# UNIVERSITY OF KENTUCKY

## COLLEGE OF AGRICULTURE

### Extension Division

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## CIRCULAR NO. 272

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# SOIL MANAGEMENT FOR KENTUCKY

Lexington, Ky.
April, 1934

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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## Soil Management for Kentucky

By GEORGE ROBERTS

The conservation of soil is a primary requisite for the continuance of human life. Mineral resources, seemingly indispensable, are luxuries compared with the products of the soil. The American people are slow to learn the importance of soil conservation. Probably no nation ever wasted its soil resources as fast as we are wasting ours, altho we have a warning in the example of China of the enormity of the consequences of soil destruction. The density of the population of China as a whole is 94 per square mile, but in 18 provinces containing most of the more level land of the country, the density is 245 per square mile. (The density of the United States is 41 per square mile.) The uplands have been so eroded that on great areas human habitation is impossible, and the people have been driven to the lowlands, where the struggle for existence is so great that human excrement is rigidly conserved for fertilizer and the roots of grain crops are dug for fuel. Rice plants are grown in beds and transplanted like our tobacco crop, in order that some other crop may be grown on the land before the rice is transplanted.

We may say: "That occurred in China; Americans will never allow their soil to deteriorate to such an extent." However, when we consider that China's agriculture is forty to fifty centuries old, while our lands have been in use for only a comparatively short time, we must realize that we are wasting them very rapidly. We are prodigal of our resources, as pioneers always are, and have little consideration for future inhabitants to whom we should recognize our responsibility for conserving resources not of our creating.

### SOIL EROSION

For a convincing statement of the enormous extent of soil erosion in this country, the reader is referred to United States

Department of Agriculture Circular No. 33, entitled "Soil Erosion, a National Menace," by H. H. Bennett and W. R. Chapline. Mr. Bennett, who has spent thirty years studying the soils of the United States, says that he "is of the opinion that soil erosion is the biggest problem confronting the farmers of the Nation over a tremendous part of its agricultural lands." He estimates that the loss from soil erosion is about twenty times as great as from crop removal.

*Some Statistics on Erosion.* In the circular referred to, Mr. Bennett makes the estimate that at least 126,000,000 pounds of plant food elements (that is, elements of the kind taken from the soil by the plant) are removed from the crop and pasture lands of the United States annually by erosion; that if only nitrogen, phosphorus and potassium (the elements bought in commercial fertilizers) are considered, the loss amounts to $2,000,000,000 annually, at the lowest cost at that time (1928) for which these could be purchased in commercial fertilizers. He further estimates the immediate or tangible yearly loss to be $200,000,000 because of the extra land cultivated or fertilizers bought to produce the crops desired. There are counties in the United States in which from 70,000 to 90,00 acres of agricultural land have been eroded beyond reclamation.

If Kentucky soils undergo only the average rate of erosion for the United States, the losses for the State would be about $34,000,000 and $3,400,000, respectively. Probably the rate of erosion in Kentucky is much greater than for the United States because of the topography of the land and the large rainfall. But these figures do not give a full picture of the losses due to erosion, for sooner or later such land becomes so eroded that it is unfiit for tillage or even pasture, and is permanently abandoned. Kentucky has much land so badly eroded that it has been abandoned or produces so little that it provides only the most meager support for its tillers. If erosion is not controlled, much larger areas will soon be in such condition that the inhabitants will not be able to support schools, roads and local government and will become a tax burden upon the State or be deprived of these advantages, which creates very serious social problems.

*Control of Erosion.* Nature's method of controlling erosion is the only effective method. Left to her own devices before soil has been depleted by man, nature keeps it covered with vgetation, and makes an effort to do so after depletion, if given the opportunity. Terracing, without a vegetative covering, is ineffective for most lands subject to washing, altho very valuable in connection with proper cropping.

Heavy rainfall causes washing on almost any sloping land unprotected by vegetation. Obviously, the steeper the slope, the faster the water moves and the greater the erosion. When the velocity of water is doubled, its power to carry material is increased thirty-two times. This fact should impress one with the necessity of doing something to reduce the velocity of the run-off and to make the soil resistant to erosion. Grass does this for farm lands better than anything else. Erosion may occur unobserved for some time because the first erosion is general sheet washing—that is, a fairly uniform removal of soil without the formation of gullies. Usually when gullies form, the largest damage has been done and the final stage of erosion has been reached. Usually little attention is given to erosion control until gullies appear.

As already stated, a grass covering is the best protection for agricultural lands. While all the land cannot be kept in grass all the time, the more good grass there is for pasture and hay, the less the area that has to be used for tilled crops to feed livestock; for with good pasture the grazing season is greatly extended and the nutritive value of the pasture is greater. If the crop land were managed according to well-proved good and simple practices, the present harvested crops of the State could be produced on two-thirds or less of the present area used for this purpose. This would allow steeper land to go back to pasture, and effect a very large control of erosion.

An erosion-control experiment at the University of Missouri,[1] conducted on land with a slope of 3.68 feet per hundred,

[1] Missouri Experiment Station Bulletin 211.

shows the effectiveness of grass in controlling erosion. Land in corn annually, eroded at the rate of 7 inches in 56 years; in wheat annually, at the rate of 7 inches in 150 years; in a rotation of corn, wheat and clover, at the rate of 7 inches in 437 years; in blugrass sod, at the rate of 7 inches in 3547 years. Only one half of a pound of nitrogen per acre was lost annually by erosion from the bluegrass sod, but forty pounds were lost with continuous corn.

The highest priced farm land in the State is in the Bluegrass region, where only about one-third of it is used for harvested crops, altho more livestock is kept per unit of land than in other parts of the State. Bourbon County, devoted almost entirely to general farming, had in 1929, 52,900 acres of crop land and 127,740 acres of pasture land, or about 70 percent in pasture. Thirty-six thousand acres were in corn, small grain and tobacco, about 20 percent of the total crop and pasture land. Without doubt, where good grass will grow, a general system of farming is best for Kentucky where the soil is so susceptible to erosion. Grass grows well in central Kentucky primarily because of the calcium (the important element in limestone) and phosphorus content of the soil, and not because farmers decided to grow livestock and provided bluegrass pasture. Livestock is prodominant because of the grass. Central Kentucky leads in the production of high-quality White Burley tobacco also because of its production of good grass, which puts the soil in ideal condition for tobacco.

In the thirty-seven counties lying west of the longitude of Louisville 44 percent of the land is in pasture, including woodland pasture and other non-plowable pasture land. The pasture is generally of poor quality. The topography and the character of the soil of this area, as well as of most other parts of the State, are such that serious erosion takes place unless the soil is protected. Anyone traveling thru the State cannot fail to see the devastating effects of erosion where grass is not generally used.

That good grass can be grown in all parts of the State by good soil management has been demonstrated beyond doubt.

Excellent bluegrass has been grown on the experiment fields in Taylor County, Muhlenberg County, Graves County, and on the Experiment Substation at Princeton, by treating the soil with ground limestone and phosphate and growing legumes with the grass. Of course, the choice of grasses for pasture is not limited to bluegrass.

An experiment in pasture production on badly worn sandstone land on the Experiment Substation at Princeton[2] shows that good pasture can be made on practically any soil of the State, no matter how badly depleted, for this land represented about as unfavorable conditions as will be found in the State. Land adjacent and similar to the pasture land produced 12 bushels of corn in 1928, a fairly good season for corn as shown by land on the same farm under fair management yielding more than 50 bushels per acre. Three 10-acre fields of similar productivity, eroded and grown up in briers and bushes, were cleared, terraced, and prepared for seeding in the fall of 1927. One field was left untreated; one was treated with 1200 pounds of ground rock phosphate per acre; and one was treated with 1½ tons of limestone and 600 pounds of superphosphate per acre. No lime or fertilizer has been used since. (These treatments will probably show decided effects for ten years.) The fields were seeded the last of August to rye, and the following spring to a mixture of orchard grass, redtop, Canada bluegrass, Kentucky bluegrass, white clover, sweet clover, common lespedeza and Korean lespedeza, at the rate of 15 pounds per acre, orchard grass predominating in the mixture. The land has been pastured with yearling steers since 1929, inclusive. The results of the tests to the end of 1933 are summarized in the following table:

[2] Pasture experiment conducted jointly by the Agronomy and Animal Husbandry Departments, E. N. Fergus and E. S. Good, leaders.

TABLE 1. EXPERIMENT IN PASTURE PRODUCTION

| Field No. | Treatment | Av. No. Steers Carried per Field | Total Gain in Weight of Steers per Field | |
|---|---|---|---|---|
| | | | In 5 Yrs. | Av. per Yr. |
| 1 | None | 2.46 | 2309 | 462 |
| 2 | Rock phosphate | 5.51 | 6353 | 1271 |
| 3 | Limestone, superphosphate | 6.36 | 6380 | 1276 |

The drouth of 1930 seriously reduced the average annual carrying capacity. Omitting 1930, the average annual gains for the 3 fields were 509 pounds, 1398 pounds, and 1430 pounds, respectively.

At the end of 1933, there was on Field 1 a thin, weak stand of the original seeding, consisting chiefly of lespedeza and redtop. Weeds and bushes made up 90 percent of the vegetation. The field is eroded badly though terraced, and on the steeper slopes little vegetation is left.

On Field 2, lespedeza and redtop were the most abundant of the pasture plants, but there was much white clover and orchard grass, with Canadian bluegrass and Kentucky bluegrass well distributed but not prominent. The stand of weeds and bushes was rather thin and on the decrease. The pasture plants constituted about 95 percent of the vegetation. Only insignificant erosion had occurred.

On Field 3, orchard grass was the dominant pasture plant. However, all the other plants were well distributed and in places abundant, with Kentucky bluegrass making a good sod in most places. Only about 1 percent of the vegetation was weeds. There was no serious erosion except in a place or two where the cattle kept the grass tramped down.

The experience of farmers in producing pastures verifies the results of experimental work. The writer has seen first-class bluegrass pastures on formerly unproductive land in eastern Kentucky and on typical upland in Fulton County. Good pastures may be seen in all parts of the State where the soil has been properly treated. It may be stated with assurance that good pastures and hay can be produced anywhere in the State by simple soil management practices, thus stopping erosion and greatly reducing the acreage of land necessary to grow the present amount of grain and tobacco. This discussion of pastures is primarily to emphasize their importance in preventing soil erosion. Grass land, when plowed for cultivated crops, erodes far less under cultivation than if grass had not been grown. Terraces can be used to great advantage on many areas. Kentucky Extension Circular 129 gives detailed directions for their construction and maintenance, and also directions for stopping gullies.

## PREVENTION OF LEACHING

There is another cause of large loss of plant nutrients from soils, not so great as from erosion, but as great as losses in crops removed from the soil, or even greater under some soil conditions; this is loss by leaching—that is, the passage of soluble plant nutrients from the soil in underdrainage waters. These losses being invisible, their magnitude can be determined only by chemical methods. Crusts on the walls of containers constantly used for boiling water which comes from wells and springs are formed from materials that have been leached largely from the soil. Water from any well or spring, evaporated to dryness, leaves a deposit of salts, part of which come from the layer of soil in which plants feed, and part from lower depths.

The most serious losses from the soil by leaching are calcium and nitrogen. These losses, of course, are greatest on soil on which nothing is growing. Nearly all soils of Kentucky, even those underlaid with limestone, are acid because of leaching of calcium and other basic elements. About the only Kentucky soils that are not acid are those in which there are numerous fragments of limestone, such as some soils in the northern Kentucky hill region and some in regions of marl deposits where outcropping marl works down a slope on to the soil below.

It is a simple matter to replace calcium lost by leaching by using lime products such as ground limestone and marl, of which Kentucky has a great abundance.[3] The replacement of

[3] According to reports of the National Lime Association, Kentucky ranked second in 1932 among the states in the use of liming materials.

nitrogen lost by leaching and erosion is not so simple. Nitrogen in commercial fertilizers is very expensive. Legumes and manure must be very carefully handled in order to maintain enough nitrogen in the soil to meet the needs of crops.

The following experiments illustrate the magnitude of losses of nitrogen by leaching: The Cornell, New York, Experiment Station[4] found that in 15 years 1124 pounds of nitrogen were lost in drainage waters from the first 4 feet of unlimed soil kept bare of vegetation, while similar soil in grass lost only 40 pounds. (These studies were made in lysimeters.)

