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AGRICULTURAL EXPERIMENT STATION
KANSAS STATE AGRICULTURAL COLLEGE

SOIL FERTILITY

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SUMMARY

1. Kansas soils have decreased rapidly in productivity during the past 50 years. The yield of corn has decreased 40 percent and the yield of wheat has decreased 17 percent during this period. The removal of large quantities of hay and grain without returning organic matter and plant food to the soil has been largely responsible for it.

2. Many soils that are of low productive capacity still contain large quantities of plant food but it is not in an available form. The addition of organic matter will aid in liberating this plant food and thereby increase the productivity of the soil.

3. If the supply of organic matter in the soil is maintained, phosphorus will be the first element of plant food necessary to add. Kansas soils are naturally low in this element: In fact, phosphatic fertilizers can be used at a profit at the present time on many of the shale and sandstone soils of the eastern part of the state.

4. The organic content of the soil may be maintained by applications of barnyard manure and by plowing under green manure crops, straw, and other crop residue. A rotation containing a hay or grass crop will also aid. Straw is an important source of organic matter and should be utilized as far as possible. It may be used as bedding, feed, or applied direct to the field. Of the green manure crops, sweet clover and cowpeas are the more important, but green manure crops should not be grown until all other sources of organic matter have been exhausted.

5. Barnyard manure is the best form of organic matter, as it decays quickly and adds considerable available plant food. Manure may be profitably used on all crops, but will usually give greater returns when applied on wheat, alfalfa, or clover.

6. Whenever possible, manure should be applied as soon as produced. Manure exposed for a period of seven months lost more than 65 percent of its value.

7. Light applications of manure as a surface dresssing on wheat may be used successfully in the wheat belt.

8. Of the three elements, nitrogen, phosphorus, and potassium, purchased in the form of commercial fertilizers, only phosphorus has given paying returns.

9. Wheat has responded profitably to applications of phosphorus on the sandstone and shale soils of the eastern part of the state, and alfalfa has responded profitably on all upland soils of the eastern one-third of Kansas.

10. Lime is needed only on the soils of the eastern one-fifth of the state. The soils of Central and Western Kansas are well supplied with lime.

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L. E. CALL and R. I. THROCKMORTON

INTRODUCTION

The soil is the most important source of wealth in an agricultural state. If it is maintained in a high state of productivity by wise systems of soil management, the people prosper. If its fertility is wasted through careless methods of farming, both the farmer and the state suffer.

Nature gave Kansas an unusually fertile soil; indeed, the soil of few states equals it. Through long ages the native grasses and legumes growing upon prairies had liberated and stored immense quantities of available plant food. When these soils were cultivated, their productivity gradually decreased, because the supply of organic matter in which most of the easily available plant food is held was destroyed by cultivation and very little effort was made to restore to the soil the loss thus sustained. Our system of farming since the settlement of the state has been a system of taking from the soil all that it would give and of returning almost nothing.

As an example, the plant food removed from Kansas soil during the past 55 years in the wheat crops alone has been worth about seven hundred million dollars, or more than the farmers of Kansas received for all the wheat grown during the last eight years. As this wheat has been largely milled outside the state, and as the bran and shorts, as well as the flour, have been fed outside the state, this fertility has nearly all been taken away, to the permanent injury of Kansas soils. Even the wheat straw, worth more than twelve million dollars for the plant food it contains, has been largely burned or otherwise wasted. The result of such a system of farm practice can easily be foretold. Table I, compiled from the reports of the State Board of Agriculture, giving the average yield of wheat, corn, and oats by five-year periods during the last 50 years, tells the story of soil waste and decreasing yields.

TABLE I.—AVERAGE YIELD OF WHEAT, CORN, AND OATS BY FIVE-YEAR PERIODS, 1865-1914

Crop	Yield in bushels per acre									
	1865–1869	1870–1874	1875–1879	1880–1884	1885–1889	1890–1894	1895–1899	1900–1904	1905–1909	1910–1914
Wheat	16.90	14.06	14.96	16.55	11.45	11.36	9.76	14.04	12.27	13.90
Corn	36.04	31.13	41.18	32.87	26.72	18.59	23.08	19.93	23.83	14.67
Oats	35.22	30.61	33.81	35.33	31.25	22.29	20.95	23.91	21.82	24.01

The acre yield of the three crops, wheat, corn, and oats, has decreased rapidly during the past 50 years. The average yield of wheat for the first 25 years of this period, 1865-1889, was 14.8 bushels per acre, while for the last 25 years, 1890-1914, the average yield has been but 12.2 bushels per acre, a reduction of 2.6 bushels per acre, or 17.4 percent. The yield of corn has decreased from 33.6 bushels per acre for the first period to 20.0 bushels for the last period, a difference of 13.6 bushels, or 40.5 percent. The yield of oats has decreased from 33.2 bushels, the yield for the first period, to 22.6 bushels, the yield for the last period, a difference of 10.6 bushels, or 32.4 percent. This reduction in yield has taken place regardless of the fact that the varieties of these crops grown during the last 25 years have been better adapted to the climate of the state than those grown during the first 25 years. This is also in spite of the fact that the soil has been much better tilled and farming operations generally have been better done during the second period than during the first.

