GROUND LIMESTONE FOR ACID SOILS.

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*On leave of absence. §Connected with Grape Culture Investigations. **Connected with Hop Culture Investigations.
BULLETIN No. 400.

GROUND LIMESTONE FOR ACID SOILS.

J. F. BARKER AND R. C. COLLISON.

SUMMARY.

In the first section of this bulletin, the chemical composition of limestones is discussed briefly, with a table showing the carbonate content and calcium carbonate equivalent of the ground limestones produced in the various quarries of the State and of the principal ones brought in from outside. The limestone formations of the State will be fully treated in a later bulletin of the Station.

In following sections are given a discussion of the practical use of ground limestone on acid soils, an estimate of the proportion of soils in the State requiring liming, and compiled data showing the returns from the use of limestone on various crops and soils. The amounts of lime needed and methods of applying it under different conditions are fully discussed. Next, burned lime and limestone are compared as correcters of soil acidity, with notes on the relation of magnesium in limestone to its practical use.

Under the heading “Fineness of ground limestone,” theoretical considerations and experiments in its use are given to show that fineness greater than necessary to allow all the material to pass through a ten-mesh sieve is not required for satisfactory use.

The bulletin closes with a brief discussion of the nature and origin of soil acidity.

COMPARATIVE VALUE OF DIFFERENT LIMESTONES.

Limestones are made up of calcium carbonate or calcium and magnesium carbonates and a varying amount of clay-like material. The better grades run above 90 per ct. total carbonates. All limestones contain a higher percentage of calcium carbonate than magnesium carbonate, the latter varying in different stones from nothing to a maximum of about 45 per ct. Those containing 10 per ct. or more magnesium carbonate are usually referred to as magnesium limestones and if they carry near the maximum amount they are also called dolomites.

[145]
According to the present state of our knowledge, magnesium limestones are fully as effective as straight calcium stones for practical use in soil improvement. In fact, a given weight of magnesium carbonate is capable of neutralizing somewhat more acidity than the same weight of calcium carbonate, 100 pounds of the former being equal to 119 pounds of the latter in this respect. The comparative value of different limestones for use on the soil is conveniently expressed in terms of their calcium carbonate equivalents. This figure is simply obtained by adding to the percentage of calcium carbonate the percentage of magnesium carbonate multiplied by 1.19, since one pound of magnesium carbonate is chemically equivalent to 1.19 pounds of calcium carbonate; thus a stone containing 76 per ct. calcium carbonate and 20 per ct. magnesium carbonate would have a calcium carbonate equivalent of 99.8. This figure will usually be but little different from that for the percentage of total carbonates.

The buyer of ground limestone is often confused by certain firms or individuals insisting upon the especial merits of some particular product. He should note the figure for calcium carbonate equivalent and bear in mind that, assuming reasonable fineness, this gives the comparative value of the product. If a stone showing a calcium carbonate equivalent of 90 can be delivered to the buyer’s railway station for $1.80 per ton, then one having an equivalent of 100 is scarcely worth more than $2 per ton; the two are valuable in the proportion of 90 to 100, allowing only for the slightly greater amount of work in hauling and applying a given quantity of lime in the lower grade stone.

For a classification and description of the limestone formations of the State, together with a map showing extent and location of same, the reader is referred to a forthcoming bulletin of this Station.

The usual method of limestone analysis determines total calcium and magnesium without regard to the form in which they exist in the stone, it being taken for granted that all is in the carbonate form. The methods used in obtaining the above analyses take account only of the carbonates in limestone, the part effective for neutralizing soil acidity, and so the figures for calcium carbonate equivalent are from 0 to 3 per ct. lower than would be obtained by total analyses.

The bases for these analyses are, in the case of companies in the State, samples taken by a representative of the Station directly
from the storage bins of the company and also from carloads shipped to farmers. The figures given are the average of from two to six samples.\footnote{The analyses reported in this bulletin have been made by R. E. Keeler, Assistant Chemist.} Samples from companies outside the State have been collected from carloads shipped to New York farmers and have been taken either by a representative of the Station or of the State Department of Agriculture or by one of the County Farm Bureau men.

THE PRACTICAL USE OF GROUND LIMESTONE.

Crops sensitive to acid soils.—Nearly all general farm crops are sensitive to an acid condition or a lack of carbonates in the soil, and thrive much better if a certain amount of lime carbonate is present. As is well known, some of these, particularly alfalfa, clover, blue grass, timothy, beans, beets, and others can scarcely be grown with success unless the soil contains a liberal amount of carbonates. A few plants actually do better on an acid soil: for instance, blueberry, cranberry, serradella and the common sorrel. In practical farming such a great majority of the crops to be grown do better on well-limed soils that it is unprofitable to have the soil in an acid condition, provided only that limestone can be obtained at an economical price. Contrary to a common impression, potatoes require a fair amount of carbonates for their best development, and since they should always be grown in a rotation with other crops usually including clover or alfalfa it is out of the question to keep the soil acid for the sake of making it easier to combat the potato scab. The use of cover crops, especially legumes, emphasizes the importance of lime in connection with fruit-growing. Comparatively little data is available as to the direct effect of liming on the growth of various fruits, but in general it is known that the tendency of lime is to check excessive wood growth and promote fruitfulness.

