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Liming for Tennessee Soils

University of Tennessee Agricultural Experiment Station

Charles A. Mooers

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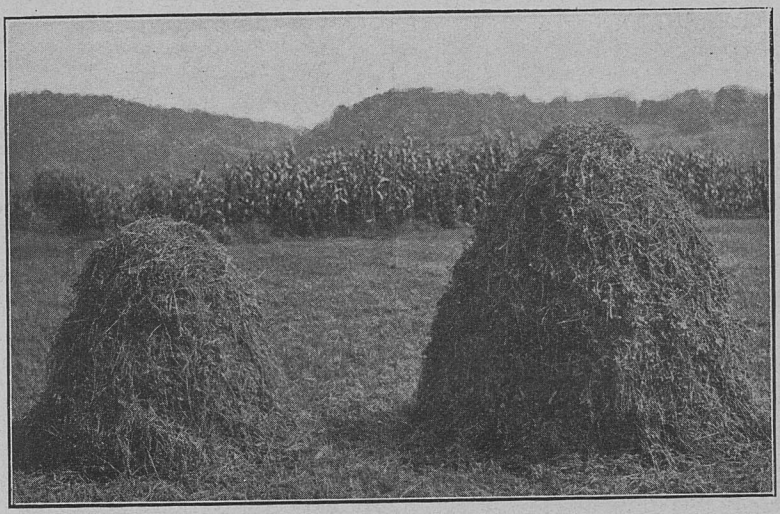

UNLIMED LIMED

Alsike Clover.

NUMBER 97 JANUARY 1913

LIMING FOR TENNESSEE SOILS

BY

CHARLES A. MOOERS

KNOXVILLE, TENNESSEE

The Agricultural Experiment Station

OF THE UNIVERSITY OF TENNESSEE

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The Experiment Station building, containing the offices and laboratories, and the plant house and part of the Horticultural Department, are located on the University campus, 15 minutes walk from the Custom House in Knoxville. The experiment farm, the barns, stables, dairy building, etc., are located one mile west of the University on the Kingston Pike. The fruit farm is adjacent to the Industrial School and is easily reached by the Lonsdale car line. Farmers are cordially invited to visit the buildings and experimental grounds.

Bulletins of this Station will be sent, upon application, free of charge, to any farmer in the State.

LIMING FOR TENNESSEE SOILS

INTRODUCTION

Lime content of Tennessee soils

The major part of the cultivated soils of East and Middle Tennessee are of limestone origin, and are called limestone soils. This expression naturally implies that there is a good supply of lime in the soil, but the results of the chemical analyses made at this Station show that the contrary is the case. In fact, the West Tennessee soils, which were derived from unconsolidated material, poor in lime, are as well supplied as many of the soils of limestone origin. In Table I are given the pounds of calcium oxide* per foot-acre dissolved out of typical soils by strong, hot hydrochloric acid.

The carbonate form

Attention should be given to the fact that in all these soils only a trace of the lime is in the carbonate form—a fact which is of particular importance from an agricultural point of view.

TABLE I—*Calcium oxide in pounds per foot-acre dissolved from various soils by means of hot hydrochloric acid* (Sp. Gr. 1.115)

Samples from	No. of counties represented	No of analyses averaged	Origin of soil	Calcium oxide per foot-acre 3,500,000 lbs. of soil
				Lbs.
Central Basin.....	8	27	Limestone	9695
Highland Rim	7	17	"	5145
" "	6	11	Siliceous limestone.....	3850
East Tennessee.....	7	22	Limestone	5285
" "	2	5	Shale	3150
West Tennessee.....	11	16	Unconsolidated material, poor in lime.....	6020
Cumberland Plateau	1	5	Sandstone	2226

*The essential constituent of limestone is calcium carbonate, which is a compound of the mineral substance, calcium oxide (the same thing as pure burnt lime) and the gas, carbon dioxide, or, as it is often called, carbonic acid gas. When limestone is "burnt" the carbon dioxide is driven off into the air, and if the limestone were pure there would be left 56 pounds of "burnt lime" (calcium oxide) from every 100 pounds of the rock. If the burnt lime be slaked with water the hydrated form of lime is produced and this hydrated form can take up carbonic acid gas from the air, so that there is reproduced the same chemical compound, calcium carbonate, as that found in the original rock. This is the reason for the lack of "strength" in air-slaked lime. One advantage in using burnt lime is the fineness of the particles obtained on slaking, but in its caustic nature lies an apparent chance for injury to the soil through destruction of humus. All the forms mentioned can unite with acids and correct soil acidity. Most of the lime in Tennessee soils is, however, already combined with some acid, chiefly with silicic and humic acids, and, though spoken of by chemists as calcium oxide, or "lime," can not correct an acid condition of the soil. The same thing may be said with regard to the "lime" found in land plaster and in phosphate rock, etc.; that is, it is combined with an acid and can not, therefore, correct other acidity.

According to a number of authorities, there should be present in the soil not less than 0.1 per cent of lime as carbonate, or the equivalent of about 6250 pounds of pure limestone dust, per foot-acre, an amount which has rarely been found in a soil sample from any section of this State. On the other hand, the world's most fertile soils contain several times this quantity. The well-known English authority, A. D. Hall, who was for some years Director of the Rothamstead Station, says: "The question of whether lime is required as a regular part of the routine of farming on a given soil can only be decided by an analysis of a soil; any soil containing less than one per cent of calcium carbonate will be benefited by liming, and when the percentage falls to 0.2 per cent, lime becomes a necessity to enable manures to exert their proper action."*

Value of the carbonate of lime

Several reasons are known why an ample supply of carbonate of lime is of special value in cultivated soils. One is that it is required for plant-food; another is that it neutralizes soil acids, which would be injurious to plant growth, especially to the growth of legumes, such as clover, alfalfa, etc.; and a third reason is that it is essential to the activities of many kinds of useful bacteria, including those which gather nitrogen from the air independently of legumes. This last item is a matter of much practical interest, for at the Rothamstead Station it was found that while a soil poor in lime gained in nitrogen to some extent when laid down to grass, the limed soils gained much more, and this too whether the grass was removed for hay or pastured, and also whether legumes were present or not present. A fourth reason is that carbonate of lime plays an important part in the mechanical condition of a soil. In particular its effect is to granulate the soil so that if heavy it becomes more open and porous and loses much of its sticky nature. On the other hand, granulation may improve a too open soil, which is made more retentive of both water and plant food. These mechanical effects are said to become evident gradually, with the continued use of lime. Also the amount required to produce the best results depends on the nature of the soil, whether heavy or light. In this connection, Russell† makes the following statement: "In general, sandy soils require only sufficient to prevent sourness, while clay soils need in addition enough to keep the texture good. Sands well supplied with calcareous water and under ordinary arable cultivation may get along with 0.1 per cent or even less calcium carbonate, while others that are being heavily dunged respond to dressings of chalk, or ground limestone, even though 0.2 or 0.3 per cent is already present. It commonly happens that 0.5 per cent of calcium carbonate proves inefficient for clay soils, and even 1.0 per cent may not be enough in highly farmed districts, especially where cattle are fed on the land and tread the soil into a somewhat sticky state."

*Fertilizers and Manures, p. 253.
†Soil Conditions and Plant Growth, p. 62.

The field experiments

During the past six years this Station has conducted numerous field experiments in order to determine the effect of liming on the most important kinds of soil throughout the State. These trials were made possible through the organization of the Middle Tennessee cooperative work, which began in 1905, and the West Tennessee Station, at Jackson, where experiments were started in 1909. Continuous liming experiments have been conducted at the Knoxville Station since 1905, and also since 1906, on rented land of a very different kind from any at the Station farm. The usual method of procedure has been to lime one half of every range where experiments with fertilizers and farmyard manure were being made, so that the effect of liming both with and without these materials was obtained. All of the common farm crops have been brought into these trials. At the West Tennessee Station special attention has been given to a comparison between burnt lime and ground limestone. Also rate-of-liming experiments have been made at a number of places in connection with the culture of alfalfa. Emphasis should be placed, however, on the fact that all of these data are valuable to the practical farmer chiefly as an indication of the probable response to liming at the outset or in the course of the first few years following the application.