It has been suggested that the decrease in yield, especially of corn, was the result of extending the corn belt into the western part of the state or into territory which by reason of its rainfall is not so well adapted to corn. A study of the acre yield of corn in some of the best corn-growing counties in Eastern Kansas, however, shows that the decrease has been even more rapid in these counties than for the state as a whole.

To understand the changes taking place in the soil under cultivation which tend to make it less productive, it is necessary to consider, among other things, the composition of the soil.

COMPOSITION OF THE SOIL

The soil is composed of small pieces of rock and small particles of partly decayed organic matter, commonly spoken of as humus. The rock particles make up the body or mass of the soil and vary in size and composition with the kind of rock from which the soil was derived and the manner in which it was formed. The rock particles contain the mineral plant foods. As they are dissolved by the actions of water, air, and decaying organic matter, the mineral foods are made available.

The plant secures some food from the soil and some from the air. The following plant food elements come from the soil: Nitrogen, phosphorus, potassium, calcium, magnesium, iron, and sulphur. With the exception of nitrogen, practically all are derived from the rock fragments. The nitrogen and a small portion of the other elements are found in the organic matter. Almost all soils contain a sufficient supply of these elements for normal plant growth, with the exception of nitrogen, phosphorus, and potassium. Besides these, calcium, commonly known as lime, is needed in some soils but usually to correct soil acidity rather than to supply plant food. Therefore, these four elements are the ones to be considered in soil fertility problems.

AVAILABLE AND UNAVAILABLE PLANT FOOD

Most of the plant food in the rock particles of the soil is not of immediate use to the plant. It can be used only after it has been made soluble. This means that,plant food exists in the soil in two forms—(1) that which is locked up in the rock particles and cannot be used by the plants, which is spoken of as unavailable; and (2) that which is in solution in the soil water and can be used by the plants at once, referred to as available. The major portion of the plant food is in the unavailable form, and since it is made available very slowly the soil contains but a very small amount of available plant food at any time. In fact, the quantity of plant food liberated from season to season from the rock particles of the soil alone would perhaps never be sufficient to produce paying crops.

Fortunately, the plant food stored in the organic matter of the soil is liberated faster, and it is from this source that plants derive the most of their available food. Fresh organic matter decays faster than old organic matter, and in decaying liberates plant food not only from the organic matter itself, but from the rock material of the soil with which the organic matter is in contact. Thus, to keep the soil productive, it is necessary to maintain in the soil at all times a store of organic matter. This may be supplied by manure, corn stalks, straw, weeds, or other forms of plant material. Deep plowing and frequent cultivating also aid in making plant food available.

AMOUNT OF PLANT FOOD REMOVED BY PLANTS

Crops vary greatly in the amount of plant food they remove from the soil. In corn, oats, and wheat, the grain removes a larger proportion of nitrogen and phosphorus than the straw, while potassium and calcium are found in greater amounts in the straw than in the grain.

Table II gives the average number of pounds of plant food removed by a number of different crops.

TABLE II.—POUNDS OF PLANT FOOD REMOVED BY CROPS

CROP	Yield per acre	Nitrogen	Phosphorus	Potassium	Calcium
Winter wheat, grain	20 bus.	28.4	4.8	5.2	0.4
Winter wheat, straw	1 ton	10.0	1.6	18.0	3.8
		38.4	6.4	23.2	4.2
Corn, grain	30 bus.	30.0	5.1	5.7	0.4
Corn, stover	1 ton	16.0	2.0	17.3	7.0
		46.0	7.1	23.0	7.4
Oats, grain	30 bus.	19.8	3.3	4.8	.6
Oats, straw	1 ton	12.4	2.0	20.8	4.5
		32.2	5.3	25.6	5.1
Alfalfa hay, early bloom	3 tons	150.0	14.0	145.0	65.0
Red clover hay, early bloom	1 ton	40.0	5.0	30.0	29.3
Prairie hay	1 ton	17.0	2.0	16.0	....

As shown in Table II, a 20-bushel wheat crop will remove from the soil in the grain and straw 38.4 pounds of nitrogen, 6.4 pounds of phosphorus, 23.2 pounds of potassium, and 4.2 pounds of calcium. The wheat required these amounts of different plant foods in approximately the proportions given. If the amount of any one of these elements in available form in the soil is appreciably less than that required by the crop, the yield is decreased regardless of the amounts of the other elements of plant food present. In other words, that element which is lowest in amount, in proportion to the amount required, will govern the productivity of the soil.

