UNIVERSITY OF KENTUCKY

COLLEGE OF AGRICULTURE

Extention Division

THOMAS P. COOPER, Dean and Director

CIRCULAR 59

(5th Edition, Revised)

LIMING THE SOIL

An excellent field of red clover in western Kentucky. Good legume crops characterize good farming. Liming is necessary for successful production of these crops on much land in Kentucky.

Lexington, Ky.
February, 1936

Published in connection with the agricultural extension work carried on by cooperation of the College of Agriculture, University of Kentucky, with the U. S. Department of Agriculture and distributed in furtherance of the work provided for in the Act of Congress of May 8, 1914.

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LIMING THE SOIL

By P. E. KARRAKER

Soils which are farmed, tend to be unproductive unless they are rightly managed. Soils in Kentucky are unproductive, in the main, because of (1) An insufficiency of organic matter and nitrogen, (2) an insufficiency of phosphorus, and (3) an acid reaction. In some soils, also, sufficient potassium may not be available for certain crops. In this publication are considered soil acidity, or acid soil reaction, and its correction by the application of a basic material. The latter is spoken of as liming the soil, since ground limestone or some other lime material is usually applied.

When a soil is unproductive from several causes, it is generally ineffective to remove but one. Hence, in considering soil acidity and liming, the reader should have in mind the other practices which increase soil productivity in Kentucky. Information about these is contained in Kentucky Extension Circular No. 272, "Soil Management for Kentucky."

Some persons think of soil productivity as related to total production of farm products, and to them, soil improvement seems useless when demand for farm products is slack. This overlooks the fact that when soil productivity is increased, not only is a greater total production possible, which can be controlled by adjusting crop acreage to demand, but a cheaper and more economical production results which is particularly desirable when prices are low and only consistently high yields are profitable. With proper soil management the present acreage of most general farm crops in Kentucky could be reduced one-third to one-half with no decrease in total production and with a lower production cost. Corn, tobacco and the other row crops could be grown on the less hilly land in the State which is most easily kept highly productive, and most of the other land could be kept in mixed legumes and grasses, for hay, pasture, and soil improvement.

SOIL ACIDITY AND ITS CAUSE

All substances, including soil, are acid, neutral, or basic. The acetic acid in vinegar and the lactic acid in sour milk are common examples of acids. Ordinary washing lye and burned lime are common examples of bases. When an acid and a base are properly put together, chemical action takes place and a new substance —a salt—is formed which is neither acid nor basic; in other words, it is neutral.

Soil contains both acid and basic constituents. If they are present in equivalent amounts, the soil is neutral. If one group is in excess of the other, the soil is accordingly acid or basic.

The basic soil constituents dissolve faster in the soil water than do the acid, and consequently are removed more rapidly in the underground drainage water in humid regions. In this way all soils in humid regions slowly become acid. Even soils in limestone regions become acid in time except on some hillsides where erosion keeps fragments of limestone and marly material at the surface. Under virgin conditions, vegetation worked against this process somewhat, by taking up bases from the lower soil layers during growth and adding them to the surface soil on decay. Cropping, as usually done, hastens the production of acidity because bases are removed from the soil in the crops and the tillage operations increase loss of bases by leaching. In humid regions most farmed soils, sooner or later, become acid to an injurious extent unless prevented by liming.

WHY ACID SOILS ARE UNPRODUCTIVE

Strong acidity is detrimental to most crop plants and to the activity of the soil microbes which promote soil fertility. This is both because of the direct effect of the acidity and its indirect effect in bringing into solution in many soils sufficient aluminum, manganese, and perhaps other substances to be injurious to crop plants. These substances are common constituents of soils but, in humid regions, they become soluble only to a slight extent except in acid soils. They are not injurious and may be beneficial when in solution in minute quantities.

Acid soils, also, are deficient in calcium and crops, which take up much of this nutrient, alfalfa for example, may not be able to get the amount needed. Many acid soils in Kentucky contain less than 2000 pounds of total calcium in the plow layer of an acre. Four tons of alfalfa contain about 100 pounds of calcium which could easily be in excess of that available in a growing season in these soils. Most crops require much less calcium than this and probably are not limited in yield in this way. Corn, for example, contains about 13 pounds in the grain and stover of a 50-bushel crop.

HOW DEGREE OF SOIL REACTION IS EXPRESSED

The degree of soil reaction is often expressed by descriptive terms. Strongly acid, moderately acid, slightly acid, neutral, slightly basic, very well cover the range in humid regions. The degree of soil reaction, also, is expressed by numbers, called pH values. These are related to the amount of acidity present in the soil in active form; technically speaking, the hydrogen ion concentration. Hydrogen ion concentration is an important part of soil acidity, but not the entire condition. The smaller the pH value, the greater the acidity. Generally speaking, pH 4-5 is strongly acid, 5-6 moderately acid, 6-7 slightly acid, 7 neutral, and above 7 basic. To show how these are related to crop growth, other conditions being satisfactory, alfalfa grows best when the pH is about 6.5 to 7.5 and with difficulty when below 6.0, and red clover best when the pH is 6.0 to 7.0 and with difficulty when below 5.5.