LIMING EXPERIMENTS IN EAST TENNESSEE

EXPERIMENTS ON THE FARM OF W. P. FORD, KNOX COUNTY

Soil description, etc.

Experiments to determine the effects of an application of 4000 pounds per acre of very finely ground limestone were begun in 1909 on the farm of W. P. Ford, Knox County. The soil was a heavy silt loam, derived from the blue, or Chickamauga, limestone of East Tennessee. This limestone decays rather readily on exposure to the air and is therefore known as "rotten" limestone. The characteristic soils derived from it are reddish-yellow in color, with red-colored subsoils, and vary from rather heavy silt loams to clays. The soil in question had been under cultivation for perhaps seventy-five years, during which time the crops grown were chiefly corn and wheat, with only an occasional crop of either cowpeas or clover. Very little manure or fertilizer had ever been applied to this tract. For three years previous to this trial the land had been used for experimental purposes in a rotation of a summer legume one year, followed by corn the next year, in comparison with continuous corn both with and without manure. The application of the ground limestone was made a short time before the planting of the 1909 corn crop and to one half of all the plots in the series.

TABLE II—*Effects of liming on the yields of corn, cowpeas, soy beans, and velvet beans. Soil a yellow-colored silt loam, derived from Chickamauga limestone (often called "rotten" or "blue" limestone), on farm of W. P. Ford, Knox County*

Crop	Exp. No.	Fertilizer, etc., per acre	Yield per acre		Remarks
			Unlimed	Limed	
			Grain Bu.	Grain Bu.	
Corn	1	None—continuous corn	32.9	38.6	4000 pounds of very finely ground limestone per acre applied to one half of each plot in 1909—corn crops of 1909 and 1911 averaged.
	2	6 tons manure, applied in 1908 and again in 1910—continuous corn	46.4	55.0	
	3	200 lbs. acid phosphate 25 " muriate of potash —continuous corn	36.6	40.5	
	4	200 lbs. acid phosphate 25 " muriate of potash—cowpeas grown and turned under in 1908 and 1910	51.8	61.3	
	5	200 lbs. acid phosphate 25 " muriate of potash —cowpeas grown for hay in 1908 and 1910	48.3	56.6	
			Hay Tons	Hay Tons	
Cowpeas	6	200 lbs. acid phosphate 25 " muriate of potash	0.36	0.85	Limed as above 1910 crops of cowpeas, etc.
Soy beans	7	200 lbs. acid phosphate 25 " muriate of potash	0.83	1.37	
Velvet beans	8	200 lbs. acid phosphate 25 " muriate of potash	1.62	2.37	

DISCUSSION OF RESULTS ON FORD FARM

As may be seen from Table II, the effect of this treatment was to give a marked increase in yield under all of the experimental conditions. The average yearly increase of corn per acre on the limed areas was 7.2 bushels, and the increase of the hay from the legumes averaged more than ½ ton per acre. The line of demarcation between the limed and unlimed sections of the plots was plainly indicated in the growing crops, the corn being taller and stronger and the legumes having a richer color and more luxuriant growth on the limed section than on the corresponding unlimed section. On an adjacent range, one-half of which was limed with burnt lime in 1906, the crops of both wheat and cowpeas were very markedly increased by the liming. The detailed yields under the different treatments are published in Bulletin

90. Recently (1912) the "cowpea-wheat" range was sown to clover, and, regardless of whether bone meal, rock phosphate, or acid phosphate had been used in the previous years, or whether the cowpea crop had been turned under or removed, a good stand of clover was obtained only where the lime had been applied. We must conclude, therefore, that liming with either material was highly profitable, and there is reason to believe that much of the tillable land derived from this formation and found in long, narrow belts throughout East Tennessee, would respond well to a similar treatment.

EFFECTS OF LIMING ON SOME COMMON FARM CROPS GROWN IN ROTATION AT THE EXPERIMENT STATION FARM AT KNOXVILLE

Location of experiments

In addition to the liming experiments on the loam soil in connection with the cowpea-wheat rotation at the Knoxville Station, results from which have been published in Bulletins 90 and 96, one half of each of three adjoining upland experimental ranges was limed in 1905. Also a duplicate series* was started at the same time on a fertile tract of low, or "bottom," land, a loam lighter in character than the upland.

Crops grown

On all ranges of both series the following crops have since been grown: 1906, wheat; 1907, clover and grass; 1908, clover and grass; 1909, corn; 1910, crimson clover, followed by soy beans; 1911, wheat; 1912, clover and grass (chiefly clover).

Amount of lime applied, etc.

Burnt lime at the rate of 1800 pounds per acre was applied after plowing in the fall and immediately previous to the seeding of the 1906 crop of wheat, but the effect of the liming on this crop was not determined, the limed and unlimed sections being harvested together. Since then, however, separate yields have been gotten, a summary of which is presented in Table III.

*These series of experiments were planned primarily with the object of determining the place in the rotation for the most profitable use of farmyard manure. The manure plots reported in Table III received from 7 to 14 tons per acre, the application being made either for or previous to the crop mentioned.

TABLE III—*Showing the effects of 1800 pounds of burnt lime per acre on the yields of the various crops grown during the first 7 years following the application—results obtained at Experiment Station farm at Knoxville*

1. ON UPLAND—A RED-COLORED, FRIABLE LOAM, THE SAME KIND OF SOIL AS THAT USED IN THE COWPEA-WHEAT ROTATION EXPERIMENTS (see Bull. 90 and 96)

Crop	No. plots averaged	Manuring	Yield per acre		Remarks
			Unlimed	Limed	
			Tons	Tons	Lime applied in fall of 1905
Alsike clover and orchard grass	3	Unmanured	0.37	1.85	1907 crop
" " " " "	12	Manured	0.88	2.17	1907 "
" " " " "	3	Unmanured	1.98	3.00	1908 "
" " " " "	12	Manured	2.36	3.38	1908 "
			Bu.	Bu.	
Corn	3	Unmanured	49.1	54.5	1909 "
"	12	Manured	62.0	70.0	1909 "
			Tons	Tons	
Crimson clover	3	Unmanured	0.87	1.62	1910 "
" "	12	Manured	1.34	1.65	1910 "
Soy beans	3	Unmanured	2.22	2.53	1910 "
" "	12	Manured	2.47	2.62	1910 "
			Bu.	Bu.	
Wheat	3	Unmanured	17.9	19.1	1911 "
"	12	Manured	24.1	25.6	1911 "
			Tons	Tons	
Alsike clover and tall oat grass	3	Unmanured	0.45	0.86	1912 "
" " " " " "	12	Manured	1.23	1.94	1912 "

2. On bottom land—a fine sandy loam, fertile and durable

			Tons	Tons	Liming the same as in upland series
Alsike clover and orchard grass	4	Unmanured	1.51	2.01	1907 crop
" " " " "	12	Manured	2.15	2.56	1907 "
" " " " "	4	Unmanured	1.28	1.56	1908 "
" " " " "	12	Manured	1.69	1.87	1908 "
			Bu.	Bu.	
Corn	4	Unmanured	85.0	88.3	1909 "
"	12	Manured	86.9	87.4	1909 "
			Tons	Tons	
Crimson clover	4	Unmanured	1.09	1.32	1910 "
" "	12	Manured	1.21	1.75	1910 "
Soy beans	4	Unmanured	2.22	2.37	1910 "
" "	12	Manured	2.87	3.05	1910 "
			Bu.	Bu.	
Wheat	4	Unmanured	30.9	30.6	1911 "
"	12	Manured	37.6	36.9	1911 "
			Tons	Tons	
Alsike clover and tall oat grass	4	Unmanured	1.51	1.68	1912 "
" " " " " "	12	Manured	2.18	2.60	1912 "

DISCUSSION OF RESULTS ON UPLAND RANGES

Effects of liming on various crops

The clover (alsike) was a failure in 1907 on the unmanured and unlimed sections and was very poor where manured but not limed. On the other hand, excellent crops were obtained on the limed sections, even where no manure was used. As would be expected, the 1909 corn crop was the largest where the clover did best, though it should be noted that there was little clover in the grass crop of 1908. Both the crimson clover of 1910 and the soy beans which followed were helped by the liming, the former in particular, but the wheat crop of 1911 was only a little benefited.