Many people have the idea that hay crops do not exhaust the soil of its fertility. A study of Table II will reveal the fact that hay crops do remove large amounts of plant food. Alfalfa and red clover remove large quantities of nitrogen, but these crops have the power of taking free nitrogen from the air, while in most other plants this element is taken only from the soil. However, if the alfalfa or clover is sold, instead of fed on the farm and the manure saved and returned to the cultivated fields, the phosphorus and potassium may be depleted even more rapidly by growing these crops than by growing grain crops.

AMOUNT OF PLANT FOOD IN KANSAS SOILS

Chemical analyses have been made of a great number of soils throughout the state.[1] Some of these analyses were of the most productive soils, while others were of some of the poorest soils of the state. An average of all the determinations of upland soils shows that the surface 7 inches contains 3,385 pounds of potassium per acre. An average of all the determinations of bottom land soils shows that the surface 7 inches contains 4,173 pounds of nitrogen, 1,167 pounds of phosphorus, and 39,000 pounds of potassium per acre.

Table III compares typical soils from various parts of Kansas with a very fertile soil.

TABLE III.—POUNDS OF PLANT FOOD IN THE SURFACE SEVEN INCHES OF TYPICAL KANSAS SOILS

Soil	Plant food in the surface 7 inches			
	Nitrogen	Phosphorus	Potassium	Calcium
A very fertile soil	6,000	2,080	34,200	11,200
Marshall silt loam, Northeast Kansas	3,620	1,060	38,800	11,200
Oswego silt loam, Riley County	4,340	1,060	36,400	13,600
Richfield silt loam, Finney County	2,480	1,340	45,200	23,400
Albion sandy loam, Reno County	1,900	500	43,800	9,800
Arkansas fine sand, Reno County	680	520	48,600	1,100
Kirkland clay, Reno County	4,100	820	40,400	48,600
Cherokee silt loam, Southeast Kansas	2,000	480	11,200	6,000
Colby silty clay loam, Jewell County	3,200	920	41,800	14,000
Bates silt loam, Cherokee County	2,800	700	12,600	7,200
Lincoln silt loam, Jewell County	4,200	1,240	43,000	46,200
Summit silty clay loam, Shawnee County	6,000	1,040	34,200	11,200
Riverton silt loam, Cherokee County	1,000	120	13,800	4,200

A study of these figures shows that practically all the soils are much below the standard of a very fertile soil in content of nitrogen and phosphorus. The potassium content is high, however, in practically all cases. The amount of calcium is sufficient for

1. See Bulletin 199, Kansas Agricultural Experiment Station.

crop needs for a great number of years, though in some sections this element is needed to correct acid conditions.

The poorest of these soils, Riverton silt loam, has only enough phosphorus to grow an annual crop of 3 tons of alfalfa for nine years, provided all the phosphorus became available. The Cherokee slit loam contains only enough phosphorus to grow 34 such crops of alfalfa. Some of the sandy soils of the Arkansas River Valley contain only sufficient nitrogen to grow 18 crops of wheat of 20 bushels each.

THE SUPPLY OF PLANT FOOD

Since potassium, phosphorus, nitrogen, and organic matter are so important in the soil, means of supplying these materials where they are needed should be considered.

Potassium.—This element occurs in the rock fragments or mineral part of the soil, chiefly in the smaller fragments such as clay and slit. It is for this reason that sandy soils are more deficient in potassium than the loam or clay soils. Of the three elements—potassium, phosphorus, and nitrogen—potassium is the most abundant in the soils of Kansas, and the supply is most easily maintained. Straw, fodder, and other forms of roughage contain the major part of the potassium removed by the plants. When these materials are returned to the soil in the form of manure, most of the potassium is returned. However, if soils become low in organic matter, the amount of available potassium may become deficient. Present indications are that the supply of available potassium will be sufficient for crop needs for many years in those soils in which the supply of organic matter is maintained.

Phosphorus.—Like potassium, phosphorus has its origin from the mineral elements of the soil, but unlike potassium, it is not found in abundance. Where good methods of cultivation are practiced and crop rotations are followed, phosphorus will be the first element of plant food necessary to supply. As shown in Table III, the supply of this element is very low in many of our soils. There is no means of replenishing the supply except by feeding crops grown on the farm or by feeding commercial feeds and returning the manure, or by using phosphorus in the form of commercial fertilizers. The farms on which grain crops are grown exclusively are losing their phosphorus the most rapidly. This is because the grain of corn, oats, and wheat contains the largest proportion of the phosphorus in the plant. When the grain is sold the phosphorus is lost as far as the farm on which it was grown is concerned.