Most other legumes grow best when the pH is 6.0 to 7.0, but many of these grow more satisfactorily than does red clover when the pH is below 6.

SENSITIVENESS OF DIFFERENT CROPS TO SOIL ACIDITY

In general, legume crops are more sensitive to soil acidity than are non-legume crops. These crops also differ among themselves in this respect. Alfalfa and sweet clover are the most sensitive. Red clover* is fairly sensitive, but can be grown successfully in some soils too acid for alfalfa and sweet clover. Crimson, alsike, and white clover and soybeans are less sensitive than red clover. These legumes respond to liming on practically any soil where red clover responds, but it is possible to grow them with fair success on land too acid for red clover. Cowpeas and the lespedezas are still less sensitive, but respond to liming on moderately to strongly acid soils.

One should not attempt to grow alfalfa or sweet clover anywhere in the State without liming, unless experience in growing the crop in similar land or chemical test of the soil indicates that liming is not necessary.

Practically all the upland soils of the State outside the Bluegrass region require liming for satisfactory growth of the clovers, particularly red clover. Soybeans, the lespedezas, and cowpeas also respond to liming on these soils. Much land in the Bluegrass region, particularly if it has been cropped heavily, can be limed profitably for red clover unless on hillsides where the soil contains native lime materials. Bottom land generally is less acid than the surrounding upland, but much of the bottom land in the State, particularly of the light-colored, silty type, probably can be limed profitably for red clover.

Most of the non-legume crops are not seriously injured by the acidity in most Kentucky soils; hence liming is not greatly needed for its direct effect on these crops. Barley and bluegrass are more sensitive to soil acidity than many other non-

*The difficulty in growing red clover successfully in Kentucky has been due not only to improper soil conditions but also to the use of seed produced outside the State under different climatic conditions and from strains which are not adapted to Kentucky. This is avoided by sowing seed from clover that has become well established in the State.

legume crops. Rye and redtop, on the other hand, are less sensitive to soil acidity than most non-legume crops.

Liming may affect some crops injuriously by favoring the growth of certain disease organisms in the soil. The potato scab organism, for example, is active in neutral or slightly basic soil, but does not thrive in moderately to strongly acid soil. Therefore land where Irish potatoes are to be grown should be limed cautiously. A similar relationship holds for tobacco. The black-root-rot organism is active in alkaline to moderately acid soil, but not in strongly acid soil. Frenching, a nutritional disease of the growing point of tobacco, which in extreme form is characterized by narrow, strap-like leaves, also has not been found to develop on moderately to strongly acid soil. For these reasons it is advisable not to lime land frequently used for tobacco more heavily than is necessary for satisfactory production of the legumes. Also it is desirable, as a rule, to lime after rather than immediately before tobacco.

TESTS FOR SOIL ACIDITY

There are chemical tests, some of them fairly simple, which indicate soil acidity and the need of liming. The necessary materials for making these tests may be purchased from several sources. Directions for their use accompany the materials.

An old test for soil acidity is the use of strips of blue litmus paper. The paper may be purchased at most drug stores. Only fairly sensitive paper should be used (that which responds to *N*/250 acid solution is very satisfactory). A strip is placed in moist soil so as to make good contact between the soil and paper and left for about ten minutes. The color turns pink or red when the soil is acid. This test is not so good as some of the newer ones. A certain amount of chemical knowledge and of familiarity with the use of these tests is desirable for correct interpretation of the results. County Agents usually are prepared to make such tests or the Experiment Station will make them on properly collected and described samples.

