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DEPARTMENT OF AGRONOMY

A PORTABLE LIME CRUSHER IN OPERATION ON A FARM NEAR FORT SCOTT

LIMING KANSAS SOILS[1]

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WHY SOILS NEED LIME

Soils need lime to replace that which has been lost either through crop removal or in drainage water. The greatest loss is from leaching by percolating water. Therefore the greatest deficiency of lime will be found under conditions of highest rainfall and on soils through which water most readily percolates, namely, sandy soils.

The removal of lime from the soil may injure plants in one of two ways. First, it may result in the development of soil acidity, which is unfavorable for the production of certain crops, and in extreme cases is detrimental to the growth of all plants. The latter condition does not exist in Kansas soils. Secondly, all plants need lime for their development. Some, however, need more lime than others. A ton of alfalfa will remove the equivalent of 90 to 100 pounds of lime (calcium carbonate) from the soil. A deficiency of lime in the soil may actually starve the growing plants. The addition of lime to the soil in adequate amounts will correct the acid condition and supply lime needed for plant growth.

1. Contribution No. 249 from the Department of Agronomy.

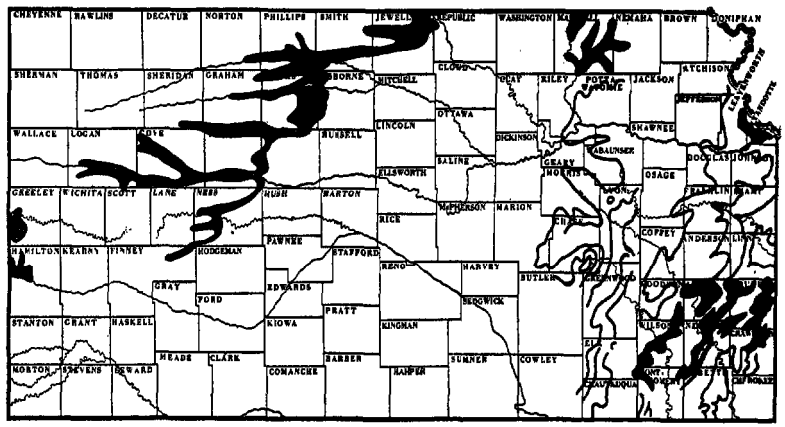
LIME

The term agricultural lime should be more familiar to those interested in the development of agriculture in eastern Kansas. It is the basic treatment needed on large areas of soil in this part of the state. The application of lime to these soils will frequently increase the effectiveness of other treatments.

Agricultural lime is any material containing either calcium or magnesium which, when added to the soil, will neutralize or correct its acidity or sourness. Any one of the following substances may be used successfully as agricultural lime:

1. Crushed limestone.
2. Burned lime.
3. Hydrated lime.
4. Marl.

The form most commonly used in Kansas is crushed limestone rock. Limestone occurs in rock strata of varying thickness and at varying depths below the surface. The principal limestone areas of the state are shown in figure 1. Outcroppings of limestone can be seen around the rims of hills in many places



Courtesy Kansas Geological Survey

FIG. 1.—The heavy lines represent the relative extent of the principal limestone areas in Kansas.

throughout the acid soil region of the state and farther west. The limestone in Kansas consists mainly of calcium carbonate plus impurities, but does carry some magnesium carbonate. The purity of limestone is an important factor in determining its value.

Another naturally occurring form of lime that is used for agricultural purposes is marl, deposits of mixtures of amorphous calcium carbonate and clay or sand loosely cemented together. In Kansas, marl is found only in the western part of the state. The high percentage of impurities, and resulting high cost of transportation restrict the use of marl largely to areas in the immediate vicinity of deposits. Since acid soils in Kansas are found only in the eastern part of the state, marl possesses very limited value as agricultural lime in this state.

Lump lime and hydrated lime may also be used for agricultural purposes. Lump lime or calcium oxide is prepared by heating limestone until carbon dioxide is driven out of the calcium carbonate. Hydrated lime or calcium hydroxide is prepared from the lump lime by the addition of water. Both lump and hydrated lime are usually carried in stock by lumber companies and sold

principally for plaster and whitewash. Such products are usually too expensive for use as agricultural lime. These two forms can be successfully prepared on the farm, but the advantage to be gained usually does not justify the extra cost involved. They also possess certain undesirable characteristics. The addition of water to lump lime may result in the generation of sufficient heat to ignite inflammable materials. Both materials are caustic, which make them undesirable to handle. It is also difficult to spread these forms upon the soil. For these reasons they should normally be used only in exceptional instances.

RELATIVE AGRICULTURAL VALUE OF DIFFERENT FORMS OF LIME

The ability of lime to correct soil acidity is dependent upon its calcium or magnesium content. The percentage of calcium or magnesium is dependent upon the chemical form and purity of the sample. Since magnesium does not occur extensively in Kansas limestone, only the calcium form need be considered. In the pure form calcium carbonate (crushed limestone) is the least effective and the burned or lump lime the most effective per unit weight in neutralizing acid. The relative value of the three forms is shown in Table I.

TABLE I.—RELATIVE NEUTRALIZING VALUES AND EQUIVALENT WEIGHTS OF PURE CALCIUM CARBONATE, HYDRATED LIME, AND BURNED OR LUMP LIME

FORM.	Relative neutralizing values.	Pounds equivalent to 2000 pounds of calcium carbonate ($CaCO_3$).
Finely crushed limestone ($CaCO_3$)	$1.00	2,000
Hydrated lime ($Ca(OH)_2$)	1.35	1,480
Burned or lump lime (CaO)	1.79	1,120

The data presented in Table I show that 1,120 pounds of pure burned or lump lime, 1,480 pounds of pure hydrated lime, and 2,000 pounds of finely crushed pure limestone are equal as far as the effect on soil acidity is concerned. The relative rate of application for pure samples should be in these proportions. Under practical conditions the actual quantities necessary to maintain these proportions will vary, depending upon the amount of impurities. Even though the quantity of hydrated lime or burned lime required is decidedly less than that of crushed limestone, their undesirable features, already enumerated, are usually sufficient to limit their use.

The agricultural value of crushed limestone is determined by its purity or quality and, to a certain extent, by the degree of fineness.

QUALITY OF LIME

The analysis of a lime sample is usually given as the calcium carbonate equivalent expressed in percentage. For example, a sample of liming material may be reported to have a calcium carbonate equivalent of 95 percent. This means that the sample under consideration is equal in acid correcting power, to lime containing 95 percent pure calcium carbonate. The sample itself may or may not be calcium carbonate. Good-quality crushed limestone should have a calcium carbonate equivalent between 90 and 100 percent. However, samples of good-quality dolomitic lime (calcium-magnesium carbonate) may have a calcium carbonate equivalent above 100 percent. The purity of the sample should always be considered when purchasing or using lime. If two samples of equal fineness, one having a purity of 100 percent and the other of 75 percent, are being considered, it should be kept in mind that 1,500 pounds of the former

material is equivalent to 2,000 pounds of the latter. A greater quantity of the 75 percent lime must be purchased, thereby increasing the cost of hauling and applying; hence the 75 percent material would actually be worth less to the farmer than three fourths as much of the 100 percent sample.

This does not mean that a low-quality lime should never be used. When an individual owns a crusher and rock of low quality is available, it will probably be more economical to use this material than to purchase a higher-quality product. The purity of a limestone can be determined accurately only by a chemical test. Therefore it is recommended that samples of the available lime materials be submitted to the Agricultural Experiment Station to be tested in order that their relative values may be determined. (See "Testing Service," page 25.)