The thoughtful farmer will realize that if he is to maintain the fertility of the soil, he must either feed the grain he produces and return the manure to the soil to partially maintain the supply of phosphorus, or eventually buy phosphorus in the form of feed or commercial fertilizer. Some of the soils in the eastern and southeastern parts of the state have already reached that stage where it is profitable to apply commercial fertilizers containing phosphorus.

Nitrogen.—This element, unlike potassium and phosphorus, is not found in the mineral matter of the soil but in the organic matter. A decrease in the amount of organic matter in the soil is followed by a corresponding decrease in nitrogen. The amount of nitrogen used by crops is large, but the amount which can be obtained from the air by means of leguminous plants is also great. In order that grain crops may receive the benefit from the nitrogen in the air, leguminous crops must be grown in rotation with the grain crops, or manure obtained from feeding leguminous crops must be applied to the soil on which the grain crops are grown.

If alfalfa and clover are grown in a rotation and the crops harvested for hay and sold, there is some question as to their value in increasing the nitrogen content of the soil. While these crops secure the most of their nitrogen from the air, the nitrogen thus secured is removed from the field when the hay is harvested. It has been estimated by some investigators that the nitrogen left in the soil by the roots and stubble is no greater than that secured from the soil, and that there is consequently no increase in total nitrogen.

If the entire crop were removed in harvesting, it is questionable if much nitrogen would be added, but in harvesting leguminous crops, especially alfalfa, a great many leaves are lost, which return to the soil. The leaves are the richest part of the plant innitrogen. As nearly as can be estimated, the loss in harvesting amounts to from 10 to 25 percent of the total quantity of leaves when the alfalfa hay is handled in the best possible manner, and when handled carelessly the loss is even greater. When alfalfa remains on the same field from 5 to 15 years and is cut, on the average, four times a season, it is not unreasonable to believe that a soil may be enriched in nitrogen in this way.

Regardless of the value of alfalfa and other legumes in increasing the supply of nitrogen in the soil on which they are grown, the fact should not be overlooked' that the largest portion of the nitrogen that these plants secure from the air is removed in the hay, and that the benefit of this nitrogen can be obtained only by feeding the hay on the farm and carefully saving and returning the manure to the soil.

THE VALUE OF A CHEMICAL ANALYSIS

Upon first thought it might be expected that if one knew the quantity of plant food removed by a plant and the quantity of plant food found in the soil, it would be a simple matter to tell, not only the crops best adapted to the soil, but the kind and quantity of plant food in the form of manure or commercial fertilizer that should be supplied to produce a maximum yield of any crop. Such reasoning is erroneous, because it does not take into consideration the fact that a large part of the plant food in the soil is in an unavailable form, a fact which analysis does not show, and that only a very small part of this large store of unavailable plant food is made available at any one time. Neither does it take into consideration the fact that the supply made available fluctuates greatly, and depends not only upon the total quantity of plant food present in the soil, but upon the supply of organic matter, the character of the weather, and the way the soil is cultivated and handled, as well as upon the crop grown.

It is therefore evident that a chemical soil analysis has certain limitations, and that an analysis of an individual soil will mean but little to the average farmer and will usually give him very little assistance in planning the kind of fertilizer to use on a special crop. It should not be understood, however, that chemical soil analyses are of no value. While they will not show with exactness whether or not a fertilizer is needed or, if needed, the kind and amount to apply to secure the best results with an individual crop like corn or wheat in a single season, they do give very valuable information as to the general plan that should be followed in maintaining the fertility of the soil. For example, if a chemical analysis of a soil shows that the soil contains an abundance of potassium, it does not necessarily follow that sufficient potassium is being liberated each season to supply the needs of the plant, but rather that if the soil is well cultivated and kept supplied with an abundance of organic matter, sufficient potassium may be made available for crops. In an instance of this kind a chemical analysis is of value in showing that the most practical thing to do is to liberate potassium from this unavailable supply in the soil itself, rather than to purchase it in an available form in a commercial fertilizer.

It is possible, therefore, from a chemical analysis to make very accurate general deductions regarding the best cropping system and fertilizing practices that should be followed on different soil types. For this reason, in connection with the state soil survey, which is being carried forward as rapidly as funds will permit, complete chemical analyses are being made of each soil type encountered. Analyses have already been made which include many of the leading soil areas of the state. Much of this information has been published in bulletins of the Agricultural Experiment Station,[1] and additional information will be published as fast as it is collected. Because this information is now available, because chemical analysis is of questionable value to the average farmer, and because this analytical work is very expensive, the Experiment Station is compelled to refuse to make analyses for individuals without charge.

