Bulletin No. 329 January, 1929

COMPARISON OF SOIL LIMING MATERIALS

Purdue University
Agricultural Experiment Station
Lafayette, Indiana

Liming acid soils is a highly profitable investment. Not only is ground limestone, and in some cases marl, easy to obtain in Indiana at reasonable cost, but its application on acid soils is a practical and efficient means of increasing the productive capacity of such soils. This method of improvement of acid soils is open to every farmer. On every acid soils, lime is usually more important than fertilizer, and in any case fertilizer will give better returns after the land is limed. The heavy types of acid soils need available phosphorus more than any other fertilizer.

Ground limestone and marl are the most economical forms of lime to use for soil liming in Indiana, though any convenient form may be used. Hydrated lime is more expensive and does not act any more quickly. Fifteen hundred pounds of hydrated lime is required to produce the same effect as 2,000 pounds of ground limestone.

To secure the maximum benefits from soil liming, clover, alfalfa, sweet clover or other legumes should be used in the crop rotation.

At least 25 per cent, or over 3,000,000 acres, of Indiana soils are seriously in need of liming. Another 25 per cent will produce clover without liming only in very favorable seasons and 75 per cent must be limed to grow alfalfa or sweet clover successfully. The present rate of liming, about 100,000 acres per year, is much too slow. Acid soils will continue to give poor returns until they are limed.

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Revised

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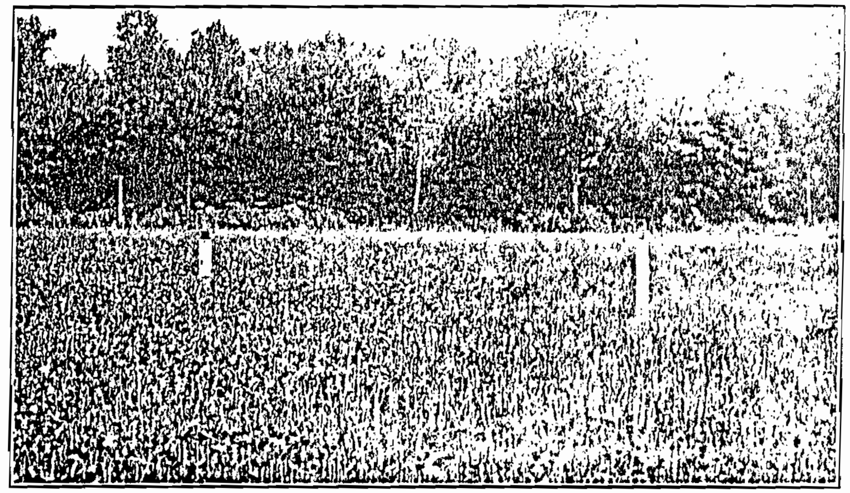

Fig. 1. Effect of ground limestone on first clover crop, Jennings County Experiment Field, 1921.
Left—3 tons ground limestone and phosphate.
Right—Phosphate alone.
The limed land has produced good clover every year for nine years.

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SUMMARY

In the experiments reported in this bulletin, ground limestone of various degrees of fineness, hydrated calcium lime, hydrated magnesian lime, magnesian limestone and lake marl have been compared as to their relative efficiency and value for liming acid soils.

Ground limestone and marl are the most practical liming materials for correcting acid soils in Indiana. The 10-mesh and 50-mesh ground limestone and marl produced as large crop increases the first year and in succeeding years as hydrated lime. Ground limestone is easily obtainable at from one-third to one-fifth of the cost of hydrated lime and in many places marl is convenient. With ground limestone at $2.50 per ton, hydrated lime is worth $3.49 per ton on the basis of their average effects in these tests. This is very close to the theoretical relative value based on calcium content.

The 50-mesh limestone has been no more effective than the 10-mesh limestone, indicating that there is no advantage in grinding finer than 10-mesh.

The 4-mesh limestone screenings have been less effective than the finer ground materials but may be satisfactorily used if applied in larger amounts.

The coarser particles of limestone screenings had a small effect during the first few years, but after that their effectiveness increased rapidly, indicating that the coarse particles in ground limestone have a definite, even though somewhat delayed, action on the acidity of the soil.

The system of applying small amounts of lime to each grain crop is not practical, at least on such acid soils as are represented on the fields used in these experiments.

Hydrated magnesian lime has proven fully as effective as pure calcium lime.

The comparison of the 1.5-ton to 2-ton applications with the 3-ton to 4-ton applications indicates that if only a limited investment in liming can be made at one time, it will be more profitable per dollar invested to lime twice as many acres at the lighter rate until the whole farm is limed and then go back and make another similar application.

The extremely heavy applications of ground limestone have produced no ill effects and there seems to be no danger of overliming these soils.

Laboratory tests on limed and unlimed plots show that with the moderate applications the lime has affected the acidity of the soil only in the surface layer.

Be sure to read the discussion of Table VII, pages 17, 18 and 19.

COMPARISON OF SOIL LIMING MATERIALS

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The application of some form of lime has become recognized as the first essential in the improvement of acid soils. Such treatment neutralizes harmful acidity and makes possible the production of larger and better crops. The common clovers, alfalfa and sweet clover cannot be successfully grown on acid soils.

Fully one-quarter of the soils of Indiana are so acid that they are urgently in need of liming. Another one-quarter are moderately acid and will grow satisfactory crops of clover only in exceptionally favorable seasons. Altogether, three-quarters of Indiana soils will respond more or less profitably to applications of lime for general crops and must be limed to grow alfalfa or sweet clover.

This widespread need of soil liming makes it highly important to know what forms of lime are most economical for the farmer to use.

Several forms of lime for neutralizing soil acidity are available to Indiana farmers. The principal of these are:

Ground Limestone.—This appears on the market in several different degrees of fineness. The coarsest is commonly known as "screenings" and is a by-product of road stone crushing plants, consisting of all the material which passess through a screen of 4 meshes to the inch, and containing a considerable quantity of dust. Another limestone product known as "fine ground limestone" is made by re-grinding road stone screenings or planer chips or is specially produced by grinding limestone rock to the desired degree of fineness. To be properly called "fine ground limestone" the material should all pass through a screen having at least eight meshes to the inch. Ten-mesh material is common in this class, but sometimes 50-mesh material is produced.

Hydrated Lime.—This is burned lime or quicklime to which enough water or steam has been added to slake it but still leave a dry product. It is the common builder's lime, but is often called "agricultural lime" or "agricultural hydrated lime" when sold for use on the land. About 1,500 pounds of this is equivalent to 2,000 pounds of pure ground limestone in acid neutralizing value, and should be so rated when comparing values for the purpose of neutralizing soil acidity.

Quicklime.—This is fresh burned lime. Eleven hundred and twenty pounds of this is equivalent to 1,500 pounds of hydrated lime or 2,000 pounds of pure ground limestone. It is very caustic and is seldom used for direct application to the land in this part of the country.

Air-slaked Lime.—This is quicklime or burned lime which has been exposed to the air for some time, taking up moisture and carbon dioxide. Fully air-slaked lime has practically the same composition as ground limestone. It usually appears as "waste lime" or "lime refuse" around lime kilns.

