UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BULLETIN 171

AGRICULTURAL LIME

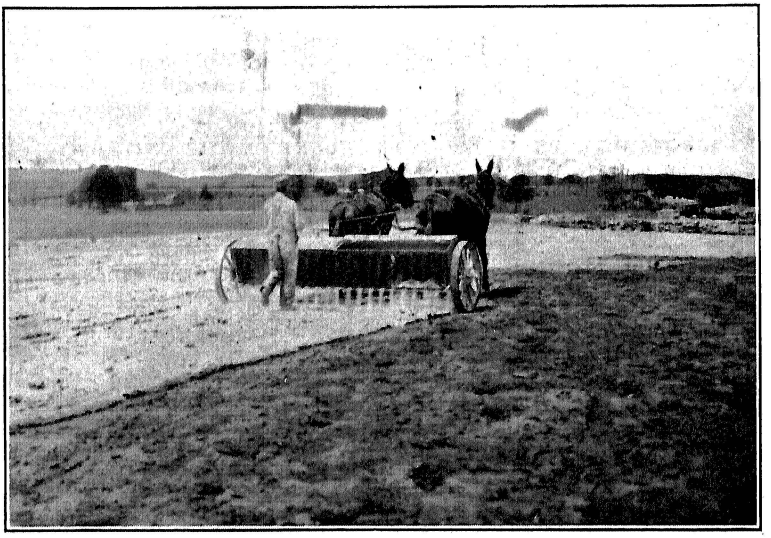

FIG. 1.—A lime spreader at work

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COLLEGE OF AGRICULTURE

Agricultural Experiment Station

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[1]In service of U. S Department of Agriculture.

Agricultural Lime*

M. F. MILLER and H. H. KRUSEKOPF

Many Missouri soils are strikingly in need of lime. This has been shown by chemical tests and by field experiments. The removal of lime from the soil with the resulting development of acidity or sourness takes place sooner or later in all soils of the humid region which are subjected to constant cropping. This is because crops remove considerable quantities of lime and because there is always some loss thru the drainage water. In the eastern states liming has been practiced almost since the beginning of agriculture in that region. This has been due partly to the fact that many eastern soils were originally poorly supplied with lime and partly to the more intensive agriculture practiced. The soils of the corn belt were originally rather well supplied with lime, altho in recent years they have begun to show a need of it. As a result, liming is extending westward and it is now more or less common in all the corn-belt states. The extent of the interest in liming among Missouri farmers is shown by the number of inquiries which are being received by the Experiment Station.

MISSOURI SOILS NEEDING LIME

The soil analyses which have been made at the Missouri Agriculture Experiment Station are not sufficient in number to make possible an accurate statement of the needs of all soil types in the state, but a sufficient amount of data is available to show that large areas of soil need liming. Of the total number of samples examined, representing in all 160 soil types, approximately two-thirds have shown some need of lime. This need varies from insignificant quantities, to five or six tons of ground limestone to the acre, considering the surface seven inches of soil as the basis for comparison. Approximately one-fourth of the samples have shown a lime need of two tons or more in this surface soil-layer.

No very accurate statement can be made as to the lands needing lime most, since this varies materially in the same soil type. In general, however the level prairies of northeast and southwest Missouri commonly need lime. Considerable areas of the rolling prairies in both north and south Missouri also need it, as well as much of the older farmed timber lands. Many of the better limestone lands of the state need little lime, altho the poorer limestone lands often need it badly. The fact that a soil is derived from limestone does not necessarily mean that the surface soil or the upper subsoil is sufficiently supplied with lime, since it may have been removed almost entirely since the soil's formation. Many farmers believe that bottom land soils are usually sour, but such is not necessarily the case. As a matter of fact the best bottom lands, particularly the newer bottoms, subject to occasional overflow, rarely need lime. Bottom and second bottom soils of a gray color, especially where

*A revision of Bulletin 146.

underlaid by a light gray layer just beneath the soil, practically always need lime. The rough to rolling brown loess soil (Knox and Memphis silt loams) bordering the bottom lands of the Missouri and Mississippi rivers and found in largest areas from the center of the state to the northwest corner needs little lime, especially in the western half.

The foregoing statements are necessarily general. They do not apply to all soils in the regions mentioned but to the more important ones. A careful test is the only means of determining with a certainty a soil's need of lime. It can be said with a reasonable degree of confidence, however, that where red clover grows well, little or no lime is needed. On the other hand, red clover failures are not always due to a sour soil. Poor drainage, a lack of fertility, unfavorable weather conditions or the lack of organic matter and available phosphates may cause a failure or a poor growth of clover even where a soil has sufficient lime. As a rule, liming is beneficial to clover where it is failing on well-drained land and it may sometimes almost insure a stand, altho manuring or the use of phosphates may often be necessary in addition. There is a general belief among farmers that the presence of red sorrel (rumex acetosella) indicates soil acidity. This plant thrives on a sour soil and often, where it has once been seeded on land which is very sour, it will grow luxuriantly, excluding more desirable plants. Patches of this plant are more or less common in all parts of Missouri but these usually come from the seed introduced with red clover and they may occur on any soil. It is only where this plant predominates to the exclusion of other plants, that soil acidity is indicated by its presence.

TESTS FOR SOIL ACIDITY.

Simple tests for soil acidity are often inaccurate or otherwise unsatisfactory. What is known as the muriatic- or hydrochloric-acid test is of considerable value. This test is made as follows: Take a small quantity (an ounce or two) of strong hydrochloric acid (sometimes called muriatic acid) and dilute with an equal amount of water. Take a handful of the soil to be tested, preferably wet and worked into a mud ball, and add a drop of this weakened acid. If an unmistakable and distinct bubbling takes place, the soil is practically certain to need no lime; the more pronounced the bubbling, the more certain it is that no lime is needed. If no distinct bubbling takes place the soil either contains very small amounts of carbonate (the lime compound which keeps soils sweet) or it is in need of lime. While it may contain too small a quantity of lime carbonate to give an unmistakable showing, it may still contain enough that the soil is not markedly sour. Hence this test gives a conclusive result only when the soil contains considerable lime carbonate.

The litmus-paper test, of which so much is said, is fairly satisfactory in the hands of one who has had experience with it, but it is very likely to give the wrong impression to one who is using it for the first time. The test is based on the fact that the chemically prepared paper, known as blue litmus paper, turns pink in contact with acid. The principal difficulty in using it is in knowing just what shade of pink really indicates soil acidity. The paper will lose its blue color even in a neutral

soil and turn a purplish color which may be mistaken for the proper pink color. Again, the length of time the paper is in contact with the soil influences the color. The paper should turn a distinct pink within ten minutes if the soil is very acid. The College of Agriculture has prepared a sheet of directions for the purpose of assisting farmers in making this test and this will be sent on application.

A rather simple chemical test, known as the Truog test, has come into use recently, which farmers may use with a fair degree of satisfaction if they will supply themselves with the necessary apparatus and materials. The method is being used at the Experiment Station with good results.