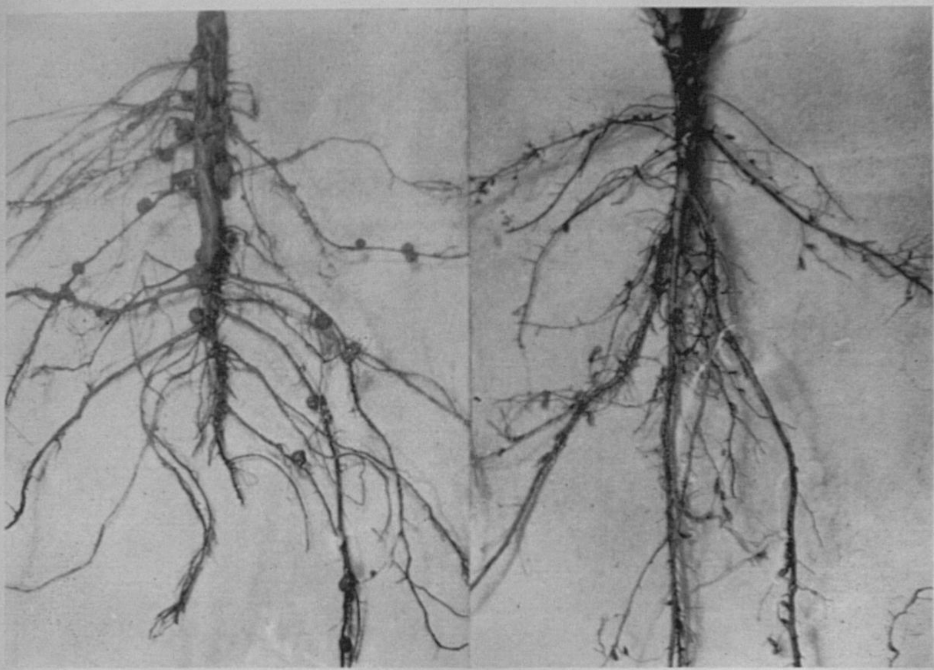
A satisfactory test of the presence of carbonate in soil or in material thought to be marl is made by adding hydrochloric acid, commonly called muriatic acid. If carbonate is present, bubbles of carbon dioxide gas are given off; that is, the material effervesces. The Experiment Station will test free of charge samples of lime materials for fineness and neutralizing value, when these are carefully taken and properly described.

EFFECT OF LIMING

Liming has a number of desirable effects in acid soil. The main one, however, is to make better conditions for the crowth of legume crops—alfalfa, sweet clover, all the clovers proper, soybeans, cowpeas, the lespedezas, etc. These crops are valuable because of their high feeding and money value, and even more so because, under proper conditions, they take the larger part of the nitrogen they need from the inexhaustible supply of the air instead of from the usually deficient supply in the soil, as other crops must do.

The low supply of nitrogen and organic matter in most soils in Kentucky is a serious obstacle to the production of larger crops. Nitrogen can be purchased in commercial fertilizers but not cheaply enough so that any considerable part of that needed by general farm crops can be supplied in this way. Nitrogen for these crops, in the main, is best obtained from the air thru the growth of legumes.

By promoting the growth of legume crops and thus making it possible to add to the supply of nitrogen in the soil, liming does much to increase the productiveness of acid soil. It should be kept in mind, however, that legumes get some of their nitrogen from the soil and that the nitrogen taken up by them, whether from the air or from the soil, is fairly evenly distributed thru the entire plant, tops and roots alike. The amount of nitrogen added to the soil by legume crops, therefore, depends to a considerable degree upon the extent to which the nitrogen in the legume tops is returned to the soil, by leaving the tops on the land, by pasturing, or, if the crop is removed, by feeding it on the farm and properly caring for and returning the manure made. In fact, legume crops such as soybeans and cowpeas, that have a relatively small part of their total nitrogen in the roots and stubble, may impoverish the soil when their entire top growth is removed from the land.



Nodules on the roots of a soybean plant (left) and a red clover plant (right). Bacteria in the nodules take nitrogen from the air, which is used by the plant and added to the soil in the legume material. Liming promotes the growth of legume crops and thus makes soil productive.

Liming acid soil also increases the yield of crops directly. It is not unusual for yields of corn and wheat, for example, to be increased several bushels per acre after liming and before a legume crop is grown. Liming does this mainly by increasing the rate at which plant nutrients of the soil, chiefly nitrogen, become available for crop use. The plant nutrients of the soil are made available largely thru the activity of certain soil microbes and these do not thrive so well in acid as in neutral soil. Liming, however, does not directly increase the availablity of the phosphorus and potassium of the soil. In fact, the opposite may be true, particularly if land is limed heavily. However, the increased growth of legume crops, when returned to the soil, does favorably affect the availability of phosphorus and potassium.

This action of liming in increasing crop yields by increasing the rate at which nitrogen from the soil becomes available, clearly tends to lower soil fertility and in time, if this were its only effect, must result in smaller crop yields. Liming and growing legume crops is a necessary and highly profitable combination for improving the fertility of acid soil but liming without growing legume crops is likely to be of small value.

Liming also produces a better physical or working condition in the soil. It does this by directly improving soil granulation and because of the favorable physical effect of the larger root systems of the crops on limed land. This effect is greatest in heavy, stiff soil and becomes more marked after liming has been practiced for a number of years.