Soils of the State in need of liming.—Three-fourths or more of the farm lands of New York State would be greatly benefited by a liberal application of lime in some form. In fact, such a treatment is fundamental to any rational method for the improvement of these soils. This is coming to be so generally recognized by practical farmers and it is a matter of such frequent discussion that it need not be advocated at length here.

The soils not at present in need of liming are those which have been naturally well stocked with limestone by reason of their having
<table>
<thead>
<tr>
<th>Name of company</th>
<th>Location of quarry, P. O. address</th>
<th>Total carbonates</th>
<th>Calcium carbonate equivalent</th>
<th>Calcium carbonate</th>
<th>Macornestum carbonates</th>
<th>Geologic formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adams &amp; Duford Co.</td>
<td>Chaumont</td>
<td>92.9</td>
<td>7.7</td>
<td>70.3</td>
<td>52.0</td>
<td>Lowville limestone</td>
</tr>
<tr>
<td>B. &amp; B. Lime &amp; Stone Co.</td>
<td>Mellenville</td>
<td>79.4</td>
<td>9.4</td>
<td>91.0</td>
<td>87.3</td>
<td>Manlius limestone</td>
</tr>
<tr>
<td>Buffalo Cement Co.</td>
<td>Buffalo</td>
<td>78.0</td>
<td>8.3</td>
<td>88.0</td>
<td>92.4</td>
<td>Cobleskill dolomite limestone</td>
</tr>
<tr>
<td>Auburn</td>
<td>Auburn</td>
<td>78.0</td>
<td>7.9</td>
<td>86.0</td>
<td>86.6</td>
<td>Onondaga limestone</td>
</tr>
<tr>
<td>Barkerdorf, H. J.</td>
<td>St. Johnsville</td>
<td>75.2</td>
<td>6.3</td>
<td>6.3</td>
<td>81.5</td>
<td>Trenton limestone</td>
</tr>
<tr>
<td>Caledonia Chemical Co.</td>
<td>Caledonia</td>
<td>78.8</td>
<td>6.6</td>
<td>85.4</td>
<td>86.7</td>
<td>Manlius limestone</td>
</tr>
<tr>
<td>Canajoharie Stone Co.</td>
<td>Canajoharie</td>
<td>78.8</td>
<td>6.6</td>
<td>85.4</td>
<td>86.7</td>
<td>Glens Falls limestone</td>
</tr>
<tr>
<td>Chazy</td>
<td>Chazy</td>
<td>78.8</td>
<td>6.6</td>
<td>85.4</td>
<td>86.7</td>
<td>Valcour limestone</td>
</tr>
<tr>
<td>Chazy Marble Lime Co.</td>
<td>Canajoharie</td>
<td>78.8</td>
<td>6.6</td>
<td>85.4</td>
<td>86.7</td>
<td>Manlius limestone</td>
</tr>
<tr>
<td>Conley Stone Co.</td>
<td>Utica</td>
<td>91.1</td>
<td>2.2</td>
<td>93.3</td>
<td>93.7</td>
<td>Stockbridge limestone</td>
</tr>
<tr>
<td>Conley Stone Co.</td>
<td>Blakeslee</td>
<td>91.0</td>
<td>1.8</td>
<td>92.8</td>
<td>94.1</td>
<td>Dover Plains</td>
</tr>
<tr>
<td>Dutchess Co. Lime Co.</td>
<td>Dover Plains</td>
<td>59.8</td>
<td>34.0</td>
<td>87.8</td>
<td>87.8</td>
<td>Stockbridge limestone</td>
</tr>
<tr>
<td>Devoe Limestone Co.</td>
<td>Accord</td>
<td>88.3</td>
<td>10.3</td>
<td>78.6</td>
<td>80.5</td>
<td>Dover Plains</td>
</tr>
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</table>