UNLIMED LIMED

Red clover from unmanured plots at the University of Tennessee Experiment Station farm. Showing the effects of a single application of 1800 pounds of burnt lime per acre made seven years previously.

Effects of liming after seven years

The second time that clover and grass appeared in the rotation is of special interest because of the marked effect of the moderate application of lime made nearly seven years previously. As may be seen from the table, the yields of the 1912 hay crop were as follows:

Unmanured and unlimed	0.45	ton of hay per acre
Unmanured but limed	0.86	" " " " "
Manured but unlimed	1.23	" " " " "
Manured and limed	1.94	" " " " "

The total effect on the crop production attributable only to the single application of 1800 pounds of burnt lime per acre may be summed up for the seven years as follows:

Total increase of all hay crops:

1. Where no manure was applied, 3.97 tons per acre.
2. Where manure was applied, 3.48 tons per acre.

Total increase of grain crops:

1. Where no manure was applied, 6.6 bu. per acre.
2. Where manure was applied, 9.5 bu. per acre.

Need of lime may vary in same field

Profitable as liming proved to be in this series, it is of interest to note that on other parts of the farm, where the soil appeared to be of similar character, liming was not found necessary to a healthy and robust growth of either alsike or crimson clover, and the writer has frequently made the observation with regard to both cowpeas and clover that a portion of a field may

UNLIMED LIMED

Red clover from manured plots at the University of Tennessee Experiment Station farm. Showing the effects of a single application of 1800 pounds of burnt lime per acre made seven years previously.

indicate a much greater need of lime, as evidenced by the light green color of the foliage, than another portion of the same field.

DISCUSSION OF RESULTS ON LOWLAND RANGES

The results obtained on the lowland plots were more marked than is indicated by the table because this range was situated on a slope, so that the lower side, which was unlimed, was both somewhat more fertile and better supplied with moisture than the upper and limed half. In spite of this handicap, the yields on the limed half are in nearly every instance superior to those on the unlimed. As in the upland series, the most marked effect of liming appeared in the increased yield of the clovers.

LIMING EXPERIMENTS IN MIDDLE TENNESSEE

Middle Tennessee may be divided into three distinct agricultural sections, namely, the Cumberland Plateau, the Highland Rim, and the Central Basin. Each section will therefore be briefly considered by itself in regard to its lime requirements.

THE CUMBERLAND PLATEAU

The soils of the Cumberland Plateau analyze very low in lime. During the past six years field experiments, some of which were extensive, have been conducted on nine different farms in Cumberland County. The results have demonstrated conclusively the great need of lime, which was found not only to increase the yields of corn, sorghum, etc., but to be practically indispensable for clover, and hence indispensable for the most substantial upbuilding of the soil.

As these soils are poor in nitrogen and humus, and light—the fine sandy loam being the prevailing type—the use of ground limestone is especially recommended.

THE HIGHLAND RIM

Although the red-colored limestone soils of the Rim are somewhat better supplied with lime than those of siliceous origin, marked response to liming on every type proved the rule. In fact, out of trials in eighteen different localities, in which seven counties were represented, there were only four instances where liming failed to be highly advantageous. In two of the four the crop was peanuts, and in the other two tobacco. In nearly all of the trials liming was tested under a variety of conditions, and some of the series could be called extensive. Also all the common farm crops were included.

For the heaviest kinds of soil burnt lime might be advisable, but in general ground limestone is the safest to use, especially on light, thin lands.

THE CENTRAL BASIN

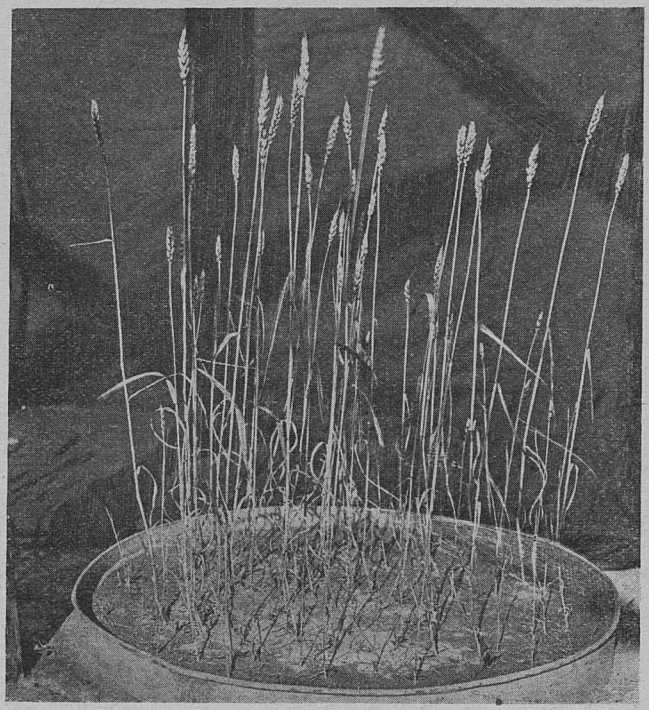
The soils of the Central Basin are on the average somewhat better supplied with lime than those of any other large area in the State. The results of the chemical analyses show, however, in numerous instances only a very moderate supply of total calcium oxide, while the amount of calcium carbonate seldom reaches 0.1 per cent. Clover has long been grown with fair success in this section, which is celebrated for its fertile soils, on which blue-grass and all crops thrive. Field experiments have been conducted in six counties, Maury, Giles, Bedford, Lincoln, Sumner and Wilson, and on ten different farms, for each of which the soil could be described as typical of the Basin. On seven of the ten liming proved highly profitable for such crops as clover and alfalfa. Phosphates, on the other hand, proved of little value, and this result bears out the findings of the chemical analyses, which generally show a high content of phosphoric acid, the element naturally very

TABLE IV—*Effect of liming on the production of red clover on typical brown loams of the Central Basin*

Fertilizer per acre	Yield per acre				Notes
	On farm of W. A. Brooks, Hampshire		On farm of Ernest Murphy, Columbia, Maury Co.		
	Unlimed	Limed	Unlimed	Limed	
	Tons	Tons	Tons	Tons	
50 lbs. muriate of potash	2.11	2.75	0.57	1.75	In each series, 1 ton of burnt lime per acre was applied to one half of each plot. Lime and fertilizer applied in 1911. The clover was sown in fall of 1911 and harvested in summer of 1912. Two crops were cut for hay on farm of W. A. Brooks.
300 lbs. acid phosphate 50 " muriate of potash Cotton-seed meal*	1.96	3.24	0.94	2.19	
No fertilizer	2.48	3.17			
300 lbs. acid phosphate 50 " muriate of potash	1.96	2.68	0.98	2.09	
300 lbs. acid phosphate	2.42	2.86	0.64	2.04	
No fertilizer	2.69	2.79	0.37	1.86	
80 lbs. land plaster	2.33	2.90	0.89	2.05	

*200 pounds per acre on farm of W. A. Brooks and 400 pounds per acre on farm of Ernest Murphy.

deficient in the Rim soils. There is the best evidence, therefore, to support the view that the natural strength and fertility of the Central Basin soils is due not so much to a superior content of lime as to a.. excellent supply of phosphate. In fact, liming can be recommended for this section as a practical means of increasing the clover crop in particular, and thereby the yields of grains and grasses. As for the Rim soils, burnt lime may be used to advantage for heavy soils, but ground limestone is advised under average conditions.



WHEAT GROWING IN UNLIMED SOIL FROM THE CUMBERLAND PLATEAU

Fertilized with phosphate, potash and nitrate of soda.

