	851	47
14	Manure and 0-20-0	1916	40
15	Manure, 0-20-0, and potash	1741	36
16	0-20-0 and potash	1877	57
17	None	1002	81
Average of five check plots		936	70
Average of 12 fertilized plots		1694	46

Effect of Potash

No increase in alfalfa production was obtained from potash fertilization on this soil which is high in exchangeable potassium. The potassium content of hay harvested from plots where muriate of potash was applied[5] was much higher than is required for the optimum growth of alfalfa.

Relation of Alfalfa Yields to Preceding Crop

Table V shows average yields of alfalfa hay, as a composite of all 17 treatments, in relation to the crop which immediately preceded the alfalfa in the rotation and to the age of the alfalfa stand. A good first-year crop of hay was produced only once in four of the comparisons where alfalfa was planted in the spring following cotton or grain sorghum. However, the average hay yield for the four years when alfalfa followed cotton was nearly as high as when it followed barley or oats. A lower hay yield was obtained following grain sorghum than following oats, barley or cotton in this study.

Yields of Other Crops in the Rotation

Winter Barley

Table VI reports average grain and straw yields of winter barley produced on the plots where alfalfa had been grown with different fertilizer treatments. Clipping data from these plots for the years 1944 through 1950 indicate that vegetative growth was about 95 percent higher on the plots fertilized with superphosphate than on the unfertilized plots.[6] The straw yields shown in Table VI do not accurately reflect the amount of grazing which might have been available, particularly in fall and winter, since in some years low temperatures in January destroyed an abundant fall and winter growth.

Korean Lespedeza

Table VII shows the average annual yields of Korean lespedeza hay produced in summer on the barley plots. When spring rainfall was low, a better growth of lespedeza was produced on unfertilized plots than on fertilized ones, due to competition for light, soil moisture and plant nutrients from a more vigorous growth of barley on the fertilized

[5]Reported in Okla. Agri. Exp. Sta. Processed Series P-360. For full citation see footnote on page 3.

[6]Data from these clipping comparisons are reported in Okla. Agri. Exp. Sta. Bul. B-414, "A study of phosphate fertilization and legume rotations for small-grain winter pastures," by Horace J. Harper (1953); page 25.

Table V.—Relation of Previous Crop to Yield of Alfalfa Hay the First, Second, Third, and Fourth Year after Planting; Averages of Treatments 1 through 17, Inclusive, on Limed Plots. (Pounds per acre)

Previous Crop	Yield of hay in—			
	First year after planting	Second year after planting	Third year after planting	Fourth year after planting
	1939	*1940*	*1941*	*1942*
Barley	1867	2754	6968	7715
Spring oats	2770	2888	7092	8410
Cotton	3513	3496	8111	7394
Grain sorghum	3449	2780	7566	7777
	1943	*1944*	*1945*	*1946*
Barley	3009	7181	8079	5814
Spring oats	2384	7252	7310	4845
Cotton	*	8484	8002	6242
Grain sorghum	**	6065	6668	5468
	1947	*1948*	*1949*	*1950*
Barley	3876	3397	2101	3411
Spring oats	6347	3880	3053	3557
Cotton	*	3115	2660	4795
Grain sorghum	*	3077	2430	4068
	1951	*1952*	*1953*	*1954*
Barley	3251	4294	4760	2096
Spring oats	3182	3646	3699	1557
Cotton	*	4691	3963	1657
Grain sorghum	*	2338	3083	1599
	Average First Year	Average Per Year Second, Third and Fourth Years		Average per year During 16 Years
Barley	3001	4881		4411
Spring oats	3671	4766		4492
Cotton	878	5217		4132
Grain sorghum	862	4410		3523

*Plots clipped to control weeds; plots were very grassy and no hay yields were obtained from spring planting.

**Volunteer grain sorghum (Darso) was abundant in spring-planted alfalfa in 1943.

land. Summer drought rather than soil fertility limited lespedeza production during many seasons.

Spring Oats

Table VIII shows the average annual yields of spring oats. The grain yield was about five bushels higher per acre on plots treated with lime than on those receiving no lime or fertilizer. The residual effect of phosphate fertilization on the limed plots gave an additional increase of about seven bushels per acre.