Marl.—This is a variable mixture of lime and earth ocurring in nature usually under marshes or muck beds or in the bottoms of glacial lakes or ponds in northern Indiana. In central Indiana, spring water deposits of marl and in southern Indiana beds of soft marl and calcareous clay are also important sources of soil liming materials. These marl beds and calcareous clays occur above, below or between ledges of limestone. As a rule, the purest marl beds in this section lie between two ledges of limestone rock. The lime contained in marl is in the form of carbonate of lime and to some extent magnesium carbonate, the same as air-slaked lime or ground limestone. Its acid neutralizing value may vary from 10 per cent to 90 per cent of that of ground limestone, depending upon its content of lime.

Sugar Factory Lime.—This is lime which has been used in sugar factories for purifying the juice containing the sugar. After having served its purpose in the sugar factory it is discarded and is a good form of lime to use on the land. On a dry basis it is about equal to ground limestone.

Other materials containing lime are the residues from acetylene plants, alkali works, mussel shells and button factory wastes.

The materials commonly offered to Indiana farmers for use on the land are ground limestone of various degrees of fineness and hydrated lime but up in paper sacks, usually

sold as "agricultural lime." These materials, therefore, are the ones which have been compared in the experiment reported in this bulletin in order to determine their comparative value for neutralizing soil acidity. On the Pinney-Purdue Experiment Field at Wanatah, lake marl has been included in the comparison because much of this material is available in northern Indiana.

Some of the ground limestone and hydrated limes are made from limestone containing magnesium. Some of these magnesian limestones contain around 45 per cent of magnesium carbonate, which has a somewhat higher acid neutralizing value than pure calcium limestone. This experiment has, therefore, included comparisons of magnesian hydrated lime and magnesian ground limestone.

Lime Materials Used

The lime materials used in these comparative tests, the screen tests and acid neutralizing value of each are shown in the following tables:

TABLE I. SCREEN TEST AND ACID NEUTRALIZING VALUE OF LIME MATERIALS TESTED ON THE PINNEY-PURDUE EXPERIMENT FIELD AT WANATAH

Liming Materials	Screen Test				Acid neutralizing value compared with pure calcium limestone at 100
	Percent through 4-mesh screen	Percent through 10-mesh screen	Percent through 20-mesh screen	Percent through 50-mesh screen	
10-mesh calcium limestone	100	95	70	37	94.5
10-mesh magnesian limestone	100	75	47	25	106.5
50-mesh calcium limestone	....	....	....	100	94.5
4-mesh calcium limestone (screenings)	100	66	46	25	89.0
10-mesh high iron limestone	100	87	57	37	94.5
4-10 mesh calcium limestone	100	23	1	0	90.5
Blast furnace slag	100	99	88	67	71.0
Marl	....	....	....	100	68.5
Hydrated calcium lime	....	....	....	100	144.0
Hydrated magnesian lime	....	....	....	100	167.0

The various liming materials used were intended to represent commercial grades. The screen tests which were made in the laboratory showed that the [illegible]esh magnesian limestone was considerably coarser than the 10-mesh calcium limestone, especially at Wanatah, although it contained noth-

TABLE II. SCREEN TEST AND ACID NEUTRALIZING VALUE OF LIME MATERIALS TESTED ON THE JENNINGS COUNTY EXPERIMENT FIELD AT NORTH VERNON

Liming Materials	Screen Test				Acid neutralizing value compared with pure calcium lime stone at 100
	Percent through 4-mesh screen	Percent through 10-mesh screen	Percent through 20-mesh screen	Percent through 50-mesh screen	
10-mesh calcium limestone	100	98	78	40	94.5
10-mesh magnesian limestone	100	90	57	34	98.0
50-mesh calcium limestone	100	100	100	100	94.5
4-mesh calcium limestone (screenings)	98	83	64	35	89.0
4-10 mesh calcium limestone	100	15	1	0	90.5
Hydrated calcium lime	....	....	....	100	144.0
Hydrated magnesian lime	....	....	....	100	167.0

ing coarser than 8-mesh. The magnesian limestone used, therefore, is not fairly comparable with the calcium limestone. Twenty per cent more of the calcium stone passed through the 10-mesh screen than of the magnesian stone used at Wanatah, and 8 per cent more in the case of the materials used at North Vernon. These differences in relative fineness of these two materials probably account for the lower efficiency of the magnesian stone in the field and should be considered in interpreting the results.

As the plan was to compare commercial products, no attempt was made to control the proportions of the finer particles. The 20-mesh and 50-mesh portions of the magnesian stone are doubtless lower than they would have been had an equal amount passed through the 10-mesh screen as in the case of the calcium stone.

The 4-mesh material used at Wanatah was about average, while that used at North Vernon was somewhat finer than the 4-mesh screenings usually delivered in Indiana. This probably accounts for the higher relative efficiency of the 4-mesh material in the North Vernon test and should be considered in interpreting the results.

The 4-10 mesh materials prepared in the field were shown by the laboratory screen test to contain considerable proportions passing through the 10-mesh screen, although practically nothing passed through the 20-mesh screen.

The 4-mesh, 10-mesh and 4-10 mesh calcium limestone and the hydrated calcium lime used in these tests came from a quarry at Mitchell. The 50-mesh calcium stone came from a quarry at Sibley, Michigan, and the hydrated high magnesium lime came from Huntington. The blast furnace slag is a by-product of the steel mills in the Calumet district. The 10-mesh high magnesium limestone used in the Pinney-Purdue test came from a quarry in the Chicago district, and that in the Jennings County test from a quarry at Vernon, Indiana. The marl in the Pinney-Purdue test was from a lake-bed deposit in Kosciusko County and the 10-mesh high iron limestone from a quarry near Evansville. The high iron stone was included in the test to determine whether the iron might be injurious to crops.

Location of Experiments and Types of Soil

The lime materials tests reported in this bulletin are located on two important types of soil which were known to be high in acidity and to respond well to liming. One of these is the Newton fine sandy loam, acid phase, on the Pinney-Purdue Experiment Field at Wanatah, Indiana. This is a dark brown prairie soil containing about 10 per cent of organic matter naturally quite unproductive on account of high acidity and widely represented in the Kankakee Valley. The other is the Clermont silt loam on the Jennings County Experiment Field at North Vernon, Indiana. This is an ashy gray timber soil occuring on upland flats. It is naturally wet and very acid and is widely represented in southeastern Indiana. The organic matter content of this soil is very low, being about 3 per cent.

The Pinney-Purdue Experiment at Wanatah

On the Pinney-Purdue field, three series of 27 one-twentieth acre plots were laid out for a three-year rotation of corn, oats, and mixed clover and timothy and the various lime materials applied in the spring of 1920. No lime has been applied since, except on plot 5 which received a second application in 1926, and plots 23 and 24 which get small applications of agricultural lime and limestone on each grain crop. All the lime materials are represented on each of the three series of plots in the same order. There are, therefore, three plots of each lime material in the experiment and each of the three crops is grown every year, rotating progressively on the three series of plots. The limestone materials were applied in equal amounts regardless of their acid neutralizing values. The hydrated limes and marl were applied in amounts equivalent to the 4-ton application of 10-mesh calcium limestone in acid neutralizing value. The 4-mesh and 10-mesh calcium limestone and hydrated calcium lime were also used at one-half the normal 4-ton rates. The 10-mesh calcium and high magnesium limestone were also applied at the rate of 16 tons per acre.

All the plots in each series, except plots 1 and 27, which are untreated, receive a uniform dressing of 0-12-12 fertilizer at the rate of 400 pounds per acre once in three years when preparing the ground for corn. All the crops are harvested, weighed and removed except the corn stalks and second growth clover and grass, which remain on the land.