The standard chemical test known as the Veitch test is the one used in most laboratories. The Experiment Station is now making considerable numbers of the Veitch and Truog tests for farmers where the soil samples are carefully taken. A sheet giving directions for taking samples for such tests will be sent on application to the College of Agriculture.

THE PURPOSE OF LIMING

The primary purpose of liming is to supply sufficient lime for crop needs and to neutralize soil acidity. Certain crops require more lime than they are able to secure from a soil which is acid and which is, therefore, deficient in lime. Furthermore most of the important types of soil bacteria are injured by soil acidity. Consequently a very acid soil should be limed for best results.

Among other effects of lime might be mentioned its action in making clay soils more friable. The ground limestone acts rather slowly in this respect, however, and it must be supplied in rather large quantities for a marked physical effect. Burned lime has the effect of increasing the amounts of available plant food in the soil, altho the effect of ground limestone in this respect is not so marked.

Lime can scarcely be classed as a fertilizer in the common use of the term since a fertilizer is a substance added to the soil solely for supplying needed plant food. The action of lime is usually not so immediate as that of a fertilizer, and as it is applied in considerable quantities its effect extends over a longer period. Where the soil needs lime badly, however, and where a liberal application is given, the effect on such crops as clover and alfalfa may be immediate and very striking.

THE RESPONSE OF DIFFERENT CROPS TO LIMING

Considerable experimental work has been done at experiment stations[1] in determining the response of various crops to liming. The results secured are naturally influenced by the amount of lime needed by the soil, as well as by other factors, so that the evidence is rather conflicting in the case of certain crops. There is, however, a striking agreement in the case of some crops and a rather general agreement in the case of others.

Among the legume crops, which respond best to liming, are al-

[1]Hartwell, B. L. and Damon, S. C. The Comparative Effect on Different Kinds of Plants of Liming an Acid Soil. R. I. Exp. Sta. Bul. 160. Mooers, C. A. Liming for Tennessee Soils. Tenn. Exp. Sta. Bul. 97.

falfa, sweet clover and the common clovers. Canada field peas, garden peas and soybeans usually give a fair response. Alsike clover will do better than red clover on poor or wet land and an impression has spread among the farmers that it will do better than red clover on acid soil. The indications are, however, that it will respond to liming almost as well as red clover on either drained or undrained land which is very acid, altho it is probably not quite so susceptible to acidity as red clover. Alfalfa and sweet clover give the best response of any of the common legumes. They require much lime for their growth.

Among the legumes which usually are little benefited by liming are Japanese clover, beans, cowpeas and peanuts.

The common non-legumes which are more or less benefited by lim-

FIG. 2.—Alfalfa on the Carthage experiment field. Two and one-fourth tons of ground limestone increased the yield of alfalfa on this field 3307 pounds per acre, as an average of two years' cuttings.

ing are corn, wheat, timothy, orchard grass, Kentucky blue grass and sorghum. Those giving little or no response to lime are rye, oats, Irish potatoes, sweet potatoes, cotton, strawberries and red top grass. Lime has been found directly injurious to watermelons.

The foregoing statements have to do with the direct effect of lime upon the various crops. It must be understood, however, that crops which may give little or no direct response to liming may be greatly benefited thru growing clover or other legumes on land which is too acid to grow these legumes without lime.

The results obtained by the use of lime on the various outlying soil experiment fields of the Experiment Station give an idea of the results to be expected from the use of lime in Missouri. These experiments have been in progress for a number of years and many of the important soil types in the state have been included. While the fields commonly represent medium to poor lands, which in most cases are somewhat more in need of lime than are the better lands of the state, the average results give a good idea of what may be expected. The following table shows the aver-

age returns which have been secured on the crops commonly grown in these experiments. The increases given are the averages of all the trials for the various crops. The lime used has always been in the form of ground limestone. This has been applied at somewhat different rates, the first application usually being from one to two tons, followed by a second application of approximately one ton after six years of cropping. The average application during the twelve years included in these averages has been approximately three tons per acre or one ton per rotation of four years. The cost of the lime has varied, rarely reaching four dollars per ton applied to the land; but this figure has been used in the calculations since at present prices it can usually be applied at a cost not exceeding this amount.

FIG. 3.—Clover on the Vandalia experiment field. A stand of clover secured by liming, on the northeast Missouri level prairie. It will be noticed that the plots which received no lime (shown behind the man in the picture) have practically no clover.

EFFECT OF LIMESTONE ON CROP YIELDS AND NET RETURNS
Average from all Experiment Fields, 1907-19

Crop	Average increase per acre due to limestone	Value of increase per acre	Annual cost of treatment per acre	Annual net return per acre
Corn	3.06 bu.	$3.06	$1.00	$2.06
Oats	—1.20 bu.	—.78	1.00	—1.78
Wheat	1.13 bu.	2.26	1.00	1.26
Clover	443 lbs.	5.54	1.00	4.54
Soybeans	167 lbs.	2.08	1.00	1.08

Total return from one ton of limestone during rotation of corn, oats, wheat, clover—$10.08.

Net return (charging for limestone at the rate of $1 an acre a year or $4.00 a ton)—$6.08.

Total return from one ton of limestone during rotation of corn, soybeans, wheat, clover—$12.94.

Net return (charging for limestone at the rate of $1 an acre a year or $4.00 a ton) $8.94.

Crop values used are as follows: Corn $1, oats 65 cents, wheat $2, clover $25 and soybeans $25.

Experiments in liming alfalfa have been carried on as a part of a series of cooperative experiments with farmers for a number of years, and in addition certain trials have been made on some of the regular outlying experiment fields. These have been reported in previous publications[1] from this station. While some of these experiments have given no return from liming, some have given very striking returns.

FIG. 4.—This farmer limed a strip across the field and afterward sowed the field to clover. The result was excellent clover on the limed strip and little or none elsewhere.

It will be seen from what has been said that lime cannot be used as a fertilizer is used, in small quantities or even in large quantities, and a remunerative return expected on the first crop of wheat, oats or corn, altho large returns may sometimes be secured on the first crop of clover or alfalfa. The effect of liming is rather that of a general soil improving agency for most crops, which raises the general level of yields. Its principal function is that of supplying lime and of sweetening a sour soil so that the very important soil building legumes may be more satisfactorily

[1]Miller, M. F. and Hutchison, C. B. Cooperative Experiments with Alfalfa. Missouri Agr. Exp. Sta. Bulletin 106.

Hutchison, C. B. and Douglas, T. R. Experiments with Farm Crops in Southwest Missouri. Missouri Agr. Exp. Sta. Bulletin 123.

produced. Liming may well be compared to drainage, in being one of the fundamental methods of soil improvement which, on sour soils, should precede fertilization and other methods of increasing yields.