**COMPOSITION OF GROUND LIMESTONE FOR SALE IN NEW YORK STATE.**
<table>
<thead>
<tr>
<th>Company, Name of</th>
<th>Town</th>
<th>Analysis</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fretz, M. W.</td>
<td>Richfield Springs</td>
<td>89.7</td>
<td>90.7</td>
</tr>
<tr>
<td>Geneva Limestone Co</td>
<td>Geneva</td>
<td>Oaks Corners</td>
<td>59.7</td>
</tr>
<tr>
<td>Harris, John</td>
<td>Saratoga Springs</td>
<td>Rollins Hollow</td>
<td>88.1</td>
</tr>
<tr>
<td>Langdon &amp; Co.</td>
<td>Elmira</td>
<td>Pekin</td>
<td>84.8</td>
</tr>
<tr>
<td>LeRoy Limestone Co</td>
<td>LeRoy</td>
<td>LeRoy</td>
<td>89.1</td>
</tr>
<tr>
<td>Medina Limestone Co</td>
<td>Medina</td>
<td>Medina</td>
<td>53.7</td>
</tr>
<tr>
<td>Norton Stone &amp; Lime Co</td>
<td>Cobleskill</td>
<td>Cobleskill</td>
<td>75.9</td>
</tr>
<tr>
<td>Otsego &amp; Herkimer R. R. Co</td>
<td>Cooperstown</td>
<td>Cullen</td>
<td>88.9</td>
</tr>
<tr>
<td>Rock Cut Stone Co</td>
<td>Syracuse</td>
<td>Rock Cut</td>
<td>70.3</td>
</tr>
<tr>
<td>Roberts, George H</td>
<td>17 State st., New York City</td>
<td>LaGrangeville</td>
<td>56.2</td>
</tr>
<tr>
<td>Sasman, Christopher</td>
<td>Salisbury Center</td>
<td>Salisbury Center</td>
<td>89.7</td>
</tr>
<tr>
<td>Solvay Process Co</td>
<td>Syracuse</td>
<td>Jamesville</td>
<td>90.1</td>
</tr>
<tr>
<td>Smith, N. T.</td>
<td>Sharon Springs</td>
<td>Sharon Springs</td>
<td>91.4</td>
</tr>
<tr>
<td>Sugar River Stone Co</td>
<td>Boonville</td>
<td>Boonville</td>
<td>90.9</td>
</tr>
<tr>
<td>Upper Hudson Stone Co</td>
<td>26 Courtlandt St., New York City</td>
<td>Verplanck Point</td>
<td>50.4</td>
</tr>
<tr>
<td>Worlock Stone Co</td>
<td>Canastota</td>
<td>Canastota</td>
<td>93.6</td>
</tr>
</tbody>
</table>

1 Marl.
2 Average analysis of samples taken from face of quarry before company began grinding.
3 Samples sent in by Mr. Harris.
<table>
<thead>
<tr>
<th>Name of company</th>
<th>P. O. address</th>
<th>Calcium carbonate</th>
<th>Magnesium carbonate</th>
<th>Total carbonates</th>
<th>Calcium carbonate equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Limestone Co.</td>
<td>Youngstown, O.</td>
<td>88.9</td>
<td>1.2</td>
<td>90.1</td>
<td>90.2</td>
</tr>
<tr>
<td>Be semer Limestone Co.</td>
<td>Youngstown, O.</td>
<td></td>
<td></td>
<td></td>
<td>No sample obtained</td>
</tr>
<tr>
<td>Kelley Island Lime &amp; Transport Co.</td>
<td>Cleveland, O.</td>
<td>75.3</td>
<td>17.8</td>
<td>93.1</td>
<td>96.4</td>
</tr>
<tr>
<td>Grangers Lime &amp; Marble Co.</td>
<td>West Stockbridge, Mass.</td>
<td>66.2</td>
<td>16.8</td>
<td>83.0</td>
<td>86.2</td>
</tr>
<tr>
<td>Edison Portland Cement Co.</td>
<td>Stewartsville, N. J.</td>
<td>86.3</td>
<td>2.9</td>
<td>89.2</td>
<td>89.8</td>
</tr>
<tr>
<td>J. E. Baker &amp; Co.</td>
<td>Bainbridge, Pa.</td>
<td>86.7</td>
<td>5.8</td>
<td>92.5</td>
<td>93.6</td>
</tr>
<tr>
<td>Security Cement &amp; Lime Co.</td>
<td>Berkeley, W. Va.</td>
<td>93.7</td>
<td>1.9</td>
<td>95.6</td>
<td>96.0</td>
</tr>
</tbody>
</table>
been derived in large part from limestone formations. Such soils can usually be recognized by fragments of limestone boulders or gravel still remaining in the surface or subsoil and washed out along gutters and streams and along the roadsides. Such land will usually grow alfalfa without much difficulty; and at present, in any community where alfalfa is commonly grown, it can safely be assumed that additional limestone is not much needed. A forthcoming bulletin, showing location of limestone outerops, will give some indication as to where natural limestone soils are likely to be found. Sections of New York especially in need of liming comprise nearly all of the southern half of the State (excepting parts of Schoharie, Albany, Dutchess, Putnam, Westchester and Orange counties), the lakefront lands bordering Lake Ontario, nearly all of Long Island, and a large proportion of the rest of the state.

*Returns from use of limestone.*—Phenomenal results are often obtained from the practice of liming the land and, since it is such results that are most talked about and made the subject of photographs, there is some danger that those just beginning the use of limestone may be led to expect too much from it. When attempting to grow certain crops, particularly alfalfa, on acid soils the use of limestone as against using no lime frequently makes all the difference between a success and complete failure, and of course the value of liming in such cases can hardly be overestimated. On very acid soils, such as occur over a large part of this State, the use of liberal amounts of limestone is fundamental to the successful production of most general farm crops, and in view of this the need of limestone has not yet been overestimated and is not likely to be. But in general the practice of liming should be expected to produce results that are mild and lasting rather than phenomenal and short-lived, and its use should be part of a systematic scheme for building up the soil in respect to its content of phosphorus, organic matter and lime carbonate and for improving its physical condition.