On a fertile piece of land on the Kentucky Experiment Station farm at Lexington, on which tobacco was grown, barley was sown soon after the tobacco was removed, while a similar piece of soil was left bare. On November 30 the barley had taken up 156 pounds of nitrogen per acre, with 19 pounds per acre of soluble nitrogen left in the first 8 inches of soil. In the bare soil there were 69 pounds of soluble nitrogen per acre in the first 8 inches, a difference of 106 pounds of nitrogen that presumably had already passed below the first 8 inches of soil by November 30. Other tests on the farm showed that most of the soluble nitrogen in the soil in the fall passes below the first 2 feet of soil by the last of March. The nitrogen lost from the soil without a cover crop was 156 pounds greater than with the cover crop, an amount equivalent to 1000 pounds of nitrate of soda. (Nitrate of soda usually sells for forty to sixty dollars per ton.)

A similar test[5] was made on a less fertile soil on the Kentucky Experiment Station farm, in which certain cover crops were sown at different dates following the harvesting of tobacco. The results were as follows:

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[4] Cornell Experiment Station Memoir 134.
[5] P. E. Karraker, Journal American Society of Agronomy, Vol. 22, No. 10.

TABLE 2. COVER CROPS AND LOSS OF NITROGEN

| Crop and Date of Sowing | Nitrogen per acre in plants and soluble nitrogen in 2 feet of soil in December | |
|---|---|---|
| | In plants | In soil |
| Barley seeded September 11 | 46 lbs. | 3 lbs. |
| Barley seeded October 10 | 20 lbs. | 19 lbs. |
| Wheat seeded October 10 | 10 lbs. | 32 lbs. |
| Wheat seeded November 7 | 2 lbs. | 35 lbs. |

By the end of the following March, practically all the soluble nitrogen had disappeared from the first two feet of soil. In this test, the nitrogen lost from ground seeded to wheat on October 10 was the equivalent of 200 pounds of nitrate of soda, while there was practically no loss from the land seeded to barley on September 11.

Tobacco is not "hard" on land, but many practices that sometimes go with its culture may cause large losses of plant nutrients. Tobacco is usually grown on the best ground, and after the crop has ceased to take up nitrogen, there is usually a considerable period of warm weather in which soluble compounds of nitrogen develop in the soil. These will be lost if there is not a cover crop on the land that makes a large growth before winter. Cover crops sown after the first of October usually do not make enough growth to take up all the soluble nitrogen developed in the soil following most cultivated crops. The richer the soil, the larger will be the losses by leaching if the soil is not fully protected. Grass is the best protection against leaching, and obviously those grasses with long growing periods, like bluegrass, are best. Rarely is any appreciable amount of soluble nitrogen found under growing grass. Of course, not all land can be kept in grass, but cultivated land should be kept covered with growing plants as much of the time as possible.

Korean lespedeza is the most generally grown legume in the State, and its use is rapidly increasing. It is a highly useful legume and should be on almost every farm in the State. However, its benefits as a nitrogen-fixation crop cannot be fully utilized unless grass is grown with it. There is considerable warm weather after lespedeza matures and also in the spring before it produces much growth. No doubt much of the nitrogen it has fixed is converted into soluble form in this period thru the decay of roots and residues left on the ground, and this soluble nitrogen is lost by leaching unless grass is growing with the lespedeza. Where lespedeza has been grown alone, a winter grain should be seeded. Usually, disking the ground is sufficient preparation for seeding grain.

## TILLAGE

Tillage may be defined as the working of the soil by mechanical means for the purpose of making its condition more favorable for crop growth. The objects of tillage may be classified as follows: (1) Improving the structure of the soil—that is, producing better granulation and general "working" condition; (2) incorporation of plant remains, manure and fertilizers; (3) control of weeds; (4) control of soil moisture; and (5) rendering plant nutrients more available under certain conditions, such as summer fallowing for summer-seeded crops. The various tillage operations may be classified as follows: (1) Plowing; (2) pulverizing operations, including various forms of harrowing, dragging and rolling; (3) compacting operations (various kinds of rollers and compactors); and (4) stirring operations commonly designated as cultivation, mainly for killing weeds and conserving moisture.

*Plowing.* Plowing is done principally to cover plant remains, to make planting easy, to make the soil more permeable to plant roots, and to make subsequent cultivation easier. Plant remains should be completely covered, and the soil should be well pulverized by the operation. The type of plow used should be governed by these two considerations. The principal types are the sod plow, the stubble plow, and the general purpose plow. The sod plow has a long, gently sloping moldboard: the stubble plow has a steep, short moldboard; and the general purpose plow is intermediate between these two. The last-named type is almost universally used in Kentucky and serves very well for most conditions of soil found in the State.

A question frequently asked relates to the depth of plowing. For practically all soils in Kentucky, 6 to 7 inches is deep enough. Subsoiling and deep tilling with special implements has not materially affected yields in experiments conducted on the Experiment Station farm at Lexington. The results of experiments on subsoiling and extra deep plowing in the United States show that plowing deeper than 7 inches generally has not produced increased yields.

The time of plowing is important. Plowing in the fall for spring planting should not be done if it will cause the soil to wash during the winter and spring. Some heavy soils, and some lighter ones low in humus, plowed in the fall, compact so badly during the winter that there is no advantage in fall plowing. Fall plowing should be done as late as possible, for if there is much warm weather after plowing, soluble nitrogen compounds will form which will be lost by leaching during the winter. If land that is inclined to wash must be plowed in the fall, washing will be somewhat lessened by setting the furrow slices on edge to make a somewhat ridged surface. Running the furrows as near at a right angle to the slope as possible also helps to control washing. A furrow slice should not be turned completely over unless necessary to cover rubbish. A jointer is helpful on sod land, and a sharp rolling coulter and jointer for covering coarse trash.

Spring plowing for spring planting should be done as far ahead of planting as possible, but final preparation of the soil for planting may be deferred till planting time unless weeds appear earlier; then these should be destroyed by disking or harrowing early in their growth.

Frequently it is advisable to disk land before plowing. This may be done to conserve moisture when plowing has to be delayed. The ground may be disked also to cause it to pulverize better on plowing. Disking may make it easier, under some conditions, to cover rubbish, while under other conditions, it may interfere by loosening the soil and causing it to shed poorly from the moldboard.

Summer plowing for summer- and fall-planted crops usually is done some time ahead of seeding. However, serious losses of nitrogen may be caused by this practice. If land is plowed in summer for seeding winter wheat, there is probably considerable loss of nitrogen, because wheat seeded at the usual time in Kentucky (October) does not make sufficient growth to take up a great deal of nitrogen. Summer plowing of wheat land in regions of heavy rainfall is partially responsible for their rapid depletion.

*Preparation of Plowed Land for Planting.* A good seed bed is a well pulverized plow layer of soil properly compacted for the kind of crop to be planted. For large seeds like corn and soybeans, no special effort need be exerted to compact the seed bed, but for small seeds from the size of wheat down, the plow layer should be fairly well compacted, with just enough loose dirt at the surface to cover the seed well.

The implement to use for preparing the seed bed after plowing depends upon the condition of the soil and the character of seed bed desired. Disking may be required where soil has become compacted after plowing. Again, a drag or a spike-tooth harrow may meet every requirement. There may be conditions where the use of a roller to press clods into the soil may be desirable before disking or harrowing, so that these implements will more effectively pulverize them.

After a seed bed has been well pulverized, it may be desirable to smooth it as a final preparation for seeding. This may be done with a spike-tooth harrow, a drag or a roller of some kind. For small seeds like alfalfa, a smooth roller may be best when the seeding is done with a clover seed drill or the seed is broadcasted and lightly harrowed in. Obviously, the smoother the surface, the better for this kind of seeding.

It is evident from this discussion that one must use his judgment in each particular case as to what implement will best make the kind of seed bed desired. Often much labor may be saved and better results produced by exercising a little forethought. The writer remembers seeing a large force of workmen and teams in a clean field from which tobacco had been harvested, breaking the soil with turning plows and following immediately with harrow and wheat drill. All that was needed to make the best seed bed was some operation like the use of a heavy harrow to provide enough loose dirt to cover the wheat properly.

*Cultivation for Weed Control and Moisture Conservation.* A great deal of misconception has arisen relative to the value of tillage to conserve moisture. Proper stirring of the surface of the soil when no crops are growing upon it does conserve moisture to some extent, and the destruction of weeds always conserves moisture. After intertilled crops like corn have reached a stage of growth in which the roots have extended well outward in the soil, little or no moisture is saved by cultivation, except through weed control. The following cultivation experiments on corn at the Kentucky Experiment Station farm well illustrate this point.

Tests were made on different methods of cultivating corn through the ten-year period of 1911 to 1920. The corn was grown in rotation with soybeans, wheat and clover. The ground on which the tests were made was manured, before planting, at the rate of approximately 10 tons per acre. Each method of cultivation was repeated three times each year. Weeds were kept down to practically the same extent in all methods of cultivation.

The average yields for ten years for the various methods of cultivation were as follows:

| | Bus. per Acre |
|---|---|
| Shallow 6 to 8 times | 55.5 |
| Deep 6 to 8 times | 56.2 |
| Shallow 3 to 4 times | 55.8 |
| Deep 3 to 4 times | 56.1 |
| No cultivation, weeds scraped | 52.9 |

The shallow cultivation was done with small shovel cultivators and averaged about 2 inches deep. The deep cultivation was done with a riding cultivator or "double shovel" and averaged about 4 inches deep. On the "no cultivation" plots the weeds were scraped with very sharp hoes, with very little disturbance of the soil.

The conclusion that must be drawn from these experiments, considered in connection with other experiments in which weeds were allowed to grow, is that the principal beneficial effect of cultivation of corn on soil of this type is the elimination of weeds. The yield of corn is usually lower with deep cultivation than with shallow, for the reason that the roots are destroyed in the surface layer of soil, which is usually richer in available plant food than the lower layers. On the Eperiment Station farm the subsoil is as rich in the mineral nutrients as the surface soil, or richer. There is more available nitrogen in the surface soil, but it is easily soluble and is carried down by the water.

The best means for producing good structure (granulation) of the soil and increasing its moisture-holding capacity is the growing of a good sod ahead of cultivated crops. Nothing else is so effective in granulating the soil and holding it in that condition as a combination of deep-rooted legumes and fibrous-rooted grass. A good sod of this kind is more effective for this purpose than any amount of manure that can be used in general farm practice. If a good sod precedes a cultivated crop, manure is valuable almost wholly for the plant food it contains. In other words, it improves structure and increases the moisture-holding capacity of the soil very little.

## DRAINAGE

Good drainage is an essential condition for productive soils for most crops, and for all crops commonly grown in Kentucky. Particularly is it true that good drainage is essential in producing tobacco of high quality.

A soil may have good surface drainage and have very poor underdrainage because of a tight subsoil. So-called "cold" land and "seepy" land are not uncommon on slopes. Sometimes level land at the foot of a slope may have better underdrainage than the slope. Many flat lands are poorly drained because there is no outlet for the water, and not because the subsoil is tight.

A poorly drained soil is usually characterized by a light-colored subsoil, frequently containing dark-colored iron concretions, and is often referred to as "buckshot" land. A well drained subsoil is usually reddish or reddish brown, and is well granulated.

Poor drainage adversely affects every quality necessary to a productive soil. It lowers the availability of plant nutrients by preventing aeration of the soil and by restricting root penetration. It inhibits bacterial activity, which is very important in making plant nutrients available, particularly nitrogen. The decay of organic matter in poorly drained soils gives rise to products that are not nearly so favorable to plant growth as those produced in a well drained soil. Poor drainage is conducive to the heaving and freezing of winter crops. If sloping land has poor underdrainage, it washes worse than if well drained.

Tiling is the only satisfactory permanent relief for poor drainage. It will often pay for itself in one to two years thru increased yields of crops. Where tile drainage is not possible, there are some other types of drainage that may be used. Open ditches, properly graded, will carry away much water. They must of course be kept cleaned out. They interfere with cultivation and require extra work in controlling weeds on their edges, but the increased yields will usually more than pay for the extra work.

Where lumber is cheap enough, box drains may be used. These are usually made of three rough boards 6 inches wide and 1 inch thick nailed together in triangular form. Drains are sometimes made of flat stones. Side walls are set up with stones resting on these. Sometimes drains are made of poles, placing two on the bottom of the ditch with a third one on top of these. These two latter forms soon fill with silt and become ineffective. Straw or some other covering should be placed above the joints before filling the ditch, to retard soil from entering them.

Bedding poorly drained soil may be helpful—that is, back-furrowing it in narrow strips so that the dead furrows between the strips run as nearly as possible with a uniform slope and serve as shallow ditches, which should lead, if possible, to an outlet.