LIMING NOT A CURE-ALL

Liming is a very necessary and important step in improving the productivity of moderately to strongly acid soil but is not a panacea for all soil ills. Lime alone is not a fertilizer in the sense of containing any of the nutrients commonly deficient for crops in Kentucky soils, except calcium for crops like alfalfa, which use much of this nutrient.* As has been noted already, liming does help to supply nitrogen by promoting the growth of legume crops which, thru the bacteria in the nodules, take nitrogen from the air and add it to the soil in the legume material. The legume crops which root deeply, also may take up appreciable amounts of the mineral nutrients, such as phosphorus and potassium, from the under soil layers, and these are added to the surface soil when the plants decay on the land. But liming does not take the place of using a phosphorus fertilizer in phosphorus-deficient soil or using a potassium fertilizer where this is needed. Most Kentucky land outside the Bluegrass region (and some in this region) is deficient in phosphorus as well as nitrogen and the effect of liming will be limited greatly unless the phosphorus deficiency is remedied. The use of phosphate on land which is both acid and phosphorus-deficient may be just as im-

*Lime materials may contain phosphorus, potassium and other nutrients, but in general the amount is too small to be important.

portant as liming, or more so, in making possible successful growth of legume crops.

MATERIALS USED FOR LIMING

The materials mainly used for liming land are pulverized limestone, marl, burned lime, and hydrated lime. Ground limestone is most commonly used in Kentucky. Limestone of good quality is widely distributed in the State and ground limestone is easily obtained and comparatively cheap in most parts of the State. Also, it is easy to handle. Limestone may be ground especially for use on the land. Small portable outfits are available for doing this on the farm. Or a by-product material may be obtained from large quarries where the rock is crushed for other uses.

Limestone contains calcium carbonate, often more or less magnesium carbonate, and a variable amount of earthy matter or impurities. The carbonates neutralize soil acidity. The extent to which magnesium carbonate is present makes little difference in liming Kentucky soils except that 84 parts of magnesium carbonate neutralize as much acidity as 100 parts of calcium carbonate).*

The impurities vary from a very small to a considerable part of limestone. The less present, the more desirable limestone is for use on land. The impurities are not harmful to soil but obviously, since they do not correct acidity, the cost of liming increases with the amount present. Since high-grade limestone is abundant in the State, it should be possible, in the main, to get ground limestone for use on the land, which contains less than 10% impurities.

Considerable marl is used in the parts of Kentucky where it occurs.** Marl contains calcium carbonate, often magnesium

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*Limestone containing much magnesium carbonate is sometimes called dolomitic limestone.

**Marl has been found in the following counties in Kentucky: Adair, Allen, Anderson, Barren, Bath, Breckinridge, Caldwell, Carroll, Casey, Clark, Clinton, Christian, Crittenden, Boyle, Bourbon, Bullitt, Daviess, Edmonson, Estill, Fayette, Fleming, Garrard, Grayson, Green, Hancock, Hardin, Hart, Henderson, Henry, Jefferson, Jessamine, Larue, Lewis, Lincoln, Logan, Madison, Marion, Mason, Meade, Mercer, Matcalf, Monroe, Montgomery, Nicholas, Nelson, Oldham, Pulaski, Russell, Shelby, Simpson, Spencer, Taylor, Todd, Trimble, Union, Warren, Washington, Wayne.

carbonate, and usually a considerable amount of earthy matter. It differs from limestone in that, generally, it contains a greater amount of earthy matter and is soft and can be dug and spread without grinding. It is a cheap and satisfactory material for liming where deposits sufficiently rich in calcium carbonate are easily accessible. Depending on the cost of other lime materials, it may be profitable to use marl when its neutralizing value is as low as 20 percent (neutralizing value of pure limestone, 100). The disintegrated particles of a good marl in the soil are smaller than those of even finely ground limestone and hence should act more quickly in the soil. Further information about marls and their use on land is contained in Kentucky Experiment Station Circular No. 32, "Marls for Liming Soils".

When limestone is burned in a kiln, the calcium carbonate gives off carbon and oxygen as carbon dioxide gas and forms calcium oxide. The product is known as burned lime or quicklime. When water is added to burned lime, the lime slakes; that is, the calcium oxide combines with water and forms calcium hydroxide. The product is known as slaked lime or hydrated lime. Burned lime and hydrated lime are both used for liming. Burned lime must be pulverized before it can be spread properly on the land. Hydrated lime, when dry, is a fine powder. One hundred pounds of calcium carbonate, when burned, forms 56 pounds of calcium oxide. This, on slaking, forms 74 pounds of hydrated lime. Therefore, for use on land, 56 pounds of pure burned lime are equal to 74 pounds of pure hydrated lime, or to 100 pounds of pure limestone.