The following average results from carefully-conducted experiments on the use of limestone on soils only mildly acid give a fair estimation of what can safely be expected from the use of limestone on land at all deficient in that material:

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1 The comparison at the Ohio station is against land three-fifths of which had received one application of lime.
At the New Jersey Station one application of two tons per acre of ground limestone gave the following increases per acre of crops grown during a period of five years following: Of grains, corn gave an increase of 4.3 bushels, oats 4 bushels, wheat 6.7 bushels, rye 8.0 bushels; of vegetables, potatoes were not increased, but beans gave a gain of 2.1 bushels, tomatoes 4870 pounds, cucumbers 3500 pounds; of forage crops, oats and peas gave an increase of 400 pounds dry matter, vetch and rape 2750 pounds, timothy and clover 690 pounds, rye and cowpeas 370 pounds.

These crops were grown in four different rotations and the average value of the increase from three rotations, including only general farm crops, is estimated by the New Jersey Station at $25 per acre, while that from the rotation including tomatoes and cucumbers in addition to potatoes, corn and lima beans was $48. In this experiment liming did not increase the yield of potatoes, but on very acid soils it will frequently do so to a marked extent. Noteworthy evidence to this effect has been brought out by the Rhode Island Station.

The Ohio Station\(^2\) reports the results of 12 years' experiments with the use of lime in a 5-year rotation of corn, oats, wheat, clover, timothy. The test was carried out on each of five different fields each year, the lime being used once in a rotation and applied at the time of preparing the land for corn. The first application was burned lime at the rate of one ton per acre, later applications were one ton of ground limestone per acre, making an average of 1½ tons ground limestone or its equivalent. The effect of the limestone can be conveniently stated in terms of the value of average increase for all crops in a 5-year rotation, allowing 60 cents per bushel for corn and its stover, 50 cents for oats and its straw, $1.00 for wheat and straw, and $10 per ton for hay. These figures are, of course, below the market price of the crops, low enough to insure the computations showing net values. In this way it can be figured from the results published by the Ohio Station that the application of lime for a 5-year period has given, when applied alone, average increases in crops worth $15.18. When applied on land receiving acid phosphate the lime has produced increases worth $17.23; on land receiving acid phosphate and potassium the increase from liming has been $20.31;

on land receiving complete commercial fertilizer $20.21, and on land receiving barnyard manure $19.63.

*Lime does not take the place of fertilizers or manure.*— The Ohio experiments illustrate the fact that lime does not take the place of other fertilizers or manures, but supplements them. Contrary to the generally accepted theory of its tendency to liberate potassium, it seldom has any practical effect of this kind. The above results show very strikingly that when limestone and fertilizers are used on the same land the effect is greater than the sum of the effects from the two used separately. Thus the sum of the values of increase from lime and acid phosphate when used on separate plats has been $38.58 per acre for each 5-year rotation, but when used together the increase has been worth $40.83. Lime and a combination of phosphorus and potassium, when used separately, have given a total increase worth $49.15. When used together the value of increase has been $54.28. The total increase from lime and complete fertilizer used separately was $57.19; used in combination $61.22. Lime and manure (16 tons per acre) used separately have produced increases worth $77.08; when used on the same land the figure is $81.53.

When the use of lime in any form is continued alone and no adequate provision made for maintaining the supply of other fertilizers and organic matter, crop yields cannot be kept up, and the returns from the use of lime in such a system become less and may finally drop below that of land unlimed.

*Amount of limestone to use.*— From a consideration of all available field experiments it seems advisable to apply as much as two tons of ground limestone per acre as an initial application wherever the soil has become distinctly in need of lime. This may then be followed with one to two tons per acre once every rotation of three to six years. These amounts will be found very profitable applications, provided only that the limestone can be obtained at reasonable prices. In some elaborate pot-culture studies at the Pennsylvania Station it was found that satisfactory results were not obtained until an application was made of at least one ton per acre in excess of the theoretical amount needed to neutralize the determined acidity of the soil. The amount required to neutralize this acidity, as determined by the method they used, varied on different plats all the way from a few hundred pounds of limestone per acre to nearly two tons.
On many soils of New York State, especially the hill lands of the southern part, two tons of limestone per acre is not enough to give most satisfactory results and so three or even four tons will often be more profitable. In preparing land for alfalfa it should be remembered that this crop is unusual in its requirements for lime and that for best results enough should be used to insure the crop an abundance of that material during the next few years. Therefore three, four or even six tons of ground limestone per acre is often not an extravagant amount to use in such a case. For purposes of plant food alone alfalfa uses calcium and magnesium to the equivalent of as much as 100 pounds of limestone to each ton of cured hay.