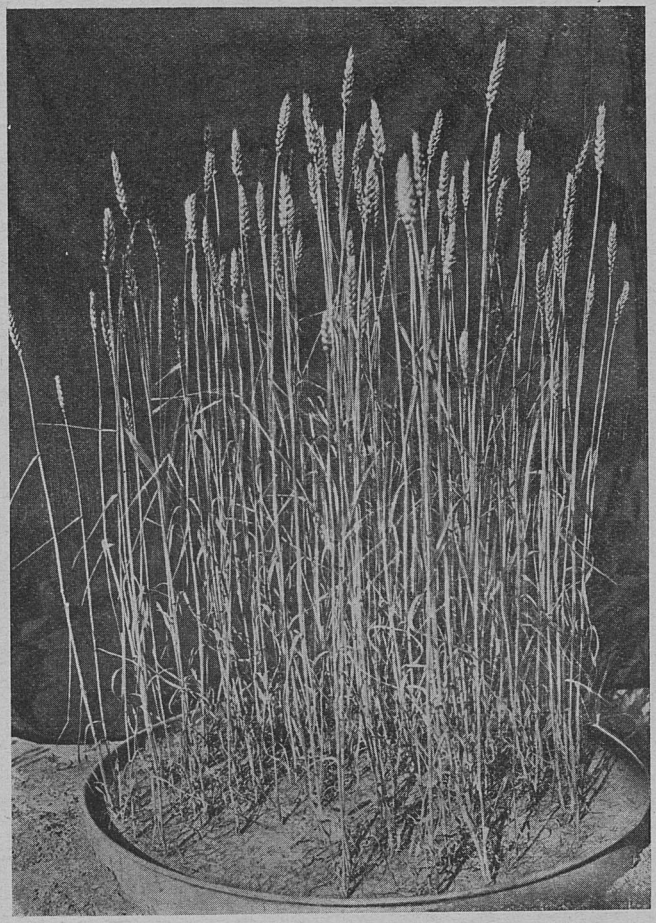
LIMING EXPERIMENTS IN WEST TENNESSEE

BURNT LIME VERSUS LIMESTONE

Description of soils

Liming experiments in which both burnt lime, applied at the rate of 1 ton per acre, and ground limestone, applied at the rate of 2 tons per acre, were begun at the West Tennessee Experiment Station in 1909. All of these trials were made in connection with some rotation experiments in which two distinct kinds of soils were involved.

One was a gray-colored heavy silt loam, which puddled easily and was therefore difficult to handle, but which had been in Japan clover pasture for many years, and hence had a fair supply of available plant food. Experiments on this type were conducted on two parallel ranges, called "A" and "B" in the table. The other soil was a common silt loam,



WHEAT GROWING IN LIMED SOIL FROM THE CUMBERLAND PLATEAU

Fertilized the same as the unlimed wheat shown on the opposite page.

in good mechanical condition, but impoverished by long-continued cropping in cotton and corn with little if any manuring. These ranges lie parallel with each other and are designated as "2," "3" and "4."

TABLE V—*Burnt lime vs. ground limestone. Experimental results obtained with various farm crops at the West Tennessee Station at Jackson—Soils: Ranges A and B, a gray-colored silt loam, very difficult to manage ("crawfishy" type); Ranges 2, 3 and 4, poor silt loam*

Crops	Range where grown	No. of plots averaged	Year of harvest	Yield per acre				Increase per acre		Remarks
				Unlimed	Burnt lime	Unlimed	Ground limestone	Burnt lime	Ground limestone	
				Tons	Tons	Tons	Tons	Tons	Tons	In all these experiments the liming was done in the early spring of 1909. The burnt lime was applied at the rate of 1 ton per acre and the ground limestone at the rate of 2 tons per acre. Only 27 per cent of the latter was fine enough to pass through a 100-mesh sieve and 19 per cent was too coarse to pass through a 20 sieve.
Cowpea hay	A & B	22	1909	0.83	0.92	0.78	0.73	0.09	—0.05	
" "	2	22	"	0.95	1.66	0.94	1.48	0.71	0.54	
Soy-bean hay	4	10	"	2.23	3.22	2.06	3.04	0.99	0.98	
Cowpea hay	3	24	1910	0.82	1.20	0.92	1.38	0.38	0.46	
Mixed sorghum and cowpea hay	4	6	"	1.87	2.65	1.85	2.77	0.78	0.92	
				Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	
Corn	A, B & 4	4	"	26.9	30.3	28.6	32.5	3.4	3.9	
Barley	4	16	"	12.7	17.3	12.4	17.2	4.6	4.8	
Wheat	2 & 3	26	"	9.5	13.5	11.6	14.8	4.0	3.2	
				Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
Cotton	A & B	10	"	884	788	1040	1028	— 96	— 12	
"	2	10	"	1500	1468	1276	1308	— 32	22	
				Tons	Tons	Tons	Tons	Tons	Tons	
Cowpea hay	3	14	1911	1.08	1.23	1.26	1.28	0.15	0.02	
Soy-bean hay	4	2	"	1.83	2.15	1.75	2.30	0.32	0.55	
Mixed sorghum and cowpea hay	4	4	"	1.26	1.46	1.31	1.37	0.20	0.06	
				Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	
Corn	A, B & 2	8	"	34.4	37.4	31.1	35.6	3.0	4.5	
				Tons	Tons	Tons	Tons	Tons	Tons	
Clover and grass	A & B	12	"	2.36	2.52	2.16	2.70	0.16	0.54	
" " "	2	12	"	0.43	1.85	0.94	2.49	1.42	1.55	
" " "	4	10	"	0.85	2.99	0.86	2.89	2.14	2.03	

TABLE V—*Burnt lime vs. ground limestone. Experimental results obtained with various farm crops at the West Tennessee Station at Jackson—Soils: Ranges A and B, a gray-colored silt loam, very difficult to manage ("crawfishy" type); Ranges 2, 3 and 4, poor silt loam—Concluded*

Crops	Range where grown	No. of plots averaged	Year of Harvest	Yield per acre				Increase per acre		Remarks
				Unlimed	Burnt lime	Unlimed	Ground limestone	Burnt lime	Ground limestone	
				Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	
Oats	A & B	6	1912	26.5	31.3	25.8	32.4	4.8	6.6	
"	2	6	"	44.6	49.4	30.6	40.9	4.8	10.3	
Wheat	3	9	"	22.9	29.6	19.8	24.7	6.7	4.9	
				Tons	Tons	Tons	Tons	Tons	Tons	
Cowpea hay	2	10	"	0.96	1.02	0.81	1.04	0.06	0.23	
" "	3	18	"	0.88	1.55	0.91	1.70	0.67	0.79	
" "	A & B	10	"	0.75	0.80	0.70	0.83	0.05	0.13	
Sorghum and cowpea hay	4	6	"	2.06	3.33	2.47	3.65	1.27	1.18	
				Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
Cotton	2	12	"	1184	1287	1430	1419	103	—11	Red clover the preceding crop, but clover little benefited by liming on A & B
"	A & B	12	"	1188	1157	1002	912	—31	—90	

Both the burnt lime and the ground limestone were strictly high-grade. The mechanical analysis of the latter was as follows:

Particles retained by a	No.	20*	sieve	.....	19.3	per cent
" " " "		40	"	.....	27.1	"
" " " "		60	"	.....	14.2	"
" " " "		80	"	.....	7.6	"
" " " "		100	"	.....	4.4	"
" that passed through	"	100	"	.....	27.4	"
					100.0	

DISCUSSION OF RESULTS AT WEST TENNESSEE STATION

Results on ranges A and B

In the trials on ranges A and B five distinct kinds of farm crops have been grown in the four years which have passed since liming. These crops are as follows: Cowpeas, corn, cotton, clover and grass, and oats. On this soil the effect of either form of lime on the cowpea crop was practically nothing, there being a slight apparent gain from the burnt lime and a slight apparent loss from the ground limestone. The yields of corn for 1910 show, however, an evident increase, amounting to 3.4 bushels per acre for the burnt lime and 3.9 bushels per acre for the ground limestone. The 1911 corn crop shows 3.0 bushels per acre increase from burnt lime and 4.5 bushels increase from the ground limestone. Excellent crops of red clover were obtained without the aid of lime; in fact, the effect of liming was scarcely evident to the eye. The yields show, however, 0.16 ton per acre increase from burnt lime and 0.54 ton increase from the ground limestone. The cotton crop of 1910 appears to have been injured by liming rather than benefited, the decrease of seed cotton attributable to the application of burnt lime being 96 pounds per acre and that due to the ground limestone 12 pounds per acre. The oat crop of 1912 was appreciably better on the limed than on the unlimed sections, the increase attributed to the burnt lime being 4.8 bushels per acre and to the ground limestone 6.6 bushels per acre. The cowpea crop of 1912 was only slightly benefited by either form of lime, and again in 1912 the cotton crop was somewhat reduced by each.