When burned lime air-slakes, it slowly takes up moisture and carbon dioxide from the air, and may be changed entirely to calcium carbonate. This process goes on much more rapidly when lime is distributed in the soil. Because of cost and inconvenience in handling, burned lime and hydrated lime are not used extensively for liming land in Kentucky, but in some parts of the State where fuel is abundant, limestone is burned and the material hydrated for use on land. Directions for doing this are contained in Kentucky Extension Circular No. 247.

If the mechanical condition is satisfactory, it makes no great difference as to their effect in the soil which lime material is used, provided the materials are applied in equal neutralizing value.

THE EFFECT OF FERTILIZERS ON SOIL REACTION

Ground rock phosphate contains much calcium but the calcium is chemically combined almost entirely with phosphorus and oxygen. Calcium in this form corrects soil acidity to some extent but not enough for applications of rock prosphate to take the place of liming on moderately too strongly acid land. Rock phosphate, also, may contain a small amount of calcium carbonate as an impurity, but this is hardly ever enough to be of practical importance. On land only slightly acid or after land has been limed once, liberal applications of rock phosphate may take the place of liming as well as supply the phosphorus needed by crops. (Rock phosphate, however, is not very effective when used on some land recently limed at a medium to heavy rate. The lime material for a time decreases the availability of the fertilizer to the crop. Superphosphate should be used on such land.)

Basic slag phosphate also corrects soil acidity. It has about the same effect in this way as one-half to two-thirds of its weight of limestone. Used in ordinary amounts, it does not lime land sufficiently which is moderately too strongly acid.

The nitrogen fertilizers, sodium nitrate and calcium nitrate, correct soil acidity. Ammonium sulfate, also a nitrogen fertilizer, makes soil acid. In general, the amount of these fertilizers used for general farm crops in Kentucky is too small for their effect on soil reaction to be very important. This is particularly true when they are used on land which is limed from time to time.

Ordinary superphosphate and the common potash fertilizers have little effect on soil reaction.

Gypsum, or landplaster, is sometimes used on land. It is calcium sulfate and does not correct soil acidity.

FINENESS OF LIME MATERIALS, AMOUNT TO USE, AND TIME OF APPLICATION

Two tons per acre is a good initial application of ground limestone for general farm crops to most acid land in Kentucky.

This is shown by experience of farmers and tests by the Experiment Station. Applications should be made thereafter as needed for successful growth of the legume crops—perhaps one to two tons every six to ten years. Tests of the effect on the legume crops of applying limestone from time to time to small areas in the field will indicate when reliming is necessary. Chemical tests, also, may be of value for this purpose.

The preceding statements apply to other lime materials when used in quantities approximately equal in neutralizing value to the quantities of ground limestone previously mentioned. Burned lime and hydrated lime, however, are not so well suited as is ground limestone for applying in fairly large amounts with comparatively long intervals between applications. This is because the particles of burned and hydrated lime are much finer than those of ground limestone and hence their effect in the soil is not so even over a period of time.

For application at the rate mentioned, ground limestone is fine enough if practically all of it will go thru a 10-mesh sieve (ten meshes to the linear inch, 100 openings in a square inch) and if it contains all the finer material from the grinding. About 50 percent of a limestone so ground should go thru a 40-mesh sieve and 25 percent thru a 100-mash sieve. The finer limestone is ground, the quicker it acts and the less is the amount required to neutralize present soil acidity. However, when used as mentioned, very fine grinding is not required and the presence of more fine material than is necessary increases loss of lime by leaching.

In general, when used as mentioned, ground limestone (or other lime material used in equal neutralizing value) may be applied when most convenient, irrespective of time in the rotation or whether before or after plowing. However, lime materials are relatively insoluble and have very little effect until mixed with the soil. The beneficial effect on legume crops, of ground limestone, used at the rate mentioned, increases for a year or more after admixture with the soil. Probably the maximum effect on clover, seeded in small grain following corn, is produced if the limestone is applied after the ground is plowed for corn.

Land should be limed more heavily for alfalfa than for general crops. Often it is profitable to apply ground limestone at the rate of 2 to 4 tons per acre for this crop. The treatment is most effective if made a year or so previous to seeding the crop.

On very acid soil, somewhat heavier liming may be desirable for general farm crops than that previously mentioned. Very heavy liming, however, is inadvisable. The application, to almost any soil, of say 8 tons of ground limestone, or more, per acre, supplies more lime than is needed, increases loss by leaching, and the cost of liming, and actually reduces crop yields, as compared with yields where more moderate liming is done. This reduction of yield comes about because very heavy liming ties up the mineral elements (phosphorus, potassium, etc.) in the soil and reduces the amount the crop can get.