There are, on many farms, small, wet areas that can be well drained by a single line of four- to six-inch tile. In the mountains of eastern Kentucky, where tillable land is scarce, there are many creek bottoms which are so wet that they are unproductive. In many cases, straightening the stream channel and keeping it clean would cause it to wear deeper and lower the water table, which would help a great deal. Often this would require community effort of landowners. Following this, some method of drainage suggested above should be used. If these bottoms were drained and properly treated, one acre would produce as much as three or four acres of the usual steep hill land that is cultivated. If, in turn, the hill lands were made into good pasture, animals could be grazed much longer and the amount of harvested feed required correspondingly reduced. This is a matter that needs serious attention thruout the mountain area, and in other areas where level tillable land is scarce.

## PLANT NUTRIENTS

A fertile soil is one which produces large yields of crops adapted to the climatic conditions under which the soil exists. There are many factors determining the productivity of a soil—weather conditions, drainage, texture (size of soil particles), structure (arrangement of soil particles, granulation or lack of it), soil reaction (whether acid or alkaline), soil organisms, organic matter content, and the content of plant nutrients. A knowledge of the plant nutrient content of soils is especially important.

The nutrient elements known to be essential to the growth of plants are carbon, hydrogen, oxygen, nitrogen, calcium, magnesium, iron, sulfur, potassium, phosphorus, and manganese. There are others that are often beneficial to plants when added to the nutrient solution, and may be proved to be essential on further investigation; among these are copper, zinc, boron, and iodine.

Carbon, hydrogen and oxygen constitute about 95 percent of the dry weight of plants. These elements are derived from the air and water. Nitrogen is the next most abundant element and constitutes about 1.5 percent of the dry weight of non-leguminous crops and about 2.5 percent of leguminous crops.

There is a sufficiency of the various soil nutrient elements in Kentucky soils except nitrogen, calcium, phosphorus and, for some crops, potassium. At least, no deficiency of the others has been observed, altho it may be possible that such deficiencies may exist under some conditions.

Nitrogen of the soil is carried in the organic matter and is subject to great loss in the decay of the organic matter unless used by plants, as has already been stated in the discussion on leaching. The ultimate source of nitrogen is the air, and the chief means of obtaining it is fixation by legumes. The fixation of nitrogen by legumes and its conservation and utilization are discussed on pages 36-41.

## LIMING MATERIALS AND THEIR USE

Soils in a region of as much rainfall as in Kentucky are nearly always acid. The exceptions, as previously stated, are those soils containing numerous limestone fragments and those in the region of marl deposits where marl from an outcrop works down a slope on to the soil below.

Lime, so called, in the soil is in the form of calcium carbonate, which is somewhat soluble in the soil water and is leached out in time. There is some calcium in acid soils which functions as a plant nutrient, but it does not serve to counteract soil acids. The primary purpose of using lime on Kentucky soils is to promote a better growth of legumes. Alfalfa, sweet clover and red clover are the most exacting in their lime requirements, but all legumes grown in Kentucky are benefited by lime. The yield of Korean lespedeza has been almost doubled by the use of ground limestone on soil of limestone origin on the Western Kentucky Experiment Substation at Princeton. The results in Table 3, on page 24, show the effect of ground limestone on various crops, both when used with and without a phosphate fertilizer.

Ground limestone is the material most commonly used for liming soil because of its cheapness and ease of handling. An abundance of limestone of good quality occurs in ninety counties lying between the mountains and the Tennessee river. Few counties without limestone are far distant from a source of supply and, provided transportation facilities are good, it can usually be obtained at low cost.

Limestone ground to pass a 10-mesh screen[6] is fine enough. It contains considerable fine material which is immediately effective, and the coarser part is dissolved fast enough to meet later needs. If a 1- or 2-ton application of very fine limestone is used, a considerable part of it is no doubt quickly lost by leaching. Ground limestone much of which does not pass a 10-mesh screen may be profitably used, for it is often so cheap that the 10-mesh material in it may be an economical purchase. Screenings of this character are for sale at many places in the State. Where a small application is used, say 500 pounds, it may be advisable to use very fine material. Some experiments conducted in pots in the greenhouse indicate that the finer material is more effective. Tests are being made at the Western Kentucky Substation on the relative effectiveness of limestone of the following degrees of fineness: 10 to 20 mesh, 40 to 50 mesh, 70 to 80 mesh, and 100 mesh and finer. Applications of one-third of a ton of each fineness are made each time wheat is sown in a rotation of corn, wheat and mixed legumes. The test has been running for seven years. The 40 to 50 mesh limestone was most effective, with 70 to 80 mesh, 10 to 20 mesh, and 100 mesh following in the order named. These results indicate that even for small applications, limestone ground to pass a 10-mesh screen contains enough fine material to be satisfactory.

*Marls for Liming Soil.* Kentucky has extensive deposits of marl, some of which is very high-grade. It has been found in seventy counties. Marl is a soft, clay-like material, generally of light color, containing calcium carbonate or a mixture of calcium carbonate and magnesium carbonate. The latter compound does not lessen the value of the marl for liming the soil. Kentucky marls range in purity from low grades up to 97 percent neutralizing value, in terms of calcium carbonate. Where limestone is

[6] A ten-mesh screen is one with ten meshes to the linear inch, or 100 meshes to the square inch.

highly expensive, marl of as low a content as 20 percent may be used profitably if the haul is not too long. A pound of calcium carbonate in marl is just as valuable as a pound of pure limestone of equal fineness. When first dug, marls may appear coarse or lumpy, but they usually readily disintegrate, after being spread, into finer particles than are commonly found in the finest ground limestone.

It is estimated that there are 30,000 farms in Kentucky which can be limed with marl within a two and one half mile haul, giving unusual opportunity for using this material. Soil lying above a marl outcrop often needs liming, while that below an outcrop usually does not, because the marl has worked down upon it.

It can quickly and easily be determined whether a substance is marl by placing a small amount in a tumbler and pouring on it a little commercial hydrochloric (muriatic) acid, obtainable at any drug store. A marl will effervesce. The purer the marl, the more vigorous will be the effervescence. The Experiment Station will test properly taken samples free of charge.

*Rates and Time of Liming.* According to the best information we have, an initial application of 2 tons of limestone per acre is the most economical rate for average Kentucky soils. For some of the more acid soils, 3 to 4 tons per acre may be profitable for alfalfa. Where, for any reason, one is unable to use limestone at the rate of 2 tons per acre on all land needing lime, it will usually be found much more profitable to use a lower rate and cover more land, except in preparation for alfalfa. There are many soils in the State on which 500 to 1000 pounds of ground limestone used with the necessary fertilizer when grain is sown will produce a first-class legume crop following the grain. Excellent crops of clover and other legumes are being produced by many farmers in the State through the use of a mixture of two parts of limestone or burned lime with one part of superphosphate drilled with small grain at the maximum capacity of the fertilizer attachment. The legume is sown on the grain in the spring. This practice has been largely used in Laurel and Taylor Counties. It is advisable first to try this on a small scale. By using this practice, a small outlay of money can be made to finance future liming. Over a long period of time it may prove to be better to use frequent small applications rather than an equivalent amount in less frequent applications.

The time of liming with reference to the crops grown is often important. Where the usual application of 2 tons or more of liming material is used, it is a good practice to apply it on land that is being prepared for a cultivated crop, like corn, to be followed by a grain crop on which the legume is to be seeded. The preparation of the land and the cultivation of the crop more thoroly mix the lime with the soil and frequently make it more effective on the legume crop than when applied immediately preceding the legume. This practice is not suggested for applications of 1000 pounds or less, which are best drilled with the grain. The stand of clover sown on grain is usually thickest in the drill furrow, and the roots have a better contact with small amounts of lime if drilled with the grain.

Lime should not be used immediately preceding tobacco. Tobacco thrives best in a moderately acid soil. Very few, if any, soils that are used for tobacco in Kentucky are too acid for the crop. Soil may be greatly improved for tobacco by lime if it is used in applications no greater than necessary for the immediate legume crop and is applied as far ahead of tobacco as possible. The ideal practice, on tobacco land, is to use from 1 to 2 tons of limestone per acre immediately following tobacco, sow a small grain, and follow with a legume and grass mixture for three to five years. There will then be no danger of injury to tobacco from the lime. Experiments confirm this as good practice.

Too heavy liming promotes the growth of root-rot organisms and also is often associated with frenching of tobacco. In the investigations of the Kentucky Experiment Station, frenching has never been found except in soils of very low acidity or in neutral or alkaline soils. If tobacco must be grown on land that has been too heavily limed, a root-rot-resistant variety should be used, and it should be well fertilized with a complete fertilizer. This tends to overcome frenching.

Injury to tobacco does not always occur from liming immediately before planting the crop or later on heavily limed soil, but occurs often enough that one should observe the foregoing precautions. The Kentucky Experiment Station has no evidence of direct benefit to tobacco from liming, and considerable evidence of injury from heavy liming and liming immediately ahead of the crop. This experience should not deter farmers from using lime on tobacco land, but should cause care to be exercised as to the amount and time of application.

If fresh burned lime or hydrated lime is used, the rates of application should be less than for ground limestone. One ton of pure limestone will make 1120 pounds of fresh burned lime or 1480 pounds of hydrated lime. The burned product disintegrates much more finely than limestone can be ground and is subject to more rapid leaching. It is well to use comparatively smaller applications of the burned products than of ground limestone and use them oftener.

The need for reliming can be determined by a simple test by the farmer that will be more reliable than any chemical test. A few years after liming at the usual rate, relime a small area and observe the effect on a legume crop. The test should be repeated preceding each legume crop appearing on the land, until a definite need for liming is observed.

Except on the highly phosphatic soils of the Bluegrass region, a phosphate fertilizer should be used with lime. On many soils of the State, lime is of little or no benefit when used alone, but in connection with a phosphate fertilizer gives large returns. An examination of Table 3, page 24, will show the importance of the combination.

## PHOSPHATE FERTILIZERS[7]

Practically all of the soils of the State are deficient in phosphorus, except part of the Bluegrass region and some of the richer river bottoms. Altho all the soils of the Central Bluegrass region are generally believed to contain large amounts of phosphorus, they differ widely in their content of this element.

[7] See Table 3 for the effect of phosphate on crops on Kentucky soils.

**TABLE 3. CROP YIELDS ON KENTUCKY SOIL EXPERIMENT FIELDS**
(Bushels per acre for corn and wheat; pounds per acre for hay)

| Crops | No. Crops Averaged | No. Corn Crops for which Manure was Used | Yield without Limestone or Phosphate | Crop Increases: For Limestone | Crop Increases: For Superphosphate | Crop Increases: For Limestone and Superphosphate |
|---|---|---|---|---|---|---|
| **Fariston Field** | | | | | | |
| Corn | 14 | None | 8.1 | 8.0 | 18.6 | 35.2 |
| Soybean hay | 16 | | 1312 | 535 | 892 | 2856 |
| Wheat | 9 | | 2.1 | 2.0 | 4.3 | 9.0 |
| Mixed clover hay | 14 | | 208 | 286 | 740 | 2006 |
| **Berea Field** | | | | | | |
| Corn | 20 | 16 | 27.4 | 11.1 | 12.6 | 19.0 |
| Soybean hay | 18 | | 2920 | 695 | 807 | 1271 |
| Mixed clover hay | 15 | | 541 | 407 | 531 | 1942 |
| **Campbellsville Field** | | | | | | |
| Corn | 13 | 7 | 30.2 | 5.8 | 21.4 | 25.9 |
| Wheat | 11 | | 5.1 | 6.0 | 6.0 | 7.9 |
| Mixed clover hay | 11 | | 1235 | 351 | 1324 | 1678 |
| **Greenville Field** | | | | | | |
| Corn | 19 | 12 | 26.2 | 2.4 | 10.1 | 20.5 |
| Soybean hay | 18 | | 1960 | 341 | 900 | 1587 |
| Wheat | 18 | | 5.0 | 1.4 | 5.7 | 11.6 |
| Mixed clover hay | 18 | | 720 | 328 | 1435 | 2401 |
| **Russellville Field** | | | | | | |
| Corn | 11 | 9 | 30.0 | 8.7 | 7.1 | 14.9 |
| Soybean hay | 11 | | 2003 | 657 | 428 | 758 |
| Wheat | 9 | | 10.0 | 0.2 | 3.2 | 7.8 |
| Clover hay | 9 | | 1626 | 1190 | 755 | 2026 |
| **Hopkinsville Field** | | | | | | |
| Corn | 8 | 4 | 33.0 | 5.9 | 3.7 | 11.7 |
| Wheat | 6 | | 6.0 | 1.0 | 5.7 | 7.3 |
| Clover and soybean hay | 6 | | 1826 | 847 | 1774 | 2542 |
| **Loan Oak Field** | | | | | | |
| Corn | 14 | 4 | 32.7 | 5.2 | 2.7 | 7.3 |
| Soybean hay | 10 | | 2495 | 372 | 269 | 719 |
| Wheat | 10 | | 11.1 | 0.7 | 1.5 | 7.3 |
| Clover hay | 7 | | 1573 | 884 | 356 | 1974 |
| **Mayfield Field** | | | | | | |
| Corn | 19 | 15 | 34.9 | 9.5 | 1.6 | 12.4 |
| Soybean hay | 16 | | 2428 | 636 | 268 | 1004 |
| Wheat | 18 | | 8.7 | 4.3 | 2.8 | 9.6 |
| Mixed clover hay | 16 | | 952 | 1720 | 447 | 2690 |
| **Western Ky. Exp. Substation—Limestone Soil** | | | | | | |
| Corn | 6 | None | 46.4 | 5.7 | 5.7 | 10.9 |
| Wheat | 7 | | 9.2 | 0.0 | 3.1 | 5.8 |
| Mixed clover hay | 6 | | 1969 | 769 | 859 | 1631 |
| **Average of all Fields** | | | | | | |
| Corn | 124 | 67 | 30.0 | 6.9 | 9.3 | 17.5 |
| Soybean hay | 89 | | 2186 | 539 | 594 | 1366 |
| Wheat | 88 | | 7.1 | 1.5 | 4.0 | 8.3 |
| Mixed clover hay | 102 | | 1183 | 754 | 913 | 2099 |