The following table shows the arrangement of the lime treatments, the rates of application, the average crop yields, the total value of the crop increases produced by each lime material to date, the cost of the application and the net returns to date.

TABLE III. AVERAGE CROP YIELDS, LIME MATERIALS TEST PINNEY-PURDUE EXPERIMENT FIELD, 1920-1927

Plot No.	Lime material and rate of application	Average yields per acre			Total value of crop increases to date	Cost of lime material	Net return to date*
		Corn bushels	Oats bushels	Hay pounds			
1	Untreated	4.7	10.2	868	....	....	....
2	No lime (check)	8.9	14.1	809	....	....	....
3	2 tons 10-mesh calcium limestone	27.7	25.6	1831	$54.27	$ 7.00	$47.27
4	4 tons 10-mesh calcium limestone	30.9	29.8	2065	65.84	14.00	51.84
5	4 tons 10-mesh calcium limestone	28.8	26.7	2024	....	....	....
6	No lime (check)	14.7	14.4	1069	....	....	....
7	16 tons 10-mesh calcium limestone	30.3	32.6	2750	67.17	56.00	11.17
8	4 tons 10-mesh magnesian limestone	29.3	31.3	2543	57.04	14.00	43.04
9	16 tons 10-mesh magnesian limestone	28.6	37.2	2707	61.44	56.00	5.44
10	No lime (check)	17.8	21.5	1205	....	....	....
11	2 tons 4-mesh calcium limestone screenings	26.0	29.3	1927	34.32	6.00	28.32
12	4 tons 4-mesh calcium limestone screenings	28.0	32.2	2114	47.52	12.00	35.52
13	4 tons between 4 and 10-mesh calcium limestone	29.0	28.3	1704	39.52	10.00	29.52
14	No lime (check)	12.6	19.6	1202	....	....	....
15	4 tons 50-mesh calcium limestone	30.4	30.9	2300	59.52	18.00	41.52
16	4 tons marl	31.8	30.5	2378	63.73	....	....
17	4 tons 10-mesh iron limestone	28.8	29.5	2154	55.05	14.00	41.07
18	No lime (check)	12.3	14.7	1149	....	....	....
19	1.4 tons hydrated calcium lime	26.6	28.6	2015	50.10	16.80	33.30
20	2.8 tons hydrated calcium lime	30.1	30.2	2026	56.35	33.60	22.75
21	2.4 tons hydrated magnesian lime	31.2	32.3	2257	62.38	28.80	33.58
22	No lime (check)	13.9	16.9	1188	....	....	....
23	300 pounds hydrated lime on each grain crop	22.3	21.8	1391	25.30	8.40	16.90
24	440 pounds 50-mesh limestone on each grain crop	22.0	21.3	1432	28.45	4.02	23.83
25	4 tons blast furnace slag	25.2	27.4	1525	44.90	....	....
26	No lime (check)	9.3	14.3	941	....	....	....
27	Untreated	4.7	9.9	965	....	....	....
	Average no lime checks	12.8	16.5	1115	....	....	....

*In calculating the values of the crop increases, corn has been valued at 60c and oats at 35c per bushel; oats straw at $3.00 and hay at $12.00 per ton. The liming materials, applied to the land, have been charged at $3.50 for 10-mesh, $3.00 for 4-mesh, $2.50 for 4 to 10-mesh and $4.50 for 50-mesh ground limestone per ton, and $12.00 per ton for hydrated lime.

An examination of Table III shows that on the Pinney-Purdue field all the lime treatments have produced good increases on each of the three crops compared with the unlimed check plots. Aside from the 16-ton application, the largest total increase to date has been produced by the 4-ton application of 10-mesh ground limestone (plot 4) amounting to $65.84. However, plot 5, which received a similar application, probably due to soil variation, has produced a smaller total increase although it received a further application of 2 tons in 1926. Marl (plot 16) stands next to the 10-mesh ground limestone in value of crop increases produced, having $63.73 to its credit. This is closely followed by the 2.4 ton application of magnesian hydrated lime (plot 21), which amount is the equivalent of the 4 tons of 10-mesh limestone in acid neutralizing value, and has $62.38 to its credit. The 50-mesh limestone (plot 15) stands next with $59.52. The 2.8 tons of hydrated calcium lime has $56.35 to its credit.

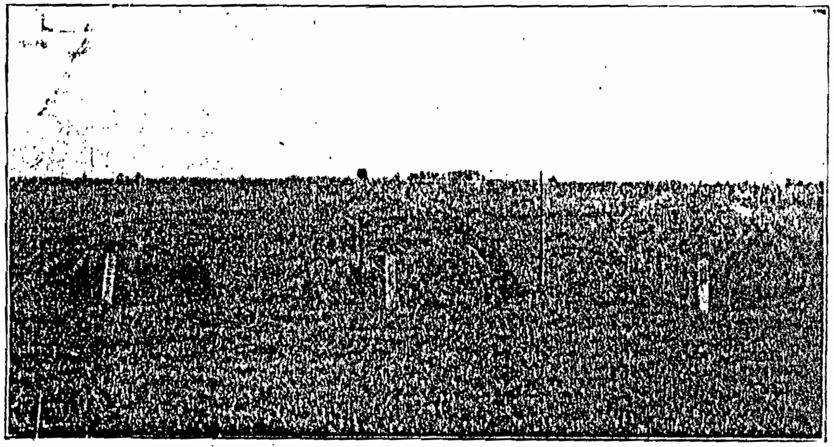

Fig. 2. Marl is just as efficient in neutralizing soil acidity as fine ground limestone or hydrated lime.

Average Pounds of Hay per Acre, 1920-1927

No lime	Fine ground limestone	Marl of equal lime content
1205 pounds of hay per acre	2360 pounds of hay per acre	2378 pounds of hay per acre

Taking next the half applications of 10-mesh ground limestone and hydrated calcium lime, the ground limestone again stands ahead of the hydrated lime. From these experiments, therefore, it appears that on the basis of equivalent acid neutralizing amounts, 10-mesh ground limestone and marl are at least as effective as hydrated lime or 50-mesh limestone. Taking out the costs of the materials, the 10-mesh limestone has netted $47.27 from the 2-ton application and $51.84 from the 4-ton application, while the hydrated lime has netted $22.75 from the 1.4 tons application and $33.30 from the 2.8 tons application. Taking the averages of the two rates of application, and counting the ground limestone at $2.50 per ton, the hydrated lime is worth relatively $3.17 per ton on the basis of the crop increases produced.

The coarser material, 4-mesh screenings (plots 11 and 12), averaging crop increases valued at $40.92, has not been as efficient to date as the equivalent amounts of 10-mesh ground limestone (plots 3 and 4), averaging $60.05. The very coarse material, between 4- and 10-mesh (plot 13), is least efficient, although in the later years it shows an increasing availabilty.

The 10-mesh magnesian limestone (plot 8), has been less effective than the 10-mesh calcium limestone. This is probably due to the fact that it was not as finely ground as shown by the screen test. As has been suggested in discussing the screen test, this should be taken into account in interpreting these results. The magnesian hydrated lime is fully equal to the calcium hydrated lime. The high iron limestone stands slightly below the magnesian stone.