In sections without local supplies of lime materials and when freight and haul costs are high, lighter liming than that previously mentioned may be admissible. Lighter liming may also be advisable on land where crops such as Irish potatoes and tobacco are frequently grown, which do better when land is moderately acid than when neutral. Such land should be limed only to the extent necessary to get fairly successful growth of red clover or other legume equally or more tolerant of soil acidity.

Five hundred to a thousand pounds of limestone per acre should be applied once per rotation for light liming. Finer grinding may be desirable for light liming than for the heavier rate, tho material which passes a ten-mesh sieve and which contains all the dust, is satisfactory. The application should be made at the time of seeding the small grain in which the legume is to be seeded the following spring. It is best applied with the fertilizer attachment to the grain drill which places the limestone in the drill row where most of the legume plants will be and the small amount of limestone will be most effective in promoting their growth. The limestone may be mixed with the fertilizer, which offers an easy way of applying both materials. Liming at this rate, aids materially in getting stands of red clover and other clovers and increases the yield of lespedeza.

At the Substation at Princeton, in 1926, ground limestone was applied at the rate of two tons per acre and at the rate of one-third ton per acre on small adjoining areas of land which was moderately acid. The clover following these applications was considerably better on the land limed heavily than on that limed lightly but it was better on the latter than on land not limed at all. Five years after the first liming, the one-third ton application was repeated on the land which had originally been limed at this rate, but the two-ton application was not repeated. The legume crop following this was much better on the land which received the two light applications than on that which received the one heavy application in the beginning. The light liming once per rotation, just before the legume is seeded, is a satisfactory liming practice on this land. If a choice must be made, probably it is better to lime a fairly large amount of land lightly than to lime a small amount at the usual heavy rate. Also, on most land in the State, outside the Bluegrass region, it is more profitable to lime lightly and use a phosphate fertilizer than to lime at the usual heavy rate and not use a phosphate fertilizer.

HOW TO SPREAD LIME MATERIALS

When much ground limestone is to be spread, a special spreader for this purpose should be used, since the spreading can be done more rapidly and evenly. There are a number of good machines of this kind on the market. The end-gate type is very satisfactory. It covers a wide strip and spreads ground limestone when wet. Manure spreaders with the special attachment for spreading ground limestone also are very satisfactory. Either of these spreads marl satisfactorily when the stones and lumps have been sieved out. The hopper type of spreader is most satisfactory for spreading hydrated or ground burned lime, as it lessens the amount of these materials flying thru the air.

Frequently marl is spread with a shovel. Ground limestone also can be spread in this way but attention should be given to evenness of spreading.

LIMING IS PROFITABLE

About 200,000 tons of lime materials are used in the State annually. This in itself suggests that liming is profitable on much land in Kentucky, but the amount used could be increased many times with equal profit, particularly if used on land which has not been limed previously. For the most part, when farmers do not lime, it is not because they believe it undesirable, but because they hesitate to incur the cost at any particular time, hoping that a future time will be more favorable in this respect. Such a policy of waiting scarcely ever is justified in regard to so important a part of building up soil productivity as is the liming of acid land. As a matter of fact, liming costs very little, since the returns from the first application usually more than carry the cost thereafter.

The results from the soil experiment fields located in different parts of the State outside the Bluegrass region strikingly show what liming does to increase crop yields.* The increases in yield from liming at these fields are shown in Table 1. The increases in yield from superphosphate, also, are shown in the table so that the effect of both materials on crop yields can be seen.

Manure was used at all these fields except Fariston and Princeton. It was applied for the corn crop on both the treated and untreated land, generally in an amount equal to that estimated would have been made by feeding the crops of the preceding rotation. The quantity of ground limestone used was equivalent to an application of about 1.2 tons per acre every four-year period and that of superphosphate to an application of about 700 pounds per acre every four-year period, tho neither was applied in just this way. These rates of application, which were used experimentally, are not necessarily the most profitable for specific farm conditions; in fact, generally, they are too heavy.

The average yield of crops at these fields on the plots which received no limestone or commercial fertilizer, is shown in Table 2. The reaction of the soil and the amount of phosphorus in the surface soil of these untreated (or check) plots, also are shown. The comparatively small amount of phosphorus is typical of that in upland soils in Kentucky outside the Bluegrass

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*Results from most of these fields are reported in detail in Kentucky Experiment Station Bulletin No. 322.

TABLE 1. Increases in yield per acre from the use of limestone and superphosphate, separately and together, at the Experiment Fields.