Table VI.—Average Annual Yields of Barley Grain and Straw in Relation to 12 Different Fertilizer Treatments, With and Without Lime; 1939 through 1957.

Fertilizer Treatment on Alfalfa		Unlimed		Limed	
Treatment No.	Fertilizer	Grain bu. per acre	Straw Lbs. per acre	Grain bu. per acre	Straw Lbs. per acre
1	None	17.1	646	20.0	838
2	0-20-0	23.9	1128	26.2	1509
3	0-45-0	25.6	1270	26.1	1485
4	Rock phosphate	23.7	1299	26.8	1435
5	None	15.8	643	20.2	902
6	4-8-4	21.9	938	25.5	1140
7	12-24-12	20.5	1007	24.4	1163
8	4-12-4	20.5	1005	24.4	1118
9	None	14.6	546	18.6	787
10	10-30-10	23.6	1012	24.0	1182
11	Manure	25.4	1208	25.7	1257
12	Manure and rock phosphate	24.1	1330	27.1	1663
13	None	17.0	736	20.2	942
14	Manure and 0-20-0	26.1	1413	28.1	1524
15	Manure, 0-20-0, and potash	26.8	1339	27.4	1467
16	0-20-0 and potash	23.1	992	27.5	1380
17	None	13.1	609	19.4	792

Table VII.—Hay Yields of Korean Lespedeza Following Barley in the Rotation; 14-year Average, 1939 through 1953.

Treatment No.	Fertilizer	Yields of Hay (pounds per acre) Limed	Unlimed
1	None	2951	2424
2	0-20-0	3239	3144
3	0-45-0	3254	2823
4	Rock phosphate	3516	2916
5	None	3039	2528
6	4-8-4	3293	2724
7	12-24-12	3044	2499
8	4-12-4	3620	2781
9	None	2896	2451
10	10-30-10	3329	2679
11	Manure	3179	2951
12	Manure and rock phosphate	2908	3187
13	None	2791	2760
14	Manure and 0-20-0	2991	2681
15	Manure, 0-20-0, and potash	2802	2740
16	0-20-0 and potash	3230	2880
17	None	2849	2373

Oat yields were not increased significantly by the residual effect of the manure applied in this study. Average straw yields were higher on limed than on unlimed plots. Average straw yields were also slightly higher from the residual effect of phosphate fertilizers and lime applied on the alfalfa than on plots where only a phosphate fertilizer was applied.

Cotton

Table IX shows the average annual yields of seed cotton. The higher average yield on plots that were limed as compared to the unlimed plots is statistically significant at the 5 percent level. Differences among the fertilized plots were not significant. However, the increases from fertilizer treatments were statistically significant as compared with yields obtained from unfertilized or plots treated only with lime.

The location of this rotation experiment was adjacent to another experiment in which cotton was planted every year. Unfertilized plots in the alfalfa rotation produced 839 pounds of seed cotton per acre as compared with 797 pounds where cotton was planted every year. Where 40 pounds of P_2O_5 per acre was applied annually to continuous cotton, the average annual yield was 960 pounds of seed cotton per acre; and where the same quantity of phosphorus was applied annually to the alfalfa in the rotation (but not to the cotton) seed cotton production was 1033 pounds per acre. The higher yield in the rotation was not

Table VIII.—Average Annual Yields of Oats in Relation to 12 Different Fertilizer Treatments, With and Without Lime; 1939-1956.

Treatment No.	Fertilizer	unlimed		limed	
		grain bu. per acre	straw bu. per acre	grain lbs. per acre	straw lbs. per acre
1	None	24.6	927	31.1	1275
2	0-20-0	35.8	1557	38.0	1785
3	0-45-0	39.4	1706	37.8	1729
4	Rock phosphate	37.4	1519	38.2	1672
5	None	24.3	877	31.1	1150
6	4-8-4	29.4	1020	32.5	1277
7	12-24-12	29.1	1070	33.8	1238
8	4-12-4	30.8	1179	33.2	1383
9	None	24.6	852	29.3	1054
10	10-30-10	33.4	1382	40.0	1398
11	Manure	36.6	1447	34.7	1587
12	Manure and rock phosphate	38.2	1800	37.7	1936
13	None	27.8	980	33.7	1320
14	Manure and 0-20-0	41.3	1845	38.0	2068
15	Manure, 0-20-0 and potash	41.1	1824	41.1	1882
16	0-20-0 and potash	37.8	1315	37.3	1589
17	None	24.0	843	29.0	1094
Avg. of check plots		25.1	896	30.1	1179
Avg. of 12 treatments		35.9	1472	36.9	1629

Table IX.—Average Annual Yields of Seed Cotton in Relation to 12 Different Fertilizer Treatments, with and without lime; 1939 through 1956.