FINENESS OF CRUSHING

A second factor that influences the effectiveness, and hence value, of crushed limestone is the fineness to which the rock is pulverized. Lime is relatively insoluble in water and yet it can neutralize soil acidity only when in solution. Since the rate at which it dissolves is proportional to the surface of the lime particles in contact with the soil water and decreasing the size of the particles increases the surface, it follows that the finer the lime is ground the more rapidly it will dissolve, and hence the more rapidly it will neutralize the acid present in the soil. Inasmuch as the dissolved lime will soon be lost from the soil, as a result of leaching, it is desirable to have only a part of the material in a very fine condition. Also very fine material is much more difficult to spread. On the other hand, very coarse material is so slowly dissolved that its value in neutralizing soil acidity, measured in terms of the increased value of the crop, may not justify the capital invested in the lime. Lime of such a degree of fineness that it will have an adequate quantity of fine material to take care of the immediate needs of the soil with a reserve of coarser material that will gradually become available within the next few years approaches the ideal. Materials much coarser than that just recommended should be discounted when purchased.

Crushed limestone of the following specifications as to fineness is recommended as best meeting the desired end: 100 percent to pass through a 10-mesh sieve or 40 percent to pass through a 100-mesh sieve.

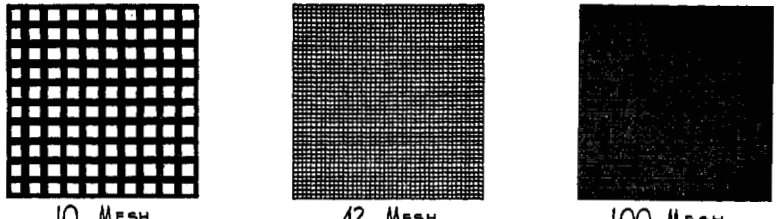


FIG. 2.—Drawings showing size of openings in screens of different meshing.

A 10-mesh sieve is one having 10 openings per linear inch or 100 per square inch, while a 100-mesh sieve is one having 100 openings per linear inch. The size of such screens is indicated in figure 2.[2]

FEEDER LIME

Crushed limestone used in livestock feeds will usually pass a 20-mesh screen. This is much finer than is necessary for agricultural lime. The extra grinding necessary to attain this degree of fineness, and the method of handling in-

2. The actual size of the openings in a screen is less than indicated by the mesh. As, for example, the openings in a 10-mesh screen are less than one tenth of an inch. The opening is one tenth of an inch minus the thickness of the wire, which has been standardized.

creases the cost of such lime so that it is usually not economical to use as ordinary agricultural lime. Furthermore, this material is frequently so finely ground that it is difficult to spread with a drill because of its fluffy character.

LIME NEEDS OF KANSAS

The need of a soil for lime is very closely correlated with the rainfall of a region. This relationship for Kansas soils is well illustrated on the accompanying map. (Fig. 3.) The most acid soil belt is in southeastern Kansas, occupying an area east of a line extending from southwestern Montgomery county to northeastern Coffey county and through Franklin and Miami counties.

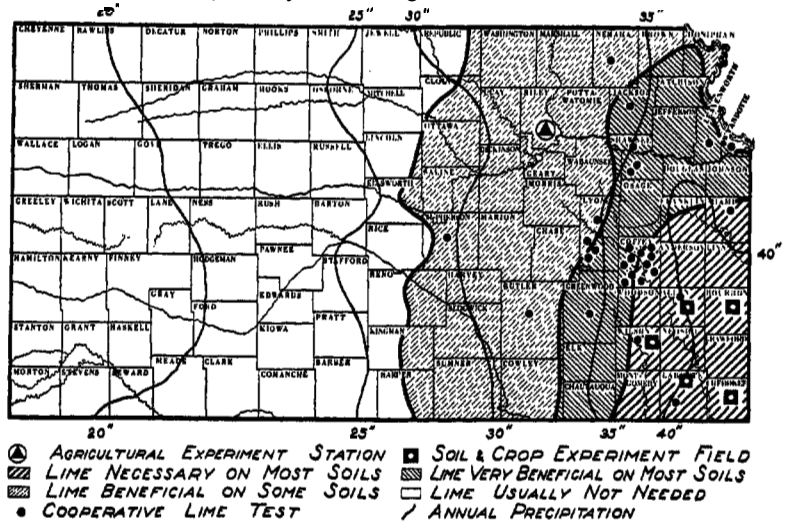


FIG. 3.—Map of Kansas showing the annual rainfall, lime needs of the soils, and the location of experimental lime plats.

This area lies largely within the region of 40 inches or more annual rainfall. Most of the soils of this area are very acid and therefore liming is the basic treatment needed. However, there are soils within this region which are not sufficiently acid to warrant the application of lime.

Adjoining this area on the west and north is a belt of soils which for the most part shows medium acidity. In general this area extends slightly west of the boundary for the 35-inch rainfall belt. There are some soils within this area which are very acid and others which are only slightly acid. Soils in this area will usually produce alfalfa and sweet clover without liming, but an increase in yield usually results from the application of lime.

The third belt of acid soils extends west to the 27- to 30-inch annual rainfall belt. Most of the soils in this area are not strongly acid and it is generally possible to produce alfalfa and sweet clover without the application of lime. However, there are many fields on which lime will give beneficial results and a few fields on which sweet clover and alfalfa will not grow without lime. This area constitutes the most important alfalfa-growing region of the state.

The soils which cover approximately the western three fifths of the state, are in general nonacid. On the extreme eastern edge of this area the soils may be slightly acid. To the west the soils become less acid and finally neutral to slightly alkaline. At other points within this region there may be local areas where the soils are slightly acid. Normal soils in this region do not need lime and crops will practically never respond to its application.

CROPS THAT NEED LIME

Of the general farm crops commonly grown in Kansas, alfalfa and sweet clover are most sensitive to a lack of lime. These crops will usually die on very acid soils. On medium acid soils where they will survive, it is usually found that the addition of lime will greatly increase the yield. The next most sensitive common crop is red clover. The other commonly grown legumes, soybeans and lespedeza, differ little in their lime needs from field crops such as corn, sorghums, oats, wheat, and flax. Any of the latter crops can be produced without lime even on the most acid soils occurring in Kansas. The yield of these crops will often be benefited by the use of lime, though not to the same extent as alfalfa and sweet clover, and rarely enough to justify its use unless these legumes are grown in the rotation. Corn is somewhat more responsive to lime than the other grain crops.

Of the various legumes commonly grown in Kansas, alfalfa and sweet clover should be given first consideration both for feed and soil improvement; the least effective legumes are the annuals, such as soybeans and the annual lespedezas. Therefore any system of soil improvement should include alfalfa and sweet clover whenever possible. For soil improvement alone sweet clover usually fits into the farm management scheme to best advantage.

Lime applied to the soil on which a cropping system including alfalfa and sweet clover is used will have a two-fold effect on the yield of nonlegumes. The first is the direct effect of the lime on the crop itself and the second is the indirect effect on the yield of the succeeding crops through the improved legume growth.

RESULTS OF FIELD LIME TESTS

Data showing the effect of lime on the yield of crops commonly grown in Kansas are available for several of the important soil types in eastern Kansas. The location of these tests is indicated in figure 3. The Agricultural Experiment station is located in Riley county and is indicated by a black triangle inscribed in a circle. This is within the area of slightly acid soils. The southeastern Kansas Experiment Fields are indicated by black squares. These are located in Cherokee, Labette, Bourbon, Allen, and Wilson counties. all of which are within the section where the soils are usually very acid. The location of the cooperative lime tests is indicated by dots. These are scattered throughout the eastern part of the state.

RESULTS AT THE COLUMBUS EXPERIMENT FIELD

The Columbus experiment field is located upon Cherokee silt loam, which has an ashy gray surface soil and a very heavy impervious claypan subsoil. The topography is practically level and during periods of heavy rainfall the water stands on the soil to a considerable extent, because of the impervious character of the subsoil. This type is the most acid soil in the state and one on which stands of alfalfa and sweet clover ordinarily cannot be maintained without the application of lime.