Field and Treatment	Corn	Wheat	Soybean Hay	Mixed Hay
	bus.	bus.	lbs.	lbs.
FARISTON FIELD				
Limestone	8.0	2.0	535	286
Limestone and superphosphate	35.2	9.0	2856	2006
Superphosphate	18.6	4.3	892	740
Limestone where superphosphate used*	16.6	4.7	1964	1266
Number of crops averaged	14	9	16	14
BEREA FIELD				
Limestone	11.1	—	695	407
Limestone and superphosphate	19.0	—	1271	1942
Superphosphate	12.6	—	807	531
Limestone where superphosphate used*	6.4	—	464	1411
Number of crops averaged	20	—	18	15
CAMPBELLSVILLE FIELD				
Limestone	5.8	2.1		351
Limestone and superphosphate	25.9	7.9		1678
Superphosphate	21.4	6.0		1324
Limestone where superphosphate used*	4.5	1.9		354
Number of crops averaged	13	11		11
RUSSELLVILLE FIELD				
Limestone	8.7	0.2	657	1190†
Limestone and superphosphate	14.9	7.8	758	2026†
Superphosphate	7.1	3.2	428	755†
Limestone where superphosphate used*	7.8	4.6	330	1271†
Number of crops averaged	11	9	11	9
HOPKINSVILLE FIELD				
Limestone	5.9	1.0		847‡
Limestone and superphosphate	11.7	7.3		2542‡
Superphosphate	3.7	5.7		1774‡
Limestone where superphosphate used*	8.0	1.6		768‡
Number of crops averaged	8	6		6
PRINCETON FIELD				
Limestone	5.7	0		769
Limestone and superphosphate	10.9	5.8		1631
Superphosphate	5.7	3.1		859
Limestone where superphosphate used*	5.2	2.7		772
Number of crops averaged	6	7		6

*Obtained by subtracting the increase for superphosphate from the increase for limestone and superphosphate.
†Red clover alone.
‡Clover and soybeans.

TABLE I—Continued.

Field and Treatment	Corn	Wheat	Soybean Hay	Mixed Hay
	bus.	bus.	lbs.	lbs.
GREENVILLE FIELD				
Limestone	2.4	1.4	341	328
Limestone and superphosphate	20.5	11.6	1587	2401
Superphosphate	10.1	5.7	900	1435
Limestone where superphosphate used*	10.4	5.9	687	966
Number of crops averaged	19	18	18	18
LONE OAK FIELD				
Limestone	5.2	0.7	372	884†
Limestone and superphosphate	7.3	7.3	719	1974†
Superphosphate	2.7	1.5	269	356†
Limestone where superphosphate used*	4.6	5.8	450	1618
Number of crops averaged	14	10	10	7
MAYFIELD FIELD				
Limestone	9.5	4.3	636	1720
Limestone and superphosphate	12.4	9.6	1004	2690
Superphosphate	1.6	2.8	268	447
Limestone where superphosphate used*	10.8	6.8	736	2243
Number of crops averaged	19	18	16	16
AVERAGE OF ALL FIELDS				
Limestone	6.9	1.5	539	754
Limestone and superphosphate	17.5	8.3	1366	2099
Superphosphate	9.3	4.0	594	913
Limestone where superphosphate used*	8.2	4.3	772	1186
Number of crops averaged	124	88	89	102

*Obtained by subtracting the increase for superphosphate from the increase for limestone and superphosphate.

†Red clover alone.

region. In a very general way, 2000 pounds in the plow layer of an acre is about the least amount of phosphorus a soil can contain and still consistently produce high-yielding crops without the application of phosphorus in fertilizers. The crop yields for the most part are small and show the low productivity of the untreated land.

As can be seen in Table 1, ground limestone applied to land which had received no commercial fertilizer gave small to large increases in yield of crops at all fields (except wheat at the Princeton field). However, because of the deficiency of phosphorus in the soil the treatment was much more effective on land to which a phosphate fertilizer also had been applied. Considering the average of all fields, the increases in crop yields from limestone

TABLE 2. Average yields per acre of untreated plots at the Experiment Fields.

Field.	Soil Region.	Soil Reaction.	Phosphorus in an acre plow layer.	Corn.	Wheat.	Soybean hay.	Mixed hay.
			lbs.	bus.	bus.	lbs.	lbs.
Fariston	Eastern Coal Field.	Strongly acid.*	820	8.1	2.1	1312	208
Berea	Devonian shale region	Strongly acid.	880	27.4	—	2920	541
Campbellsville	Waverly Region	Between moderately and slightly acid.†	733	30.2	5.1	—	1235
Russellville	Western limestone region	Moderately acid.	1040	30.0	10.0	2003	1626
Hopkinsville	Western limestone region	Moderately acid.	720	33.0	6.0	—	1826
Princeton	Western limestone region	Moderately acid.	850	46.4	9.2	—	1969
Greenville	Western Coal Field	Between moderately and strongly acid.	660	26.2	5.0	1960	720
Lone Oak	Purchase Region	Strongly acid.	682	32.7	11.1	2495	1573
Mayfield	Purchase Region	Strongly acid.	960	34.9	8.7	2428	952

*The soil of this field is more acid than the average of the soils of the Eastern Coal Field.