HOW TO MAINTAIN THE FERTILITY OF THE SOIL

The methods of farming generally practiced by the farmers of the state have not maintained the fertility of the soil, as has already been shown by the data given in Table I. The practices which have been largely responsible for the decreased productivity are (1) erosion, or the washing away of the surface soil by heavy rains; (2) the depletion of the organic matter of the soil; (3) lack of a rotation, or growing the same crop continuously; (4) the failure to grow a sufficient acreage of leguminous crops in rotation with other crops to maintain the nitrogen content of the soil; and (5) the depletion of the supply of the mineral elements of plant food.

If the fertility of the soil is to be maintained in the future, farming methods must be so changed that these poor practices will be corrected so that the losses of organic matter and plant food will either be prevented or additional supplies added to the soil.

HOW TO PREVENT EROSION

In some parts of Kansas, especially on the rolling soils in the eastern part of the state, a large quantity of plant food has been lost through erosion. On many of these soils the loss by this means has been much more rapid than the pain from the agents

1. Kansas Agricultural Experiment Station Bulletins 199, 200, 207, 208, and 211.

of weathering. Since the most fertile part of the soil is the upper few inches, it is necessary to keep this part in place.

Since erosion is caused by running water, any practice which increases the water-holding power of the soil will decrease erosion. Deep plowing, adding organic matter, and working the ground at right angles to the slope of the land are all effective methods of checking the wash, and therefore assist in preventing soil erosion. Steep slopes in a field should be kept in grass or hay instead of cultivated crops. The grass furnishes a protection to the surface of the ground while the roots bind the soil particles together and hold them in place. If it is necessary to plow or list sloping fields, they should be worked parallel to the slope of the land instead of up and down hill. Fields worked on the contour hold water for a longer time after a rain, which in turn gives the soil greater opportunity to absorb it, thus decreasing the quantity draining from the field as well as decreasing the rate of flow of the run off water. When the furrow is up and down the slope, it forms a natural drainage channel which soon becomes deeper and thus carries away large quantities of the most fertile part of the soil.

Figure 1 shows a field that has been badly eroded because it has been listed up and down the hill. There are thousands of such fields in Kansas. Practices of this kind are responsible for the rapid exhaustion of the producing power of many soils of the state.

Fig. 1.—Severe erosion caused by listing up and down a slope. Such fields should be seeded permanently to grass

ORGANIC MATTER

Organic matter decays rapidly in a cultivated soil. The more frequently the soil is plowed and the more intensely it is cultivated, the more rapid the loss of this material. Soils cropped continuously to corn, kafir, or other cultivated crops are usually depleted in organic matter more rapidly than soils cropped to small grain, while soil seeded down to alfalfa or grass crops may increase rather than decrease in organic matter.

VALUE OF ORGANIC MATTER

It is important to keep a soil well supplied with organic matter because it holds practically all of the nitrogen in the soil, consequently as the supply of organic matter decreases the nitrogen decreases. Organic matter is also important as an aid in holding moisture and keeping the soil in good tilth. A soil depleted of its organic matter runs together and crusts badly after rains. It bakes if worked a little wet, and plows up lumpy if plowed dry. It also absorbs water slowly and will hold less water than a similar soil well supplied with organic matter. Organic matter is also the principal food of the bacteria that make available plant food for plants. In brief, organic matter is so important that it may be safely said that practically all of the so-called worn-out land in Kansas is unproductive not because it is deficient in plant food, but because with the low supply of organic matter present there is not sufficient plant food made available to give profitable yields. When this land is again supplied with organic matter these soils will become almost, if not quite, as productive as they were originally. Any attempt to permanently increase the fertility of such soils without first supplying organic matter to them will be financially unsuccessful.

LOSS OF ORGANIC MATTER FROM CULTIVATED SOILS

The fact that the soil has been rapidly depleted in organic matter when it has been continuously under cultivation is clearly shown by the following data comparing the carbon content of some old cultivated soils with the carbon content of the same soil in an uncultivated or virgin condition. Carbon is the chief constituent of organic matter, and the organic matter content of a soil is usually expressed as carbon in a chemical analysis.

Table IV gives the difference in carbon and nitrogen content of soils left in native meadow and pasture as compared with the same soils under cultivation.

TABLE IV.—DECREASE IN NITROGEN AND ORGANIC MATTER IN KANSAS SOILS[1]

COUNTY	Soil type	Cropping system	Pounds per acre	
			Nitrogen	Organic matter
Riley	Oswego silt loam	Native meadow	4,980	122,400
		Cultivated to wheat and corn for 30 years	3,700	85,600
Brown	Marshall silt loam	Native meadow	5,480	139,200
		Average of six cultivated soils (Rotation of corn, oats, and wheat.)	4,240	106,800
Russell	Sedgwick clay loam	Native buffalo pasture	4,260	98,400
		Thirty years in wheat	2,960	64,400
Allen	Oswego fine sandy loam	Native meadow	3,760	83,600
		Cultivated to corn and broom corn	2,440	46,400
Butler	Sedgwick clay loam	Native pasture	4,280	106,400
		Cultivated to corn and forage crops	2,800	66,800
Greenwood	Osage silty clay loam	Native meadow	4,600	113,600
		Corn, 30 years	3,400	73,200
Greenwood	Summit silty clay loam	Catalpa grove	5,200	126,000
		Average of five cultivated soils	3,400	76,400
Reno	Reno loam	Native pasture	3,400	74,800
		Average of three cultivated soils	1,920	36,400