The very light periodic applications of 300 pounds of hydrated lime and 440 pounds of 50-mesh limestone on each grain crop (plots 23 and 24), have produced relatively small crop increases when compared with the large single applications (plots 19, 20 and 15), amounting to $25.30 and $28.45, respectively, as compared with $50.10, $56.35 and $59.52 for the heavier single applications at the end of the seventh year. There has never been a good stand of clover on these plots. With liming materials so cheap, the application of such small amounts year by year is unwise and economically unsound as the results are small and the labor cost of the repeated applications is too great. In the case of the small application of ground limestone on each corn and oats crop, the net return to date after paying for the material has been $23.83 as against $51.84 from the 4-ton single application of 10-mesh limestone. In the case of the small application of hydrated lime, the net return to date has been $16.90 as against $33.30 from the 1.4 tons and $22.75 from the 2.8 tons single applications.

The 16-ton applications of ground limestone (plots 7 and 9) were made to see if liming might be overdone on this land. The results indicate that there is no harmful effect, although these large amounts have not been as profitable to date as the 2-ton and 4-ton applications. Laboratory tests on the soil indicate that there is more wastage of lime from the heavily lined plots than there is from the plots not so heavily limed.

The Jennings County Experiment at North Vernon

On the Jennings County Experiment Field, three series of 23 one-twentieth acre plots were laid out for a three-year rotation of corn, wheat and mixed clover and timothy and the various lime materials applied in the fall of 1920 for wheat and in the spring of 1921 for corn and for soybeans which took the place of clover as the hay crop the first year. No lime has been applied since, except on plot 5 which received an additional application of 2 tons of 10-mesh ground limestone in 1927, and plots 19 and 20, which get small applications of hydrated lime and fine ground limestone on each grain crop. All the lime materials are represented on each of the three series of plots in the same order. There are, therefore, three plots of each lime material in the experiment and each of the three crops is grown every year, rotating progressively on the three series of plots.

In this experiment the limestone materials were applied in equal amounts regardless of their acid neutralizing values. The hydrated limes were applied in amounts equivalent to the 3-ton application of 10-mesh calcium limestone in acid neutralizing value. The 4-mesh and 10-mesh calcium stone and the hydrated calcium lime were also used at one-half the normal 3-ton rates and the 10-mesh calcium and magnesian limestones were applied to two plots at 12 tons per acre.

All the plots in each series, except plots 1 and 26, which are untreated, receive a uniform dressing of 2-12-6 fertilizer at the rate of 400 pounds per acre once in three years on the wheat. The first corn crop on each series received 5 tons of manure per acre. All the crops are harvested, weighed and removed except the second growth clover and grass, which remain on the land.

The following table shows the arrangement of the lime treatments, the rates of application, the average crop yields, the total value of the crop increases produced by each lime material to date, the cost of the application and the net returns to date.

TABLE IV. AVERAGE CROP YIELDS, LIME MATERIALS TEST JENNINGS COUNTY EXPERIMENT FIELD, 1921-1927

Plot No.	Lime material and rate of application	Average yields per acre			Total value of crop increases to date	Cost of lime material	Net return to date*
		Corn bushels	Wheat bushels	Hay pounds			
1	Untreated	31.3	5.0	952	....	....	....
2	No lime (check)	43.0	12.7	1472	....	....	....
3	1.5 tons 10-mesh calcium limestone	53.4	16.0	2601	$30.15	$ 5.25	$33.90
4	3 tons 10-mesh calcium limestone	56.0	19.4	3035	51.66	10.50	41.16
5	3 tons 10-mesh calcium limestone	54.6	19.2	3206	....	....	....
6	No lime (check)	46.9	14.0	2371	....	....	....
7	12 tons 10-mesh calcium limestone	58.6	22.0	3545	61.85	42.00	19.85
8	3 tons 10-mesh magnesian limessone	54.0	18.9	3207	38.85	10.50	28.35
9	12 tons 10-mesh magnesian limestone	50.8	20.7	3158	51.31	42.00	9.31
10	No lime (check)	46.3	14.6	1909	....	....	....
11	1.5 tons 4-mesh calcium limestone screenings	52.4	17.3	2835	30.43	4.50	25.93
12	3 tons 4-mesh calcium limestone screenings	56.1	19.5	3135	45.34	9.00	36.34
13	3 tons between 4 and 10-mesh calcium limestone	52.0	17.6	2861	31.29	7.50	23.79
14	No lime (check)	46.2	14.2	2072	....	....	....
15	1 ton hydrated calcium lime	53.5	18.4	2839	38.50	12.00	26.50
16	2 tons hydrated calcium lime	54.9	20.3	2915	51.82	24.00	27.82
17	1.8 tons hydrated magnesian lime	51.2	20.3	2861	48.74	21.60	27.14
18	No lime (check)	42.7	13.5	1598	....	....	....
19	300 pounds hydrated lime on each grain crop	44.2	15.1	2201	18.34	8.40	9.94
20	440 pounds 50-mesh limestone on each grain crop	45.1	15.7	2371	26.95	5.39	21.56
21	3 tons 50-mesh calcium limestone	51.4	18.4	2672	52.01	13.50	38.51
22	No lime (check)	39.7	12.2	1474	....	....	....
26	Untreated	30.4	5.2	718	....	....	....
	Average no lime checks	44.3	13.7	1816	....	....	....

*In calculating the values of the crop increases, corn has been valued at 60c and wheat at $1.25 per bushel; corn stover at $3.00, wheat straw at $2.50, and hay at $12.00 per ton. The liming materials, applied to the land, have been charged at $3.50 for 10-mesh, $3.00 for 4-mesh, $2.50 for 4 to 10-mesh and $4.50 for 50-mesh ground limestone per ton, and $12.00 per ton for hydrated lime.

An examination of Table IV shows that on the Jennings County field, all the lime treatments produced good increases on each of the three crops compared with the unlimed check plots. From the standpoint of total profits, the largest net increase to date has been secured from the 3-ton application of 10-mesh ground limestone (plot 4).

Comparing the different materials and taking first the lighter applications, it is seen that the 1.5 tons of 10-mesh ground limestone has netted $33.90 to date, while the 1.5 tons of 4-mesh screenings have netted $25.93, and the 1 ton of hydrated lime has netted $26.50. The 3-ton application of 10-mesh ground limestone has netted $41.16; the 3 tons of 4-mesh screenings have netted $36.34; the 2 tons of hydrated calcium lime have netted $27.82, and the 1.8 tons of hydrated magnesian lime have netted $27.14.

On the basis of crop increases produced without reference to cost, the light and heavy applications of 10-mesh limestone have averaged $45.40, while the equivalent acid neutralizing amounts of hydrated lime have averaged $45.16. These results give hydrated lime a relative value of $3.74 per ton when 10-mesh ground limestone costs $2.50 per ton.

The 3-ton application of 50-mesh limestone (plot 21) has produced only 35 cents more total crop increase than the 3 tons of 10-mesh limestone (plot 4), indicating that with such liberal applications it does not pay to grind limestone any finer than 10-mesh with its dust, as is also shown in the experiment at Wanatah.

The 10-mesh magnesian limestone (plot 8) has not been as effective as the 10-mesh calcium limestone (plot 4), probably due to the fact that it was not as finely ground. As has been suggested in discussing the screen test, this should be taken into account in interpreting these results. Ton for ton the hydrated magnesian lime is practically equal to hydrated calcium lime (plots 16 and 17).