Results on ranges 2, 3 and 4

On ranges 2, 3 and 4 the five crops tested on ranges A and B were grown, and in addition the four following: Soy beans, wheat, barley, and a mixture of sorghum and cowpeas for hay. An examination of Table IV will show that both forms of lime gave markedly increased yields for all the crops except cotton, and it is evident from these results that a direct application of lime may be detrimental to this crop, which behaves in strong contrast to all the others. The most favorable effects of liming were noticeable on the clover,

*By a No. 20 sieve is meant a wire sieve having 20 square openings per linear inch, or 400 per square inch. In a like manner 40, 60, etc., refer to the number of openings per linear inch.

which, in fact, was a complete failure where unlimed, even on those plots which were well dressed with stable manure. The next most noticeable results were obtained with soy beans, the yields of hay being increased nearly one ton per acre from either form of lime.

Burnt lime vs. ground limestone

The most important feature of these experiments consists, however, in the comparative returns from burnt lime on the one hand, and from ground limestone on the other. A study of Table V shows that the returns are very close. If the increased yields of all hay attributable to liming be summed up, we find an average increase for each crop harvested of 0.67 ton per acre for the burnt lime and 0.69 ton per acre for the ground limestone. If the increased yield of all kinds of grain crops be averaged in a similar manner we find an average increase of 4.5 bushels for the burnt lime and 5.5 bushels for the ground limestone. We would conclude, therefore, that in these trials 2 tons of ground limestone proved somewhat superior to 1 ton of burnt lime.

EXPERIMENTAL RANGES AT THE WEST TENNESSEE STATION

One half of every range was limed and the increased growth of wheat on the first range to the left is evident; also of clover on the next range, where the figure is standing on the line of separation between the limed and unlimed sections.

THE EFFECT OF LIMING ON DIFFERENT FARM CROPS

"Sour" land

That an application of lime may not affect all crops alike is well known. Clover and alfalfa are examples of farm crops which are especially sensitive to a deficiency of lime, and soils where they fail to thrive until limed and which redden blue litmus paper are called "acid" or "sour." The behavior of different farm and garden crops when grown on both limed and unlimed soil of this character has naturally received much attention on the part of agricultural investigators, but in particular by Dr. Wheeler, until recently Director of the Rhode Island Station. Out of 80 or more farm and garden crops tested by him on an acid soil only a few were found not to be benefited by liming. A list of the latter is as follows:

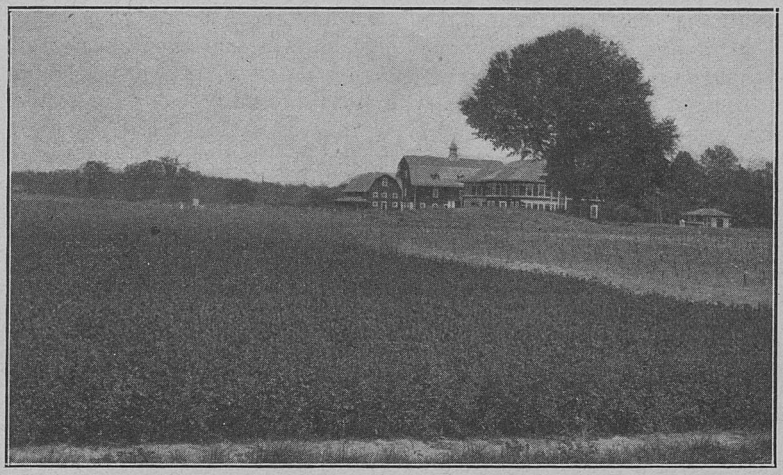
Crops not benefited by liming (from Wheeler's list)	Notes on effects of liming (according to Wheeler)
Adzuke beans	Injured
Cowpeas	Injured
Lima beans	"Disadvantageous"
White beans	Injured
Blue lupines	Decidely injured
Seradella	Injured
Blackberries	"Thrive on very acid soil"
Strawberries	With slight acidity lime would be expected to be "of little or no worth"
Concord grapes	"Indifferent to lime," but Delawares "injured in a marked degree by sour soil"
Red top	No benefit
Rhode Island bent	No benefit
Sheep fescue	No benefit
Sweet vernal	No benefit
Millet	Injured
Watermelons	"Decided injury"

TABLE VI—*Effect of liming on various crops according to trials made on common uplands in the State of Tennessee. These tests were made on soils where liming was necessary in order to get a fair crop of clover*

Crops which were a practical failure without liming	Crops decidedly helped	Crops moderately helped	Crops little affected	Crops injured
Alfalfa	Crimson clover	Timothy	Red Top	Cotton
Alsike clover	Cowpeas	Kentucky blue-grass	Rhode Island bent	Peanuts
Red clover	Soy beans	Tall oat grass	Sweet vernal grass	Watermelons
White clover	Velvet beans	Tall meadow fescue	Sheep fescue	
	Hairy vetch	Italian rye grass	Rye	
	Garden beets	Corn	Tobacco	
	Cantaloupes	Sorghum	Strawberries	
	Cucumbers	Barley	Sweet potatoes	
	Summer squash	Wheat	Irish potatoes	
		Oats	Egg plant	
		Millet	Lima beans	
		Orchard grass	Burpee stringless beans	
		English rye grass		
		Bromus inermis		
		Bermuda		
		Rhodes grass		
		Soudan grass		
		Tomatoes		
		Peppers		
		Japan clover		

Effects of liming on different crops in Tennessee

The writer has tested at the Stations at Knoxville and Jackson, and elsewhere in the State, many of the common farm and garden crops, and as a result Table VI has been prepared in an attempt to show the comparative effects of liming on different crops. The results are generally in accordance with Wheeler's. That some differences should appear is not surprising, especially as the soil at the Rhode Island Station is markedly different in several important respects from any prominent Tennessee type. Also it should be remembered that liming may give increased crop production not only by the correction of acidity, which was the particular object of Wheeler's experiments, but also because of other effects, in particular



ALFALFA AT THE WEST TENNESSEE STATION

A success only when limed.

the increase of the soil supply of available nitrogen, produced by liming, as was found to be the case in the cowpea-wheat rotation experiments reported in Bulletin 96 of this Station.

Probable reason for the response of the cowpeas to liming

In fact, for the latter reason, and not because of the correction of acidity, the cowpea has been found to respond especially well to liming, but does so at the expense of the soil supply of nitrogen. Another crop which, in apparent variance with Wheeler's list, has been found very responsive to liming is German millet. In one experiment on a humus-rich sour meadow, where soy beans made a vigorous growth without lime, millet failed completely where no lime was applied, but grew vigorously on an adjoining limed area. In this connection, attention is called to the fact

that soy beans, although able to thrive on the very sour meadow, are apt to respond well to liming on average upland and are in this respect very similar to cowpeas, and like them draw on the nitrogen of the soil.

Cotton and peanuts may be injured by liming

Particular attention is now called to two important crops, cotton and peanuts, which have been found to be injured by liming in experiments conducted on the soils and in the sections of the State where each is grown extensively. Another prominent crop, tobacco, can be placed in the doubtful column, for in some trials it has appeared to be injured by liming, and in others somewhat benefited. Of course soils may be discovered which are so poor in lime as to require an additional supply before any of these crops can be produced to advantage, but until such evidence is obtained liming the land immediately preceding them should be avoided. This does not imply that common land, such as that experimented on, should never be limed where these crops are to be grown, for liming may be of indirect value, at least for tobacco, and probably for cotton. For example, the yield of cotton on range 2 at the West Tennessee Station was reduced by the liming until in the rotation the cotton followed red clover, which had profited greatly from the liming, in which case the increased supply of available nitrogen in the clover residues caused the cotton to fruit somewhat better on the limed than on the unlimed sections. With peanuts, however, a different condition is presented, for this is a leguminous crop, and therefore able to get a part of its nitrogen from the air. In our experiments on the peanut soils of this State liming has almost invariably increased the growth of tops, but has proved somewhat deterimental to the production of nuts, a result which would naturally follow a too abundant soil supply of nitrogen. On much poorer land the effect of liming peanuts might be reversed.