It will be seen from this table that soils which have been cultivated 30 years have lost from 25 to 30 percent of their nitrogen and from 30 to 35 percent of their organic matter. It will also be noted that the decrease in both nitrogen and organic matter has been more rapid when cultivated crops have been grown continuously than when a rotation has been followed.

ROTATIONS THAT WILL MAINTAIN ORGANIC MATTER

It is evident that soils under cultivation are gradually depleted in organic matter and that the methods of farming commonly practiced are neither maintaining the content of organic matter nor the productivity of the soil. It is therefore imperative that greater effort be made to use every possible source of supply of organic matter. One of the first essentials to the maintenance of organic matter is the adoption of a cropping system that includes a leguminous crop. However, even a small grain crop alternated with corn will maintain the organic matter much better than corn grown continuously; but where leguminous crops like alfalfa, sweet clover, red clover, and cowpeas are introduced into the rotation, the supply of organic matter is still better maintained. This point is well shown by Tables V and VI giving the results of

1. Swanson, C. O. The loss of nitrogen and organic matter in cultivated Kansas soils and the effect of this loss on the crop-producing power of the soil. Jour. of Indus. and Engin. Chem. 7:529-532. 1915.

rotation experiments at the Kansas and Missouri Agricultural Experiment Stations.

TABLE V.—EXPERIMENTS IN CROP ROTATION, MISSOURI AGRICULTURAL EXPERIMENT STATION[1]

ROTATION	Yield of corn, 1905
Corn continuously, 17 years	11.8 bus. per acre
Corn, wheat, clover, 17 years	50.7 " " "
Corn, oats, wheat, clover, timothy, 17 years	54.2 " " "
Corn, wheat, clover (manured)	77.6 " " "

It will be seen in the results from the Missouri station that where corn has been grown continuously for 17 years the yield has been reduced to 11.8 bushels per acre. Where a rotation of corn, wheat, and clover has been practiced the yield for the same year was 50.7 bushels per acre, and where barnyard manure was added in the same rotation the yield reached 77.6 bushels per acre.

TABLE VI.—CROP ROTATION, KANSAS AGRICULTURAL EXPERIMENT STATION

ROTATION	Yield of corn, 1917
Corn continuously, 8 years	17.6 bus. per acre
Corn, corn, wheat, 8 years	22.7 " " "
Corn, cowpeas, wheat, 8 years	32.8 " " "
Corn, corn, wheat, and cowpeas (*a*), 8 years	34.5 " " "
Corn, wheat, and alfalfa, (*b*) 8 years	44.9 " " "

(*a*) Cowpeas sown after wheat as a green manure crop.
(*b*) Alfalfa four years, corn two years, wheat one year and followed by corn.

At this station the work has been of much shorter duration than similar work at the Missouri station. Corn has been grown continuously for only eight years, yet in this period of time the effect of continuous cropping to corn in reducing the yield has been marked. The yield last season (1917) on upland soil where corn had been cropped continuously for eight years was 17.6 bushels per acre. In a simple rotation of two crops of corn and one of wheat the yield of corn was 22.7 bushels. In the same rotation when cowpeas were sown after harvesting the wheat and plowed under in the fall before frost the yield was increased to 34.5 bushels per acre. In a rotation consisting of corn, cowpeas, and wheat where cowpeas were cut for hay, the yield of corn was 32.8 bushels

1. Miller, M. F. The fertility of the soil. Mo. Agr. Expt. Sta. Cir. 69:1-19. Figs. 3. 1914.

per acre. On a field that grew alfalfa four years, corn two years wheat one year, and then corn again, in 1917 the yield was 44.9 bushels per acre. The results secured from rotating crops have been striking. The more important benefits derived from the rotation have undoubtedly been the control of insects and diseases and the increase in the supply of organic matter which has aided in the liberation of plant food from the unavailable store in the soil.