The rotation used on the fertility plats prior to 1931 was: (1) Corn, (2) oats and sweet clover, (3) sweet clover plowed under for green manure in the summer, (4) wheat, and (5) wheat. For the crop season of 1931 and thereafter the rotation has been: (1) Corn, (2) soybeans for seed, (3) flax, (4) wheat, and (5) oats and sweet clover. During both periods one series of plats was growing alfalfa. This crop was left on a given series until the stand became unsatisfactory, which was usually after three to five years. This series was then plowed and included in the regular rotation and another was seeded The sweet clover was plowed under the spring of the second year and followed by corn. The lime was applied to all treated plats in 1924 at the rate of three tons of ground limestone per acre before seeding any crop. There has been no subsequent liming.

The value of lime for the various crops is indicated in Table II in which is given the average annual yield of the crop on both the lime and the un-

treated plats, and the average increase in yield from lime. In addition the estimated monetary return from lime is also given. The size of these and all other experimental plats referred to in this publication equaled one tenth acre, but yields are expressed on the acre basis.

TABLE II.—THE EFFECT OF LIME IN A ROTATION ON THE YIELD OF CROPS, COLUMBUS EXPERIMENT FIELD (*a*)

Cherokee county

CROP.	Number of years.	Average annual acre yield (*b*).		Increase due to lime.	Estimated value of annual increase.
		Lime, 3 tons per acre.	Untreated.		
Alfalfa	9	2.08	0.58	1.50	$15.00
Corn	6	27.14	18.90	8.24	3.30
Flax	5	10.69	7.98	2.71	4.07
Oats	9	27.50	22.60	4.90	1.23
Wheat	14	21.06	15.76	5.30	3.98
Soybean seed	5	10.11	8.98	1.13	1.13
Total estimated value (6 years)					$28.71
Average annual increase per acre for all crops					4.79

(*a*) For the data showing results from lime on the Columbus, Moran, Parsons, Rest, and Fort Scott experiment fields, the authors are indebted to I. K. Landon, formerly in charge of these fields.

(*b*) Average of all data obtained on the field up to and including the 1935 results.

Alfalfa on the untreated plats gave an average annual yield of 0.58 ton per acre over a nine-year period. Grass and weeds practically always made up a relatively large portion of this yield. The stand has never been maintained except for a very short period after seeding. The average increase from lime alone has been 1.5 tons per acre. When lime is combined with manure or a phosphatic fertilizer or both, much greater increases will be secured. These data indicate the indispensable nature of lime for alfalfa on the Cherokee silt loam soil.

While no yields have been obtained for sweet clover, because of its utilization as a green manure crop, the apparent effect of the lime on this crop has been approximately the same as that on alfalfa. The sweet clover on the untreated plat has practically always been a complete failure.

The effect of lime on the soybeans should be noted. An increase of only 1.13 bushels per acre is obtained from liming the soil. Like alfalfa, the soybean is a legume, but in many respects it is inferior to alfalfa. However, these data indicate that this legume can be grown successfully without lime even on the Cherokee silt loam soil. This is also true of such legumes as lespedezas and cowpeas, but these crops are inferior to alfalfa from the standpoint of total yield of high-quality feed and soil improvement.

The monetary value of the lime can be closely approximated by assigning arbitrary values to the crops produced and then determining the value of the crop Increases. This has been done in Table II. In this and subsequent tables the following unit values have been used in all monetary calculations: Alfalfa and clover hay, $10 per ton; corn, 40 cents; flax, $1.50; oats, 25 cents; wheat, 75 cents; and soybean seed, $1 per bushel,

The relative value of lime for the several crops is indicated in Table II. The total represents the probable annual value of the increase from a six-acre area, one acre of which is devoted to the production of each of the crops indicated. The average annual acre value of the increase from the rotation on this basis is $4.79. It should be kept in mind that three tons of lime per acre were applied in 1924, and none during the next ten years. The estimated value of the lime over the 10-year period has been $47.90 or $15.97 per ton. Just how long the effect of this original three-ton application will last cannot be stated definitely; however, the indications are that another application will not be necessary for a few years.

The value of the increase attributed to alfalfa is not strictly correct, because the stand of alfalfa on the unlimed plat was so poor that the production of alfalfa without lime would not be attempted under normal conditions. The production of some other crop would be more profitable. On the basis of the values used in computing the crop returns, flax gave the highest annual gross return per acre on the untreated soil; namely, $11.98. The total gross value of alfalfa on the limed plat was $20.80 per acre annually. This is a difference of $8.82 the minimum annual acre value that should be credited to lime for alfalfa. If crops of a lower value than wheat were produced the value of the lime on alfalfa would be proportionately higher.

The average annual return for alfalfa has been several times greater than that for any other crop. In order to realize the greatest return from lime it is probably necessary to include alfalfa in the rotation. The investment is usually too great for the average farmer to lime his entire cultivated area any one year. Therefore it is common practice to lime only a portion of the tillable area in any one season. Because of the relatively greater return from lime in the case of alfalfa it is especially desirable to lime previous to this crop. When the stand becomes thin another area should be limed and seeded to alfalfa and the old field broken and put into the general rotation. The lime will continue to pay returns after the alfalfa is removed.

The results obtained on the Columbus experiment field are applicable to all typical soils of the Cherokee series.[3]

RESULTS AT THE MORAN EXPERIMENT FIELD

The soil on which the experimental work has been conducted at Moran is predominately Woodson silt loam plus a small area of Parsons silt loam. Both, however, are claypan soils. That is, the surface soils are underlain by a heavy clay layer. The claypan is not so dense as that which occurs on the Columbus experiment field. (The two types can be distinguished by the color. The Woodson silt loam is dark gray to black in the surface; the Parsons silt loam is a light gray.)

The rotation upon this field prior to 1931 was: (1) Corn, (2) corn, (3) oats, (4) wheat, and (5) red and alsike clover. Beginning with the crop season of 1931 and thereafter the rotation has been: (1) Corn, (2) corn, (3) soybeans for seed, (4) oats and red clover, and (5) ed clover for hay (soybeans substituted for red clover when the latter failed). During both periods one series of plats was growing alfalfa. This crop was left on a given series until the stand became thin, which was usually after three to five years. When it was plowed and included in the regular rotation another series was seeded to alfalfa.

The plat treatments permit of two comparisons as to the effect of lime on the yield of crops. They are: (1) Lime and untreated; and (2) lime + manure, and manure alone. These comparisons for the various crops are shown in Table III.

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3. The soil series on a given farm can be found by referring to the soil survey report of the county, provided such a report is available.

TABLE III.—EFFECT OF LIME IN A ROTATION ON THE YIELD OF CROPS, MORAN EXPERIMENT FIELD (*a*)

Allen county

CROP.	Number of years.	Average annual yield per acre.		Increase from lime alone.	Estimated value of annual increase.	Number of years.	Average annual yield per acre.		Increase from lime when used with manure.	Estimated value of annual increase.
		Lime alone, 3 tons per acre.	Untreated.				Lime + manure.	Manure alone.		
Alfalfa	13	1.81	1.03	0.78	$7.80	13	2.23	1.76	0.47	$4.70
Corn	18	32.35	26.12	6.23	2.49	14	28.96	24.71	4.25	1.70
Oats	9	41.20	36.25	4.95	1.24	8	44.34	42.15	2.19	.55
Wheat	4	11.32	10.21	1.11	.83	4	12.82	11.66	1.16	.87
Red clover hay	6	1.06	.75	.31	3.10	3	1.04	.62	.42	4.20
Soybean hay	3	.75	.70	.05	.....	3	.68	.70	—.02	.....
Soybean seed	4	10.55	10.26	.29	.....	4	11.32	11.43	—.11	.....