FORMS OF LIME

There are three lime compounds which may be used for agricultural purposes. These are the lime oxide, commonly called burned lime or lump lime; the lime hydrate, usually called water-slaked lime; and the lime carbonate, such as ground limestone or old air slaked lime. The lump lime which is commonly sold in barrels in this state cannot be ap-

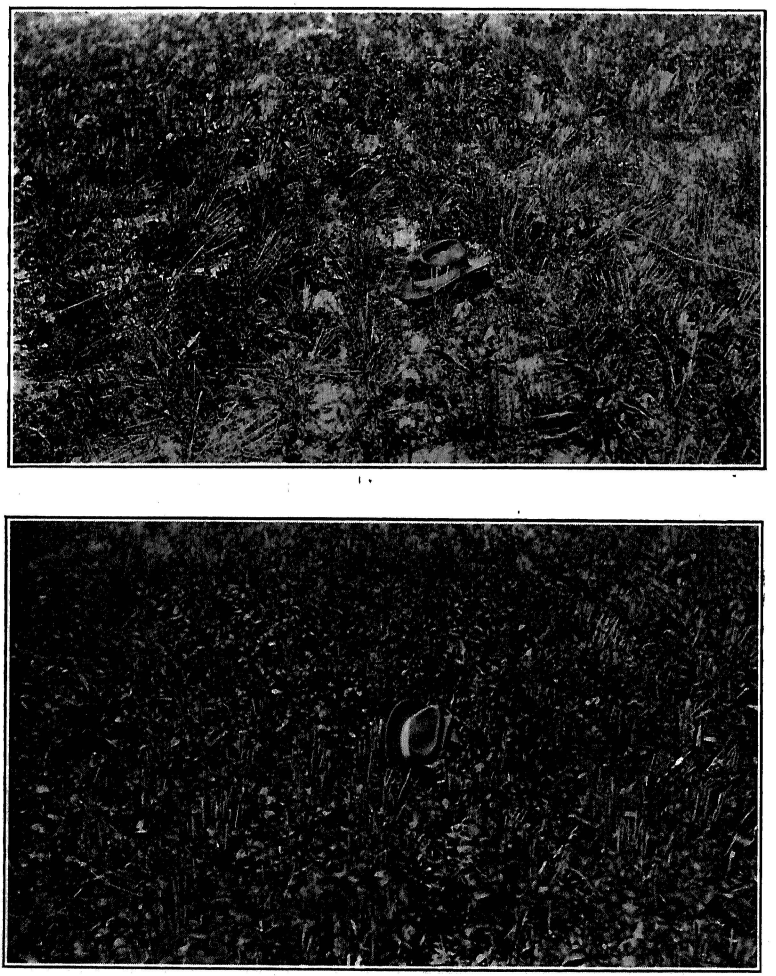

FIG. 5.—Young clover on the Hurdland soil experiment field. The plot shown above received no lime; the one shown below received ground limestone at the rate of 8000 pounds per acre or enough to sweeten the surface seven inches of soil. Otherwise these plots were treated exactly the same.

plied in this form without slaking. In the eastern states where lump lime is much used, it is often piled in the fields, covered with earth and allowed to slake by absorbing moisture from the earth or from rains, after which it is scattered and worked into the soil. In this slaked form the lime is largely in the form of the hydrate of lime. In some localities the lump lime is ground to about the fineness of corn meal, then scattered and worked into the soil, where it is allowed to slake. There is difficulty in handling it, however, because of its caustic nature and the danger of air-slaking during shipping. It must also be scattered sometime before a crop is put in because of the danger of injuring the seed.

Water-slaked lime or lime hydrate is being sold, to a certain extent, for agricultural purposes. It is put out in bags by certain lime companies in a form convenient for distribution. Like the ground lump lime, water slaked lime should not be used in large quantities at the time of putting in the crop as it is somewhat caustic, altho much less so than the lump lime.

The lime carbonate, represented on the market principally as ground limestone, is the most common form of agricultural lime in Missouri. It is being put out by a number of companies and is being ground to various degrees of fineness. This form of lime has no caustic properties and may be applied at any time. Old air-slaked lime is practically all lime carbonate and has therefore approximately the same composition as ground limestone. Fresh air-slaked lime contains large quantities of lime hydrate, since it has taken up moisture from the air in slaking. Air-slaked lime from the kilns may contain considerable quantities of lump lime, cinders or trash and must usually be sifted if it is to be scattered with a lime distributor.

The kind of lime to use should be determined almost entirely on the basis of the amount of active lime (calcium oxide) one can buy for a dollar. In order to determine this it should be remembered that approximately 2000 pounds of finely ground limestone, or old air-slaked lime, is required to equal 1100 pounds of lump lime, or 1500 pounds of fresh water-slaked lime, where all are made from a good quality of high calcium limestone. With a delivered price on each, one can figure the cheapest form in terms of active lime when hauled and spread. It will be found that in most localities, excepting those within wagon haul of a lime kiln, the ground limestone will be the cheapest form to apply. In buying such a stone it is always well to get a definite statement from the company as to the percent of carbonate it contains, since this varies considerably with different quarries. Moreover, an analysis of the face rock of a quarry does not always show the composition of the ground limestone produced. This is due to the fact that the different ledges in a quarry will often vary in composition, and to the further fact that beds of flint or chert frequently occur which are not considered in the analysis of the quarry rock but which may be mixed with it in quarrying, thus giving the crushed stone a much lower content of carbonates than the limestone itself.

FINENESS OF GRINDING LIMESTONE

There is considerable difference of opinion regarding the fineness to which limestone should be ground. The basis for comparison is that of the fineness of the sieve thru which it passes. For instance, a large part of the limestone on the market is ground fine enough to pass a ten-mesh sieve; that is, a sieve with ten holes to the linear inch or one hundred to the square inch. Some of the coarser of these commercial grades will pass a four-mesh sieve only, while some of the finer grades will pass a hundred-mesh sieve.

The few experiments which have been made comparing limestone pulverized to different degrees of fineness show that it is the fine dust which gives most immediate results in sweetening the soil. There is of course some immediate effect of the coarser material but this is slight. It has been shown also that the finer the material the more rapid is its loss from the soil, other things being equal. This fact is of importance in determining the lasting effect of the limestone.

From the experimental evidence at hand the indications are that it is fairly safe to estimate the proportion of limestone which passes the forty-mesh sieve as representing the approximate amount which is active in the soil the first year. The per cent of the different sized particles in ground limestone varies considerably. Sieve analysis indicates, however, that a product all of which will pass a ten-mesh sieve usually contains from 60 to 70 per cent passing a forty-mesh sieve. A ground limestone which is so coarse that it passes but a four-mesh sieve usually contains from 40 to 50 per cent that will pass a forty-mesh sieve; thus it would contain much less immediately active material than the ten-mesh stone. A number of companies are putting out an eight-mesh material. This being only slightly coarser than the ten-mesh stone, is quite satisfactory for agricultural use.

All things considered it seems that the best stone to use is one ground fine enough to pass an eight-mesh or a ten-mesh sieve. However, where coarser material can be obtained at low cost, it may pay to use it, provided larger amounts are applied so as to supply about the same amount of fine dust as when eight or ten-mesh material is used. This question must be decided, therefore, upon the relative costs of the different grades of material. It would rarely be wise to consider coarser material than that passing a four-mesh sieve.