On the basis of equal acid neutralizing amounts, the light applications of hydrated lime and 50-mesh limestone on each corn and wheat crop (plots 19 and 20) show the limestone to be more effective than the hydrated lime, as both the crop increases and the net returns have been higher. This system of liming has been less profitable than the single large applications. It was impossible to get a stand of clover on these plots until the sixth year, whereas good stands have resulted every year from the seedings on the single 3-ton applications.

The coarse material between 4 and 10-mesh (plot 13) has been considerably less effective than either the 4-mesh or 10-mesh material (plots 12 and 4), although it has neutralized enough acidity to get fair stands of clover, usually mostly alsike.

The 12-ton applications, which were made to see if liming could be overdone on this land, have produced no harmful effects, although these large amounts have not been as profitable to date at the 3-ton and 1.5-ton applications.

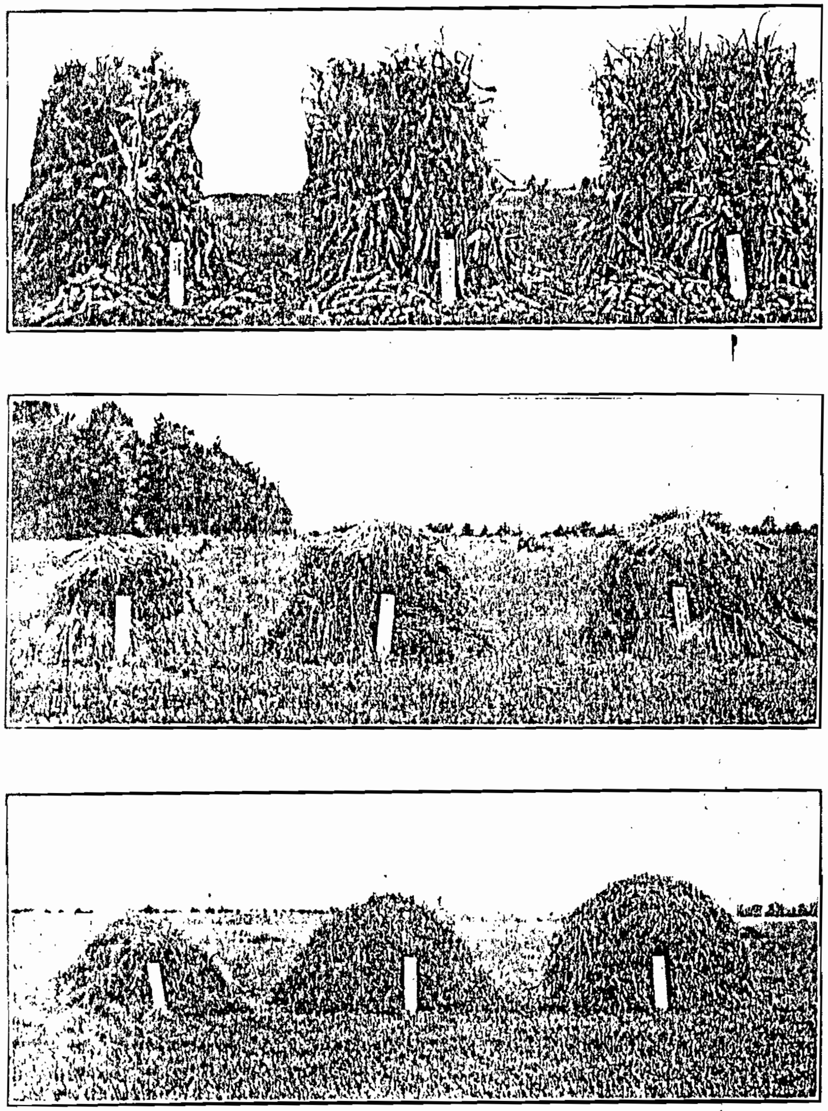

Fig. 3. Effects of ground limestone on corn, wheat and clover at two different rates of application. Jennings County Experiment Field, 1922.

Average Yields of Crops, 1921-1927

	Unlimed	1.5 Tons 10-mesh limestone per acre	3 Tons 10-mesh limestone per acre
Corn	43.9 bus.	53.4 bus.	56.9 bus.
Wheat	12.5 bus.	16.9 bus.	19.4 bus.
Clover	1472 lbs.	2691 lbs.	3035 lbs.
Total value of crop increase in 7 years		$39.15	$51.66

Action of the Different Liming Materials by Years

To see how the different liming materials have acted from year to year the progressive total values of the crop increases per acre produced by each have been tabulated for the Pinney-Purdue field in Table V, for the Jennings County field in Table VI and for the average of the two fields in Table VII. The values shown are the per acre averages for the three crops in the rotation for the particular year. For convenience in making comparisons the liming materials are grouped according to equivalent rates of application.

It is perhaps unnecessary to discuss in detail the results on the separate experiment fields. The differences in the returns from the various liming materials are in the same direction

TABLE V. SUMMARY OF THE PINNEY-PURDUE LIME MATERIALS TEST, 1920-1927, SHOWING TOTAL RETURN PER ACRE AT THE END OF EACH YEAR

Liming materials and per acre rates of application*	Average acre values of crop increases at end of each year†							
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year
2 tons 10-mesh calcium limestone	$6.70	$14.72	$20.33	$29.20	$36.87	$39.44	$45.43	$54.27
2 tons 4-mesh calcium limestone (screenings)	4.67	10.46	14.61	20.20	26.10	28.10	32.04	34.32
1.4 tons hydrated calcium lime	4.76	10.62	18.40	26.36	34.15	36.92	43.35	50.10
4 tons 10-mesh calcium limestone	8.20	16.84	23.27	31.44	42.30	45.78	51.92	65.84
4 tons 4-mesh calcium limestone (screenings)	6.15	11.10	15.05	22.80	32.50	34.48	41.37	47.52
4 tons 50-mesh calcium limestone	6.38	13.86	18.67	29.00	40.40	43.16	49.06	50.52
2.8 tons hydrated calcium lime	5.43	12.10	16.60	26.00	36.45	39.74	46.74	56.35
2.4 tons hydrated magnesian lime	5.22	13.34	19.13	30.20	39.55	43.10	51.85	62.38
4 tons 10-mesh magnesian limestone	8.22	14.04	18.90	26.12	36.50	39.68	48.18	57.04
5.5 tons marl	7.40	13.90	19.24	34.32	41.55	44.12	50.00	63.73
4 tons 10-mesh high iron limestone	5.84	10.34	14.93	23.96	35.20	37.68	44.92	55.07
4 tons 4-10 mesh calcium limestone	2.41	5.76	8.02	14.00	25.15	27.50	34.93	39.52
4 tons blast furnace slag	3.05	7.02	10.33	22.20	29.55	30.74	39.92	44.90
10 tons 10-mesh calcium limestone	8.52	16.28	21.26	28.68	43.45	46.50	55.53	67.17
10 tons 10-mesh magnesian limestone	9.26	14.68	21.05	29.64	39.30	43.02	52.71	61.44
300 pounds hydrated lime on each grain crop	2.52	6.88	9.01	12.32	15.00	15.00	21.33	25.30
440 pounds 50-mesh limestone on each grain crop	2.17	4.66	7.45	13.44	18.30	18.48	24.59	28.15

*All applications were made in 1920 only, except the last two at the bottom of the table which were applied for each crop of corn and oats.