Treatment No.	Fertilizer	Yields	
		Unlimed lbs. per acre	Limed lbs. per acre
1	None	893	999
2	0-20-0	1121	1138
3	0-45-0	1141	1152
4	Rock phosphate	1133	1138
5	None	932	1005
6	4-8-4	1004	1029
7	12-24-12	1015	1000
8	4-12-4	1004	1002
9	None	889	906
10	10-30-10	1150	1046
11	Manure	1088	1132
12	Manure and rock phosphate	1109	1173
13	None	936	992
14	Manure and 0-20-0	1133	1073
15	Manure, 0-20-0, and potash	1133	1118
16	0-20-0 and potash	1070	1100
17	None	873	922
Avg. of check plots		905	965
Avg. of 12 treatments		1092	1092

statistically significant. However, the differences between the fertilized and unfertilized plots were significant at the 5 percent level in both experiments.

Darso Grain Sorghum

Table X shows average annual yields of grain sorghum in the rotation. Production was significantly higher on limed than on unlimed plots. There were no significant differences among the fertilizer treatments. The average production of grain sorghum from 1931 to 1955 was 36.1 bushels per acre on plots where the alfalfa was fertilized with manure and superphosphate. In another experiment on the same soil, corn production in a three-year rotation with oats and cowpeas on plots

Table X.—Average Annual Yields of Darso Grain Sorghum in Relation to 12 Different Fertilizer Treatments, with and without lime; 1937-1955.

Treatment No.	Fertilizer	Yields	
		Unlimed Bu. per acre	Limed Bu. per acre
1	None	33.2	37.3
2	0-20-0	39.5	42.3
3	0-45-0	39.6	42.7
4	Rock phosphate	39.6	42.7
5	None	33.3	37.6
6	4-8-4	35.8	40.2
7	12-24-12	35.9	40.0
8	4-12-4	34.4	38.6
9	None	30.1	35.8
10	10-30-10	36.2	39.7
11	Manure	38.7	41.3
12	Manure and Rock phosphate	40.7	43.1
13	None	32.8	37.3
14	Manure and 0-20-0	39.2	41.9
15	Manure, 0-20-0, and potash	40.1	43.2
16	0-20-0 and potash	33.9	41.2
17	None	29.6	35.2
Average of check plots		31.8	36.6
Average of 12 treatments		37.8	41.4

fertilized with manure and superphosphate averaged 25.8 bushels per acre for the same period.

Yields of Other Crops Before and After Alfalfa In First Eight-Year Rotation

Table XI summarizes the four-year average yields obtained on Strip A before alfalfa was grown on it (1931-34) as compared with yields on Strip B after alfalfa had been grown for four years on unlimed soil. Average yields of corn and cotton were very low from 1935 through 1937 because of very unfavorable summer weather. Corn was not planted in 1938, and the cotton data were lost for that year. Grain sorghum yields also were low from 1935 to 1937, but good yields were obtained in 1938. Oat yields were good during three of the four years from 1931 to 1934 and from 1935 to 1938.

Spring Oats

Some increase in grain yields of spring oats was obtained by phosphate fertilization before alfalfa had been grown on the land. A greater increase was obtained from manure. When oats followed the alfalfa,

Table XI.—Effect of Fertilizer Treatments on Yields of Other Crops Before and After Alfalfa was Grown; First 8-year Rotation.