(*a*) Average of all data obtained on the field up to and including the 1935 results.

The lime alone plat and lime and manure plat received an initial application of crushed limestone at the rate of 3 tons per acre prior to the first seeding of wheat or alfalfa. No additional lime has been applied. The manure was applied at the rate of 8 tons per acre before the second corn crop in the rotation and before the alfalfa.

The figures showing the average annual increase from lime alone indicate an appreciable return from lime for some crops (alfalfa, 0.78 ton; red clover, 0.31 ton; corn, 6.2 bushels; and oats, 4.95 bushels) and only a very slight, if any, return for the wheat and soybeans (hay or seed). By comparing these data with the results obtained at Columbus, it is obvious that lime is not so badly needed on the soil at the Moran field as on the soil at Columbus. For example, the average increase from alfalfa at Moran has been 0.78 ton as compared to 1.5 tons at Columbus.

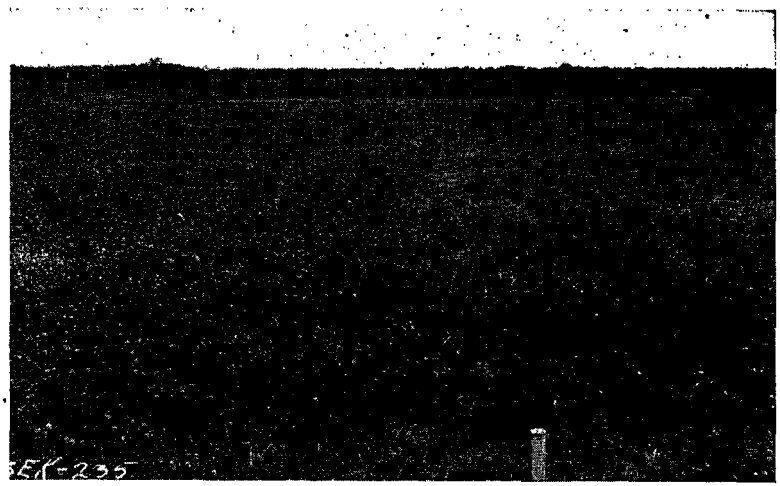

FIG. 4.—Effect of lime on red clover. Left, limed; right, untreated.

Much of the increase at Moran has come the first year after seeding the alfalfa, when lime is especially effective. After the plants become established the difference between the lime plat and the untreated plat is usually not great. The crop can maintain its stand without lime possibly because of the presence of an abundance of lime in the lower subsoil.

The average annual increase from lime when used with manure indicates a very slight reduction in the effectiveness of lime. This reduction is not sufficient to indicate that manure takes the place of lime, because even when manure is used with lime, the alfalfa yield has been increased by 0.47 ton as a result of the lime. The two treatments should go together whenever possible.

The monetary evaluation of the crop increases from lime is made on the basis of crop values previously mentioned and the calculated results are shown in Table III.

Soybeans are not included in making these calculations since the increase in yield from liming has been insignificant as far as determining the monetary increase from lime is concerned.

Alfalfa, with an average annual acre value of $7.80 for the increase from lime, has given the most profitable return. Red clover ranks next (fig. 4) with an average annual acre value of $3.10 for the increase, followed by corn, the increase from which has an annual acre value of $2.49. The value of the yield increase for either oats or wheat is slight.

FIG. 5.—Sweet clover on Parsons silt loam, Parsons experiment field. Left, manure; right, lime three tons per acre. Manure will not take the place of lime.

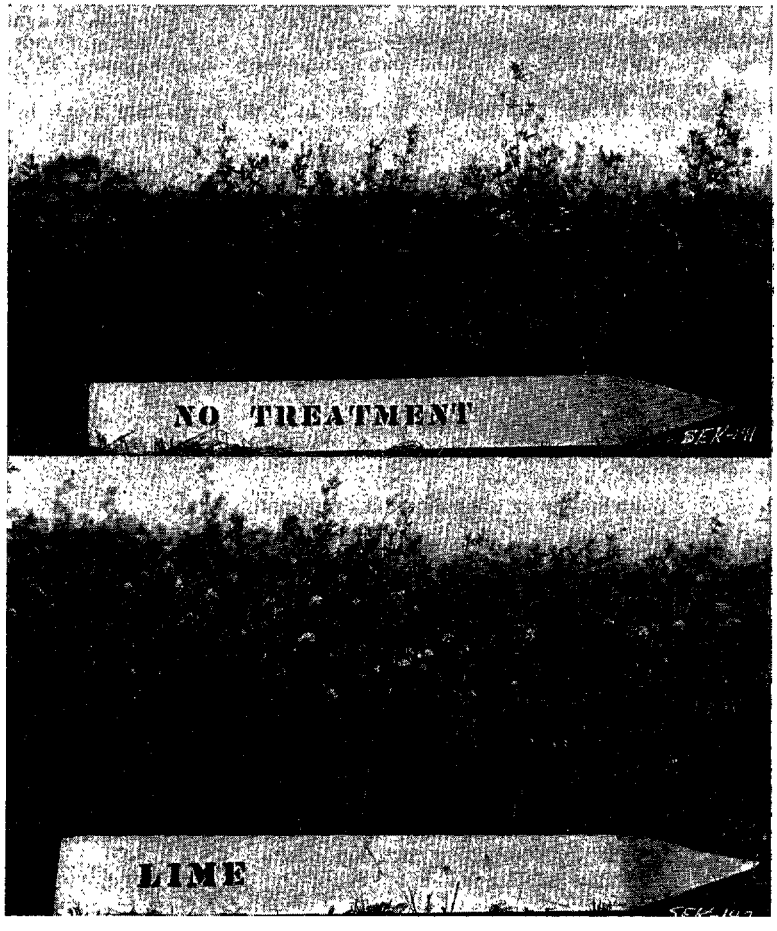

FIG. 6.—Alfalfa plats at the Parsons experiment field on Parsons silt loam. Above, alfalfa on an untreated plat; below, alfalfa on a limed plat. Note the thin stand of alfalfa and the presence of weeds and grass above.

Inasmuch as alfalfa should remain on the soil about four years the total value of increased alfalfa yield from lime would be about $31.20. This in itself is great enough to pay for the three-ton application of lime and leave a good profit.

RESULTS AT THE PARSONS EXPERIMENT FIELD

The soil on the Parsons field is a Parsons silt loam, a light-gray silt loam surface soil underlain by a very heavy yellow brown subsurface (claypan) which changes gradually to a lighter yellow subsoil. The claypan is similar to that on the Moran field.

The rotation used on this field was: (1) corn, (2) oats, (3) wheat, and (4) red and alsike clover. Beginning with 1928 sweet clover used as a green manure crop was substituted for the clover. (Fig. 5.) Alfalfa has been grown on one series of plats until the stand became thin, usually three to five years. (Fig. 6.) After it was plowed and included in the regular rotation, another was seeded to alfalfa. Soybeans was substituted when the clover failed. Crushed limestone was applied on the limed plats at the rate of three tons per acre prior to the first crop of alfalfa or clover. Manure was applied to the manure plats at the rate of eight tons per acre previous to corn and to alfalfa. The work as conducted permits of two comparisons of the effect of lime on crop yields; namely, (1) lime with untreated, and (2) lime plus manure with manure alone. These comparisons are made in Table IV.

The greatest average annual acre increase in yield from lime alone has been shown by alfalfa (0.67 ton), followed by clover (0.48 ton), and that in turn by corn (8.08 bushels), oats (6.68 bushels), and wheat (2.75 bushels). Liming has not appreciably influenced the yield of soybeans either as hay or seed. For the majority of crops grown (alfalfa, corn, oats, clover) the manure has reduced slightly the effect of the lime. The reduction is in no instance great enough to indicate that lime is not desirable when manure is applied.