†In calculating the values of the crop increases, corn has been valued at 60c and oats at 35c per bushel; oat straw at $3.00 and hay at $12.00 per ton.

TABLE VI. SUMMARY OF JENNINGS COUNTY LIME MATERIALS TEST, 1921-1927, SHOWING TOTAL RETURN PER ACRE AT THE END OF EACH YEAR

Liming materials and per acre rates of application*	Average acre values of crop increases at end of each year†						
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year
1.5 tons 10-mesh calcium limestone	$2.43	$7.04	$14.32	$19.60	$24.60	$31.58	$39.15
1.5 tons 4-mesh calcium limestone (screenings)	1.97	6.38	9.41	15.88	21.00	24.88	30.43
1 ton hydrated calcium lime	3.76	10.16	15.41	21.36	25.85	31.38	38.50
3 tons 10-mesh calcium limestone	3.06	8.66	17.08	27.12	33.25	42.24	51.66
3 tons 4-mesh calcium limestone (screenings)	3.45	9.38	14.15	23.56	29.50	37.26	45.34
3 tons 50-mesh calcium limestone	3.79	10.62	19.77	27.40	36.90	43.14	52.01
2 tons hydrated calcium lime	4.37	11.56	19.34	29.40	36.55	41.68	51.82
1.8 tons hydrated magnesian lime	2.01	10.50	16.93	26.88	33.95	40.30	48.74
3 tons 10-mesh magnesian limestone	3.18	8.22	16.04	22.88	27.40	31.36	38.85
3 tons 4-10 mesh calcium limestone	1.97	5.86	9.37	14.24	18.25	24.10	31.20
12 tons 10-mesh calcium limestone	9.06	13.66	21.53	32.72	41.15	52.48	61.83
12 tons 10-mesh magnesian limestone	6.76	11.42	18.67	31.08	37.25	45.08	51.31
300 pounds hydrated lime on each grain crop	-1.01	1.44	4.48	8.04	10.20	12.08	18.34
440 pounds 50-mesh limestone on each grain crop	.38	3.20	6.72	13.12	15.40	19.88	26.95

*All applications were made in 1921 only, except the last two at the bottom of the table which were applied for each crop of corn and wheat.
†In calculating the values of the crop increases, corn has been valued at 50c and wheat at $1.25 per bushel; corn stover and wheat straw at $2.50, and hay at $12.00 per ton.

on both fields in most cases. In a few cases the differences are reversed. The hydrated lime has produced larger increases than the fine ground limestone on the Jennings County field during the first five years, while the reverse has occured throughout on the Pinney-Purdue field at Wanatah. This difference may be due to the fact that the two soil types are vastly different. However, the ground limestone has been much more profitable than the hydrated lime every year on both fields. The hydrated magnesian lime has been more effective than the hydrated calcium lime on the Pinney-Purdue field, while the reverse has occured on the Jennings County field. The 10-mesh limestone has been more effective than the 50-mesh limestone on the Pinney-Purdue field, while the reverse has occured on the Jennings County field.

Considering Table VII, which shows the average of the two fields, is should be noted first that the 10-mesh ground lime-

TABLE VII. AVERAGE RESULTS OF LIME MATERIALS TEST ON JENNINGS COUNTY AND PINNEY-PURDUE EXPERIMENT FIELDS, FIRST SEVEN YEARS

Liming materials and per acre rates of application	Average acre values of crop increases at end of each ye						
	1st year	2nd year	3rd year	4th year	5th year	6th year	7th ye
1.75 tons 10-mesh calcium limestone	$4.56	$10.88	$17.32	$24.40	$30.73	$35.51	$42
1.75 tons 4-mesh calcium limestone (screenings)	3.32	8.42	12.01	18.04	23.55	26.49	31
1.2 tons hydrated calcium lime	4.20	10.41	16.90	23.80	30.00	31.15	40
3.5 tons 10-mesh calcium limestone	5.63	12.75	20.17	29.28	37.77	43.71	51
3.5 tons 4-mesh calcium limestone (screenings)	4.80	10.24	14.85	23.18	31.00	35.87	43
3.5 tons 50-mesh calcium limestone	5.08	12.24	19.22	28.20	38.65	43.15	50
2.4 tons hydrated calcium lime	4.90	11.83	18.01	27.70	36.50	40.71	49
2.1 tons hydrated magnesian lime	4.06	11.92	18.03	28.54	36.75	41.70	50
3.5 tons 10-mesh magnesian limestone	5.70	11.13	17.47	24.50	31.05	35.53	43
3.5 tons 4-10 mesh calcium limestone	2.10	5.81	8.60	14.12	21.70	25.80	35
14 tons 10-mesh calcium limestone	8.79	14.07	21.39	30.70	42.30	49.19	58
14 tons 10-mesh magnesian limestone	8.01	13.05	19.86	30.36	38.27	44.05	52
300 pounds hydrated lime on each grain crop	.75	4.16	6.71	10.18	12.60	13.51	10
440 pounds 50-mesh limestone on each grain crop	1.27	3.03	7.08	13.28	16.85	19.18	25

stone has been fully as effective the first year as the hydrate lime in both rates of application, and that the 4-mesh screer ings have been almost as effective in the heavier rate of a plication. There has been a common belief that hydrated lim acts more quickly than ground limestone. This is not born out in these tests. According to these experiments ther seems to be no good reason why farmers should use hydrate lime when the equivalent in ground limestone can be pu chased and applied at from one-third to one-quarter of th cost of hydrated lime. Averaging the gross returns from th two rates of application in each case and counting the 10-mes limestone at $2.50 per ton, the hydrated lime shows a rela tive value of $3.49 per ton. It is interesting to note tha this relative value is very close to the theoretical acid neu tralizing basis of comparison, which rates 74 pounds of pur hydrated lime as equivalent to 100 pounds of pure groun limestone. On the average the 10-mesh limestone also ha been fully as effective at the beginning and throughout as th 50-mesh limestone. It seems, therefore, that there is no ad vantage in grinding limestone finer than 10-mesh when applications are made at the rates here compared.

Perhaps the next most important point brought out in these experiments is that, at least on such highly acid soils, the application of small amounts of either hydrated lime or ground limestone annually of for each grain crop is not nearly as effective as applying at least two tons per acre at the beginning.

The 4-mesh limestone or so-called "screenings" has not been as effective as the 10-mesh material at either rate of application.

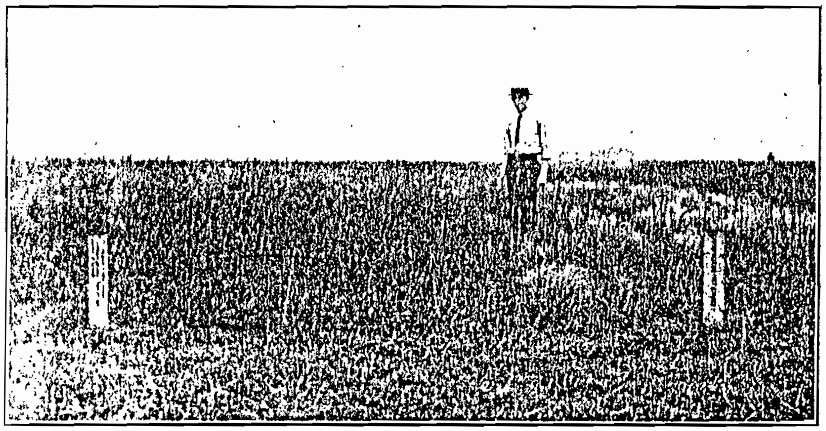

Fig. 4. Effect of ground limestone on mixed hay, Pinney-Purdue Experiment Field, 1922.
Left—4 tons ground limestone and fertilizer.
Right—Fertilizer alone.