HOW MUCH LIME SHOULD BE APPLIED TO ONE ACRE OF LAND?

The quantity of either burnt lime or ground limestone to apply per acre in order to get the most profitable returns is a practical question, which can hardly be answered with entire satisfaction, especially as there may be a wide variation in the lime requirements of different soils on the same farm. As an example of this, at the Jackson Station the soil of ranges A and B proved to have much less need of lime than ranges 2, 3 and 4. However, since the uplands of Tennessee are residual soils, and each of several distinct types on which experiments have been made covers large areas, at least a general idea can be gotten as to the amount of lime to use. The data given in Table VII, together with the effects of liming reported in the other experiments, are of value in this connection.

TABLE VII—*Results of rate-of-liming experiments on the production of alfalfa*

Farm of	Kind of soil	Season of	Yield of hay per acre				Notes
			2 tons of ground limestone	4 tons of ground limestone	6 tons of ground limestone	8 tons of ground limestone	
			Tons	Tons	Tons	Tons	
Marion Smith, Warren County	Red soil of Highland Rim	1910	3.53	3.28	4.00	3.33	Except on farm of Hugh Moss, liming necessary in order to get a profitable crop of alfalfa.
W. T. Blue, Warren County	" " " " "	1910	4.04	3.60	3.19	3.75	
		1911	2.56	2.29	2.18	2.11	Phosphate, potash and manure in liberal amounts applied to all plots alike.
G. A. Scheffler, Coffee County	Gray soil of Highland Rim	1911	4.11	4.18	4.71	4.55	
		1912	3.05	2.25	2.97	2.21	
W. W. Hix, Bedford County	Brown loam of Central Basin	1911	4.38	4.56	5.01	4.36	The size of the plots varied from ¼ acre to 1 acre. Experiments were therefore under practical field conditions.
		1912	4.87	3.79	4.51	4.67	
Hugh Moss, Wilson County	" " " " "	1911	5.67	5.98	6.12	5.68	
		1912	4.84	5.04	5.08	3.96	
	Average		4.12	3.89	4.20	3.85	

DISCUSSION OF THE RATE OF LIMING TRIALS

Kinds of soil used

In Table VII are the yields of alfalfa hay gotten from each of four rates of liming; namely, 2, 4, 6, and 8 tons of ground limestone per acre. The fineness of the limestone particles was about like that reported on page 18. The first three sets of the experiments were conducted on Highland Rim soils, which were so much in need of lime that the alfalfa was practically a complete failure where none was used, but even under this condition the results of both the one and two-year trials indicate that the 2-ton application was ample. The lime requirement was not so great for either of the last two series, which were conducted on brown-colored loams of the Central Basin. In the Bedford County series the unlimed alfalfa yielded, the first season after seeding, less than one-half as much hay as where 2 tons of ground limestone were applied, and the second season the unlimed crop was not worth harvesting. In the Wilson County series the unlimed plot yielded nearly as well as the limed, so that the somewhat larger yields obtained where the 4 and 6-ton applications were made as compared with the 2-ton rate must be attributed to inequalities in the soil.

Size of plots and their manuring

In all of these sets the plots were extra large—one-fourth acre to one-half acre each—and all the plots of a series were manured and fertilized alike, at the rates of 12 tons of manure per acre, together with a heavy application of phosphate and potash.

One ton of burnt lime or 2 tons of ground limestone per acre apt to be sufficient

The fact that these experiments without exception show that 2 tons of ground limestone satisfied the needs of the alfalfa as well as any larger amount, is significant. The experimental results gotten on forty different farms scattered through the three divisions of the State indicate 1 ton per acre of burnt lime or 2 tons of ground limestone to be ample for several years.

SOME PRACTICAL CONSIDERATIONS IN REGARD TO LIMING

The various materials used

Various materials may be used to supply the soil with the kind of lime which will correct acidity. Those of common occurrence may be enumerated as follows:

Burnt lime
Hydrated lime
Air-slaked lime
Ground limestone (marble included)
Dolomite, which may be burnt or the rock finely ground
Wood ashes
Marl

Burnt lime as a granulator of a heavy soil

Writers on this subject usually call attention to the special value of burnt lime as a means of granulating a heavy, sticky soil. The writer has not been able to detect any pronounced result of this kind. The soils investigated have been either loams or silt loams and none extra heavy. Hall mentions the fact, however, that this granulating effect is very noticeable in the limed fields at Rothamstead as compared with the unlimed, and that it becomes evident only in the course of time and as the result of the thorough incorporation of lime with the soil, as would be the case after repeated liming.

Hydrated lime

Commercial hydrated lime is in a convenient form for immediate use, but as it is the same substance as that obtained by slaking the lump lime with water, it can not be recommended as generally economical for agricultural purposes.

Dolomite

Dolomite, or magnesium limestone, is of common occurrence throughout East Tennessee, and of late the question as to its agricultural value has often been asked. This Station has not enough experimental evidence on hand to be able to make a satisfactory comparison with the high-grade limestones commonly used. In the only trial made by the Station the results obtained from ground dolomite rock have been practically identical with those from similarly ground high-grade limestone. We have also known dolomite to be used with excellent returns on various farms in this section, and have never heard of detrimental effects even where extra-heavy dressings have been made. The experimental results obtained by other Stations are favorable to its use. Dr. C. G. Hopkins, as the result of pot experiments made at the Illinois Station, and after using ground dolomite on his own farm in Southern Illinois, makes the following statement in regard to it:

"There is no likelihood of any but beneficial effects from initial applications of 5 to 6 tons to the acre; and subsequent applications of 2 tons per acre every four or five years would probably never produce injury. On the other hand, it is highly probable that the element magnesium applied in dolomitic limestone may produce quite as much benefit for its own sake as will the element potassium on most soils where it proves more or less beneficial."*

EQUIVALENT QUANTITIES OF VARIOUS MATERIALS

It may be assumed for practical purposes that 2 tons of ground rock are required to equal 1 ton of burnt lime.

1⅓ ton of hydrated lime is required to equal 1 ton of fresh burnt lime.

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*Soil Fertility and Permanent Agriculture, p. 171.

1½ ton of air-slaked lime, if dry and fine, may be taken as approximately the equivalent of 1 ton of burnt lime.

Of wood ashes, roughly, 3 tons are required to furnish the amount of lime in 1 ton of burnt lime.

Marl is not of common occurrence in the State, and as the composition is uncertain an analysis is necessary to determine its value.

METHOD OF APPLICATION

Burnt lime

Burnt lime when slaked to a powder is very disagreeable to handle, so that some farmers refuse to use it. The lump lime may, however, be placed in small heaps over the field at convenient distances for distribution and allowed to slake to a fine powder, either uncovered, or, better, after being covered with earth, when it may be scattered with a shovel without much inconvenience. But the scattering should not be done when the ground is wet. Perhaps the greatest drawback to this plan is the chance that a very heavy rain may make "mud" of the lime, in which event its proper distribution is rendered impossible.

Ground limestone

To get the most even and economical distribution of ground rock or similar material, a distributor is generally essential. The best results are obtained from a special machine, though a manure spreader may be used to considerable advantage. On the other hand, it will not pay a man with only a few acres to be limed to buy a spreader for the purpose. The land should be laid off into acre lots, or less, at the outset, and the ground rock may be taken from a wagon and scattered with a shovel.