COST OF LIMESTONE

The price at which ground limestone is sold at the different commercial crushers in Missouri varies from $1 to $5 a ton. The material varies both in purity and fineness of grinding. The lower price named, in most cases, is for the product from crushing plants which crush rock for concrete and road building purposes and sell the finer material for agricultural use. This product is usually the screenings which pass a four- or eight-mesh sieve. The higher price mentioned is for stone of a good grade which has been pulverized to a flour, in some cases all of it passing a 100-mesh sieve.

Recently, some crushing companies have adopted the plan of quoting

prices on their product according to its degree of fineness and purity. In general, ground limestone all of which will pass an eight- or ten-mesh sieve and of satisfactory purity for agricultural use can be purchased in carload lots for $1.50 to $2.50 a ton, f. o. b. cars at crusher.

Where limestone can be shipped direct to the user over one road, the freight rates are reasonable, so that the material can be shipped a considerable distance without excessive cost. However, when it is necessary to ship over two railroads, each road has a minimum charge, thus making the freight rather high, even for short hauls.

SMALL GRINDERS FOR HOME GRINDING OF LIMESTONE

Farmers remote from the railroad or from a satisfactory lime supply will doubtless find it more economical to grind their own limestone where a good rock is available.[1] Various companies are now putting small porta-

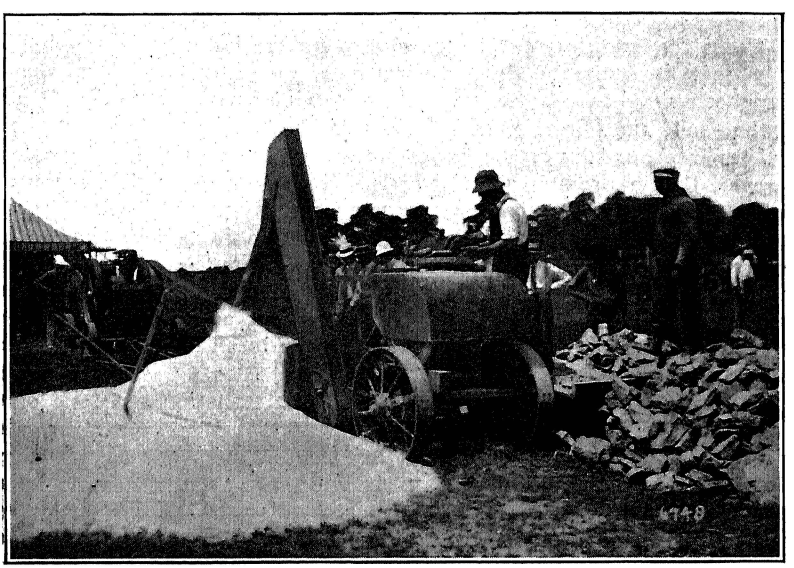

FIG. 6.—A portable limestone grinder in operation.

ble limestone grinders on the market. The cost of these grinders depends principally upon their size, but those suitable for the use of individual farmers, or groups of farmers cooperating in grinding stone, will cost from $500 to $2,400. Such grinders have a capacity of from one to five tons an hour, depending upon the size of the machine, the kind and dryness of the rock and the fineness of grinding. A fair size for community work is a machine having a capacity of two or three tons an hour, costing $1,200 to $1,500 and requiring a twenty to twenty-five horse power engine. The cheaper machines mentioned are mostly single action pulverizers. They are being used with satisfaction.

[1]Those interested in grinding limestone should write the College of Agriculture with reference to having the quality of the stone tested before preparing to grind.

In selecting a grinder care should be taken to see that it will handle pieces of stone at least four inches in thickness. Some grinders will not handle rock which has not first been crushed by another machine or broken by hand. The best of these large-size, portable machines will take in stone measuring from four to six inches thick and eight to twelve inches wide.

In estimating the cost of grinding limestone on the farm, the interest and depreciation on the outfit, the labor, fuel, oil, repairs and the cost of quarrying the stone must be considered. While the cost of quarrying varies widely under different conditions it seems that seventy-five cents a ton is about the average cost for this work. The cost of grinding varies in most cases from $1 to $2 a ton. In some localities a man owning a portable crusher goes from farm to farm and does grinding for farmers who have previously quarried the stone. The charge for this grinding, exclusive of quarrying, varies from $1 to $2 a ton. A group of farmers cooperating in buying a grinder with a capacity of two to three tons an hour might reasonably expect to get the stone quarried and ground to an eight- or ten-mesh fineness at a cost varying from $2 to $2.25 a ton where the crew is efficient. It is not unusual, however, to have the cost exceed this amount. So much depends upon the accessibility and ease of quarrying the stone, the cost of power and the efficiency of the crew that the price is certain to vary widely under varying conditions. The limestone is often found in deep valleys, or rough country, so that hauling the stone becomes an important item. A mistake is often made in not providing enough power for efficient grinding, which greatly increases the cost to the ton. It must be remembered too that the rock must be comparatively dry to grind readily and this often necessitates loss of time when the quarried stone is wet or covered with snow.

An investigation has been made of the cost of producing ground limestone among the men who have used these portable crushers in this and other states. While the estimates vary widely, a fair average of the costs of the separate items, under what might be termed favorable conditions and efficient management, would be as follows:

		Cost for 20 tons	Cost per ton
QUARRYING STONE (20 tons)—			
(Drilling, shooting and sledging stone to proper size for crushing ing) 3 men, 1 day @ $5		$15.00	$0.75
GRINDING (20 tons)—			
Engineer and 25 H. P. Engine, 1 day @ $12 (including fuel and oil)		12.00	.60
One foreman, 1 day @ $4		4.00	.20
Two helpers, 1 day @ $3		6.00	.30
CHARGE FOR CRUSHER—			
(Based on crusher of 20 tons a day capacity, approximate present value $1,400)			
(a) 10% annual depreciation in value	$140.00		
(b) 5% annually for replacing worn parts	70.00		
(c) 7% annual interest on investment	98.00		
Total annual charge	$308.00		
Estimated annual run in average community, 60 days at 20 tons a day	1200 tons		
Charge for use of crusher on the basis of these estimates		5.00	.25
Total cost		$42.00	$2.10

It will be noticed that labor for quarrying has been charged at $5 a day. This may seem too high. However, if three men quarry and prepare twenty tons of stone for the crusher daily for any length of time, they will need to be experienced and efficient in this work. Perhaps cheaper labor can be secured but in most cases the total cost of quarrying and preparing stone for the crusher will amount to seventy-five cents a ton.

The charge for the use of the crusher is based on a $1,400 crusher used for a 60-day, 1200-ton annual run. Should the annual tonnage vary, the depreciation in value and cost of replacing wearing parts would vary accordingly without appreciably affecting the charge per ton.

Whether it will be cheaper to grind the limestone in the neighborhood or buy it and ship it in, will depend upon the delivered price at the station, the length of the haul, the quality and accessibility of the limestone in the community and the cost of grinding. It would seem from the information available at this time that, generally speaking, the local grinding of stone will be limited to those communities in which good stone is readily accessible and which are located at such a distance from the railroad that the cost of hauling becomes excessive.