The monetary value of the lime as determined from the crop increases and the previously assumed unit values for the different crops is also shown in Table IV.

The average annual acre value of the increase is somewhat higher than at Moran for most crops. As pointed out previously and as confirmed by the Parsons data, the alfalfa (fig. 6) is the most responsive to lime of the crops grown, followed by clover and then by corn.

The results obtained on the Parsons field should apply to typical soils of the Parsons series.

RESULTS AT THE REST EXPERIMENT FIELD

The Rest experiment plats are located on Labette silt loam, a dark-brown surface soil gradually merging into a reddish-brown subsoil of heavier texture. At a depth of 4 to 6 feet is a layer of limestone.

The rotation at the beginning of the experiment in 1924 was: (1) Kafir, (2) oats, (3) wheat, and (4) red and alsike clover. Alfalfa was grown on one series of plats until the stand became thin, usually three to five years, after which it was plowed and included in the regular rotation, and another was seeded to alfalfa. In 1926 the wheat was replaced by flax. The plan of the experiment was such as to make possible three comparisons showing the effect of liming; namely, (1) lime and untreated; (2) lime plus manure and manure alone; and (3) lime plus superphosphate and superphosphate alone. The effect of these treatments on different crops is shown in Table V.

The limed plats received crushed limestone at the rate of three tons per acre prior to the first crop of wheat or alfalfa. Manure was applied at the rate of eight tons per acre preceding corn and alfalfa.

TABLE IV.—THE EFFECT OF LIME IN A ROTATION ON THE YIELD OF CROPS, PARSONS EXPERIMENT FIELD (*a*)

Labette county

CROP.	Number of years.	Average annual yield per acre. (*b*)		Increase from lime alone.	Estimated value of annual increase.	Number of years.	Average annual yield per acre.		Increase from lime when used with manure.	Estimated value of annual increase.
		Lime alone, 3 tons per acre.	Untreated.				Lime + manure.	Manure alone.		
Alfalfa	8	1.52	0.86	0.67	$6.70	8	2.22	1.73	0.49	$4.90
Corn	9	33.82	25.58	8.06	3.22	9	38.94	33.53	5.41	2.16
Oats	7	45.15	36.42	6.68	1.67	7	53.54	47.47	6.06	1.51
Wheat	9	18.96	16.22	2.75	2.06	7	24.30	21.13	3.17	2.38
Soybean seed	3	8.67	9.06	—.39	.....	3	11.03	8.09	2.94	.....
Soybean hay	2	1.48	1.35	.13	.....	2	1.67	1.39	.27	.....
Clover hay	2	.90	.42	.48	4.80	2	1.56	1.36	.20	2.00

(*a*) Average of all data obtained on the field which was abandoned after the 1933 crop season.
(*b*) Alfalfa, clover, and soybean hay in tons, all other crops in bushels per acre.

TABLE V.—EFFECT OF LIME IN A ROTATION ON THE YIELD OF CROPS, REST EXPERIMENT FIELD (*a*)

Wilson county

CROP.	No. of yrs.	Average annual yield per acre.		Increase from lime alone.	Estimated value of annual increase.	No. of yrs.	Average annual yield per acre.		Increase from lime used with manure.	Estimated value of annual increase.	No. of yrs.	Average annual yield per acre.		Increase from lime used with superphosphate.	Estimated value of annual increase.
		Lime alone, 3 tons per acre.	Untreated.				Lime and manure.	Manure.				Lime + superphosphate.	Superphosphate alone.		
Alfalfa (*b*).....	8	1.57	1.43	0.14	$1.46	8	2.12	1.73	0.39	$3.90	8	2.11	1.54	0.57	$5.70
Corn.....	5	31.28	30.45	.83	.....	5	35.33	34.53	.80	.....	5	29.88	29.46	.42	.....
Oats.....	5	42.26	41.74	.52	.....	4	59.89	57.62	1.21	.....	5	50.74	48.10	2.64	.....
Flax.....	5	13.53	12.17	1.36	.....	5	14.72	14.34	.38	.....	5	13.87	12.98	.89	.....
Kafir.....	6	25.76	25.37	.39	.....	4	25.40	21.58	3.82	.....	6	27.06	27.41	—.35	.....
Clover hay.....	3	1.49	1.45	.04	.40	2	2.13	1.82	.31	3.10	3	2.19	1.73	.46	4.60

(*a*) Average of all data obtained on the field which was abandoned after the 1931 crop season.
(*b*) Alfalfa and clover hay in tons per acre, all other crops in bushels per acre.

The results from the use of lime alone show practically no advantage for the treatment. Even the yield of alfalfa has not been increased appreciably. Lime used with manure and lime used with superphosphate have shown progressive increases in yield of alfalfa and clover. The increase from lime on all other crops is very small regardless of the associated treatments.

Because of the very small increase in yield of other crops only alfalfa and clover are considered in determining the monetary value of lime at Rest. These values are also shown in Table V.

Lime alone has not produced sufficient increase in yield of any crop tested to justify its use. When used with manure or superphosphate, however, the increases that can be credited to lime are sufficient to more than pay the cost of liming and still leave a profit.

RESULTS AT THE FORT SCOTT EXPERIMENT FIELD

The Fort Scott fertility plats are located in part on Summit silt loam and in part on Parsons silt loam. Only results obtained from plats on the Summit silt loam are here considered. The Summit silt loam has a dark brown to black surface soil and a friable brown to yellow subsoil of somewhat finer texture.

The rotation followed on this field has been: (1) Corn, (2) corn, (3) oats, (4) wheat, and (5) red and alsike clover. Alfalfa was grown on one series of plats until the stand became thin, usually three to five years. It was then plowed and included in the regular rotation and another series was seeded to alfalfa. Soybeans were substituted when clover failed.

The set-up of the fertility work makes possible two comparisons showing the effect of lime on crop yields; namely, (1) lime and untreated, and (2) lime plus manure and manure alone. The data secured from this field are given in Table VI.

TABLE VI.—THE EFFECT OF LIME IN A ROTATION ON THE YIELD OF CROPS, FORT SCOTT EXPERIMENT FIELD

Three-year average from series A, B, and C only

CROP.	Average annual yield per acre.		Increase from lime alone.	Average annual yield per acre.		Increase from lime used with manure.
	Lime alone, 3 tons per acre.	Untreated.		Manure and lime.	Manure.	
Alfalfa (a)	1.77	1.80	—0.03	2.29	2.23	0.06
Corn	25.05	23.74	1.31	.....	.....	.....
Oats	44.54	44.54	0	49.62	48.72	.90
Wheat	19.80	17.27	2.57	19.61	20.08	—.47

(a) Alfalfa in tons per acre, all other crops in bushels per acre.

Lime had no significant effect on the yield of any of the crops, the actual recorded increases being as follows: A decrease of 0.03 ton in yield of alfalfa; 1.31 bushels increase in yield of corn; no increase in yield of oats; and 2.57 bushels increase in yield of wheat.

These increases are so slight as to indicate that lime is not a limiting factor in crop yield on this particular soil.

These results are applicable to typical soils of the Summit series, and lime is not generally recommended for these soils.

RESULTS AT THE AGRICUTURAL EXPERIMENT STATION, MANHATTAN

Liming has been included as a treatment in the experimental plats at the main station at Manhattan for more than twenty years. A summary of the yields from limed plats is compared with yields from unlimed plats in Table VII.