On the Experiment Station farm of 600 acres at Lexington, the amounts range from 18,000 pounds of phosphorus in 2 million pounds of soil (an acre to the depth of about 7 inches) down to 2100 pounds. Within a few miles of Lexington there are soils containing as low as 1600 pounds in 2 million pounds of soil.

Crops grown on a soil containing less than 1500 pounds of phosphorus will likely respond to its use unless the soil has been unusually well managed, including the return of liberal amounts of manure or crop residues. When the phosphorus content is around 2000 pounds or lower, a field test on crops should be made.

The soils outside of the Bluegrass region contain, on the average, only about 900 pounds of phosphorus in 2 million pounds of soil. Most soils this low in phosphorus show a large response to phosphate fertilizer whether used alone or in connection with lime. Some of the soils west of the Tennessee river show little response to phosphorus fertilizers without liming, but show a decided response after liming. In general, on these soils, lime used alone produces larger returns than phosphate fertilizers used alone. Most of the soils of the State outside of the Bluegrass region respond so greatly to both lime and phosphate fertilizers that both should be used where it is possible to do so. Table 3 shows results on the various Kentucky soil experiment fields from limestone and superphosphate used singly and in combination. The yields without lime or phosphate show that most of those soils were in a low state of productivity. The averages shown in the table include the yields from the beginning of the work. Only the results for the corn rotations are given. The reader is referred to Kentucky Experiment Station Bulletin No. 322, which shows results in detail from the use of various phosphates and other fertilizers, and shows the improvement in yields in the latter years of the experiments over those of the earlier years. Also, results for tobacco rotations are given.

The unlimed and unfertilized land in these experiments has had the same crop rotation and the return of manure on the same basis as the limed and fertilized land. Manure, when used, was applied for the corn crop at a rate equal to the weight of the crops removed in the preceding rotation, except for a few applications in the beginning of the experiments when all plots were manured uniformly at about 6 tons per acre. When these facts are taken into consideration, the fundamental importance of lime and phosphate in the restoration and maintenance of productiveness is at once evident.

The average rate at which limestone was used in these experiments was approximately 600 pounds per acre per year; for superphosphate, approximately 175 pounds per acre per year. On the older fields the average rates were less. The materials were not applied every year. On some of the fields the limstone was applied within the first four or five years of the experiments, after which no more was used, a period in some instances of sixteen years. The phosphate was generally applied in sufficient quantity on one crop to serve for the other crops in the rotation.

The fertilizer materials commonly used to supply phosphorus are ordinary superphosphate, double (sometimes called treble) superphosphate, bone meal, basic slag, and raw ground rock phosphate.

Ordinary superphosphate contains 16 to 20 percent of phosphoric acid. ("Phosphoric acid" is the term used by the fertilizer trade. The phosphoric acid content of a fertilizer is 2.3 times the content of the element phosphorus.) It is made by treating raw ground phosphate rock with approximately an equal weight of sulfuric acid, which converts a large part of the phosphorus into a water-soluble form. The product contains about half its weight of calcium sulfate, the same chemical compound as the natural mineral gypsum.

Double superphosphate is made by first producing phosphoric acid from phosphate rock. This acid, in turn, is used to treat a high-grade phosphate rock. The product usually contains from 40 to 45 percent of phosphoric acid in the same form as in ordinary superphosphate, but it contains little or no sulfur. There is no evidence that there is a deficiency of sulfur in Kentucky soils. Studies by the Kentucky Experiment Station at seven places in the State over a period of two years showed that an average of 30 pounds of sulfur per acre per year is contained in the rainfall, which is more than enough to meet crop needs. The lowest found at any place was 17 pounds per acre.

The grades of superphosphate on the market ranging in percentage of phosphoric acid between the ordinary superphosphate and the double superphosphate are made by mixing the two in the required proportions. For Kentucky conditions the choice of a superphosphate may safely be made on the basis of comparative prices, which can be determined by dividing the ton price by the percentage of phosphoric acid.

Bone meal is an effective source of phosphorus, particularly on unlimed land. The Kentucky Experiment Station has made one test, at Fariston, comparing steamed bone meal and superphosphate over a period of eighteen years, on unlimed land. They were used on a basis of equal amounts of phosphoric acid. The bone meal was somewhat more effective. (See Kentucky Experiment Station Bulletin 322.)

Basic slag is a by-product of the refining of steel from iron ore containing phosphorus. The grade sold in Kentucky ranges from 8 to 10 percent of phosphoric acid. In a test on the Campbellsville Experiment Field, basic slag has produced practically the same results as superphosphate. (See Bulletin 322.) Basic slag has a neutralizing value of about 50 percent of its weight of pure limestone, which may be sufficient to decidedly affect the growth of clover and other legumes when fair to heavy applications are used.

Raw ground phosphate rock is sometimes used as a fertilizer. It usually contains about 30 to 32 percent of phosphoric acid. The phosphorus is in the form of tricalcium phosphate, hence rock phosphate contains a large amount of calcium. The product has a neutralizing value of about 5 to 12 percent of its weight of pure limestone.

The phosphorus of rock phosphate is not nearly so readily available as in the other forms of phosphate described, but the comparison should not be made on the basis of equal amounts of phosphorus, but on the basis of equal costs. Rock phosphate contains twice as much phosphorus as 16 per cent superphosphate and usually can be purchased at a much lower price per ton than superphosphate. If, for example, it costs one half as much per ton as superphosphate and 200 pounds an acre a year of the latter is being used, 400 pounds per year of rock phosphate should be used in comparing their relative profitableness. Four times as much phosphorus will be added in the rock phosphate as in the superphosphate, and the residue of phosphorus accumulated in the soil has value. However, pound for pound, that accumulated from superphosphate has a greater value. The phosphorus of the highly phosphatic soils of the Central Bluegrass region is largely in the same form as rock phosphate.

Instead of applying rock phosphate each year, it is better to apply enough at one time for a rotation. The first application is best applied and disked in before breaking the ground. Subsequent applications may be applied after breaking, but it should be disked in deep.

The Kentucky Experiment Station has made tests, at several places in the State, of raw ground rock phosphate in comparison with superphosphate, on the basis just mentioned. Under many conditions rock phosphate produced excellent results. On unlimed soil it was as effective as superphosphate or more so. On some limed soil it was less effective than superphosphate. In no test was it more effective on limed land than superphosphate, altho in some cases it was practically as good. It was particularly effective on the Campbellsville (Taylor County) Soil Experiment Field when used without lime, but lime used with it decreased its effectiveness.[8] This is because too much lime was used in the beginning of the experiments, before we had learned much about the relationship of liming to the availability of phosphates.

Rock phosphate may be expected to be effective on any phosphate-deficient soil in the State when unlimed, but where lime is to be used, information should be obtained as to the effect of lime on its availability on that type of soil. In the absence of that information, it is better to use superphosphate.

[8] The results of these experiments are given in detail in Kentucky Experiment Station Bulletin 322.

Fineness of grinding affects the availability of rock phosphate. It should at least be ground to pass a 100-mesh screen. Whether finer grinding justifies the extra cost of the material has not been fully determined by field results. Material all of which passes a 100-mesh screen usually contains a considerable amount of finer material.

It is not possible for a crop to take up all of any fertilizer elements that it needs if only the amount needed is added to the soil. There never is a complete uptake of any element, no matter how soluble it is, for the roots cannot come in contact with all of it. The phosphorus in superphosphate is largely soluble in water, but it becomes insoluble soon after being incorporated with the soil. It is slowly brought back into solution as the crop needs it, largely by carbonic acid exuded by the roots in contact with it. Almost no phosphorus is lost from the soil by leaching. The accumulation of phosphorus in the soil from regular use of phosphate fertilizers through a period of years may be sufficient to be of considerable importance. On three of the Kentucky soil experiment fields, from 1913 to 1930, superphosphate was applied in amounts that averaged 160 pounds per acre per year, 200 pounds per acre being used in the earlier part of the period and 100 pounds in the latter part. Rock phosphate was used in comparison at twice the rate for superphosphate. Since 1930, inclusive, the phosphates have been left off of half of some of the plots and continued on the other half. As an average of 12 tests on 5 corn crops, 6 tests on 6 wheat crops. and 12 tests on 9 hay crops, the yields have been as large where the phosphates were omitted as where their use was continued. There was a slight but insignificant decrease where superphosphate was left off, and a corresponding increase where rock phosphate was left off.

When prices for crops are good, phosphates and potash, when needed, can be used in quantities that will return a profit and leave a reserve in the soil which will serve through periods of low prices when the farmer does not feel justified in spending money for fertilizers. This statement may be illustrated by results on one of the experiment fields, where 900 pounds of superphosphate on limed ground in a three-year rotation of corn, wheat and clover produced an average of 2 bushels more wheat and 760 pounds more hay than 600 pounds of superphosphate produced. With wheat at $1.00 per bushel and hay at $10.00 per ton, the extra increase considerably more than pays for the extra fertilizer, while the increase in crops withdraws only a small fraction of the phosphorus in the extra fertilizer, leaving a reserve in the soil.

## POTASH FERTILIZERS

Based upon analyses of 388 samples of soil from the various soil areas of the State, the potassium content ranged between the extremes of 11,200 pounds and 69,000 pounds in 2 million pounds of surface soil. The lowest average content for a soil area was about 18,000 pounds, and the highest average was about 34,000 pounds. The average of the various soil areas was about 27,500 pounds.[9]

The easily soluble potassium (an indication of availability) does not always vary in proportion to the total amount in the soil. For example, the total potassium in the samples from the Waverly (southern Kentucky) area was 19,600 pounds, and the easily soluble was 338 pounds, whereas in the samples from the Cincinnatian area (northern Kentucky) the total was 31,960 pounds, and the easily soluble 366 pounds.

There are many conditions that affect the availability of soil potassium. Drainage is important. Poor drainage restricts root penetration, and, therefore, the amount of contact roots can make with soil particles. Poor drainage also restricts the circulation of air in the soil and thus inhibits bacterial activity, which is important in rendering soil plant nutrients available.

The amount of organic matter that finds its way back into the soil in manure and crop residues is a highly important factor. On the average, about three fourths of the potassium taken from the soil by grain crops is contained in the stalks and straw, and about nine-tenths of the potassium in feed given animals is voided in the dung and urine. If crop residues and manure are re-

[9] Kentucky Experiment Station Bulletin 193.

turned to the soil, large amounts of potassium will be returned. The decay of this organic matter not only liberates the potassium contained in it, but also causes a greater liberation of potassium from the soil minerals.

The kind of crop grown also has an important effect on availability of potassium. For example, on one soil experiment field potassium fertilizers produce considerable effect on corn on unlimed soil where the yield is about 25 bushels without potassium in the fertilizer, but on limed soil where the yield is 40 bushels there is little increase from its use. The reason probably is that where lime is used, clover grows and takes up potassium from the lower depths of the soil and leaves a considerable part of it in the roots and stubble of the clover, which becomes available to the corn, whereas on the unlimed land clover does not grow. The growth of clover, by supplying nitrogen, also causes a much larger growth of non-leguminous crops with a correspondingly larger root system which can more effectively get potassium from the soil.