AMOUNT OF LIME TO USE

The amount of lime to use depends primarily on the deficiency of lime in the soil and the kind of lime. As ground limestone is almost invariably the cheapest form to apply in Missouri, recommendations are usually based upon this material. The determinations which have been made as to the amount of ground limestone required for the surface seven inches of an acre of the various soils of Missouri show a variation from nothing up to five or six tons. A few have shown even higher lime requirements. These determinations are based on the surface seven inches of an acre because it is in this layer that plant roots and beneficial bacteria are most active.

As a general rule it can be said that applications of one to two and one-half tons of a good grade of ground limestone would be likely to give good results. The amount to apply depends not only upon the lime need of the soil but also upon its fertility. Crops grown on fertile soils do not seem to be injured so much by lack of lime as when grown on poorer soils. Since lime is being continually removed from the soil it is necessary to lime at more or less regular intervals . Applications of one to one and a half tons of ground limestone once in four to six years would be considered reasonable rates on soils showing a need for lime seriously to affect the growth of clover. On very acid soils larger amounts may often be applied with profit. It is commonly recommended to make the first application heavier than the succeeding ones. An acidity test of the soil should be made and the need for lime determined before undertaking the matter of liming.[1]

METHODS OF APPLICATION

Lime should be applied on plowed land and worked into the surface three to five inches of soil with disk and harrow. It may be plowed under,

[1]The College of Agriculture will give such assistance as is possible in determining the acidity of soils.

particularly where the land is disked before plowing, but for most satisfactory results the lime should be well mixed with soil. Top dressing is recommended only in the case of permanent pastures or meadows in which case the loose, porous nature of the sod allows the lime to wash into the soil much better than on other lands.

The fall season is usually the best time of year to apply lime since the roads are generally best at that time and the soil is not likely to be wet. There is also more leisure of men and teams at that season. Where wheat is grown, lime can well be applied on land prepared for this crop. Little return must be expected on the wheat but the clover crop following should be greatly benefited, assuming of course that the soil needs liming, that it is sufficiently fertile to grow clover and that it is well drained. It may be applied, however, at any time when the land is being prepared for a crop. If the land is plowed and then leveled by a disk or drag harrow before scattering the lime, the working in of the lime may serve as the final preparation of the seed bed.

Lime is most readily applied with a lime spreader, several kinds of which are now on the market.[1] These spreaders broadcast a strip from six to ten feet wide depending on the size, and the spreading is done evenly. They may be hitched behind the wagon and the lime shoveled into the hopper from the wagon box or they may be filled at intervals and handled as a drill. As this is an implement which is used but a very few days during the year it is best for several farmers in a neighborhood to buy one in cooperation.

A manure spreader may be used for spreading lime by throwing some manure or dirt in the bottom or by tacking canvas over the apron to prevent the lime sifting thru. The apron must be run slowly in order to prevent too heavy spreading. The spreader may be set for a given number of loads per acre and the amount of lime for each load regulated accordingly. Endgate seeders are sometimes used, but they are not very satisfactory, particularly if the lime is fine and dry.

A fertilizer attachment on a grain drill may be used for applying limestone but unless the amount to be applied to the acre is small, this method is slow. Few drills will handle more than 800 pounds to the acre so that the ground must be gone over more than once. Some drills having larger capacities have been placed on the market recently but where much lime is required a lime spreader is to be preferred. The drill has the advantage of drilling the limestone into the soil but further mixing is necessary if the work is properly done.

It is possible to build homemade spreaders at a moderate expense. All that is necessary is a good-sized hopper mounted on substantial wheels with a shaft passing lengthwise thru the hopper. This shaft should bear agitators which stir the lime out of holes in the hopper bottom. The rate of spreading can be regulated with a slide which opens or closes the holes.

It has been found that the work of practically all lime spreaders is influenced by the wetness of the limestone. It is often very difficult to spread wet stone. Where farmers grind their own stone it is usually found advantageous to spread the limestone as fast as it is ground and not allow

[1]Lists of companies handling ground limestone and lime spreaders will be furnished on application to the College of Agriculture.

it to get wet before spreading. Limestone which is shipped in is best handled in closed box cars and it should be spread as the car is unloaded. If possible the work should be arranged so that two or more teams haul while one spreads the limestone in the field.

Lime may be scattered by hand satisfactorily if the area to be covered is small, but for large areas hand scattering is too expensive. It may be scattered with a shovel from a wagon if the limestone is not too fine and dry. It may be hauled to the field, dumped in piles then scattered from the ground. Piles of two hundred pounds approximately fifty feet apart each way, will give about two tons per acre.

MISSOURI LIMESTONE SUITABLE FOR AGRICULTURAL PURPOSES

The increasing interest shown in the grinding of limestone for agricultural purposes, particularly by individual farmers and groups of farmers, makes it important that information be supplied as to the location in Missouri of suitable limestone outcrops. There is no doubt that the grinding of limestone is to become a very important industry.

Missouri contains great deposits of high grade limestone which lend themselves ideally to grinding. The wide range of geological formations which have the proper chemical composition for making agricultural lime affords an inexhaustible supply of raw material so situated as to be available for economic production. There are few counties in Missouri which are entirely lacking in limestone formations, altho many of the rock strata in the southern part of the state are not well suited for development. Missouri is the largest producer of lime among the states west of the Mississippi river, and the state is excelled in lime production by only five others. This large production indicates the possibilities in supplying ground limestone, for in general, limestone which is suited for the making of lime for the trades is also adapted for use in agriculture.

The quality of limestone varies both chemically and physically, within wide limits. Consequently only those limestones should be used which are relatively pure carbonate. It is the lime and magnesium carbonates which possess the alkaline properties for neutralizing the soil acids. The impure limestones contain more or less material other than carbonates, such as iron compounds, silica and clay. These impurities when present in sufficient amounts give rise to cherty or flinty limestones, to argillaceous or clayey limestone, and others, depending on the amount and character of the impurity present.

The composition which a limestone should have for making good ground limestone for agricultural purposes, depends somewhat on conditions, but in general it may be stated that more than ten per cent of impurity is objectionable, except in special cases. The greater the proportion of impurity, the greater is the amount of stone required in order to produce a given amount of calcium and magnesium carbonate. Thus, a ton of pure limestone will produce one ton of carbonate, but to produce a like amount from a stone only 80 per cent pure, would require the pulverizing of one and one-fourth tons of the material. The greater cost of quarrying, grinding, hauling and applying the impure stone is at once apparent. In

those regions where only the relatively impure limestones are available, however, their use even at the increased cost of handling may be more economical than the use of the higher grade material which must be shipped in at a considerable cost in freight. This is a matter which must be determined locally. High-grade stone contains 95 per cent or more of calcium carbonate, or its equivalent in combined calcium and magnesium carbonates; medium grade contains 85 to 95 per cent; low grade 75 to 85 per cent and inferior grade under 75 per cent.