The 1.5-ton to 2-ton applications have been less effective per acre than the 3-ton to 4-ton applications. However, in practice, if only a limited investment in liming can be made at one time it will be more profitable per dollar invested to lime twice as many acres at the lighter rate until the whole farm is limed and then go back and make another similar application.

The hydrated magnesian lime has been fully as effective as the hydrated calcium líme, and if applied in equal volume it might be expected to be the more effective of the two materails. The magnesian limestone used in these experiments has not been as effective as the calcium limestone. This may be explained by the fact that the magnesian limestone was

not as finely ground as the calcium limestone. If the two materials had been ground equally fine they would doubtless have produced similar results, and is would seem safe to conclude that farmers need not be particular as to which of these two kinds of limestone they use if the fineness of grinding and the cost are similar.

In Figure 5 the data in Table VII are plotted to show graphically the average annual effects of the various liming materials, the curves showing the gross values of the crop increases produced each year.

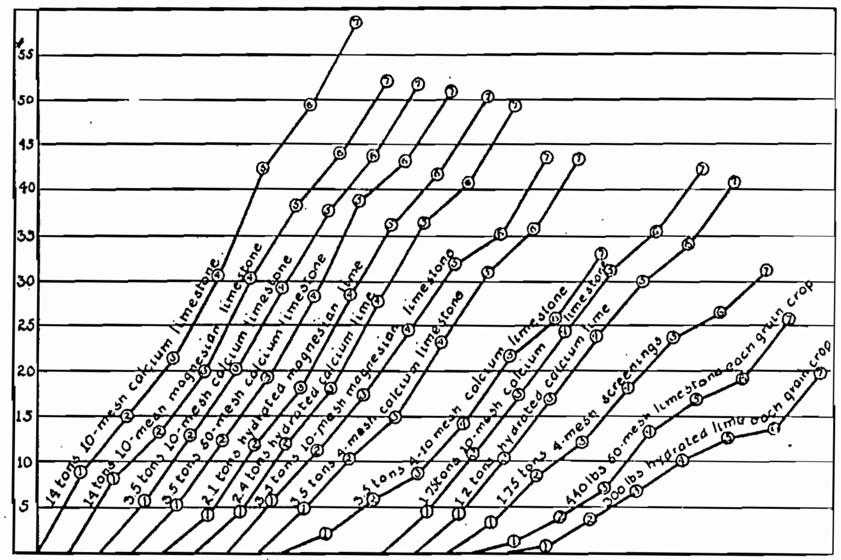

Fig. 5. Annual effects of the various liming materials during the first seven years as shown by the value of the total average crop increases for the two tests. The numbered circles mark successive years.

It is interesting to note that the first year effects of chemically equivalent applications of the hydrated limes and all grades of limestone were practically identical with the exception of the 4-10 mesh material and the lighter (1.75 tons per acre) application of 4-mesh screenings. Ten-mesh stone has been as effective as either hydrated lime or 50-mesh stone, as these materials parallel each other very closely throughout the seven-year period. They have also given increases close to those of the very heavy 14-ton applications.

The lighter (1.75 tons) application of 4-mesh screenings has fallen considerably behind the finer materials from the beginning and the 3.5-ton equivalent also shows a tendency to lag behind the finer materials. The magnesian limestone used carried little more fine material than the calcium screenings, which probably accounts for the similarity in their effects. The magnesian lime shows a slight advantage over the calcium lime.

The 3.5-ton application of 4-10 mesh material from which all the fine portion was screened out shows an interesting trend. It produced small increases for the first three years and then began to come up much faster, indicating that the coarse particles have a definite, even though somewhat delayed, action on the acidity of the soil.

The very light applications of hydrated lime and limestone applied to each grain crop started with very small increases, but their effects have increased as the total amount applied increased with successive applications. The seventh year jump in the effects of these light applications is an evidence of the close relationship between lime and clover in improving acid land. A good stand of clover was not obtained on the Jennings County field from these treatments until the sixth year. The residues of this crop plowed under for corn and another good crop of clover the seventh year were improtant factors in the large increases in the last year of the period.

Figure 6 shows graphically the total gross returns from the different calcium materials at the end of seven years, the cost of the material on the land, including interest charges, and the net value of the increase.

The 10-mesh limestone has produced slightly larger increases than equivalent applications of hydrated lime and considerably larger than the 4-mesh screenings. However, the cost of ground limestone in this state is so much less than that of hydrated lime that the net returns are about four times larger for the heavier applications of 10-mesh limestone and over 60 per cent larger for the light applications. The total increase from the 4-mesh limestone has not been as large as that from hydrated lime, but the net returns have been over three times as large in the case of the heavier applications. The lighter application of screenings shows less advantage over the equivalent application of lime.

The system of applying small amounts of hydrated lime every year or so has not proven satisfactory in these tests.

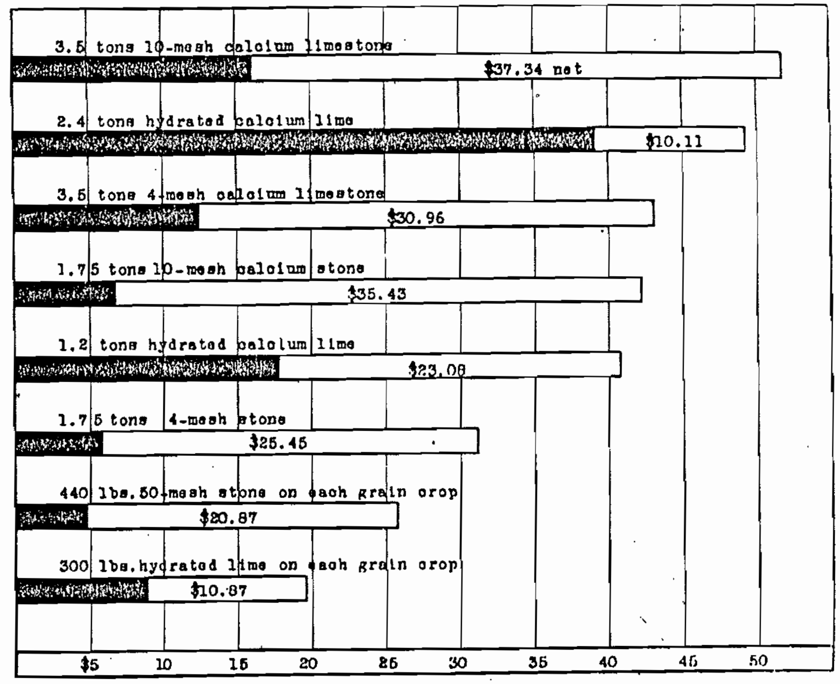

Fig. 6. Average effects of the various liming materials at the end of the seventh year of the two tests. The total length of each bar represents the total value of the crop increases; the shaded portion represents the cost, including interest charges, and the blank portion shows the net return.