Any soil is likely, sooner or later, to become deficient in potassium if crops are removed from it with no return of manure or crop residues. This is a common observation in experimental work.

Potassium fertilizers may produce little or no effect on such crops as corn, wheat, soybeans and clover, and may produce a decided effect on such crops as alfalfa and tobacco. The reason is that the first group of crops, because of a lower potassium content or a longer growing period, get sufficient potassium from the soil, whereas alfalfa and tobacco, of different habits of growth, must have a larger amount of potassium in a shorter time. Alfalfa requires about 45 pounds of potassium per ton of hay and has only 5 or 6 weeks in which to obtain it in cuttings after the first one, whereas a 50-bushel corn crop requires about 35 pounds and has a much longer time to obtain it. Alfalfa failures may be caused by potassium deficiency, particularly where it has been grown on the same soil for a long time. The belief is common that alfalfa improves soils, but it is one of the most exhausting of crops in its draft on the soil mineral nutrients. Potassium deficiency in alfalfa is shown by whitish specking of the leaves.

Potassium deficiency in tobacco is indicated by small plants with puckered and rough leaves, with considerable mottling of a light yellow color which begins at the margins and the tips. In more advanced stages small spots of dead tissue appear, and the margin and tip of the leaf turn downward. There are few soils on which potassium fertilizers will not produce good effects on tobacco unless they have been unusually well managed through the return of manure or other forms of organic matter, such as plowing under a heavy sod in which legumes have grown.

Potassium deficiency in corn is indicated by the leaves turning brown and dying prematurely from the edge toward the midrib.

The principal materials used to supply potassium are sulfate of potash and muriate of potash. The fertilizer trade expresses potassium content as "potash," which is 1.2 times the content of the element potassium.

The availability of the two forms is essentially the same, and it makes little difference which is used, except for tobacco. A heavy application of muriate of potash may injure the quality of tobacco. Experiments by the Kentucky Experiment Station[10] indicate that it is safe to use up to 50 pounds of muriate of potash per acre for tobacco. The amount of muriate of potash used to furnish the "potash" in a fertilizer is approximately double the percentage of potash. For example, 100 pounds of a fertilizer with 5 percent of potash from "muriate" contains 10 pounds of muriate of potash.

## NITROGEN FERTILIZERS

As has been stated, the nitrogen content of plants is much larger than that of any of the other elements that come from the soil. A 50-bushel crop of corn requires about 75 pounds of nitrogen against about 12 pounds of phosphorus and 35 pounds of potassium. If a sufficient supply of available mineral nutrient elements cannot be developed in the soil by good soil man-

[10] Kentucky Experiment Station Bulletin 334.

agement, they must be supplied from outside sources. If nitrogen is deficient, it is easily possible to increase the soil supply by growth adapted legumes. Some of them require preliminary treatment of the soil, as for example, liming and phosphating the soil so that clovers and alfalfa will make satisafctory growth. The maintenance of sufficient soil nitrogen is the most difficult soil management problem, in that it requires more knowledge and skill than is required to maintain a supply of any other plant nutrient.

Commercial materials supplying nitrogen may be used profitably under some conditions, but by far the larger part of the nitrogen should be supplied by the growing and utilization of legumes and the use of farm manure. The chief field for the use of commercial nitrogen is in growing crops of high value per acre, such as garden crops and tobacco.

The commercial materials supplying nitrogen fall into two general classes—organic and inorganic. The principal materials are:

| | Approximate Percentage of Nitrogen |
|---|---|
| **Organic** | |
| Tankage—ordinary | 5–10 |
| Dried blood | 9–14 |
| Cotton seed meal | 5– 7 |
| Urea (synthetic) | 46 |
| **Inorganic** | |
| Nitrate of soda | 16 |
| Sulfate of ammonia | 20 |
| Calcium nitrate | 15 |
| Ammonium nitrate | 35 |
| Ammonium sulfate-nitrate (Leuna salpeter) | 26 |
| Calcium cyanamid | 20–25 |
| Calurea (urea + calcium nitrate) | 34 |

Nitrogen in organic materials is usually less effective than in the inorganic materials. However, where large applications are being used, it may be advantageous, particularly in sandy or otherwise very porous soils, to have part of the nitrogen in the organic form.

Of the inorganic materials the nitrates have the highest immediate availability, and ammonia salts the next highest.

A source of fertilizer nitrogen not listed in the above groups is ammonium phosphate of various grades, made by treating superphosphate and phosphoric acid with ammonia. The nitrogen has about the same availability as in sulfate of ammonia, and the phosphorus about the same as superphosphate.

## MIXED FERTILIZERS

Mixed fertilizers may contain the three common fertilizer ingredients, nitrogen, phosphoric acid and potash,[11] or a combination of any two of them. The common method of expressing the analysis is to state the percentage of nitrogen, phosphoric acid and potash in order, as for example, 4-8-4, 0-8-4, and 4-8-0. A fertilizer ratio expresses the ratio of the percentage of ingredients in the lowest terms. For example, a 4-8-4 analysis is a 1-2-1 ratio. Among analyses of a 1-2-1 ratio found on the market are 5-10-5, 6-12-6, and 12-24-12.

Superphosphate is the source of phosphoric acid in practically all mixed fertilizers. The potash is almost exclusively in the form of muriate and sulfate of potash. Both are of about equal effectiveness, but when used in excess, muriate of potash may be harmful to tobacco. (See page 32.) Many different materials are used to supply nitrogen in mixed fertilizers. For a partial listing of fertilizer materials, see pages 26-33.

A fertilizer containing nitrogen, phosphoric acid and potash is called a "complete" fertilizer. Some complete fertilizers are made by using a single material, ammonium phosphate, to supply nitrogen and phosphoric acid. The latter material is used in making high-analysis fertilizers. So far as nitrogen, phosphoric acid and potash are concerned, the high-analysis fertilizers seem to be as effective on most soils as the lower analyses, on the basis of equal amounts of the ingredients. The ordinary mixed fertilizers carry other elements which may have decided value on certain soils in the United States, but so far as known, Kentucky soils are not among them.

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[11] If it is desired to know the percentage of phosphorus in a fertilizer, multiply the percentage of "phosphoric acid" by 0.436. Multiply the percentage of "potash" by 0.83 to get the percentage of potassium.

Uniform distribution of the high-analysis fertilizers is more important than with lower analyses, for the reason that they are more apt to injure plants when concentrated by irregular distribution.

Whether to use a high or a low analysis should be determined largely by price. For example, a 4-8-4 analysis is one-third the strength of a 12-24-12 and should cost, delivered at the farm, only one third as much as the latter, to be as cheap.

Recommendations on the use of lime and fertilizers for various crops are given on pages 49-57.

## HOME MIXING OF FERTILIZERS

The following directions are submitted for the home-mixing of fertilizers. Having decided upon the materials to be used in the fertilizer and the analysis desired, proceed as follows:

1. Multiply each figure of the analysis by 20. The product is the number of pounds of each fertilizer ingredient in a ton of the fertilizer.

2. Divide each of these quantities by the percentage of the ingredient in the respective material and multiply by 100. This gives the number of pounds of each material required for a ton of mixed fertilizer.

3. The sum of the materials taken from 2000 pounds gives the number of pounds of filler required.

As an example of the working of these rules, a bill of materials for a 4-8-4 fertilizer (1-2-1 ratio) is calculated, using

Nitrate of soda containing 16 percent of nitrogen.

Superphosphate containing 20 percent of phosphoric acid,

Muriate of potash containing 50 percent of potash.

| | |
|---|---|
| 4 percent of nitrogen × 20 = | 80 lbs. of nitrogen per ton of mixture |
| 8 percent of phosphoric acid × 20 = | 160 lbs. of phosphoric acid per ton of mixture |
| 4 percent of potash × 20 = | 80 lbs. of potash per ton of mixture |

| | |
|---|---|
| 80 lbs. of nitrogen ÷ 16 × 100 = | 500 lbs. of nitrate of soda |
| 160 lbs. of phosphoric acid ÷ 20 × 100 = | 800 lbs. of superphosphate |
| 80 lbs. of potash ÷ 50 × 100 = | 160 lbs. of muriate of potash |
| | 1,460 lbs. |
| Filler required | 540 lbs. |
| | 2,000 lbs. |

If no filler is used, the ratio remains the same (1-2-1) and 73 pounds of the 1460-pound mixture without filler contains the same amount of nutrients as 100 pounds of the 2000-pound mixture with filler. Without the filler the mixture is a little stronger than a 5-10-5 analysis.

Dried soil screened thru an 8- to 10-mesh sieve makes a satisfactory filler. Ground limestone may be used as a filler without any injurious effect on the fertilizer and with good effect on most crops, except tobacco.

To mix, spread the bulkiest material evenly on a tight floor or on smooth, hard earth. Spread on this the next bulkiest material, and so on until all have been placed. Shovel the pile over, as in mixing concrete, until thoroughly mixed. Mixing should be done as near using time as convenient, as there may be some caking. For home mixing, only materials in good mechanical condition should be used.

## SOIL ORGANIC MATTER AND NITROGEN

*Legumes and Nitrogen Fixation.* As previously stated, the maintenance of soil nitrogen is the most important problem in soil management, and this involves the maintenance of organic ("humus") matter in the soil, for soil nitrogen is a constituent of the organic matter. The character of the soil organic matter is therefore as important as the amount, and often more so. For example, a ton of legume plants turned under may greatly increase the following crop, whereas a ton of wheat straw turned under may decrease it for reasons to be stated later.

Nitrogen accumulation in the soil must come, under most conditions, from the growing of legumes and their return to the soil in some form. Harvested legumes may or may not leave more nitrogen in the soil than they remove. The best information available indicates that on soil of average productivity, legumes obtain about one-third of their nitrogen from the soil and two thirds from the air, if well inoculated. Legumes use available soil nitrogen, and the richer the soil is in available nitrogen, the less will be the fixation from the air.

Assuming that red clover grown on soil of medium fertility obtains one-third of its nitrogen from the soil, there is no increase of nitrogen in the soil from the growth of the clover if all growth is removed, for the nitrogen of the clover plant is distributed fairly uniformly through the tops and roots, whereas about two-thirds of the weight of the entire plant is in the part removed for hay and one-third in the roots and stubble. Since the first year's growth and the second growth of the second year usually are left on the ground or grazed, the crop may thus contribute to the soil nitrogen supply tho harvested. If soybeans are removed, there is a decrease in soil nitrogen, for the percentage of nitrogen is less in the roots and stubble than in the tops, while the roots are only about one-eighth of the whole plant. Field experiments show that soybeans so handled reduce yields of other crops grown in rotation as compared with the effect of clover.[12] Cowpeas are but little more effective.

The following table[13] gives approximately the relative weight of tops and roots, and the percentage of nitrogen in each, for some of the commonly grown legumes:

TABLE 4. NITROGEN IN TOPS AND ROOTS OF LEGUMES

| | Percent of Nitrogen | | Ratio Between Weight of Tops and Roots |
|---|---|---|---|
| | Tops | Roots | |
| Red clover | 2.70 | 2.34 | 2:1 |
| Crimson clover | 2.85 | 2.29 | 3:1 |
| Alfalfa | 2.56 | 2.03 | 2:1 |
| Sweet clover | 2.41 | 2.04 | 3:1 |
| Cowpeas | 2.70 | 1.45 | 6:1 |
| Soybeans | 2.58 | 1.91 | 7:1 |

[12] See Kentucky Experiment Station Bulletin 331, pages 236-41.

[13] Reprinted by permission from "Green Manuring" by A. J. Pieters, published by John Wiley and Sons, Inc.

Extensive data are not available for lespedeza, the most extensively grown legume in Kentucky. Some studies at the Kentucky Experiment Station indicate that the ratio of the weight of tops to roots is about 2 to 1.

The idea is very common that the growing of any legume crop improves the soil, though removed from the land. Such practice is very exhausting of the mineral nutrients, particularly calcium, phosphorus and potassium, and as already indicated, some of the legumes may also leave the soil with less nitrogen.