THE EFFECT OF LIMING ON THE NITROGEN AND HUMUS CONTENT OF THE SOIL

Experimental results from cowpea-wheat plots

There is a widespread belief that burnt lime, although increasing the crop yields at first, is destructive to humus, so that, if a faulty system of management be followed, which does not allow adequate manuring of the soil or the frequent production of clover, or the like, the soil may finally be worse off than if no lime had been used. This subject has been investigated by this Station in connection with a rotation of cowpeas and wheat. The soil from each of 20 plots was analyzed for both nitrogen and humus at the outset of the experiments and before the application of burnt lime (1800 pounds per acre), which was made to one half of every plot. At the end of two years, and again at the end of five years, soil samples were taken from both the limed and the unlimed half of every plot and the content of nitrogen and humus again determined. The

results are published in detail in Bulletin 96 and show that the liming did reduce the supply of both nitrogen and humus. As the average of four plots where the cowpea crop was removed annually for five years, 102 pounds per acre more nitrogen and 1623 pounds per acre more humus were found in the surface 8 inches of the unlimed soil than in the corresponding limed area. As the average of 12 plots where the cowpea crop was turned under for green manure each year for the five years, 88 pounds more of nitrogen per acre and 1159 pounds more of humus were found in the unlimed than in the limed soil. Attention should be called, however, to the fact that when the increased yields of the various crops were taken into consideration, there was found to be very little actual waste of nitrogen attributable to the liming. Also where the cowpea crop was turned under annually and only the wheat removed the humus supply of the limed sections was maintained.

Experimental results in a rotation with clover

In the upland series of experiments reported in Table III, which were conducted on plots adjoining the cowpea-wheat rotation plots, and in which clover was a decided success under liming and an almost complete failure otherwise, no loss of nitrogen was detectable at the end of two years in the limed soil as compared with the unlimed, and this too in spite of the fact that larger crops of all kinds had been harvested on the limed than on the unlimed sections.

Ground limestone safer than burnt lime

Considering the general need of liming in order to get the best results with clover and grass, in the judgment of the writer, no one should hesitate to use burnt lime if the object be to get these crops for soil improvement purposes. Ground limestone, however, on account of its coarse grains, is considered much less liable to cause waste of soil nitrogen and humus than burnt lime, which if properly applied is in a very fine state of subdivision and is, at the outset, at least, chemically active.

THE LITMUS TEST FOR LIME REQUIREMENT

Litmus paper

The litmus test for the lime requirement of a soil has been in use for a number of years and is the best simple test that can be recommended at the present time. Litmus paper, both red and blue-colored, can be obtained at any drug store for about 10 cents per package. Its value as an indication depends on the very great sensitiveness of litmus toward acids and alkalies, the blue paper being changed to red by an acid and the red paper being changed to blue by an alkali.

Method of procedure in litmus test

There are a few simple precautions in the testing of a soil. A good method of procedure is as follows: Prepare two or three clean cups or deep saucers and a spoon by rinsing each carefully in pure rain water, which should be tested by each kind of paper to see that no change in color is produced by it. Place a few spoonfuls of the soil to be tested in a cup, add a little of the pure water until a thin paste is made with the soil, dip an unused strip of blue litmus into the paste, being careful not to touch with the fingers the part of the strip dipped into the paste, allow it to remain in contact with the mixture for ten minutes, then remove and rinse off the soil particles in another cup of the pure water. If the soil be not in special need of lime, no change can be detected in the color of the litmus, in which event the test may be repeated, using red litmus, which if turned even slightly blue indicates an alkaline condition of the soil, and hence no need of liming. If the blue litmus be changed to a distinct red, the lime requirement is high, but even a faint reddening indicates a low content of carbonate of lime, so that liming is apt to be profitable.

Some precautions

The use of fresh and well-prepared litmus paper and either pure rain or distilled water are of prime importance. Old and faded litmus paper should not be used. The interpretation of the change in color of the paper requires some experience, especially as soils do not as a rule produce the sharp reaction obtained with strong acids or with an alkali such as lime water or ammonia. Several samples should be tested both from different parts of the same field and from different fields, having as widely different soils as possible. For comparative results the details of the test should be exactly the same throughout; that is, the soil-and-water paste should be of the same consistency and the litmus should remain in contact with it for the same length of time, etc.

LIME IN RELATION TO SUCCESS WITH CLOVER

Red clover an unexcelled crop for soil improvement

Common red clover is a highly valued crop throughout the State, not only for hay and pasture, but also as a soil improver. For the latter purpose the writer considers that it is unexcelled wherever it can be satisfactorily grown, and should be considered as indispensable in connection with the economical upbuilding of the land. Certainly it is not being grown either as extensively or successfully as the demand warrants. Many farmers have found it to be a failure on their land, and many others do not seem to realize that they are getting only a partially successful crop. As a matter of fact a really first-class stand and crop are seldom to be found. In view of the importance of liming in this connection, a brief

discussion of the most important conditions affecting both red and alsike clover in Tennessee is undertaken here. Also an application of the principles involved can be made to other crops.

The red clover disease

For twenty years or more there has been a specific fungous disease, which has caused great damage, amounting often to complete failure of red clover on clover lands throughout the State. The damage is done chiefly in the midsummer months, and is easily recognized by the blackening of the leaves and stems of the plants, the majority of which are killed during the first season. This disease is fully discussed in Bulletin 75, by Bain and Essary. Alsike clover is not subject to this disease, and has therefore been sown frequently, and with fair results, as a substitute for red clover. Bain and Essary, by collecting seed from red clover plants that had survived in an affected field, have succeeded in getting a strain which is comparatively little injured by the disease and which has been called "Resistant" red clover. The particular point to be made here is that liming, though helpful, does not prevent even serious damage by this disease, which has repeatedly been found to flourish on both limed and unlimed soils.

Phosphate and potash

The soil supply of available phosphoric acid and potash has much to do with the successful production of clover. Potash occasionally proves to be of value in hay production, and can not therefore be left out of consideration. The need of phosphoric acid is both much more pronounced and more general over the State than that of potash, and acid phosphate has proven to be a highly profitable fertilizer material for this crop on a number of soils, such as those found on the Highland Rim, for example. It may be noted that acid phosphate contains two elements of plant food in addition to phosphoric acid, one being calcium, the essential constituent of lime, and the other being sulphur. The latter element is present in combination with lime in the form of calcium sulphate, or land plaster, which constitutes about one-half of acid phosphate. The balance of the lime is combined with phosphoric acid. It is not surprising, therefore, to find that acid phosphate does not take the place of either burnt lime or ground limestone. Also these in turn have not, in any of the trials made by this Station, taken the place of an application of phosphate. That is, liming did not to any appreciable extent make available to plants the relatively insoluble and unavailable phosphates of the soil. The conclusion is therefore reached that if either phosphoric acid or potash is needed by our soil, it should be supplied by the proper fertilizer material, but that liming should be looked upon as a wholly independent matter.

Farmyard manure

Every farmer recognizes the value of farmyard manure as an aid to the successful production of clover. It contains all of the plant-food elements, and is in addition an alkaline material, which counteracts soil acidity; but this effect is so small that only an extraordinary manuring would equal a two-ton application of ground limestone. The data of Table III show that the combination of lime and manure gave far better results than were gotten where either was used by itself. This does not mean that they should be mixed and applied together, which would be a mistake,* but that liming gives excellent results on manured land.

Time of seeding

The general custom is to sow clover early in the spring; and this may be advisable under favorable conditions, but numerous trials made in all three sections of the State have demonstrated that the seeding may be done to advantage in late summer or early fall. With this object in view, the land is turned if possible in July and kept well-harrowed until a favorable seeding time in the latter part of August. If seeding is done at this time the red clover disease does not prevent a first-class cutting the following year, though the stand may be lost afterward through the ravages of the disease. Alsike clover may be sown to advantage at this time rather than in the spring, especially if the land be poor so that a spring seeding is apt to fail. By this means, together with attention to liming, phosphating, and manuring, a fine crop of clover can be gotten on almost any upland in the State; and it has been found that the liming may immediately precede this seeding with excellent results. In the case of burnt lime the application need be only harrowed into the surface of the soil, but the ground limestone should be thoroughly mixed throughout the soil to the depth of plowing.

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*Caustic lime liberates ammonia from ammonium salts, such as ammonium carbonate, which is found in stable manure.