TABLE VII.—EFFECT OF LIME ON YIELD OF CROPS IN ROTATIONS, MANHATTAN

CROP.	Average annual yield per acre, 1927–1932 (*a*).		Increase from lime alone.	Average annual yield per acre, 1911–1930 (*b*).		Increase from lime used with manure.
	Lime alone.	Untreated.		Manure + lime.	Manure.	
Corn (*c*)	40.26	37.86	2.40	36.41	36.52	0.11
Oats	31.49	27.08	4.41	.....	.....	.....
Wheat	18.81	15.25	3.56	22.77	22.35	.42
Alfalfa	.....	.....	.....	3.10	2.90	.20

(*a*) Results from a three-year rotation consisting of corn, oats, and wheat.

(*b*) Results are from a rotation which for the first 10 years was corn, corn, and wheat, but which for the last 10 years was corn, wheat, and wheat. During both periods one series of plats produced alfalfa for a four-year period, after which this area was plowed and included in the regular rotation. From Technical Bulletin 40, "Twenty Years of Soil Fertility Investigations."

(*c*) Alfalfa in tons per acre, all other crops in bushels per acre.

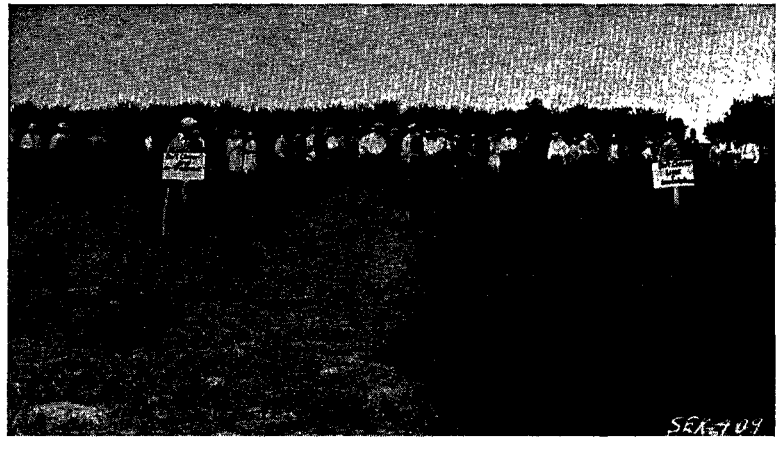

FIG. 7.—Sweet clover plats on the farm of Mr. John Timmons, Wilson county. Left, no treatment; right, lime and inoculation.

The increases at Manhattan from the use of lime either alone or with manure are so small that its use is not recommended for soils similar to those on which these experiments were conducted. It should be recalled that Manhattan is in the region where the soils are only slightly acid (page 5), therefore, the results obtained are not surprising. This, however, should not be interpreted to mean that there are no soils within this area where lime is beneficial. Cooperative tests with farmers indicate that there are some soils where lime will give a good response at least in alfalfa yields.

RESULTS OF THE USE OF LIME ON ALFALFA IN COOPERATIVE TESTS

Coöperative tests have afforded an opportunity to study the results of the use of lime in producing alfalfa and sweet clover (fig. 7) on many soil types under actual farm conditions. These tests have been located mostly in the eastern half of the state.

Results on Parsons Silt Loam

A series of plats was established on the farm of A. M. Dunlap, Carlyle, Allen county, in 1914. The soil is Parsons silt loam with a fairly heavy silt loam surface soil and a claypan subsoil. This is quite characteristic of relatively large areas of the upland soil in southeastern Kansas and is the same as the soil on the Parsons experiment field.

The yields secured on the plats which received no treatment, limestone, manure, and manure and limestone from 1915 to 1923, are given in Table VIII. Ground limestone was applied broadcast at the rate of two tons and manure 10 tons per acre in 1914, but no subsequent treatments were given. The cash value of the increase in yield from lime is calculated on the basis of $10 per ton for the alfalfa hay.

TABLE VIII.—YIELD OF ALFALFA ON PARSONS SILT LOAM, A. M. DUNLAP FARM, CARLYLE, ALLEN COUNTY, 1915 TO 1923

Tons per acre

YEAR.	Limestone, 2 tons in 1914.	Untreated.	Increase from lime alone.	Manure, 10 tons, limestone, 2 tons in 1914.	Manure, 10 tons in 1914.	Increase from lime used with manure.
1915	0.78	0.53	0.25	1.62	1.13	0.49
1916	1.38	.85	.53	2.27	1.67	.60
1917	2.85	2.48	.37	4.57	4.48	.09
1918	1.41	1.07	.34	2.19	1.93	.26
1919	1.72	.81	.91	3.35	1.42	1.93
1920	3.52	(a) 0	.....	4.58	(a) 0	.....
1921	2.02	0	.....	2.92	0	.....
1922	1.62	0	.....	2.65	0	.....
1923	1.51	0	.....	1.71	0	.....
Total, 1915–1919	8.14	5.74	2.40	14.00	10.63	3.37
Five-year average, 1915–1919	1.63	1.15	.48	2.80	2.13	.67
Estimated value of total increase, 1915–1919	.....	.....	$24.00	.....	.....	$33.70
Estimated value of annual increase	.....	.....	4.80	.....	.....	6.70

(a) Complete failure due to disappearance of stand.

These data show the value of lime in maintaining stands of alfalfa on Parsons silt loam soil. The alfalfa had completely disappeared at the end of five years on both the untreated plat and the plat which received manure alone.

The application of two tons of crushed limestone alone per acre increased the annual value of the alfalfa hay $4.80 per acre over a five-year period and $12.29 over a nine-year period. Where lime and manure was compared with

manure alone, the value of the average annual increased yield due to lime was $6.74 over the five-year period and $16.91 over the nine-year period. The nine-year comparison is not altogether justifiable since upon the disappearance of alfalfa some other crop would have been grown.

The total value of the increased hay yield secured from the use of two tons of ground limestone per acre in 1914 amounted to $23.98 over a five-year period, and $110.60 over a nine-year period. The value of the total increased hay yield of the lime and manure plat over manure alone amounted to $33.69 in five years and $152.23 in nine years. Lime with manure was more valuable than lime alone.

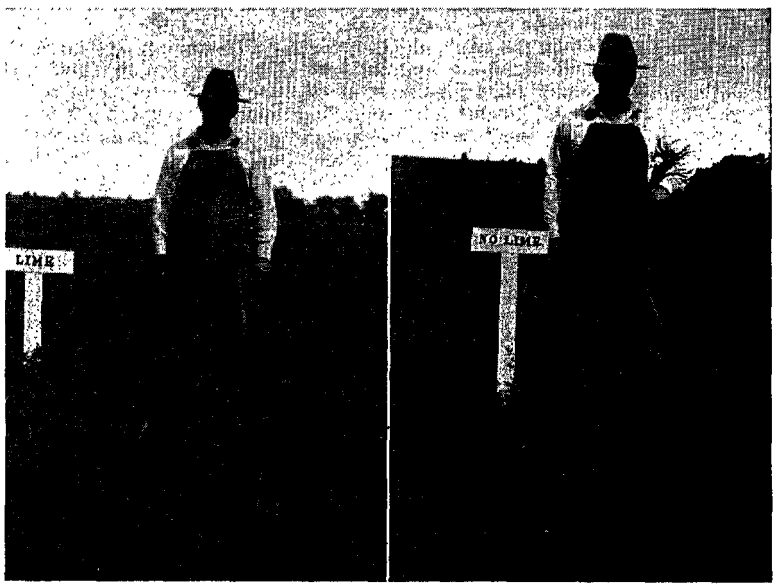

FIG. 8.—Picture taken in an alfalfa field in Coffey county. Left, lime; right, untreated.

Results on Other Soil Types

Numerous coöperative tests located in other counties have given interesting information. In all of these tests lime was applied broadcast before the alfalfa was planted at the approximate rate of 1,000 pounds of air-slacked lime or 4,000 pounds of ground limestone per acre. These materials were not applied in equivalent amounts.