Methods of applying.—By means of a special lime or fertilizer distributor is the most satisfactory way of getting limestone on the land. In this manner it can be spread with much less work and the same amount will effectively cover more ground than if scattered by hand or with a manure spreader. The fertilizer attachment of a grain drill has too small capacity for practical use in distributing limestone. It is best to apply the limestone to the rough ground after plowing, thus mixing it more thoroughly with the soil by diskimg and harrowing. It is in the line of good practice to apply any form of lime as long as practicable before seeding the first crop to be benefited by its application. Fall-plowed land furnishes an excellent opportunity for the application of limestone. Also summer-plowed land, to be seeded to grain in the fall and to clover or grass the following spring, furnishes a good opportunity for its application. In general it is much better to apply limestone in the summer and fall when the roads are good, the land firm, and work not so pressing, rather than in the spring when there is haste to get in the crops and conditions are not so good for hauling and applying.

Field tests for the need of limestone.—Soils which contain in their surface or near subsoil fragments of limestone are not in need of liming. Soils which turn blue litmus-paper pink* are nearly always in need of liming. In the eastern states soils with a light color, gray, grayish brown, or yellowish shade, are usually in need of liming. Whenever serious difficulty is experienced in growing good

* It is not necessary to neutralize all the acidity of a soil to get results from liming, so after an application of lime has been made and some good results observed the soil may still be capable of turning blue litmus paper pink. But in such cases further benefit will usually follow the application of more lime.
crops of common red clover or of alfalfa the need of liming is strongly indicated.

The litmus-paper test for soil acidity may be made as follows: Obtain a ball of wet soil about the size of the fist, break it open and insert a double thickness of blue litmus-paper (obtainable at any drug store). Press the ball firmly together and allow to stand as much as a half hour. If at the end of this time the paper in contact with the soil has distinctly changed to a pink color there is positive evidence of acidity and it may safely be assumed that benefit will follow liming. Of course it is best to make a number of tests in different parts of the field and the subsoil should be examined as well as the surface. The practice sometimes recommended of placing a piece of filter paper between the litmus paper and the soil renders the test of no value. The litmus must come in direct contact with the soil.

It is now nearly always possible to tell in advance whether or not a soil is in need of liming, without waiting for the slow and expensive method of trying out an application in the field. Besides, one year’s trial may often fail to give conclusive results.

TECHNICAL SUBJECTS RELATING TO THE USE OF LIMESTONE.

Nature and use of burned lime.—Not only natural raw ground limestone but also freshly-burned and hydrated lime may be used for the purpose of supplying lime to soils deficient in lime carbonate. Freshly-burned and hydrated limes, however, rapidly change over to the carbonate form on being applied to the soil; that is, they very soon become of the same composition as ground limestone, a process familiar to every one in the changes that lime mortar undergoes on standing. If it were not for this fact neither of the caustic forms of lime could be used on the soil, for as long as they exist in the caustic condition they are liable to be injurious.

When pure calcium limestone (CaCO₃) is completely burned it loses 44 per ct. of its weight in the form of carbon dioxide gas (CO₂). The resulting product, which is calcium oxide or quicklime, contains just as much actual lime as the original limestone. It follows, then, that 56 pounds of pure quicklime are chemically equivalent to 100 pounds of pure limestone and will neutralize the same amount of acidity
when applied to the soil. The above weight of quicklime slaked with just the right amount of water forms 74 pounds of hydrated lime, 
\((\text{Ca(OH)}_2)\). When either of these compounds is exposed to the air for a long time it completely recovers the carbon dioxide \((\text{CO}_2)\) lost in burning; thus "air-slaked" lime is of the same composition as pulverized limestone. If the limestone has a part of its calcium carbonate replaced by magnesium carbonate the latter undergoes changes similar to those outlined above. Limestone nearly always contains a certain amount of impurities, consisting chiefly of clay-like material. On burning, this material does not lose in weight like the rest of the stone, consequently burned lime will contain a higher percentage of impurities than the stone from which it is burned. Also, burned lime begins to take up weight again as soon as it is exposed to the air. The figures above, then, are changed somewhat in actual practice. For practical purposes it may be remembered that 1200 pounds of freshly-burned lime, 1500 pounds of hydrated lime and 2000 pounds of ground limestone all contain approximately the same amount of actual lime and are capable of neutralizing the same amount of acidity when applied to the soil, provided all forms are of good grade. Bulk lump lime offered to the agricultural trade at $4 to $5 per ton is not as good grade as that considered in these figures. In fact, it often contains the ashes from the coal used in burning, may contain some unburned core, and may be partly air-slaked. Ground limestone (or its equivalent "air-slaked lime"), freshly-burned lime and hydrated lime are the only three forms that can properly be called lime or that can be used for neutralizing the acidity of the soil. Marl is the same in composition as ground limestone and when it contains the same percentage of carbonates is of equal value. "Agricultural lime," "Land lime," etc., are only trade names given to any one of the three forms or a mixture of them.