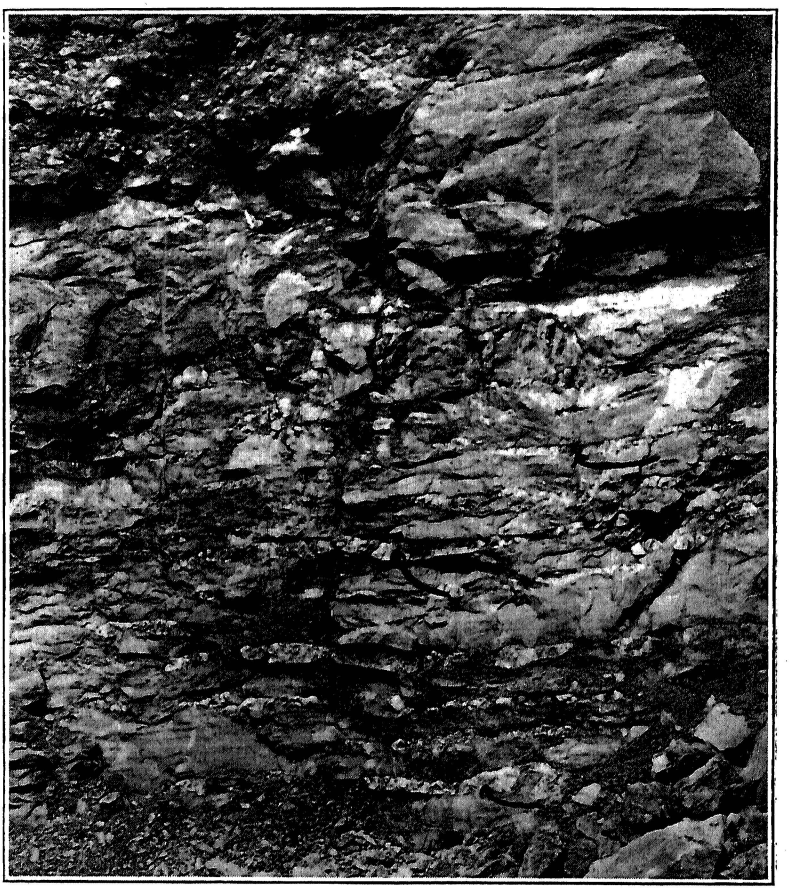

FIG. 7.—Face of quarry in Burlington limestone showing characteristic lenses and nodules of chert. This impurity should be discarded when limestone is used for agricultural lime.

A large amount of limestone in Missouri is of high grade, and considered from an agricultural viewpoint, it constitutes one of the most valuable resources of the state. While most limestones contain the carbonate largely in the form of calcium carbonate, which is usually considered the most desirable form for agricultural purposes, many of them contain greater or less quantities of magnesium carbonate also. The rocks

now being ground for agricultural purposes in Missouri are almost entirely high calcium stones but as shown in the accompanying map a large part of the limestones of south Missouri are high in magnesium. So far as soil sweetening is concerned, the magnesium carbonate is not objectionable[1] and limestones may contain almost one-half the carbonate in the form of magnesium carbonate, as in the case of the true dolomites, and still be ground for agricultural purposes. The application of very large quantities (five tons or more) of magnesium carbonate is not considered desirable on most soils, however, so that the high calcium stones are generally preferred, except on soils which are naturally low in magnesium.

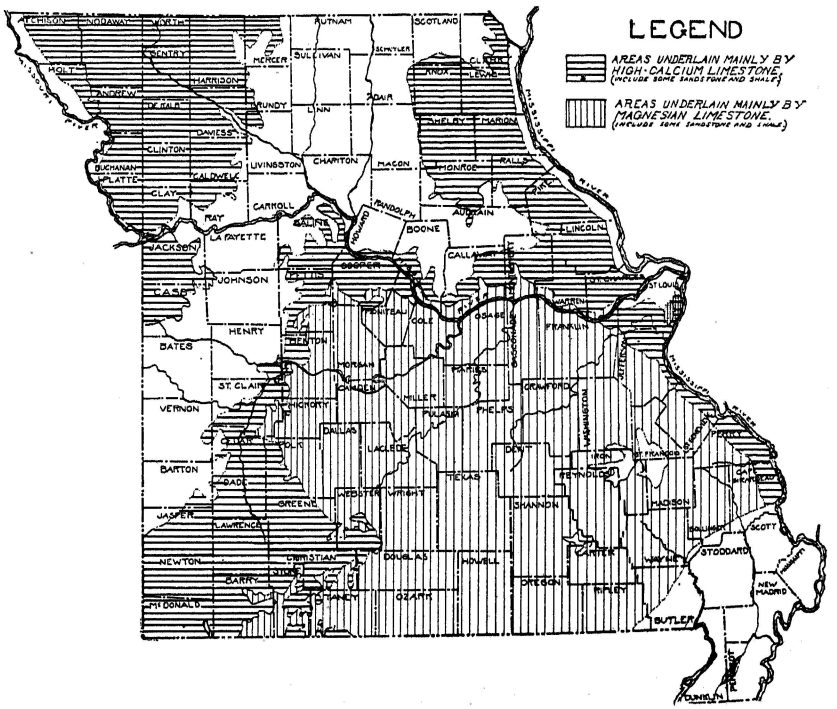

FIG. 8.—Map of Missouri showing the areas underlain by high calcium and by magnesian limestone. The white area shown in the central part of the state contains some thin beds of limestone which occasionally outcrop along the streams. (From State Geological Map, published by H. A. Buehler, State Geologist, Rolla, Missouri.)

As far as its physical properties are concerned, any kind of limestone is suitable for agricultural lime. Fine-grained, dense stone is as valuable as the coarsely crystalline stone, provided the purity is the same. Evidently one of the first points to be considered in the manufacture of ground lime-

[1]Chemically considered, magnesium carbonate is slightly more effective than calcium carbonate as a neutralizing agent, one part of magnesium carbonate being equivalent to one and nineteen hundredths parts of calcium carbonate. One hundred pounds of stone containing sixty-five per cent calcium carbonate and thirty per cent magnesium carbonate with five per cent impurity would actually have a neutralizing power equal to one hundred pounds of pure calcium carbonate. If it contained less than 5 per cent of impurity its neutralizing power would equal more than one hundred pounds of pure calcium carbonate.

stone is the selection and opening of a suitable deposit. It should be ascertained that the quality is reasonably uniform thruout the deposit and that a sufficient quantity of stone is above drainage level, so that the quarry floor will not be continually under water. Transportation facilities and other details of similar importance should be carefully considered.

The various limestone formations occurring in this state differ widely in chemical composition and physical characteristics. Their value, however, depends not only upon their chemical composition, but upon their thickness, location, the quantity of stripping necessary and their general accessibility. In the succeeding paragraphs is given a general description of the major groups of limestones occurring in Missouri, which are suitable for agricultural purposes. No attempt is made to describe each formation occurring in the several groups, and only such characteristics are given as will assist in determining the general utility of the strata under consideration. For a detailed report on the limestone resources of Missouri the reader is referred to Volume II, Second Series, of the publications of the Missouri Bureau of Geology and Mines, Rolla, Missouri.