THE VALUE OF A LEGUME IN A ROTATION

The benefits derived from a rotation of crops come not only from the, increased supply of organic matter but from the increase in nitrogen secured by growing leguminous crops. Every rotation in Eastern Kansas should include a leguminous crop, and where possible a leguminous or grass crop should occupy the land at least one-fourth of the time. A study of the farming practices of different Kansas counties reveals the fact that where counties have similar climatic conditions, those growing the largest acreage of leguminous crops and having the largest proportion of the cultivated land in tame grasses are the ones that are more nearly maintaining the fertility of the soil. A comparison of the corn

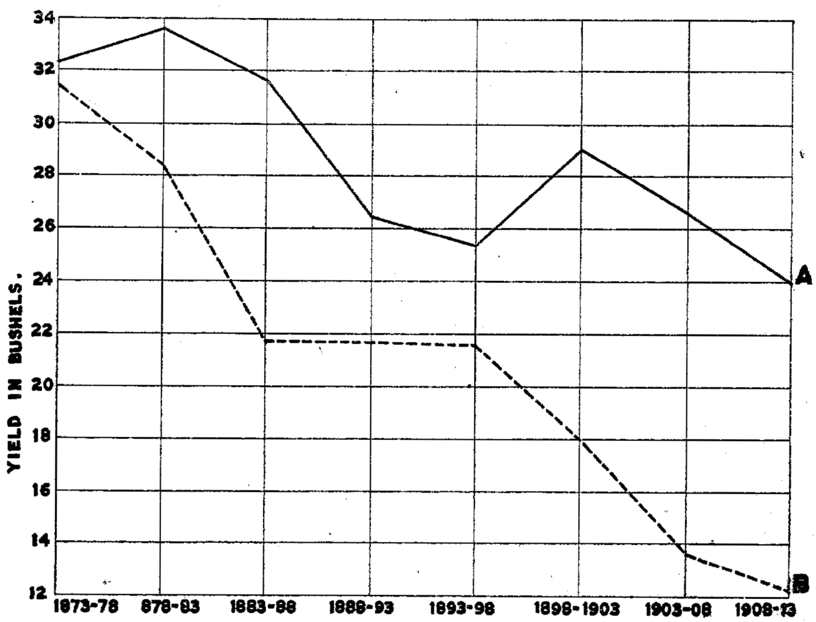

Fig. 2.—Chart illustrating the relative effect of grain farming (B) and mixed farming (A) on the decrease in yield of corn

yields of two counties in Eastern Kansas, each having an annual rainfall of more than 35 inches, shows a very marked difference in the reduction in yield of corn in the past 40 years. These counties for convenience will be called A and B. Figure 2 gives the average yield of corn in these counties by five-year periods from 1873 to 1913.

The average yield of corn for the first five-year period, 1873-1878, was practically the same for both counties, about 32 bushels per acre. For the last period of the 40 years, 1908-1913, the yield in County A was 24 bushels per acre, but 8 bushels less than the yield 40 years previous. In County B the yield for the last five-year period, 1908-1913, was only a little over 12 bushels per acre, a decrease of almost 20 bushels, and two and one-half times as great as the decrease in County A. That the difference in exhaustion of fertility in the two counties can be largely explained by the difference in farming methods followed is well shown in Table VII, giving a comparison of the farm practices of these two counties. The crop acreages are those reported by the State Board of Agriculture for the year 1912.

TABLE VII.—A COMPARISON OF THE FARM PRACTICES OF TWO COUNTIES IN KANSAS FOR 1912

	County A	County B
Area, square miles	589	558
Area cultivated, acres	230,079	213,458
Corn area, acres	71,680	69,930
Wheat area, acres	49,488	15,100
Clover area, acres	54	4,532
Alfalfa area, acres	163	10,212
All tame grasses, acres	1,859	26,145

It will be seen that the two counties are approximately the same size, that the acreage under cultivation is practically the same, and that there is also very little difference in the acreage in corn. The most striking difference is in the area devoted to leguminous crops—clover and alfalfa—and tame grasses. In County A, where the yield of corn has decreased so rapidly, only about two thousand acres, or less than 1 percent of the land under cultivation, is devoted to these crops. In County B, where the depletion of the soil has been less rapid, about forty-one thousand acres, or over 19 percent of the total area under cultivation, is in grasses, clover, and alfalfa. There is little doubt that the tame grasses and leguminous crops grown in rotation with corn and wheat were responsible for the maintenance of fertility in this county. Because these crops were grown, a larger number of livestock was kept on the farms, and manure was available for fertilizing purposes. The results secured from entire counties thus serve to substantiate the results secured from the experiments in crop rotation at both the Missouri and Kansas stations.

STRAW AN IMPORTANT SOURCE OF ORGANIC MATTER

Wheat straw is undoubtedly one of the most valuable by-products of the farms of Kansas. At the present time a large quantity of straw is burned or otherwise destroyed. This practice results in a loss that neither the individual farmer nor the state as a whole can afford. This straw, if properly used on the land, would supply not only organic matter to the soil and thus greatly increase its productivity, but would also add several million dollars worth of plant food annually. When the straw is burned the organic matter is not only destroyed, but most of the plant food is lost as well.