Legumes should be used in some way to return more nitrogen to the soil than is left in the roots and stubble. This may be done by turning the crop under, by pasturing it, or by feeding it and returning manure. Turning a regular legume crop under usually is not an economical use, except perhaps in a hurried preparation for some crop of high value per acre. If legumes, such as vetch and crimson clover, can be used as winter cover crops, they of course may be turned under. In pasturing, considerable residue is left on the ground and manure is dropped on the land, tho not well distributed. In feeding, about three fourths of the nitrogen in the feed consumed is voided by animals, on the average, nearly one-half of it being in the urine. If sufficient bedding is used to absorb the urine and the manure is not allowed to heat, a large part of the nitrogen of feeds may be returned to the soil in a form more available than in the original material.

Red clover and sweet clover are particularly favorable legume crops to precede non-leguminous crops because of their large, fleshy roots, which readily decay and furnish available nitrogen. Alfalfa is usually not so favorable, because generally it has been allowed to stand as long as it will produce hay, which means that a heavy draft has been made on soil minerals, while the roots do not decay so readily as red clover and sweet clover roots.

Lespedeza is also a favorable crop to precede non-legumes when properly used. If used in rotation, as is red clover, and only pastured the first year and allowed to reseed itself, there is considerable material left on the ground which contributes to the nitrogen of the soil. Lespedeza, of course, grows under many conditions where red clover will not grow. Tests by the Experiment Station indicate that on soil that will grow good red clover, lespedeza is about as effective in maintaining yields of corn and wheat in rotation as is red clover.

Obviously, in order to get the largest fixation of nitrogen through legumes, the soil must be put in favorable condition for their growth. Practically all of the soils of the State require the addition of either lime or phosphate or both. An examination of the table, on page 24, shows the very great effect of these treatments on the yield of legumes on the various soil experiment fields. Even common and Korean lespedeza, which will make a thick stand and more or less growth where red clover will not grow at all, and which have a reputation as "poor land" crops, usually are greatly benefited by lime, as well as by phosphate. On the Western Kentucky Experiment Substation the average yield of lesepdeza hay for six years on soil treated with superphosphate was 2225 pounds per acre, while on soil treated with limestone and superphosphate it was 3785 pounds. The average yields of corn following lespedeza on the two treatments were 41 bushels and 54 bushels, respectively, and for wheat following the corn, 10.7 bushels and 13.7 bushels.

Not only does the use of lime and phosphate, when needed, greatly increase yields of legumes, but it also increases the percentage of nitrogen in them. Much of the increase, no doubt, is due to greater nitrogen fixation, altho some of it may be due to greater availability of soil nitrogen caused by the influence of the lime and phosphate on nitrification. Several analyses by the Experiment Station indicate that the nitrogen in a ton of soybean hay is increased an average of about 10 pounds by lime and superphosphate, as compared with beans grown on untreated soil. This is equivalent to more than 60 pounds of protein, a significant fact in the feeding quality of the hay. The calcium and phosphorus content of legumes is also increased by the treatment, and this is important in animal nutrition.

Legumes are just as important in mixture with pasture grasses as they are in rotation with non-leguminous crops. An experiment[14] on the Experiment Station farm at Lexington illustrates this point. In 1923, bluegrass was sown on land that would make 50 to 60 bushels of corn to the acre. With one part of it white clover was seeded, and all kinds of legumes were kept out of the other part. Volunteer sweet clover appeared on the legume plot and was allowed to mature, after which it was removed. The next year the bluegrass was harvested. The grass with the legume yielded 2400 pounds of hay per acre, and that without the legume, 870 pounds. White clover was continued with the grass where the sweet clover had been. Usually the grass was clipped and left on the ground, but it was harvested twice more. The total yield of 3 cuttings of grass was 6100 pounds per acre on the legume plot, and on the plot without legumes it was 2600 pounds. Analysis of the grass at the grazing stage in two different years showed that the grass grown with the legume contained 33 per cent and 44 percent more protein than the grass grown alone. At the end of 8 years, 18 inches of soil under the grass without the legume had gained 62 pounds of nitrogen per acre, while 70 pounds was removed in harvested grass and dead grass removed in the spring; the soil under the legume and grass mixture had gained 406 pounds, while material removed contained 278 pounds, or a gain of nearly 700 pounds per acre. Grass had almost disappeared from the non-legume plot, altho there was a little gain in total nitrogen in the first 18 inches of soil, but on the grass-legume plot the grass was vigorous.

The nitrogen problem involves not only the fixation of nitrogen by growing legumes and its return to the soil, but its conservation and its use by non-leguminous crops.

As already stated, plowing a soil early in the fall and leaving it unplanted thru the winter may result in considerable extra leaching of nitrogen, as compared with late fall or spring plowing. Land from which a cultivated crop has been removed loses much by leaching unless thoroly protected by a cover crop, as was shown in the discussion of leaching. Rotations should be so planned as to keep the ground covered with growing crops as

[14] Conducted by P. E. Karraker.

much of the time as possible with as little expense as possible for seed and tillage. For example, a rotation of corn, soybeans, wheat and clover is unsatisfactory because of the expense of seeding a winter cover crop following corn, plowing again for beans, and seeding beans. Furthermore, if manure is used on corn, a considerable residue is left which furnishes nitrogen for beans and reduces nitrogen fixation by the beans. Compare with this a rotation of corn, wheat and two years of a mixture of grass and legumes, or two years of alfalfa in place of the mixture. Only one plowing is required, and one seeding of grass and legumes on the wheat serves for two years. The ground is kept more thoroly covered and leaching is reduced. Wheat, instead of a legume crop, feeds upon the residue of manure used on corn. As much, and sometimes more, hay will be produced in the latter rotation as in the first if the soil is in condition to grow the legumes.

Where grass is not grown with lespedeza and no winter cover crop is used following it, there is probably considerable loss of nitrogen by leaching. The lespedeza stops growing comparatively early in the fall, and it is late in making much growth in the spring. It is quite likely that considerable nitrogen fixed by the lespedeza becomes soluble in the interim. Many farmers disk the lespedeza sod and sow a winter grain and get a grain crop or pasture, followed by a lespedeza crop from voluntary seeding. Studies are under way by the Experiment Station to determine the loss and saving of nitrogen under these conditions.

*Crop Residues.* Adding organic matter in the form of such crop residues as cornstalks and wheat straw or by turning under rye when it has approached the heading stage often reduces the yield of non-leguminous crops following. The reason is that these materials have a wide carbon-nitrogen ratio—that is, the percentage of nitrogen is low compared with carbon. The soil organisms that produce the decay of these materials must have nitrogen in the process and, not getting enough from the material, they take available nitrogen from the soil and thus compete with the crop. This is the chief explanation of the detrimental effects often following the turning under of rye in late stages of growth. In such cases it would probably be better to remove it, so far as the crop immediately following is concerned. Non-leguminous cover crops, such as rye and wheat, should be turned under by the time they are 12 inches high. At this stage the percentage of nitrogen is much higher than nearer maturity. The best use of carbonaceous matter like stalks and straw is to pass it thru the stalls, where it may become saturated with urine, which narrows the carbon-nitrogen ratio and causes decay without competition for available soil nitrogen.

There is one crop residue in Kentucky that has large value for direct return to the soil that is largely wasted. With 1000 pounds of White Burley leaf there are about 500 pounds of stalks, and with 1000 pounds of dark leaf there are about 300 pounds of stalks. A ton of Burley stalks contains, on the average, about 60 pounds of nitrogen and 65 pounds of potash. In a ton of dark tobacco stalks there are about 70 pounds of nitrogen and 80 pounds of potash. The amount of phosphorus in the stalks is negligible.

A large portion of the nitrogen and potash in tobacco stalks is soluble in water. If exposed to rain, the most valuable portion of the nutrients is lost. It is common to see tobacco stalks outdoors, often under the eaves of the barn. Sometimes the stalks are piled or spread in the field in the fall or winter. In either case soluble nitrogen is lost, for after stripping time it is usually too late to benefit a crop. There is enough fertilizer value in the stalks to justify the expense of storing them under shelter until spring. They should not be spread until about the time spring growth begins. Forty dollars per ton for nitrate of soda and muriate of potash is 12.5 cents per pound for nitrogen and 4 cents a pound for potash. At these prices for the fertilizer constituents in tobacco stalks, Burley stalks would be worth about ten dollars per ton, and dark tobacco stalks about twelve dollars per ton.

## FARM MANURE

Farm manure is a far more important source of plant nutrients than its care and use in the State indicate. There are in Kentucky approximately 1,500,000 animal units (an animal unit is 1000 pounds of live weight), which produce about 15,000,000 tons of excrement annually, worth, at conservative prices for fertilizers, about $30,000,000, an average of about $120 per farm.

Perhaps 60 percent is a liberal estimate of the amount of this manure that is utilized. The wastage of manure represents several times the normal expenditure for fertilizers in the State. It is impossible completely to prevent wastage, but it could be greatly reduced. The most valuable constituent of animal manure is nitrogen, more than one-third of which is in the urine. The next most valuable constituent is potassium, nearly two-thirds of which is in the urine. When animals are not in stalls, the urine is almost wholly lost. Even when voided on pasture land, it is so concentrated in spots that it is of little value. The solid manure dropped on pastures is ineffective unless the dunghills are broken up and scattered, and this is seldom done. On pasture fields a drag of some kind should be used for scattering the dunghills. Altho this has often been suggested to Kentucky farmers, very few practice it. A section harrow can be adjusted and weighted to do this work very well.

When animals cannot get much grazing, there is little reason for letting them run out. It would be better to keep them under cover and provide sufficient bedding to absorb the urine. When it is not necessary to clean the stalls frequently, probably the best way to conserve manure is to allow it to accumulate in the stalls, with just enough bedding to absorb the urine. The tramping of the animals compacts the manure enough to prevent much heating. Beef cattle often are fed under enclosed sheds, where manure for the feeding period accumulates with little loss. It has been found that cattle take on weight faster when confined.[15]

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[15] Kentucky Experiment Station Bulletin 242.

Many farmers state that they do not have sufficient bedding, since they do not grow grain. Corn stover may be fed and the refuse used for bedding. Some farmers shred stover, which makes it more effective for bedding. On many farms there are weeds, sedge grass and other wild growth which, if cut before seeds mature, would make excellent bedding. Sometimes a heavy coating of dead crab grass and lespedeza is burned off in the spring before plowing which could have been raked up and used for bedding.

If manure must be removed frequently from the stalls, it may be stored with little loss by piling it in the open in straight-sided ricks packed down enough so that it will not heat. Keeping the pile wet is beneficial so long as water does not pass thru it. The best method of storage is on a concrete floor with a coping 12 to 18 inches high; a shed may be built over it. The manure should be packed and kept wet enough to prevent heating. Removable boards may be used above the coping to form walls.

The amount of plant nutrients in the excrement of animals varies with the feed consumed. For example, a high-protein hay, like alfalfa, produces excrement much richer in nitrogen than timothy hay. The composition of manure varies also with the kind of animals. Manure from dairy cows contains much more water than manure from horses. Sheep produce the driest manure. The excrement of milk-producing animals is not so rich as the excrement of the same animals on the same feed when not producing milk. Poultry manure and sheep manure are richer in nitrogen than other manures. Average farm manure, including bedding, contains about 10 to 12 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash per ton.

It is extremely difficult to determine the average composition of manure. Table (5) gives the approximate amount and composition of manure (urine included) excreted by different classes of animals per 1000 pounds of live weight per year.

If the manure from different animals were dried, there would be little difference in the production per 1000 pounds of live weight of the different classes of animals.

TABLE 5. PRODUCTION AND FERTILIZER INGREDIENTS OF MANURE[16]

| | Tons | Pounds of Fertilizer Ingredients per Ton of Fresh Manure | | |
|---|---|---|---|---|
| | | Nitrogen | Phosphoric Acid | Potash |
| Horse | 9.1 | 14 | 5 | 11 |
| Cow | 12.7 | 12 | 3 | 9 |
| Hog | 15.5 | 10 | 7 | 8 |
| Sheep | 6.2 | 19 | 7 | 20 |

[16] From Lyon and Buckman, "The Nature and Properties of Soils" (1922), pp. 501 and 514, by permission of The MacMillan Company, publishers.

On the average, about 1.5 tons of manure is produced for each ton of feed and bedding used. In practical farm feeding under cover, it should be possible to save a ton of manure for each ton of feed and bedding used.

The effectiveness of farm manure in increasing crop yields depends very largely on the rate at which it is used, how it is used, and the soil on which it is used. If used without a phosphate fertilizer, on the average Kentucky soil, it is not nearly so effective as if used with phosphate. The richer the soil is in nitrogen, the less effective the manure; or, in other words, the smaller the amount of manure necessary to supply the soil nitrogen deficiency.