Figure 8 shows the general distribution of the major groups of limestone formation suitable for the manufacture of agricultural lime.

LIMESTONE OF NORTHWEST MISSOURI

THE UPPER COAL MEASURES

The Upper Coal Measures (Missourian) of the Pennsylvanian series contain very large quantities of high grade limestone. This formation underlies the greater part of northwest Missouri, including all the territory west of a line drawn from near the central part of Cass County to the northwest corner of Mercer County. The strata composing it have a total thickness of more than twelve hundred feet, and consist of interstratified limestone and shale, with occasional beds of sandstone. The beds of the former vary in thickness from a few inches to fifteen or twenty feet, with occasional beds of greater thickness. In general, the thicker beds underlie the shale and sandstone and are most exposed in Jackson, Platte, Clay, Buchanan, Clinton, Caldwell, Daviess, and Mercer counties. Only a few of the more important and thicker beds have been named. Of these, the most widely exposed is known as the Bethany Falls limestone. It can be traced from Cass County north to the Iowa line. It is rather pure and well suited for group limestone. The Iola, Dennis and Mound Valley limestones, exposed in Jackson County, and numerous other limestone ledges outcropping thruout the northwestern part of the state, have sufficient thickness, as well as the correct composition, for use in the manufacture of agricultural lime. More than one hundred limestone quarries are found in the region of the Upper Coal Measures in northwest Missouri. The greater proportion of these are producing stone of such purity that it would be well adapted for agricultural lime.

The thick deposits of glacial drift and loess occurring in this region often make good stone inaccessible. In general, it is in the bluffs bordering the larger stream valleys and the Missouri river in the southern part of the Upper Coal Measure area, that the limestone ledges are exposed.

Where no bluffs occur, the necessity of removing (stripping) the thick beds of soil overlying the limestone adds so much to the cost of quarrying usually to make it impracticable.

LOWER COAL MEASURES

The region occupied by the Lower Coal Measures is a rather irregular belt of varying width, extending from Jasper County in a northeasterly direction to the Iowa state line. It consists mainly of shale and sandstone with comparatively thin and unimportant interstratified beds of limestone. The latter are rarely exposed and with few exceptions are too thin and impure to warrant exploitation.

LIMESTONES OF SOUTHWEST, CENTRAL AND NORTHEAST MISSOURI

The most extensive and by far the most important region of high grade limestone in Missouri extends from the southwestern part of the state in a northeasterly direction to the Missouri river, where it turns eastward and finally spreads out covering the eastern portion of the state both north and south of the river. (See Fig. 8). The several formations occurring in this region consist mainly of limestone and are known as the Mississippian series. A small disconnected area occurs along the eastern edge of St. Genevieve and Perry counties. The Mississippian limestone is mostly high calcium stone and is the most suitable for the manufacture of ground limestone to be found in the state . Much opportunity exists for developing local crushing plants.

The most important formation of this series is known as the Burlington limestone. It has a maximum thickness of 350 feet and is the surface rock over the greater part of the area occupied by the Mississippian series. It is identified by its coarsely crystalline and fossiliferous texture and white to buff color. Varying amounts of chert (often incorrectly called flint, which is black) occur thruout the formation, either in layers or scattered thru the rock, but when quarried this is easily separated from the limestone. This stone is exceptionally free from impurities, and the ledges which are quarried contain from 90 to 99.5 per cent of calcium carbonate.[1] Excepting in portions of northeast Missouri, this limestone is usually covered with a slight amount of stripping and can be quarried with comparative ease.

The St. Louis limestone has its maximum development in St. Louis County, but it also occurs in the northeastern part of the state and in St. Genevieve County. The formation consists of thin to heavily bedded, fine grained, white to gray-colored limestone. The content of calcium carbonate varies from 70 to 95 per cent, which would indicate that much of this formation is suitable for use in the preparation of ground limestone.

Several other formations of the Mississippian series, such as the Chouteau and Louisiana limestones consist dominately of calcium carbonate, but on account of their limited distribution, and because they are generally associated with the Burlington limestone, they are of comparatively little

[1]Buehler, H. A. Lime and Cement Resources. Missouri Geological Survey, Vol. VI. Second Series, pp. 233-239.

importance. For the most part these formations outcrop in the eastern part of the state and along the Missouri river between Warren and Cooper counties. On account of their varying thickness and irregular distribution their fitness for utilization must be determined locally.

Thruout the region of occurrence of the Mississippian limestones, outcrops of ledge rock are numerous, and as a rule are accessible and easily quarried. In fact, in the more broken parts of this region there is hardly a square mile of territory that does not have ledges of stone that could be utilized for manufacturing agricultural lime. Even the development of the many quarries, now used for the production of coarse building stone, could be made to produce an unlimited supply of crushed limestone. Large quarries are located in Lincoln, Greene and Jasper counties, but possibilities for similar development are found thruout the belt of Mississippian rock.

LIMESTONES OF SOUTHEAST MISSOURI

The relatively pure limestones of the extreme eastern part of the state south of St. Louis County can supply an unlimited amount of material for ground limestone. They belong to a wide range of geologic ages—Cambrian to Pennsylvanian—and embrace strata that are especially well suited for the production of agricultural lime. Their total thickness is several hundred feet, and they are therefore present in sufficient quantity, wherever they occur, to warrant working. Moreover, the prevailing hilly topography in the region of these rocks provides extremely favorable conditions for the location of quarries.

These formations lie along the eastern edge of the Ozark region extending from the Missouri river, in the western part of St. Louis County, southward to the lowlands of Cape Girardeau County. The majority of outcrops occur in the eastern third of the counties bordering the Mississippi river. These same formations also are exposed in the eastern parts of Lincoln, Pike and Ralls counties in the northeastern part of the state, and the southern parts of St. Charles and Warren counties.

In color the limestones vary from gray to blue, and in texture from coarse grained to fine grained. Probably the most important formations of this region are the Kimmswick and Plattin formerly called the Trenton limestone. They vary from coarsely crystalline to fine grained, while occasional beds contain chert nodules. The purity of the formations and the thickness of the exposed ledges fit them for the manufacture of ground limestone. They are extensively quarried in St. Louis, St. Genevieve and Cape Girardeau counties for the manufacture of lime and building stone. The Spergen limestone, of remarkable purity occurs in St. Genevieve County and outcrops at various places in the river bluffs. To the west of the river counties, in St. Francois, Madison and Washington counties, extensive beds of dolmitic limestone of Cambrian age occur. The most important of these is the Bonne Terre, a rather pure magnesium limestone, between 500 and 600 feet thick in places. It contains no chert, and is well suited for agricultural lime. The chat of the lead mines is largely from this formation. In general, the southeastern part of the state contains inexhaustible beds of high-grade limestone, easily accessible for quarrying and well suited to the manufacture of ground limestone.