Treatment No.	Fertilizer	Oats				Corn (bu./A.)		Grain Sorghum (bu./A.)		Seed Cotton (lbs./A.)	
		Grain (bu./A.)		Straw (lbs./A.)							
		Before	After	Before	After	Before	After*	Before	After**	Before	After*
1	None	30.3	30.4	624	1061	17.1	10.5	32.4	7.3	945	283
2	0-20-0	32.8	42.7	1024	1736	17.8	13.0	32.5	7.1	1020	296
3	0-45-0	36.1	40.2	1099	1640	18.1	13.0	35.2	6.9	1048	303
4	Rock phosphate	36.8	39.3	1089	1554	19.4	13.7	32.1	6.8	980	307
5	None	31.9	31.7	932	1003	19.2	12.5	34.4	6.8	901	318
6	4-8-4	38.6	35.9	1100	1273	19.4	13.4	34.6	7.0	1013	283
7	12-24-12	34.1	38.3	1080	1368	18.3	12.0	33.7	6.9	994	297
8	4-12-4	35.7	39.7	1081	1439	17.7	12.2	32.8	6.6	993	318
9	None	30.7	33.7	799	1144	18.2	11.4	32.3	7.5	829	292
10	10-30-10	40.7	38.3	1269	1415	17.7	13.8	34.2	7.3	965	337
11	Manure	41.6	41.4	1253	1546	19.1	14.6	35.5	7.1	1089	287
12	Manure and rock phosphate	37.1	36.5	1203	1599	18.1	14.0	36.0	7.7	1050	317
13	None	32.8	35.3	990	1295	18.3	11.8	34.9	9.6	991	343
14	Manure and 0-20-0	38.0	40.0	1250	1603	18.7	13.5	34.6	9.4	1051	317
15	Manure, 0-20-0, and potash	41.4	43.0	1210	1905	17.4	12.7	34.4	9.1	1041	283
16	0-20-0 and potash	34.7	43.8	1009	1670	18.7	12.9	34.7	9.6	966	343
17	None	31.7	33.7	906	1195	15.9	11.6	31.0	8.5	924	322

*1935-1937.
**1935-1936.

phosphate fertilization and the residual effect of the unlimed alfalfa increased grain yields about 10 bushels per acre. The manure had no effect on grain production when applied on plots where the previous alfalfa crop had been fertilized with superphosphate.

Cotton

Some increase in cotton yield was obtained from phosphate fertilization in 1933 when seasonal conditions were highly favorable for cotton production, but no significant increases were obtained from phosphate fertilization during the other three years. Cotton yields were very low from 1934 to 1937.

Grain Sorghum

Grain sorghum yields were not increased by either phosphate fertilization or manure during the 1931-34 period. Apparently a well managed deep soil containing 1.8 percent of organic matter will produce as high a yield of Darso grain sorghum as can be obtained under average climatic conditions in this area. Lime applied in the summer of 1936 provided a significant increase in grain sorghum production in 1938 and following years.

Corn

Corn was not a profitable crop during four of the seven years from 1931 to 1937 and only one good crop of corn was produced during this period. Yields of the five check plots averaged by years were: 1931, 19.9 bushels; 1932, 37.5 bushels; 1933, 4.0; 1934, 9.6; 1935, 21.8; 1936, 7.2; and 1937, 5.7 bushels per acre. In 1932, when seasonal rainfall was favorable for corn, the average yield from the 12 fertilizer treatments was only 2.6 bushels higher per acre than the average yield from the unfertilized plots. The highest yields were about 42 bushels per acre that season.

Labor Income from Crops in the Rotation

Yield data obtained in this experiment were used as a basis for calculating the returns to labor (labor income) produced by each of the crops included in the rotation.

Returns to labor were calculated by estimating, for each crop, the yield necessary to meet the costs of land rental (or ownership) plus the costs of planting and harvesting the crop. This was considered the break-even yield, and any yield above this quantity was considered as

Table XII.—Average Annual Labor Income Per Acre from Crops Grown in the Rotation, and Frequency of Years in Which no Labor Income was Produced, on Limed Plots Receiving 200 Pounds of 0-20-0 Annually.

	Average labor income per acre per year	Frequency of crops producing no labor income	Period of years included in analysis
Alfalfa	$14.15*	2 out of 17	1938-1954
Cotton	23.90	2 out of 18	1938-1955
Grain sorghum	17.50	2 out of 19	1938-1956
Spring oats	6.97	3 out of 18	1938-1954
Barley	5.36	5 out of 19	1938-1956

*Costs of fertilizer and lime charged to the alfalfa.