The spreading of manure requires care to prevent losses. Manure spread in the fall and winter may lose considerable nutrients by washing, particularly on steep slopes, and possibly some by leaching. Manure spread in warm weather and not disked or plowed it may lose considerable ammonia by volatilization as the manure dries.

The place in the rotation and the amount to use are important. Some experiments on these points were made on the Experiment Station farm in a rotation of corn, wheat and clover. Land without manure yielded a little more than 50 bushels of corn per acre.[17] Manure was slightly more effective for corn when applied after the clover sod was broken than before, but not enough so to justify the extra labor and risk involved in de-

[17] See Kentucky Experiment Station Bulletin 331, pages 241-44.

laying planting. Manure applied before breaking was slightly more effective on wheat and clover following corn than manure applied after breaking. Manure in excess of 4 tons per acre on this soil did not justify its use, but 4 tons increased the yield about 10 bushels per acre.

Manure applied on wheat in early winter was no more effective for wheat than manure used on land for the preceding corn crop, but was a little more effective on clover following, altho not enough so to offset the loss of 5 bushels in increase in corn following the clover, as compared with manure applied for corn.

Manure applied on young clover soon after wheat harvest was a little more effective on clover than when applied elsewhere in the rotation, but not enough to offset the loss of 5 bushels in the increase in corn following the clover, as compared with manure applied for corn. In rotations similar to this it seems best to apply manure to the cultivated crop following the sod. These results support the common practice of farmers in using manure at a lower rate on larger areas when it is scarce.

Fifteen tons of manure applied every other year for corn in continuous culture was not so effective in maintaining yields as was a rotation of corn, wheat and clover without manure.

As previously stated, in a good rotation of crops, such as corn, wheat and clover, or other rotations containing legumes and grass, the soil is put in good condition by the roots and stubble of the crops so that it works well and holds water well. Any additional organic matter is valuable almost wholly for its plant nutrients.

That manure has little or no effect in conserving moisture in a good rotation is shown by 8 tons of manure in these tests producing only one-half of a bushel more corn, as an average of four comparisons, than did 4 tons. In an experiment on tobacco in a four-year rotation of tobacco and wheat followed by clover and orchard grass for two years, an average of 18 tons of manure per acre applied before the tobacco crop produced only 54 pounds more tobacco than 200 pounds of nitrate of soda carrying only about one-sixth as much nitrogen. This does not mean that 200 pounds of nitrate of soda is as valuable as 18 tons of manure. The nitrate of soda furnished practically all the nitrogen needed by the tobacco beyond what it obtained from the soil, while the manure furnished an excess.

## PLANNING AND ESTABLISHING ROTATIONS

Planning and establishing rotations is not so easy as may appear to some before attempting the task.

Simple rotations—that is, those for which as many fields are required as there are years in the rotation—are comparatively easy to establish. The crops in a four-year rotation of corn, soybeans, wheat and clover would appear as follows:

| Year | Field 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | Corn | Clover | Wheat | Beans |
| 2 | Beans | Corn | Clover | Wheat |
| 3 | Wheat | Beans | Corn | Clover |
| 4 | Clover | Wheat | Beans | Corn |

There are other rotations that are more confusing. For example, a six-year rotation of tobacco for two years, wheat, clover, and two years of grass following clover, requires only three fields, on which the crops would appear as follows:

| Year | Field 1 | 2 | 3 |
|---|---|---|---|
| 1 | Tobacco | Grass | Wheat |
| 2 | Tobacco | Grass | Clover and grass |
| 3 | Wheat | Tobacco | Grass |
| 4 | Clover and grass | Tobacco | Grass |
| 5 | Grass | Wheat | Tobacco |
| 6 | Grass | Clover and grass | Tobacco |

In this rotation wheat and clover appear in alternate years, while tobacco and grass appear each year.

Another type of rotation is that in which each field takes its turn lying in grass or a hay crop, while the other crops rotate on the other fields. This may be illustrated by corn, wheat, clover and bluegrass, which would appear as follows:

| Year | Field 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | Corn | Clover | Wheat | Grass |
| 2 | Wheat | Corn | Clover | Grass |
| 3 | Clover and grass | Wheat | Corn | Grass |
| 4 | Grass | Clover | Wheat | Corn |
| 5 | Grass | Corn | Clover | Wheat |
| 6 | Grass | Wheat | Corn | Clover |
| 7 | Grass | Clover & grass | Wheat | Corn |
| 8 | Corn | Grass | Clover | Wheat |
| 9 | Wheat | Grass | Corn | Clover |
| 10 | Clover | Grass | Wheat | Corn |
| 11 | Corn | Grass | Clover & grass | Wheat |
| 12 | Wheat | Corn | Grass | Clover |
| 13 | Clover | Wheat | Grass | Corn |
| 14 | Corn | Clover | Grass | Wheat |
| 15 | Wheat | Corn | Grass | Clover & grass |

It will be noted that the grass rotates with the main part of the rotation. In a rotation of this character the number of fields required is one more than the number of crops in the main part of the rotation, and the grass crop occupies a field for a number of years equal to the number of fields. The number of rounds of the main rotation on a field between two periods of grass will be the same as the number of fields in the rotation. Alfalfa for hay could be made to fit into this type of rotation. This would avoid growing it on the same land too long or too often. A great many alfalfa failures are caused by growing it too much on a given piece of land.

Another type of rotation is the alternation of simple rotations. For example, a rotation of corn, wheat and clover may be run on one set of three fields while a rotation of tobacco, wheat and clover is run on another set. When corn and tobacco have completed a round on their respective sets of fields, they exchange positions. This keeps tobacco from appearing too often on the same ground. However, a simpler and better adaptation of this rotation is to have three fields and have corn and tobacco in the same field. In the second round of the rotation, tobacco is grown on a different part of the field from where it was grown in the first round.

## SUMMARY AND RECOMMENDATIONS

1. The greatest losses from soils are caused by erosion and leaching, both of which are best controlled by keeping the soil

covered as much of the time as possible with growing crops. A mixture of grasses and legumes makes the most effective covering for this purpose.

2. *Rotations.* For harvest crop land a rotation of crops should be used which includes one legume crop in a two- to four-year rotation. If the rotation is made longer by adding grass, the grass mixture should contain a legume which will persist as long as the grass continues. The choice of legume will depend upon the productivity and treatment of the soil and the use to be made of the crop. A mixture of alfalfa, clover, and a small amount of timothy is good as hay. Lespedeza may well be added to all pasture mixtures, and to hay mixtures where there is much likelihood of the failure or poor growth of other legumes in the mixture.

The crops in the rotation should be such that the land is occupied with growing crops as much of the time as possible, to prevent erosion and leaching. They should also be such as reduce plowing and seeding of special cover crops to a minimum.

3. *Use of Manure and Legumes.* As much manure should be produced and carefully saved as good management of the livestock permits. The amount of manure that can be saved depends upon the methods of feeding, pasturing and housing. When animals are kept under cover, a ton of manure can be saved for a ton of feed and bedding used. Usually manure is most profitably used for corn and tobacco.

None of the legumes will greatly increase the nitrogen content of medium to good soil, if removed. If pastured or fed and the manure made by feeding them is returned to the soil, the nitrogen content may be increased. Where soybeans and cowpeas are removed from the soil, without the return of manure, the nitrogen content of the soil may be lowered. If the manure made from feeding them is returned, more nitrogen may be added to the soil than is withdrawn. All pasture mixtures should contain persisting legumes in order to maintain sufficient nitrogen to meet the needs of the grass. Most of the potash of feeds consumed is voided in animal excrements. If manure is not conserved and returned to the cropped soil, sooner or later potash deficiency may be expected. This deficiency may be hastened by the growing of legumes if manure is not returned. Plant nutrients in manure are usually more available than in crop residues.

4. *The Use of Liming Materials.* Most of the soils of the State need liming. Some exceptions are found in the hill region of northern Kentucky and in the vicinity of marl deposits. On most of the acid soils of the State, yields of the so-called acid-tolerant legumes, soybeans, cowpeas and lespedeza, usually are increased profitably by the use of lime. Except for the high-phosphorus soils of the Bluegrass region, the upland soils of the Purchase region, and possibly some river bottom soils that do not overflow, lime used without a phosphate fertilizer is not highly effective. Even for the Purchase region a combination of the two is desirable, but phosphates without lime are not highly effective on these soils. Two tons of limestone per acre, or its equivalent, is a satisfactory application for most soils.

On land on which tobacco is to be grown, only moderate applications of a liming material should be used, and it should be applied as far in advance of the tobacco crop as possible. There is no evidence in any of the experimental work of the Experiment Station that liming directly benefits tobacco, but there is evidence of lowering of yields and of injury to quality by the improper use of lime. Two tons of limestone per acre immediately preceding the crop has produced injury, and heavy liming has injured tobacco grown some years later. There is, however, evidence of much improvement from the proper use of lime thru its effect on legumes in the rotation. These experiences should not deter farmers from using liming materials on tobacco land, but should cause care as to the amount used and the time of using it. Where too much lime has been used, its injurious effects on tobacco may be overcome to some extent by liberal fertilization with high-grade complete fertilizer.

Where liming materials are expensive on account of long haul or other causes, it is recommended that ground limestone or hydrated lime be drilled in with small grain at the maximum capacity of the drill. This should greatly benefit the clover and grass mixtures sown on the small grain. It should first be tried on a small scale. The practice is giving excellent results in many parts of the State. It is especially recommended on land on which tobacco is to be grown. The plan has the merit of enabling the farmer to grow legumes on a large area with a small outlay for liming materials. If the soil is deficient in phosphorus (see use of phosphate fertilizers, next section, No. 5), the lime may be mixed with superphosphate, or mixed fertilizer containing a liberal amount of phosphorus, in the ratio of two to one, and drilled with grain as suggested. However, quicklime and hydrated lime should not be mixed with fertilizers containing ammonium salts.

5. *The Use of Phosphate Fertilizers.* Except for the high-phosphorus soils of the Bluegrass region, it is suggested that 300 to 400 pounds per acre of superphosphate, or its equivalent of other phosphate fertilizer, be used for the small grain crop on which will be sown a legume and grass mixture of the character desired for hay or pasture. Much land in the State is so slightly acid that fairly good yields of red clover can be grown without liming, if phosphate fertilizers are used liberally and adapted strains of red clover are sown. Many clover failures are due to the use of unadapted clover seed of foreign origion or from certain regions in the United States. There is reason to believe that at least some of the clover failures on the various soil experiment fields were caused by the use of unadapted seed. In some years clover was as good or nearly as good on fertilized but unlimed plots, on some fields, as on limed plots similarly fertilized. It is believed that adapted seed was a greater factor in these instances than seasonal conditions.

For soils that are not limed, raw ground phosphate rock has been found as effective as one half its weight of 16 percent superphosphate. Two parts, by weight, or rock phosphate contain four times as much phosphorus as one part of 16 percent superphosphate. On some types of soil, such as in the region of Campbellsville, rock phosphate is particularly effective in producing clover (see Kentucky Experiment Station Bulletin 322, pages 377-8). Basic slag and bone meal are also highly effective sources of phosphorus.

6. *The Use of Complete Fertilizers on Grain and Hay Crops.* If a phosphate fertilizer has been used for grass and clover as recommended in No. 5 and manure is used on the following crop, a moderate application of phosphate fertilizer usually will be sufficient for corn or other crops except tobacco. However, there are cases in which a complete fertilizer may be more profitable than a phosphate fertilizer. The following tests are suggested: For corn, compare 100 to 150 pounds of superphosphate per acre, or its equivalent of other phosphate fertilizer, in the hill or row with 100 to 150 pounds per acre of a complete fertilizer containing not less than 3 percent each of potash and nitrogen and 10 to 12 percent of phosphoric acid. The best method of hill application is to place the fertilizer in bands on each side and a little below the level of the seed. The two fertilizers should be tested side by side for a few years until it is demonstrated which is the better practice for the farmer's soil conditions.

A complete fertilizer generally gives corn a better early growth than phosphate fertilizer, but unless the soil is moderately fertile, this advantage may not be maintained. A complete fertilizer is more apt to be profitable on fairly productive land than on either poor or very productive soil. The complete fertilizer may be effective on late plantings and on poorly drained soils. The same comparison of fertilizers may be tried on small grain and the clover and grass sown with it, using 300 to 400 pounds of each fertilizer.

It should be kept in mind that the small amount of complete fertilizer commonly used in the hill or row for corn and small grain furnishes only a small part of the needs of the crop for nitrogen and potash, and that, at present prices of crops and fertilizers, the main supply of these elements is best maintained by the production and proper use of legumes and manure. However, the complete fertilizer properly used as a "starter" may be profitable under the conditions already mentioned.