**Ground limestone vs. caustic lime.**—Because of the caustic properties and finely powdered condition of burned lime the theory has often been advanced that it is better to use than the carbonate. There is no evidence, however, from any carefully conducted field test to show that this is ever the case. On the other hand, nine years of comparative trials in the field at the Ohio Agricultural Experiment Station, four years at the Tennessee Station, eleven years at the Maryland Station, elaborate experiments at the Pennsylvania Station
and at the Rhode Island Station, together with much other evidence
from this and from foreign countries, have shown that ground lime-
stone gives at least as good results and often better than its equivalent
in burned lime. These experiments cover soils of various types,
containing much and little organic matter; and they deal with small,
medium and large applications of lime and with nearly all general
farm crops. These experiments entirely discredit the theory that
burned lime is any more effective for soil improvement than chemical
equivalents of ground limestone. They show that ground limestone
is likely to produce better results on the average than burned lime.
Ground limestone is safer to use, since applied in almost any quantity
at any time, it can have no injurious effect. (Excepting that it,
as any material capable of neutralizing acidity, produces conditions
more favorable to development of potato scab.) Instances are on
record of positive injury to crops from the use of caustic lime. Ground
limestone is so much more convenient to handle that this fact alone
will usually lead the farmer to decide in its favor after he has once
had experience in applying the two forms.

Limestone is a neutral material and does not exert a distinct
alkaline reaction excepting when in contact with an acid. Even
very weak acids easily decompose the limestone, setting free carbon
dioxide and allowing the calcium or magnesium to combine with
the acids, thus neutralizing them. There is no difficulty about the
“availability” of ground limestone. If any acid condition is present
in the soil it is easily neutralized by the limestone.

Magnesium limestones.— As previously explained, magnesium lime-
stones are such as have a part of their calcium carbonate replaced
by magnesium carbonate. In the highest magnesium limestones
the two carbonates are found in a ratio equal to that of their mole-
cular weights (100 : 84), 100 parts calcium carbonate to 84 parts
magnesium carbonate. It may also be noted that in these relative
quantities the two are capable of neutralizing the same amount of
acidity, since a molecule of one is as good as a molecule of the other
for that purpose. Eighty-four pounds of magnesium carbonate is
then able to neutralize the same amount of soil acidity as 100 pounds
of calcium carbonate. In order to compare two limestones carrying
different proportions of the two carbonates it is well to compute
the percentage of calcium carbonate that would be equal to the

\footnote{For further account of these experiments see Circular 27 of this Station.}
magnesium carbonate present and then add this computed percentage to the percentage of calcium carbonate. The results will be the calcium carbonate equivalent.

Owing to the fact that caustic lime made from magnesium limestone more often produces injurious results when used on the soil than caustic lime from straight calcium stones, objection has grown up to the use of magnesium lime in any form. Also it has been proved that highly magnesian limestone when used in excessively large quantities (more than ten tons per acre at one application) may produce injury. But there is little if any evidence to indicate that magnesium limestone used in reasonable quantities or in amounts that anyone can afford to pay for will be any less beneficial than a like amount of calcium limestone. There is a large amount of evidence to the effect that magnesium limestones are likely to produce slightly better results than non-magnesium limestones. Magnesium as well as calcium is one of the essential elements of plant food and there is evidence that on many soils additions of magnesium are needed for this purpose. The above mentioned book takes up this question as well. The New Jersey Station has recently published (Bulletin No. 267) the results of an extensive field test in which it was found that magnesium limestone gave somewhat better results than the non-magnesium. Bulletin 107 of the Tennessee Station indicates that magnesium limestones are more prompt in neutralizing acidity than non-magnesium. The Illinois Experiment Station has made use of 10 tons per acre of magnesium limestone on acid soils and obtained good results. In connection with the growing of alfalfa on the hill lands of southern New York, this Station has in the last two years used on two different farms four tons per acre of dolomitic limestone in comparison with a like amount of non-magnesium limestone. In each case the test was made on one-tenth-acre plats in duplicate. No difference was detected in the effect on the alfalfa crop of the two different kinds of limestone. Without lime in some form alfalfa could not be grown on these soils.

The evidence on the comparative value of magnesium and non-magnesium limestones for use on acid soils is such that there is no reason for any discrimination against the magnesium limestones.

They should be valued according to their calcium carbonate equivalent.

_Fineness of ground limestone._—For practical use in the improvement of acid soils it is not important to have limestone ground extremely fine. There is plenty of evidence to warrant the conclusion that if limestone is ground fine enough so that the total passes a sieve with ten meshes to the linear inch and contains _all the fine material_ produced in grinding it is as fine as need be for practical use, where the material is applied not oftener than once in a rotation of at least three years.

Under natural soil conditions limestone is much more soluble than most other soil constituents and is easily leached away. The easy solubility of this material is illustrated by the fact that the carbonates in many feet of limestone have often been leached away to form one foot of soil, which is made up mainly of the impurities contained in the lime rock. Also the caves and sink-holes found in limestone regions are due to the dissolving away of the rock by underground waters. The deposits of marl so frequently found in this State represent lime carbonate dissolved out of the surrounding lands. In an even more forceful way the solubility of limestone is illustrated by the large quantities of it contained in spring and well waters, it being the material which makes such water hard and which is deposited as a crust in kettles and boilers when the water is evaporated. More than this, the conditions found in an acid soil are about the most favorable of any in nature for the easy solubility of limestone.