Per acre yields used as break-even points were:
Alfalfa hay: 2,500 pounds, plus cost of 200 lbs. of 0-20-0 and the lime.
Cotton: 480 pounds seed cotton (about 160 pounds of lint).
Grain sorghum: 16.5 bushels.
Oats: 22 bushels
Barley: 16 bushels.

being return to labor. For all crops except cotton, the return to land (that is, rental; or cost of ownership) was figured as one-third of the crop. For cotton, it was one-fourth. In computing the costs of planting and harvesting, all costs of buying and applying fertilizer were charged against the alfalfa. A charge for custom baling of alfalfa and for hired cotton pickers (snapping) was included.

The results of these calculations are shown in Tables XII and XIII.

The grazing value of the lespedeza would have been greater than the value of the barley grain in about three out of four years. Winter grazing of the barley could have increased the labor income from barley above that shown for spring oats. A forage sorghum would have benefited more than either grain sorghum or cotton from nitrogen fixed by alfalfa on this type of land.

Corn was profitable in only three of the seven years it was included in the rotation.

Summary

Alfalfa was grown in an eight-year rotation with four other crops from 1931 through 1954 on a Norge loam soil containing 1.8 percent of organic matter in the plowed layer and slightly acid in both surface and subsoil at the time the experiment was started. Twelve different fertilizer treatments were applied on all plots from 1931 through 1938, and

Table XIII.—Break-even Yields of Alfalfa Required to Pay Cost of Production, and Frequency of Crops Producing a Labor Income; for Various Fertilizer Treatments (1938-1954 except as noted).

Soil Treatment	Break-even yield (lbs./A.)	Frequency of crops producing a labor income
Unlimed and unfertilized	2,400	1 out of 22*
Limed only	2,500	5 out of 17
0-20-0, unlimed	2,665	9 out of 17
0-20-0 unlimed	2,665	11 out of 22*
Rock phosphate and lime	2,625	15 out of 17
0-20-0 and lime	2,765	15 out of 17
Manure and 0-20-0, limed	2,965	16 out of 17
Manure and Rock phosphate, limed	2,825	16 out of 17
Manure and 0-20-0	2,865	16 out of 22*
Manure and Rock phosphate	2,725	19 out of 22*

*1931 through 1954, excluding 1935 when no alfalfa was harvested.

thereafter only on the area in alfalfa. One-half of each plot was limed in 1936 and again in 1952.

Crops grown in the four-year rotation were Darso grain sorghum, cotton, spring oats and corn from 1931 through 1937. In 1938, corn was replaced by winter barley with Korean lespedeza overseeded in the spring.

Average annual yield of alfalfa hay on unlimed and unfertilized plots was 1,361 pounds per acre from 1938 through 1954. On limed plots it was 2,298 pounds per acre. Where rock phosphate, 0-20-0 or 0-45-0 was applied on limed plots, it was about 5,500 pounds per acre, with no significant differences among the three sources of phosphate. Yields were significantly lower on plots where various mixed fertilizers supplied smaller quantities of P_2O_5 per acre. Manure alone produced less hay than did phosphate fertilization; but manure in combination with either rock phosphate or 0-20-0 produced about 6,750 pounds per acre. Potash had no effect; the soil on the experimental area contained an abundant supply of exchangeable potassium.

First-year hay yield was less than 900 pounds per acre when alfalfa was planted in the spring following cotton or Darso grain sorghum, and more than 3,000 pounds per acre from fall-planted alfalfa following winter barley or spring oats. However, as an average of four four-year rotations, annual average yields were: Following barley, 4,411 pounds;

following oats, 4,492 pounds; following cotton, 4,132 pounds; and following sorghum, 3,523 pounds per acre.

Average annual yields of other crops grown in the rotation are reported in the text, in relation to (1) effect of fertilizers applied directly to these crops from 1931 through 1938, (2) residual effects where the crops followed alfalfa given various fertilizer treatments from 1939 through 1954, and (3) effect of following four years of alfalfa as compared to yields before alfalfa had been grown on the land.

Average annual labor income per acre is reported for alfalfa, cotton, grain sorghum, oats and barley on limed plots where 0-20-0 was applied, and break-even yields of alfalfa hay are reported for various fertilizer treatments.