7. *Fertilizers for Tobacco.* Very few soils are so fertile that it will not be profitable to fertilize tobacco grown on them, at average prices for tobacco and fertilizers. During a period

of thirteen years it has been found profitable to fertilize tobacco on the Experiment Station farm on soil that has produced an average yield of leaf of a little more than 1300 pounds an acre without fertilizer.

As a general recommendation for both White Burley and dark tobacco, a complete fertilizer of approximately a 1-2-1 ratio is suggested, with a minimum of 4 percent of nitrogen and potash. Some analyses of this ratio are 4-8-4, 6-12-6, 12-24-12. etc. It is not necessary that the ratios conform exactly to these figures. For example, on soils that are very deficient in phosphorus the proportion of phosphoric acid may be increased. For sandy soils the potash may be increased. Where it is believed that the soil is well supplied with nitrogen, a fertilizer lower in nitrogen may be used, and if the tobacco does not grow well and is of a pale color, a side dressing of soluble nitrogen fertilizer may be applied when the plants are 6 to 8 inches high.

If it is positively known that a soil is very high in phosphorus, as in some soils in central Kentucky, a mixture containing nitrogen and potash may be used. A mixture of 200 pounds of nitrate of soda, or 150 pounds of sulfate of ammonia, and 75 pounds of potash salts makes a satisfactory acre application for tobacco on such soils. However, unless one is sure of a high phosphorus content of the soil, it is safer to use a complete fertilizer. Phosphoric acid is the least expensive part of a fertilizer and its cost is small in comparison with the value of the tobacco. The superphosphate in 500 pounds of the average tobacco fertilizer costs about $2.50.

"Muriate of potash" may be used for tobacco in applications not to exceed 50 pounds of the salt per acre with little or no danger of injuring the quality of the tobacco. (The amount of muriate or sulfate of potash used to furnish the "potash" ($K_2O$) is approximately double the figure for potash. For example, 500 pounds of 5-10-5 fertilizer with the potash from muriate would contain approximately 50 pounds of muriate of potash.) Where heavier applications of potash are used, part or all of it should be in the sulfate form.

Fertilizer is most effective when applied in the row, but great care must be used to prevent the plants from coming in contact with the fertilizer. The best placement is in bands about 6 to 8 inches apart and 3 or 4 inches deep, with the plants set midway between. If the transplanter does not have such an attachment, a one-horse fertilizer drill may be used to place the two bands. If a setter is used that drops the fertilizer ahead of the tobacco plants, adjustments should be so made that the planter shoe pushes the fertilizer to the sides of the row. If the fertilizer is mixed with the soil in the row before setting, it should be thoroly done in a strip 8 to 12 inches wide. Thoro mixing is to be emphasized.

If the tobacco transplanter does not have a fertilizer attachment, the fertilizer is of necessity applied before setting the tobacco. There is an advantage in this, for the fertilizer may be applied a week or ten days ahead of setting, which lessens danger of injury to plants.

Since there is no implement for placing the fertilizer in the hill for dark tobacco, continuous row application, as for Burley, is perhaps as good as any method. If placed in the hill, extra care should be used in mixing it with the soil, and it should be applied a week or ten days before setting.

The amount of fertilizer to use for tobacco probably can best be judged by the estimated productivity of the soil in terms of corn yield. For soils that produce 30 to 40 bushels of corn per acre in a good season, 500 to 600 pounds (4-8-4 or equivalent) of fertilizer per acre is recommended for tobacco; for soils that make 50 to 60 bushels, 400 to 500 pounds. For very rich soils a small amount of fertilizer may be effective in giving the tobacco a good start. If fertilizers of higher analysis are used, the amount should be reduced proportionately.

If as much as 10 or 12 tons of good manure per acre can be used, 200 to 300 pounds of superphosphate in the row or 400 to 500 pounds broadcast may be expected to give excellent results. (See Greenville Field, Bulletin 322.) If less manure than this is used, a complete fertilizer will likely prove more profitable than phosphate alone. (See Campbellsville and Mayfield fields, Bulletin 322.)

Tobacco should be grown only on well drained soil kept productive by the use of legumes, grass and manure. Land thus prepared for tobacco produces quality and yield at the least expense of any method of soil management.

8. *Fertilizing Alfalfa.* Alfalfa grown alone or used in the hay mixture has shown a decided response to potash on the various soil experiment fields. Alfalfa not only contains a large amount of potash, but requires it in a short period of growth. Unless the land is liberally manured or potash fertilizer is used, alfalfa is apt to suffer from lack of potash. In all seedings of alfalfa it is recommended that a test be made for the need of potash. This may be done by applying muriate of potash at the rate of 200 pounds per acre on a plot that has been limed and fertilized with a phosphate fertilizer. If potash shows beneficial effects, the remainder of the crop may be top-dressed immediately following a cutting.

Alfalfa makes such a heavy draft on the soil that top-dressing with fertilizers is often needed unless very large amounts are applied at seeding time. After the stand is two or three years old, or whenever it does not appear vigorous, it is advisable to make a top-dressing test by applying superphosphate (500 pounds per acre) on a small area, and superphosphate and muriate of potash (500 and 200 pounds per acre, respectively) on an adjoining area. If either treatment increases yields sufficiently, the remainder of the field may be treated accordingly. These tests are best applied before spring growth begins. On phosphorus-deficient soils, alfalfa should have about 200 pounds of superphosphate, or its equivalent, for each year it stands.

A top-dressing test was made at the Western Kentucky Experiment Substation, beginning in the spring of 1931, on four- and five-year-old alfalfa that had been limed at the rate of 2½ tons of limestone per acre and fertilized with superphosphate at the rate of 400 pounds per acre, when sown. There or more cuttings of hay had been removed each year after the year of seeding, and the alfalfa had begun to thin out. The tests consisted in top-dressing with 500 pounds of superphosphate per acre, with 500 pounds of superphosphate plus 200 pounds of potash, and a check without top-dressing. The tests were made in quadruplicate and located in two fields. Only one application of fertilizers was used in the three years, and nine cuttings were made. The total yield for all cuttings of alfalfa not top-dressed was 15,012 pounds per acre. Phosphate top-dressing increased this yield by 6483 pounds, while potash in the top-dressing further increased the yield by 641 pounds. About half of the total increase for phosphate was in the first year.

When alfalfa is sown for the first time on soil that is deficient in nitrogen, a medium application of soluble nitrogen fertilizer may be helpful in supporting the crop until inoculation becomes effective. An application supplying 15 to 20 pounds of nitrogen per acre is suggested in connection with other fertilizers.

9. *Top-dressing with Nitrogen.* Top-dressing with soluble nitrogen fertilizers is profitable under some conditions on small grain, timothy for hay, bluegrass and orchard grass for seed, and pastures (see next paragraph). The prices of crops and fertilizer materials will be a large factor in the profitableness of the practice. The use of nitrogen top-dressings is most likely to be profitable in backward springs and on thin land, but is not likely to be profitable except on land well supplied with phosphorus and potassium, either naturally or by application.

10. *Top-dressing Pastures.* On the phosphatic soils of the Bluegrass region, pastures may be made to afford earlier grazing by top-dressing with a soluble nitrogen fertilizer. The first dressing should be given just before spring growth begins: usually the last week in March is about the right time. This may be profitable for those farmers who have to buy feed. Dressings at intervals during the grazing season will increase growth, particularly in those pastures that do not have a legume in them. The continued use of nitrogen top-dressing on pastures may materially reduce the proportion of legumes in the herbage. For most farmers it is much better to put the soil in condition to grow legumes and put them in the mixture when sowing the

pasture. White clover and lespedeza kept in the mixture will provide nitrogen for the grass.

Outside the Blugrass region, where the soil is generally deficient in phosphorus, it will be profitable to top-dress pastures with a phosphate fertilizer unless the land was heavily fertilized with phosphate when the pasture was sown. On most soils needing phosphate fertilizer, about 100 pounds of ordinary superphosphate, or its equivalent of some other phosphate, should be used for each year the pasture stands, until the land is brought up to a high state of production, after which the use of phosphate may be discontinued for a while.

Often it is profitable to top-dress pastures with some liming material, altho it is much more effective to work both the lime and phosphate into the soil before seeding the pasture. If lime and phosphate are applied in sufficient quantities, legumes in mixture with the grass will generally supply sufficient nitrogen. If the growth of grass is poor after dressing with phosphate and lime, nitrogen may be used as indicated above. Sometimes dressing with complete fertilizer may be more profitable, but this can be determined only by field test.

If the manure dropped on pastures by animals were well scattered each winter after the grazing season is over, it would make the manure much more effective, and it would be a decided help to the grass. This can be done by using some form of drag, such as a section harrow with the teeth well slanted back.

## THE VALUE OF CHEMICAL TESTS OF SOILS AS A BASIS FOR FERTILIZER RECOMMENDATIONS

Many persons have the impression that it is possible, from a chemical analysis of the soil, to prescribe exactly the best fertilizer for producing both yield and quality in crops. Particularly does this seem to be believed by many growers of tobacco, vegetables and flowers.

It is not possible, by a chemical test, to predict what the availability of plant nutrients will be in a given soil for a given season, for this is largely influenced by seasonal conditions and by soil characteristics that cannot be measured by chemical tests.

For example, in a week or two of favorable weather, as contrasted with unfavorable weather, a larger amount of nitrogen may be made available than is contained in the usual application of fertilizer.

By a chemical test of a soil it can readily be determined whether lime is present or absent. A determination of the amount of phosphorus and its solubility shows whether there is a deficiency, a sufficiency, or whether the soil is on the border line between, and gives a good basis for recommendations on the use of this element. Chemical tests for nitrogen and potassium will show whether the soil contains a large or small amount of them, but will not show availability within limits narrow enough to be of value in prescribing a fertilizer analysis. For example, whether to use 500 pounds of a 4-8-4 or 500 pounds of a 6-10-6 fertilizer involves a difference of 10 pounds each of nitrogen, phosphoric acid, and potash. No chemical test has yet been devised that is delicate enough to determine availability of these nutrients in the soil within these limits. To repeat, a chemical test does not enable one to prescribe satisfactorily an exact fertilizer analysis and amounts for various crops. However, field tests conducted in many parts of the State do give a fairly satisfactory basis for recommending fertilizers for various crops.

The Experiment Station will make, without charge, tests for lime and phosphorus if the samples are taken according to the following directions: Select a place that fairly represents the field to be sampled. Take soil from ten different places well distributed over an area of not less than one acre. Take the soil uniformly to the depth of 6 inches, in equal amounts at each place. Mix these portions thoroly and take out a pint as a sample for test. The following information should accompany the sample: Location of farm; lime and fertilizers used within the last five years; crops grown, in order, for the last five years; an estimate of how much corn the land will produce under average seasonal conditions. It may be safely assumed that practically all soils outside the Bluegrass region and some river bottoms are deficient in phosphorus.

Many county agents have equipment for making lime and phosphorus tests and are glad to render the service.

## PUBLICATIONS

Any of the following publications on soils and crops will be sent free to citizens of Kentucky upon request addressed to the Director of the Experiment Station, Lexington, Ky.

Bulletin No.

277 Soils of the Purchase Region of Kentucky.
299 The Hopkinsville Soil Experiment Field.
318 Adaptability of Red Clover from Different Regions to Kentucky.
322 Report on Soil Experiment Fields.
324 Analysis of Red Clover Failures in Kentucky.
328 Tobacco Diseases.
331 Soils and Fertilizer Experiments—Station Farm, Lexington.
334 Comparative Effect of Muriate and Sulfate of Potash on the Composition and Quality of Burley Tobacco.
339 Black Stem of Alfalfa, Red Clover and Sweet Clover.

Station Circular No.

32 Marls for Kentucky Soils.

Extension Circular No.

54 Elementary Lessons on Soils.
56 Lessons on Farm Crops.
59 Liming the Soil.
70 Alfalfa.
77 Management of Tobacco Plant Beds.
81 Crimson Clover.
129 Soil Erosion and its Control.
155 Production, Care and Use of Farm Manure.
163 Better Land Utilization in Kentucky.
174 Making Limestone More Available to Farmers.
218 Sweet Clover.
223 Loading and Spreading Marl.
230 The Production of White Burley Tobacco.
232 Soybeans and Cowpeas for Hay.
242 Practices in Seeding Meadows and Pastures.
247 Burning Limestone for Agricultural Use.
258 Korean Lespedeza.
Mimeograph reports on work on the Western Kentucky Experiment Substation.