TABLE VIII—*Prominent Tennessee soils, with notes on their lime requirements*

Section of State	Origin of soil	Soil description	Notes on the lime requirements
East Tennessee Valley	1. Dolomite	Gravelly loams. Ridge lands as a rule very gravelly. Color of soil variable, commonly gray or light red, occasionally a rather deep red. Subsoil a red clay.	Chemical analyses show a low content of lime. In field trials the yields of clovers and alfalfa have been markedly increased by liming; also other common crops were benefited.
	2. Slate or shale	Silt loams inclined to be shallow and "crawfishy." Color of soil variable, commonly gray or grayish-yellow, with yellow or reddish-yellow subsoil. Often forms valley lands of inferior fertility.	Chemical analyses show a low content of lime. These soils are derived from slates and shales of different formations and vary greatly in character. In the limited number of field trials made, liming has given marked increases in yields of clover, cowpeas, etc.
	3. Chickamauga limestone ("rotten," or "blue," limestone)	Silt loams to clays. Heavy soils, grayish and reddish-yellow in color, with reddish-yellow subsoil.	New lands sometimes show a fair lime content. Old lands are apt to be poor in lime. In field experiments on old land an application either of 1 ton of burnt lime or 2 tons of ground limestone per acre proved very profitable.
	4. Marble and other limestones producing dark red or mulatto soils.	Loamy soils distinguished by their dark red color.	These soils are much more apt to be well supplied with lime than any other upland type in East Tennessee. Liming is advisable for alfalfa and may be profitable, especially on old fields, for other crops.

TABLE VIII—*Prominent Tennessee soils, with notes on their lime requirements —Continued*

Section of State	Origin of soil	Soil description	Notes on the lime requirements
	5. Alluvial deposits	Sandy, fine sandy loams, silt loams, etc.	Lime supply apt to be at least fairly good. A fertile fine sandy loam at the Station farm was found to respond profitably to liming, especially for clovers and alfalfa. See Table III.
Cumberland Plateau	Walden sandstone	Fine sandy loams, occasionally silt loams and sandy soils.	Content of lime very low. Liming essential to best results in soil upbuilding, but should not be excessive — say 1000 to 2000 lbs. of burnt lime per acre; but a larger quantity of ground limestone may be applied to advantage—2 tons per acre.
Highland Rim	1. Blue limestone, etc.	Heavy silt loams of dark red ("mulatto") color, with heavy red-colored subsoils. Also gray and brown-colored light silt loams with red subsoils.	Soils apt to be low in lime. In numerous field experiments liming has been found to be necessary in order to get alfalfa; also yields of clover and cowpeas markedly increased. Liming not always profitable for either peanuts or tobacco.
	2. Siliceous limestone	Light silt loams of grayish color, with either reddish or yellowish subsoils—the "Barrens" type.	Chemical analysis shows very low content of lime, but these soils do not always respond with much profit to liming. Liming is recommended, however, and should be considered as a necessity in permanent soil upbuilding. Applications should be moderate in quantity, as in advice for Cumberland Plateau soils.

TABLE VIII—*Prominent Tennessee soils, with notes on their lime requirements —Concluded*

Section of State	Origin of soil	Soil description	Notes on the lime requirements
Central Basin	Blue limestone, etc.	Brown-colored silt loams, with brownish or yellowish-red subsoils. Also grayish soils, with yellowish-red subsoils and in the vicinity of Murfreesboro red-colored soils, with red subsoils.	These soils analyze the highest in lime of all the soils in the State. Clover is grown more successfully than over any other large area in the State. In a few experiments, liming did not prove to be needed by alfalfa. In several other trials liming proved very beneficial to red clover, as well as to alfalfa.
West Tennessee	Unconsolidated material, poor in lime	Gray and brown-colored silt loams predominate. Subsoils red, yellowish-red, etc.	The most fertile lands, such as are found in Obion County, are not apt to need lime, at least for clover. Old land on Station farm at Jackson responds markedly to liming. Liming apt to be highly profitable over a large part of this section for all crops except cotton.

SUMMARY

RESULTS OF CHEMICAL ANALYSIS

The chemical analysis of Tennessee uplands shows a low content of calcium oxide—2226 to 9695 pounds per foot-acre for representative soils. The amount of calcium carbonate is very low—nearly always less than 0.1 per cent.

FIELD EXPERIMENTS IN EAST TENNESSEE

Two tons per acre of very finely ground limestone applied in 1909 to a soil derived from Chickamauga (blue) limestone gave an increased yield, averaging 7.2 bushels of corn per acre for each of the years 1909 and 1911. In 1910, crops of cowpeas, soy beans, and velvet beans were each increased about one-half ton of hay per acre. On an adjoining range 1 ton per acre of burnt lime applied in 1906 gave markedly increased crops of both cowpeas and wheat grown under a variety of experimental conditions. At the end of six years, when sown to red clover, an excellent stand was obtained on the limed section, regardless of previous cropping and fertilizing, while the unlimed section was a failure throughout.

On upland at the Knoxville Station, 1800 pounds per acre of burnt lime applied in 1905 gave markedly increased yields of each of the various crops grown since that time. At the end of the seventh year after the liming, alsike clover was a decided success on the limed sections, but an almost complete failure elsewhere, even on well-manured plots. On fertile bottom land liming also proved profitable.

FIELD EXPERIMENTS IN MIDDLE TENNESSEE

THE CUMBERLAND PLATEAU

The results of the field experiments on nine different farms all indicate that liming is one of the fundamental essentials to the profitable production of general farm crops.

THE HIGHLAND RIM

The results of field experiments on eighteen different farms, in which seven different counties were represented, prove the general profitableness of liming on the soils of this section.

THE CENTRAL BASIN

In seven out of ten trials on typical brown loams of the Central Basin, liming proved profitable, and the indications are that the average uplands of this section are in need of lime in order to give the best results with red clover, the most important crop for soil improvement purposes.

FIELD EXPERIMENTS IN WEST TENNESSEE

Liming experiments were conducted for four years on two types of soil at the Jackson Station. One was a heavy, gray-colored silt

loam, and the other was a common brownish silt loam of good texture, but only the latter responded in a pronounced manner to liming. On the latter soil, cowpeas, soy beans, red clover, corn, sorghum, wheat, barley, oats, and cotton were each thoroughly tested under a variety of fertilizer and manuring conditions. Red clover was a complete failure unless limed, and all of the crops were markedly increased by liming, with the exception of cotton, which suffered a slight reduction in yield.

COMPARISON BETWEEN BURNT LIME AND GROUND LIMESTONE

Throughout the four years' trials with the nine crops at the Jackson Station a comparison was obtained between the effects of 1 ton of burnt lime and 2 tons of ground limestone. The increased yields were in general very close, but the results were slightly in favor of the ground limestone.

RATE OF LIMING EXPERIMENTS

Three series of experiments with ground limestone applied at four different rates, namely, 2, 4, 6 and 8 tons per acre, were conducted on ¼ to 1-acre plots in three different localities on the Highland Rim and also in two different counties of the Central Basin. In each series the crop grown was alfalfa, and in every case the same amounts of manure and fertilizer were used for each rate of liming. Although in four out of the five trials, liming proved necessary to the profitable production of alfalfa, 2 tons of the ground limestone per acre proved ample, the yields of hay being practically the same for each of the different rates.

THE EFFECTS OF LIMING ON DIFFERENT FARM CROPS

The effects of liming on different farm crops have received attention, and the results are generally in harmony with those obtained by Wheeler at the Rhode Island Station.

Two prominent farm crops, peanuts and cotton, were found to be adversely affected by liming in tests made on the soils and in the section of the State where each is grown most extensively. It is advisable, therefore, to avoid an application of lime immediately preceding these crops. The results should not, however, be construed to mean either that liming will not prove profitable on other soils or that land of the character used should never be limed if these crops are regularly grown, as in a systematic rotation which includes clover. In the latter case liming, by enabling the successful production of clover, might be of much value to the succeeding crop of cotton.

THE LITMUS TEST

The litmus test is recommended as the best simple indication of the lime requirements of a soil.