For most of the coöperative tests complete yield data are not available. Frequently yields were obtained from only one or two cuttings per season and for only one year. Inasmuch as the actual increase per cutting will vary, it is impossible to draw accurate conclusions from the available data. However, the figures together with field observations do give additional information as to the value of lime. The results show among other things that the value of lime on different soils is variable. Therefore when considering the use of lime it is more important to consider the soil than the region.

An increase of two tenthsof a ton or more of cured alfalfa hay per acre per cutting has been obtained on both upland and bottom land in Coffey county (fig. 8) and on upland in Wilson, Labette, Linn, Shawnee, Jackson, and Nemaha counties. Less than two tenths of a ton per acre per cutting increase

TABLE IX.-RESULTS OF COÖPERATIVE TESTS WITH FARMERS WHERE LIME HAS BEEN USED IN THE PRODUCTION OF ALFALFA

Location of tests; soil descriptions

Tests in which increased yields from the use of lime amounted to two tenths ton or more of cured hay per acre per cutting.		Tests in which increased yields from the use of lime amounted to less than two tenths ton of cured hay per acre per cutting.	
County.	Description of soil.	**County.**	Description of soil.
Coffey..	Upland; located at seven points in the county.	Butler.	Upland, limestone soil.
Coffey..	Bottom land: located at four points in the county.	Greenwood..	Second bottom; clay subsoil, well drained, fertile.
Jackson..	Upland clay loam.	Lyon.	Heavy black soil, Neosbo river bottom.
Labette.	Upland, medium fertility.	McPherson..	Upland clay loam.
Leavenworth.	Upland clay loam, medium fertility.	Miami.	Upland clay loam.
Lyon.	Upland sandy clay loam.	Sumner	Upland silt loam containing some sand.
Nemaha.	Upland of glacial drift origin.	Wyandotte.	Upland silt loam, heavy subsoil.

was obtained on upland in Wyandotte, Miami, Butler, McPherson, and Sumner counties and on bottom land in Lyon and Greenwood counties. These results should not be interpreted to mean that all soils within a county will give the same response to lime as the ones on which the tests were conducted. As has been previously stated some soils within an area may show response to lime while others will not.

Table IX gives the location and description of soil where the effects of lime upon yield of alfalfa have been tested cooperatively. The tests have been divided into two groups depending upon whether the yield was increased by two tenths of a ton or more per acre per cutting. This increase would be approximately six tenths of a ton or more per acre annually.

BROADCAST APPLICATION OF LIME

RATE AND TIME OF APPLICATION

The rate at which lime should be applied broadcast varies from one to three tons per acre.[4] The heavier rate should be applied to very acid silt loam and silty clay loam soils. The lighter applications should be made to sandy soils

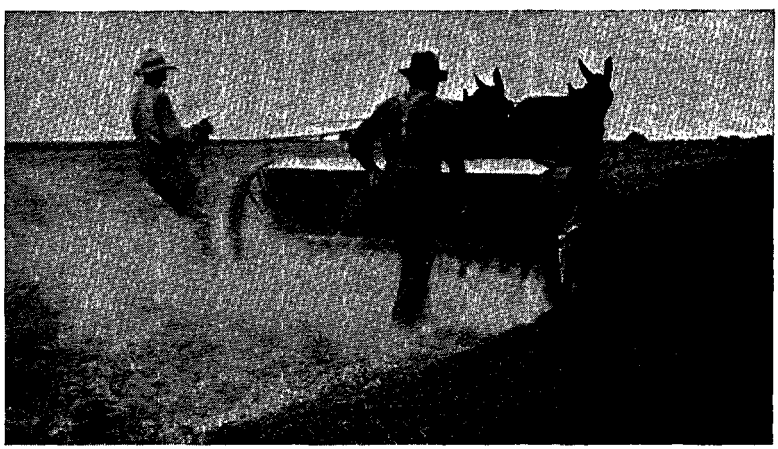

FIG. 9.—Spreading lime with a lime drill in preparation for alfalfa seeding.

and heavier soils which are less acid. While on some soils a rate less than one ton may be satisfactory for a few years, it is questionable whether an application of less than one ton per acre broadcast is economical. The effect of one good application should last about ten years and the cost of distributing two tons is but little more than that of one ton.

Lime should be applied normally preceding alfalfa, sweet clover, or red clover. It should be spread on the soil long enough in advance of seeding the crop to allow time for the lime to be worked into the surface soil. This can be done most economically by spreading the lime after the soil has been plowed in preparation for the crop. If the soil is not to be plowed the lime should be spread ahead of the first tillage operation. Subsequent disking and harrowing necessary for seedbed preparation will also incorporate the lime into the surface soil without additional tillage.

4. The statements made here refer to good-quality crushed limestone. If other forms of lime are used, the rate must be varied. See page 24.

METHOD OF APPLICATION

Any convenient method of spreading may be employed. Several very satisfactory mechanical spreaders are on the market. These include the drill types (fig. 9), end-gate spreader, special attachments for manure spreaders (fig. 10), and the combined fertilizer and grain drill (fig. 11). Also satisfactory homemade spreaders can be built. The spreading of lime with a shovel can be done, but is much more laborious and it is difficult to spread the lime uniformly. If the fertilizer and grain drill is used and a large quantity is applied it will be necessary to go over the land several times, since the maximum rate of application for these machines is relatively low. Any type of spreader should be calibrated before being used, otherwise the actual rate of application may not even approximate the desired rate.

Courtesy John Deere Plow Company

FIG. 10.—A manure spreader equipped with a lime-spreading attachment.

USE OF LIGHT LIME APPLICATIONS IN GROWING LEGUMES

Farmers in eastern Kansas who desire to grow sweet clover on soils deficient in lime can do so at a small expense for lime. For years it was thought that two tons of limestone per acre must be applied in order to grow sweet clover successfully on very acid Kansas soils. Such an application involves a considerable cost per acre. Tests conducted on farms in eastern Kansas during the last few years have shown that 300 to 500 pounds of ground limestone per acre, drilled with sweet clover seed, will greatly increase the yield on many soil types. In these tests ordinary agricultural limestone was drilled with the seed at planting time by using a combination grain and fertilizer drill[5] with

5. Farmers who do not have a fertilizer attachment have reported success by mixing the lime and seed and sowing the mixture through a grain drill. The Agricultural Experiment Station has no experimental data on this method.

grass seeder attachment. (Fig. 11.) On the basis of the results from these tests, recorded in Table X, and from the experience of farmers, this method of applying lime for the production of sweet clover is recommended. The results are for two years and the values recorded represent the total production of weed-free cured sweet clover hay.

FIG. 11.—Combination fertilizer and grain drill.

TABLE X.—YIELDS OF CURED SWEET CLOVER HAY AS INFLUENCED BY 300 POUNDS OF GROUND LIMESTONE PER ACRE DRILLED WITH THE SEED

Pounds per acre

COUNTY.	Soil type (a).	Limed.	Unlimed.	Increase in yield on limed area.
Douglas	Labette silt loam	356	207	149
Jackson	Marshall silty clay loam	576	54	522
Jefferson	Summit silt loam	1,313	162	1,151
Linn	Shallow summit silt loam	4,726	2,746	1,980
Miami	Summit silt loam	1,914	317	1,597
Nemaha	Shelby silt loam	2,194	645	1,549
Riley	Oswego silt loam	2,142	1,967	175
Saline	Lancaster sandy loam	5,016	1,702	3,314
Washington	Ladysmith heavy silt loam	4,571	1,225	3,346
Cloud	Type not determined; of limestone origin,	3,466	3,952	—386
Coffey	Type not determined	464	219	245

(a) Soil types are possibly not accurate since only Riley county has been covered by a soil survey.