When limestone is ground to pass a 10-mesh sieve from \( \frac{2}{3} \) to \( \frac{3}{2} \) of the product will pass a 40-mesh, depending somewhat upon the nature of the stone and upon the kind of machinery used. The entire product, then, is about as fine as representative samples of "finely ground" bonemeal. A mechanical analysis of these materials has been found in our laboratory to be as follows:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Passing 10-mesh</th>
<th>Passing 20-mesh</th>
<th>Passing 40-mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>94%</td>
<td>62%</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>92</td>
<td>72</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>67</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>72</td>
<td>44</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>69</td>
<td>49</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>82</td>
<td>56</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>90</td>
<td>66</td>
</tr>
</tbody>
</table>
FINENESS OF 10 MESH LIMESTONE.—Concluded.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Passing 10-mesh</th>
<th>Passing 20-mesh</th>
<th>Passing 40-mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>100%</td>
<td>91%</td>
<td>63%</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>82</td>
<td>62</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>93</td>
<td>67</td>
</tr>
<tr>
<td>11</td>
<td>100</td>
<td>85</td>
<td>56</td>
</tr>
<tr>
<td>12</td>
<td>100</td>
<td>86</td>
<td>62</td>
</tr>
<tr>
<td>13</td>
<td>100</td>
<td>91</td>
<td>67</td>
</tr>
<tr>
<td>14</td>
<td>100</td>
<td>80</td>
<td>55</td>
</tr>
<tr>
<td>15</td>
<td>100</td>
<td>75</td>
<td>50</td>
</tr>
</tbody>
</table>

FINENESS OF GROUND BONE MEAL.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Passing 10-mesh</th>
<th>Passing 20-mesh</th>
<th>Passing 40-mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96%</td>
<td>82%</td>
<td>65%</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>76</td>
<td>58</td>
</tr>
<tr>
<td>3</td>
<td>94</td>
<td>91</td>
<td>54</td>
</tr>
</tbody>
</table>

Fineness in bonemeal is more important than in ground limestone; for under soil conditions limestone (CaCO₃) is more soluble than bonemeal (Ca₃(PO₄)₂), is used in quantities ten to twenty times as great per acre, and costs about one-tenth as much per ton. Yet bonemeal of the above fineness is everywhere on the market and, excepting for its cost, is a favorite form of phosphorus fertilizer.

Some results from the Ohio Experiment Station bear directly on this subject. Different forms of lime and different amounts have been tried out in a rotation of corn, oats and hay (clover and timothy), the lime being applied once in the three years; manure is also used in the rotation at the rate of eight tons per acre. The following table gives the average value of increase for a three-year period due to both lime and manure. The five-year average is the first data published and the nine-year the last. The results from 500 and 2000 pounds per acre of burned lime are given to show that the comparison of different forms is based on quantities smaller than give maximum results on the soil in question.

**Value of Average Crop Increase per Acre for 3-Year Period.**

<table>
<thead>
<tr>
<th></th>
<th>(Ohio Station)</th>
<th>Average of 5 years</th>
<th>Average of 9 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshly-burned lime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 lbs. per acre</td>
<td>$9.65</td>
<td>$19.02</td>
<td></td>
</tr>
<tr>
<td>1000 &quot;</td>
<td>11.65</td>
<td>20.07</td>
<td></td>
</tr>
<tr>
<td>2000 &quot;</td>
<td>14.70</td>
<td>23.41</td>
<td></td>
</tr>
<tr>
<td>Ground limestone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10-mesh)</td>
<td>12.96</td>
<td>21.05</td>
<td></td>
</tr>
<tr>
<td>Air-slaked lime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1780 &quot;</td>
<td>11.77</td>
<td>22.57</td>
<td></td>
</tr>
<tr>
<td>Hydrated lime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1320 &quot;</td>
<td>11.82</td>
<td>20.75</td>
<td></td>
</tr>
</tbody>
</table>

The ground limestone was of such fineness that the total passed only a 10-mesh sieve, yet it has given fully as good results as chemical
equivalents of burned lime, air-slaked lime or hydrated lime, any of which is an impalpable powder.

The Tennessee Station (Bulletin No. 97) compared burned lime with ground limestone for a period of four years on a variety of crops and found the limestone to give somewhat better results. The ground limestone was of such fineness that 19 per ct. did not pass a 20-mesh sieve. The burned lime was slaked and so reduced to a powder.

Rhode Island Station Bulletin No. 145 reports experiments showing that ground limestone was fully as effective as air-slaked lime, even for immediate results. The fineness of the limestone is not given.