Three hundred pounds of lime per acre applied to each grain crop has netted only $9.68 worth of crop increase without making any charge for the extra work involved in making four applications of the material to the land. The equivalent application of 50-mesh limestone has given better total and net results, but not as satisfactory as the system of applying larger quantities of ground limestone all at once.

Time Required to Pay Costs and Net Returns in Succeeding Years

Table VIII shows the point at which each of the applications represented in Figure 2 returned its cost, including interest at 6 per cent, and the total net return at the end of each succeeding year. The interest charges are stopped with the year that the returns paid the costs. No credit for interest on the returns is included, it being allowed to go towards paying the extra harvesting costs of the crop increases.

TABLE VIII. NET RETURNS PER ACRE AT THE END OF EACH YEAR AFTER DEDUCTING FIRST COST AND INTEREST AT 6 PER CENT*

Liming materials and per acre rates of application	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year
1.75 tons 10-mesh calcium limestone	-$1.03	$4.02	$10.46	$17.54	$23.87	$28.65	$35.43
1.75 tons 4-mesh calcium limestone (screenings)	—2.24	2.55	6.14	12.17	17.68	20.62	25.45
1.2 tons hydrated calcium lime	—11.00	—5.72	—.09	6.02	12.16	16.31	23.08
3.5 tons 10-mesh calcium limestone	—7.35	—.90	5.72	14.83	23.32	29.26	37.34
3.5 tons 4-mesh calcium limestone (screenings)	—6.33	—1.52	2.46	10.79	18.61	23.48	30.96
2.4 tons hydrated calcium lime	—25.63	—20.43	—15.07	—8.01	—.04	1.64	10.11
300 pounds hydrated lime on each grain crop	—.52	1.55	2.86	5.03	6.18	5.85	10.87
110 lbs. 50-mesh limestone on each grain crop	.57	2.53	4.98	10.48	13.35	1[illegible].96	20.87

*In these calculations the liming materials have been charged, applied to the land, at $3.50 for 10-mesh, $3.00 for 4-mesh, $4.50 for 50-mesh ground limestone per ton, and $12.00 per ton for hydrated lime.

The data in Table VIII shows the investments in both of the lighter single applications of limestone to have paid out in the second year and the heavier applications in the third year with the net for the 10-mesh considerably larger than that for the 4-mesh screenings. With the hydrated lime it took four years for the light and six years for the heavier applications to return the costs. In the system of light periodic applications the 50-mesh stone has given much better net returns from the start than the equivalent applications of hydrated lime. This system is not practical for Indiana where by-product limestone is so cheap and large single applications give so much greater returns.

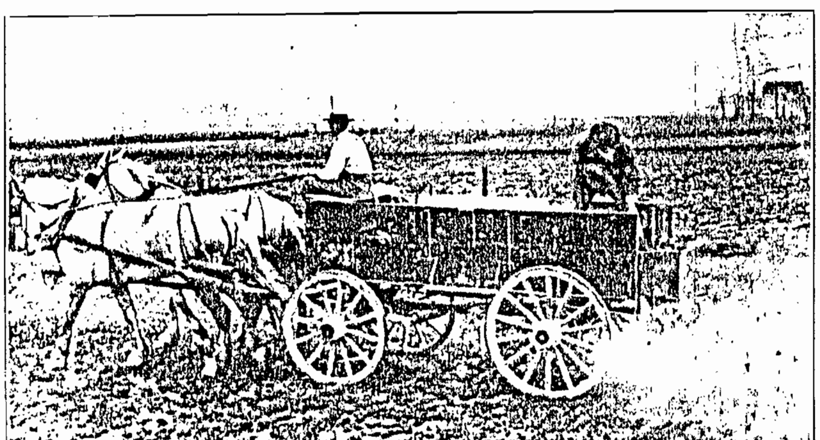

Fig. 7. Applying ground limestone with an endgate spreader.

Chemical Tests on the Limed and Unlimed Soils

After six years on the Jennings County field and seven years on the Pinney-Purdue field, samples of the soils on the unlimed plots and on some of the variously limed ones were analyzed. Twelve tons of limestone per acre had just neutralized the acidity in the surface 6 inches of the Jennings County soil, while the Pinney-Purdue surface soil was still slightly acid, even where 16 tons had been applied. The layer from 6 to 12 inches had been affected only slightly and the subsoil below 12 inches showed no effects, even with these heavy applications. The smaller applications tended to neutralize the surface layer, but still left it quite acid. In spite of this condition good clover stands have been secured every year on all limed plots on the Jennings County soil except those where the very light applications have been made on each grain crop. The soil on the Pinney-Purdue field is quite drouthy and clover failures are common. Two clover crops and five soybean hay crops have been grown there.

It is not practical to apply enought lime to neutralize all the acidity, even in the surface six-inch layer. The crop increases from the medium applications have been almost as large and much more profitable than those from the heavy applications.

On the Jennings County field all soil layers are acid to a depth of 10 feet and on the Pinney-Purdue field to a depth of 6 feet. Below these depths there is plenty of lime. The analyses of the upper layers showed that much of the lime applied had disappeared. The crops removed contained some lime, but the amount was small. The lime must have been leached down through the subsoil in the form of nitrates and to a lesser extent as sulphates or chlorides. In these forms it would not neutralize the caids in the subsoil. While the analyses showed no changes in acidity below 12 inches from the surface there were slight increases of combined calcium and magnesium in the subsoil layers.

How to Tell When A Soil Needs Liming

The frequent failure of red clover, alfalfa or sweet clover is a good indication that the soil is acid and in need of liming. Sweet clover and alfalfa are the most sensitive to lack of lime. Red clover will sometimes grow on soils too acid for sweet clover. Likewise alsike will sometimes be found where red clover fails. Other crops are indicators of still more acid soils, but for general farming, when the clovers fail, it is time to lime.

Sometimes a field may be acid in one part and not acid in another. If a mixture of sweet clover, alfalfa, alsike and timothy are seeded, the crops will make a map bv which the lime may be spread. It would be waste of money to lime land where alfalfa will grow well. As previously stated in this bulletin, it is not necessary to use enough lime to completely neutralize all the acidity. A very slight acidity is not harmful and it is often the most profitable.

Practically all county agricultural agents and many vocational agriculture teachers have equipment for testing soils for acidity. The Agronomy Department of the Agricultural Experiment Station will test soils for farmers who so desire. One-half pound samples are about right. Take the sample of the particular kind of soil from five or six spots, mix that and mark it so it may be identified. Prepare another mixture for each different type of soil. It is often a good idea to send both surface and subsoil samples of each kind of soil. The subsoil should be taken from below the plow depth to about one foot.

When to Apply Lime

Liming may be done when convenient. Quicker results will be secured when the lime is disked into the plowed soil. It is almost as good to apply it to sod or to top dress other crops. Growing wheat may be limed during the fall or winter. Such liming will benefit legumes seeded with the wheat in the spring.

Lime may be spread by hand with a shovel from a wagon, or it may be distributed with an endgate seeder as illustrated in Figure 7. Other types of lime spreaders built like a grain drill are often used. Sometimes manure spreaders are used.

It should be remembered that lime will not take the place of fertilizer or manure and that it should be used in addition to these materials.

The Amount of Limestone to Apply

If a soil is acid enough to require liming at all, it will pay to apply at least one ton of finely ground limestone to the acre. Some soils may require as much as four tons to the acre.

After the first application, one or two tons per acre applied every six to eight years will usually be sufficient to keep the soil in good condition.