†The soil of this field is less acid than the average of the soils of the Waverly region.

applied to land which had not received superphosphate were: corn, 6.9 bus., wheat, 1.5 bus., soybean hay, 539 lbs., and mixed hay, 754 lbs. The increases ascribable to limestone on land that had received both limestone and superphosphate were: corn, 8.2 bus., wheat, 4.3 bus., soybean hay, 772 lbs., and mixed hay, 1186 lbs. At the Mayfield and Lone Oak fields in the Purchase region,

Corn at the Greenville Soil Experiment Field on land treated with ground limestone and superphosphate (left) and on land not treated. The yield per acre on the treated land was 49 bushels and on the other 26 bushels. Lime and phosphate was first applied eleven years prior to this crop. The rotation was corn, soybeans, wheat and mixed grass and legumes, mainly red clover. The average yield of mixed hay, mainly clover, (16 crops) at this field was 720 pounds per acre on the land not treated and 3121 pounds per acre on the land treated with ground limestone and superphosphate.

limestone applied alone increased crop yields more than superprosphate applied alone. At the other fields superphosphate applied alone increased crop yields as much as or more than limestone applied alone. At all the fields, however, it was more profitable to use both limestone and superphosphate than either alone.

Liming and the use of a phosphate fertilizer has been the most profitable fertilizer treatment used at the experiment fields on land typical of the upland in the State outside the Bluegrass region. On the average this treatment has practically doubled yields and returned a net profit of more than $3.00 for every dollar invested. This treatment and the proper use of legume crops insure a high level of productivity on land where erosion is controlled; without it, poor soils are inevitable and only a bare existence on the land is possible. This treatment is almost as profitable for pastures as for general crops. It enables practically as good pastures to be produced on much land in the State as those in the Bluegrass region, as has been well shown by tests on sandstone land at the Western Kentucky Substation at Princeton. Even bluegrass grows satisfactorily on much land in the State after it has been limed and a phosphate fertilizer applied. The best and most profitable use of rolling to hilly upland in the State is for good pastures. More are not found outside the Bluegrass region mainly because the fact is ignored that pastures require and respond profitably to the same treatment as cropped land.

The better growth of crops, particularly small grain, sod, and pasture, on land which has been limed and treated with phosphate, also helps very much to control erosion. In fact, the most important requisite for controlling erosion on much Kentucky land is to make it productive enough to grow an effective vegetative cover.

At the soil experiment field at Lexington, on land typical of the best of the inner Bluegrass region, liming has given no increase of importance in yield of corn, soybeans, wheat, and clover in rotation. Liming has been necessary, however, to successfully grow alfalfa and sweet clover on this land. At other places on the Experiment Station farm, liming has given good

A good pasture of orchard grass, bluegrass and white clover on poor sandstone land at the Western Kentucky Substation after liming and the application of superphosphate (left). The field at the right was similar land and was seeded and managed exactly the same except that it was not limed and treated with superphosphate.

increases of red clover, and has improved bluegrass pastures.

From 1914 to 1920 the Experiment Station carried on experiments on the Lincoln Institute farm, located about one and one-half miles west of Simpsonville in Shelby County in the outer Bluegrass region. As an average of all comparisons, limestone applied at the rate of 2 tons per acre every four years (oftener than necessary when applied at this rate) increased the yield of soybean hay 713 pounds per acre and that of clover hay 995 pounds per acre. The land was probably less productive than the average of that in the outer Bluegrass region.

Land in the Bluegrass region varies widely in reaction. Many slopes in the hilly sections are not acid, contain marl and fragments of limestone at the surface, and grow alfalfa and sweet clover successfully without liming. Other land in the Bluegrass region is acid to the degree that red clover will not grow without liming. Possibly most land in the Bluegrass region, except the slopes just mentioned and land which has been kept in pasture practically all the time, needs liming for the most successful growth of red clover or any other crop equally sensitive to soil acidity.

According to records obtained by county agents, about as much lime materials have been used in recent years on the land in some of the better counties in the Bluegrass region as in counties in any other part of the State. However, it should be kept in mind that, on the average, most of the soils in this region, tho containing no limestone or marl, except on the slopes mentioned, do contain much calcium as calcium phosphate which functions slowly to neutralize soil acidity.

Fairly satisfactory farming can be done probably for a long time to come on such land, without liming, by proper selection of legume crops and by careful soil management which, in particular, avoids the frequent growing of cultivated crops.

Chemical tests help somewhat to determine the extent to which liming is needed on land in the Bluegrass region. The landowner, however, should depend mainly on simple crop tests on his own or on similar land, where liming is tried on the legume crops desired to be grown.