The increases in yield from light applications of lime varied from practically nothing to over 3,000 pounds per acre in these tests. Similar results have been secured by some farmers who have used light lime applications in

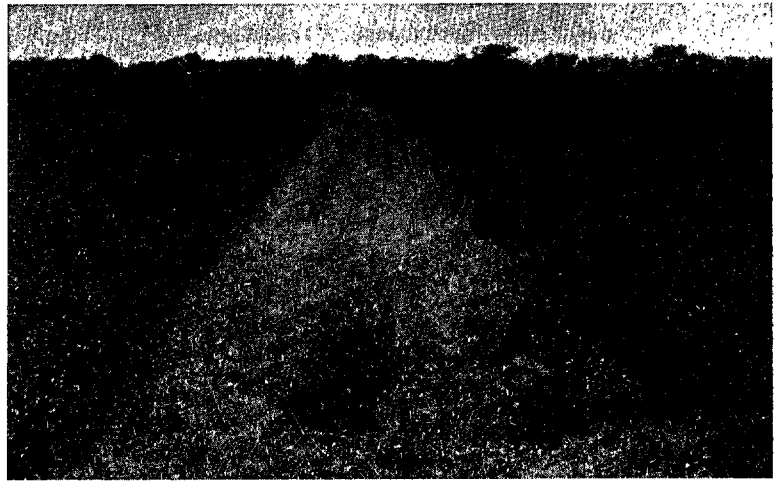

FIG. 12.—Sweet clover on Cherokee silt loam in a field of Mr. W. H. Shaffer, Columbus, Cherokee county. Left, 300 pounds of lime per acre drilled with the seed; right, 75 pounds of lime per acre drilled with the seed; center, no lime.

producing sweet clover. This practice has been successful on the Cherokee silt loam soil, the most acid soil type within the state. Sweet clover without lime is a complete failure on this soil. (Fig. 12.)

AMOUNT OF LIME TO USE IN LIGHT APPLICATIONS

Experiments to determine the rate of applying lime when drilled with sweet clover seed have been conducted in Cherokee county on the Cherokee silt loam soil. The surface soil has a lime requirement of 1½ to 2 tons per acre. In these tests commercial agricultural limestone, all of which passed through a 10-mesh screen and approximately 30 percent of which passed through a 100-mesh screen, was used in comparison with a very fine material, 88 percent of which passed through the 100-mesh screen.

In 1929 sweet clover was seeded in a light stand of oats. When 75 pounds per acre of the very fine lime was drilled with the seed about half a stand resulted. The stand improved with an increasing rate of this material up to 200 pounds. Under the same conditions, the commercial limestone (30 percent passing through a 100-mesh screen) produced the maximum stands at rates of from 300 to 500 pounds per acre. Without lime the sweet clover was a complete failure.

In 1931, sweet clover was seeded in a thin stand of wheat with fine lime applied at the rates of 100, **200,** 300, and 500 pounds per acre. The plat which received 100 pounds per acre had a noticeably poorer stand than the others. The sweet clover that received 300 pounds per acre was in every way equal to that which received 500 pounds. Here again sweet clover without lime was a complete failure.

In each of these tests the sweet clover on the limed areas lived through the winter and grew vigorously the next spring. There were many nodules on the roots in the immediate vicinity of the limestone, but very few at a greater depth.

On the basis of these and other tests an application of 300 to 500 pounds per acre of ordinary crushed limestone is recommended when the material is drilled with sweet clover seed. Very finely powdered limestone, such as is used for livestock feed, is not generally recommended, since it is difficult to drill this type of material satisfactorily.

LIGHT LIME APPLICATIONS FOR ALFALFA

Some experimental results have been secured on the use of light applications of lime, 300 to 700 pounds per acre, in growing alfalfa. The results secured to date do not indicate that this method will be entirely satisfactory for alfalfa. The yields secured with 300 to 700 pounds of ground limestone per acre drilled with the seed have been lower than those secured with 4,000 pounds per acre broadcast, but higher than those from the areas not receiving the limestone. On the basis of the results thus far secured, this method is not recommended for alfalfa production.

HOME CRUSHING AND PORTABLE CRUSHERS

In many communities and on many individual farms there is a supply of limestone available which, when pulverized, will make excellent material for treating the soil. Limestone which is available on the farm is usually the cheapest source of agricultural lime, provided a crusher can be secured for grinding.

Unless a farmer is fortunately situated, the greatest difficulty in home crushing is securing the use of a good crusher. Pulverizers equipped to crush and sieve agricultural limestone cost from $500 to $1,500. This is a larger investment than many farmers are able to make profitably unless they plan to do custom grinding.

The problem of securing a crusher may be solved by the farmers of a community by contracting enough grinding with an individual to enable him to

purchase a machine, or by forming a community company and purchasing a machine, or by an organization's purchasing a machine and arranging with some individual to run it. The latter method has been used successfully in Bourbon and other eastern Kansas counties. (See cover page.)

The Bourbon County Farm Bureau purchased a lime pulverizer in February, 1925. Orders for crushing were taken and the machine routed by the County Farm Bureau. A young farmer of the county furnished the power and ran the pulverizer. A charge of $1.25 per ton was made for grinding. At that time limestone of similar quality was costing the farmer $2.50 per ton on the track at most shipping points within the county.

The use of the pulverizer was a success. It enabled the farmers to secure agricultural lime at less cost than they could have without the pulverizer. During the first ten months, 2,240 tons of limestone were pulverized. The project was a financial success for both the farm bureau and operator.

TESTING SERVICE

The Agricultural Experiment Station maintains a free testing service for both soil and lime samples sent in by residents of the state. The soil samples are tested qualitatively for acidity or lime needs. Lime samples are analyzed for purity and fineness of grinding. The results of these tests, together with such recommendations as can be made, are sent to the owner as soon as possible.

TAKING SOIL SAMPLES

A sample should consist of several individual samples from an area in the field that appears to be uniform. These samples may be taken with a spade or trowel or other instrument. The immediate surface should be removed and the sample taken just below this. The sample should then be put in a container and at least five other such samples taken and put in the same container. These should be mixed thoroughly and the sample to be sent to the Agricultural Experiment Station taken from this composite sample. About 1 pint of soil should be sent. If there is more than one type of soil in the field, each different type should be sampled separately. The samples should then be labeled, giving the name and address of the sender, his identification of the sample, and the legal description of the land from which the sample was taken. The latter is used by the station, if a soil survey has been made of the area, as a means of determining the soil type. A letter should accompany the sample in which should be given a general description of the soil and a statement as to the crops to be grown.

TAKING LIME SAMPLES

The most important point in connection with taking lime samples is to endeavor to secure a representative sample. If a pile of crushed lime is to be tested, the sample should be made up by taking small quantities from several parts of the pile. About a cupful of material should be sent. If uncrushed rock is to be tested several small stones representative of the material should be sent. Address all samples to: Department of Agronomy, Agricultural Experiment Station, Manhattan, Kan.

WHEN NOT TO USE LIME

There has been a considerable amount of publicity as to the value of lime in Kansas during the last few years. Much of it is warranted, but some is unwarranted. Lime in the place where it is needed is profitable; but applied to a soil where it is not needed, it is an unnecessary expense. Lime on many fields in eastern Kansas has paid large profits, but on others it has not paid the cost of hauling. A farmer may save hours of labor and much expense by having his soil tested before applying lime, unless the needs of the soil are known from previous experience.

INFORMATION RELATIVE TO LIME DEALERS

The county agricultural agent can supply the names of responsible lime dealers. The Department of Agronomy keeps a list of lime dealers within the trade area of Kansas. While an effort is made to keep this list up to date, no claim is made for its completeness. This information will be sent upon request to the departments. Address requests to: Department of Agronomy, Agricultural Experiment Station, Manhattan, Kan.

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