LOCATION AND COMPOSITION OF SOME MISSOURI LIMESTONES

County	City	Geol. Horizon	Calcium Carbonate	Magnesium Carbonate	Location
Andrew	Amazonia	Upper coal measures	84.11	8.74	Lower bed in Atwood quarry
Bates	Worland	Lower coal measures	89.45	0.27	Heavy bed opposite K. C. S. depot
Benton	Warsaw	Jefferson City	47.01	38.86	Cotton Rock
Boone	Rocheport	Burlington	97.60	0.75	
Buchanan	St. Joe	Upper coal measure	95.11	1.59	17 foot ledge, St. Joe, north of city
Caldwell	Breckenridge	Bethany Falls	94.60	0.31	Complete ledge Breckenridge Stone Co.
Cape Gir.	Cape Gir.	Kimmswick	99.52	0.50	Cape Lime and Marble Co.
Cass	Greenwood	Bethany Falls	94.69	0.61	Ledge south of city
Christian	Republic	Burlington	99.07	.05	Rogers White Lime Co.
Clinton	Plattsburg	Upper coal measures	89.30	1.30	Plattsburg limestone, south of city.
Cole	Jefferson City	Jefferson City	41.84	37.44	
Cooper		Chouteau	96.38	0.76	Lower beds at Chouteau Springs
Crawford		Cambro Ordovician	95.23	1.31	Marble
Daviess	Jameson	Bethany Falls	84.00	6.93	A. B. George Quarry
Douglass	Ava	Cambro Ordovician	53.76	44.69	One-half mile east of city
Franklin	Port Royal	Kimmswick	98.50	0.50	
Greene	Phenix	Burlington	99.06	0.58	Phoenix Stone & Lime Co.
Harrison	Bethany	Bethany Falls	94.64	0.35	Ledge exposed just west of city.
Howard	Glasgow	Lower coal measures	93.02	0.50	From ledge in railroad cut north of city
Iron		Cambro Ordovician	89.07	3.75	
Jackson	Independence	Iola	97.42	0.52	K. C. Portland Cement Co.
Jasper	Carthage	Burlington	98.57	0.65	Carthage Marble & White Lime Co.
Jefferson	Byers Station	Kimmswick	97.70	0.51	Union Sand and Material Co.
Lafayette	Lexington	Lower coal measures	86.38	0.15	Ledge below coal one mile west of city
Lawrence	Pierce City	Burlington	99.28	0.16	Pierce City Lime Co.
McDonald	Noel	Burlington	94.54	1.32	Hughes Stone Co. quarry above lower bed
Marion	Hannibal	Burlington	98.87	0.62	Hannibal Lime Co.
Mercer	Princeton	Bethany Falls	93.40	0.94	T. W. Ballew, quarry lower ledge.
Newton	Grand Falls	Burlington	98.18	0.65	
Nodaway	Skidmore	Upper coal measures	71.59	0.36	Ledge one-half mile west of city.
Perry	Wittenburg	Mississippian	95.36	2.85	Four miles south of city
Pettis	Sedalia	Chouteau	49.21	31.57	Rymer Bros. Quarry
Pike	Louisiana	Burlington	97.80	0.47	Marble Head Lime Co.
Platte	Weston	Upper coal measures	87.86	4.82	18 foot ledge
Ralls	Ilasco	Burlington	97.99	0.42	

LOCATION AND COMPOSITION OF SOME MISSOURI LIMESTONES

County	City	Geol. Horizon	Calcium Carbonate	Magnesium Carbonate	Location
St. Clair	Osceola	Burlington	98.59	0.09	Hallewell Cement Co.
St. Francois	Desloge	Cambrian	55.41	39.54	
Ste. Genevieve	Ste. Genevieve	Spergen Hill	98.80	0.53	Ste. Genevieve Lime & Quarry Co.
St. Louis	St. Louis	Kimmswick	98.96	0.52	Glencoe Lime & Cement Co.
St. Louis	St. Louis	St. Louis	96.09	0.90	White Ledge, Stolle Stone Co.
Saline	Gilliam	Burlington	98.67	0.04	One-half mile northwest of city
Vernon	Eldorado Springs	Burlington	94.54	0.65	Two miles N. W. of city
Washington		Cambro Ordovician	53.50	42.30	
Worth	Denver	Upper coal measures	96.16	0.49	Ledge south of mill.
Wright		Cambro Ordovician	53.72	40.97	

From Table No. XVII, page 233-239 'Lime and Cement" Missouri Bureau of Geology and Mines Vol. 6, second series.

LIMESTONES OF THE OZARK REGION

The limestones of the Ozark region are almost entire magnesian stones, the amount of magnesium carbonate varying from a few per cent to as high as forty per cent. They are available at almost any place along the streams or by stripping the overlying material which varies in thickness according to the region. In most places away from the streams the covering is too thick to warrant stripping. The varying composition of closely associated beds makes it impossible to state the value of these stones for agricultural purposes, without an examination of the individual ledges.

A source of limestone which might be utilized are the large piles of chat at the lead and zinc mines. Analyses show them to vary in composition from less than ten per cent to more than eighty-five per cent carbonate so that an analysis is always necessary to determine the value of individual chat piles.

SUMMARY

1. Approximately two-thirds of the samples of Missouri soils examined have shown a need of lime. About one-fourth of these have shown a lime need of two tons or over in the acre seven inches.

2. The satisfactory production of red clover or alfalfa may be taken as an indication that a soil is in no serious need of lime, altho not all clover or alfalfa failures are due to a lack of lime in the soil.

3. The kind of lime to apply depends principally upon the cost. In determining this matter it must be remembered that it is the applied cost per unit of calcium (CaO) applied that is the important consideration. As a rule in Missouri ground limestone is the cheapest form to apply.

4. Limestone can be ground by portable grinders at a moderate cost. In regions so far removed from the railroad that the cost of hauling becomes excessive, this means of securing ground limestone is often economical.

5. The finer a limestone is ground the more active it is in the soil, but since the cost increases with the fineness of grinding, a fineness that will allow the material to pass an eight-mesh or a ten-mesh sieve may be considered a good grade. The coarser the material the larger the application required for immediate results.

6. The amount of limestone to apply depends primarily upon the needs of the soil and crop and upon the quality and fineness of the stone, but the usual application is from one and one-half to two and one-half tons to the acre. Applications of one to one and a half tons of a good grade of stone once in four to six years would be considered reasonable, on soils showing enough acidity to affect seriously the growth of clover.

7. Lime is best applied with a lime spreader on land plowed for a crop, allowing the preparation of the seed bed to work it thoroly into the surface four or five inches. It may be plowed under if it is disked into the surface soil before plowing.

8. Missouri has much limestone suitable for agricultural purposes. The most extensive region of high-grade, high calcium stone extends from southwest Missouri in a northeasterly direction to the Missouri river, spreading out and covering the eastern part of the state both north and south. The Ozark limestones contain much magnesium and while thes are not usually considered quite so desirable as the high calcium stones they are very satisfactory for agricultural purposes.