Artificial (precipitated) calcium carbonate has been compared with "Limestone meal" and the latter found to give fully as good results, even for the first crop.5

In a comparison of crushed marble of different degrees of fineness it has been found that material passing a one-millimeter (20-mesh) sieve but coarser than a ¾ millimeter (40-mesh) gave practically as good results as that finer than ¾ millimeter, even for the first crop.6

In some lime and fertilizer experiments in connection with the growing of alfalfa on the hill lands of southern New York during the past three years, the authors have compared, along with other treatments, the following, each treatment being applied to duplicate one-tenth-acre plats:

<table>
<thead>
<tr>
<th>Ground limestone 2 tons per acre</th>
<th>Basic slag 500 lbs. per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated lime equivalent to 2 tons G. L. per acre</td>
<td>&quot; &quot; &quot;</td>
</tr>
<tr>
<td>Ground limestone 4 tons per acre</td>
<td>&quot; &quot; &quot;</td>
</tr>
<tr>
<td>Hydrated lime equivalent to 4 tons G. L. per acre</td>
<td>&quot; &quot; &quot;</td>
</tr>
</tbody>
</table>

The limestone has been approximately 10-mesh and has cost $1 to $1.50 per ton f.o.b. cars at shipping point, while we have paid $8 to $10 per ton for the hydrated lime at shipping points to insure getting the very best grade for comparison. This experiment has been tried in Chautauqua County, Schuyler County, Tioga County and Ostego County. In three of the cases the liming was done only a few weeks previous to seeding the alfalfa. In each of the four experiments a good stand of alfalfa was secured on these four plats, although on one field the alfalfa was later badly winter killed.

5 Experiment Station Record, 21:624.
6 Rep't Penn. State College, 1900.
In no case was there any noticeable difference between the use of the ground limestone and the hydrated lime. Without lime in some form a stand of alfalfa could not be secured. There is a strong indication that four tons of limestone or its equivalent is not enough to give maximum results on any of these fields.

On the ordinary farm it is scarcely practicable nor advisable to attempt to go over all the cultivated land with an application of limestone more frequently than once in four to eight years. Besides, an ordinary system of crop rotation lends itself to the practice of liming only about once in three to six years; unless, of course, the material is applied as a top dressing, which is not so effective as mixing it with the soil. Especially does this apply to alfalfa growing. The problem, then, is not what is the minimum amount of limestone and maximum fineness for greatest net profit the first year, but rather what quantity and fineness will give the greatest net return over a period of at least three years. If enough 10-mesh limestone is used to last for that length of time it will, without question, give fully as good results the first year as a somewhat smaller amount of extremely fine material.

Increased fineness means increased cost of production. Also limestone ground as fine as dust can hardly be handled in bulk and must be sold in sacks, which adds as much as one dollar per ton to the cost. Ten-mesh limestone, which is about the consistency of bonemeal, can be readily used in bulk.

In view of all the above facts, therefore, it seems entirely unnecessary to urge that limestone be ground any finer than that the entire product pass a 10-mesh sieve and contain all the fine material produced in grinding.

Nature of soil acidity.—In natural soil processes acids are constantly being formed incidental to the decay of organic matter. These acids consist of carbonic acid, various organic acids and strong nitric acid (HNO₃). All have ability to combine with and remove from action the bases present in the soil. The formation of organic acids is familiar to everyone in the souring of milk, in the production of sauerkraut, in the fermenting of silage, and in the manufacture of wine and vinegar from fruit juices. Nitric acid is formed from the nitrogen of organic matter by the process of nitrification. In the production of almost any ordinary crop as much as 100 pounds of nitrogen per acre is converted into nitric
acid. Under favorable conditions 200 pounds or more of nitrogen per acre are commonly transformed into nitric acid. One hundred pounds of nitrogen forms 450 pounds of nitric acid which is capable of using up 357 pounds of calcium carbonate. The carbonic acid and organic acids produced at the same time would be capable of using up a much larger quantity of limestone than this. If carbonates are not present to combine with these acids they attack the silicate compounds of the soil and extract from them their basic constituents, such as calcium, magnesium, sodium and potassium. Acids are added to the soil to some extent by the use of many commercial fertilizers. When 500 pounds of acid phosphate is added to the soil enough acid is introduced to use up about 200 pounds of limestone. By the use of ammonium sulphate \((\text{NH}_4)_2\text{SO}_4\) a small amount of sulphuric acid \((\text{H}_2\text{SO}_4)\) is formed, as the plants use up the ammonia and leave the free sulphuric acid behind. Carefully conducted field tests show that plots treated with ammonium sulphate become acid sooner than plots alongside treated with a similar amount of nitrogen in nitrate of soda or dried blood. When free sulphur is added to the soil, as in the dusting of plants for fungus diseases, it is soon oxidized to sulphuric acid and relatively large quantities of acid may be formed in this way.

It is not correct to say that acid soils are due to an accumulation of acids, such as described above, for hardly an appreciable amount of acid is ever present in the free state in any soil. But the acids remove the bases from the soil, first the carbonates and then the basic constituents of the silicates; and when this process has gone on long enough the soil becomes deficient in basic materials. It is then potentially acid; that is, it behaves as an acid in the presence of basic materials or a compound like limestone which readily parts with its basic constituents in the presence of even very weak acids.