The most economical way of handling straw is to utilize as much of it as possible for feed and bedding, applying the manure produced therefrom to the soil. When it is not possible to follow this method, the straw can be applied as a surface dressing on wheat during the winter or as a top dressing on corn or sorghum ground at the rate of 1 to 1.5 tons to the acre. Heavier applications are not advisable on growing wheat. When top dressings of this kind are made the straw acts as a surface mulch and aids in the conservation of moisture. Later, it becomes incorporated in the soil mass and supplies organic matter and plant food.

Straw may be applied by spreading from hay rack by use of fork or it may be spread with a straw spreader. There are several straw spreaders on the market at the present time.[1] Some of these spreaders may be attached to the rear end of an ordinary hay wagon or header barge, while others include the wagon and rack. Regardless of the method used, the straw should always be spread evenly.

1. The following companies manufacture straw spreaders: Union Foundry and Machine Company, Ottawa, Kan.; Manson Campbell Company, Kansas City, Mo.; Advance Spreader Campany, Minneapolis, Minn.; Eclipse Manufacturing Company, Wichita, Kan.; and International Harvester Company, Chicago, Ill.

GREEN MANURE AS A SOURCE OF ORGANIC MATTER

When it is impossible to supply sufficient barnyard manure, Straw, corn stalks, weeds and other forms of plant material to maintain the supply of humus in the soil, it may become necessary to grow a crop to plow under to supply organic matter. Crops used for this purpose are called green-manuring crops. There are two kinds of green-manuring crops—(1) leguminous crops, including such crops as cowpeas, soybeans, clover, and sweet clover; and (2) non-leguminous crops, including such crops as rye, buckwheat, turnips, and sorghum. Where conditions are favorable

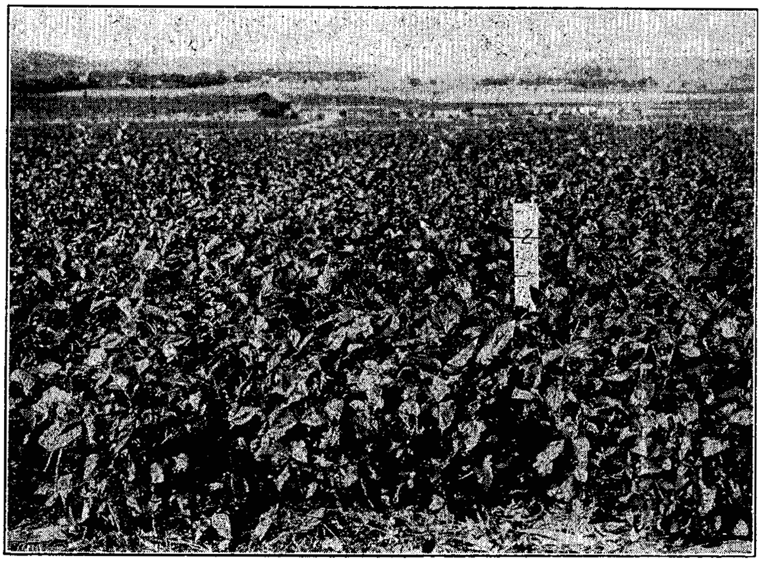

Fig. 3.—Cowpeas drilled in close rows on disked wheat stubble after harvest

for growing leguminous crops, they are preferable, since they add nitrogen as well as organic matter to the soil. When clover is grown it is often possible to harvest the first crop for hay and to plow under the second growth in the fall for green manure.

Cowpeas make an excellent green-manuring crop in the eastern half of Kansas where they can be grown successfully. One of the best practices is to sow the crop on disked or plowed wheat or oat stubble land as soon after harvesting the small grain crop as possible. (Fig. 3.) It may be drilled in close rows or in rows wide enough apart to permit of cultivation. If it is drilled in rows for cultivation, 1 peck of seed will plant an acre, while if drilled in close rows, 1 bushel of seed should be used. It should be plowed under just before frost and the field planted to corn, kafir, or some other annual sorghum crop the next spring, rather than to a fall crop like wheat. When handled in this way the green material will partially decay during the winter months and the undesirable effects of seeding on a loose seedbed of undecomposed organic matter will be avoided. Many times it is found advisable to pasture the cowpeas during the last part of August and September and to turn under only the stubble.

SWEET CLOVER FOR GREEN MANURE

Sweet clover is one of the most valuable of the green-manuring crops. It makes a rapid, rank growth, and when plowed under adds large quantities of organic matter and nitrogen to the soil. (Fig. 4.) It is a hardy, vigorous feeding crop, and can therefore be started successfully on soils so poor that other crops make an unsatisfactory growth. For this reason this crop is especially well adapted to growing for soil improvement on eroded hillsides and in fields in a very low state of fertility. Fields of this kind can often be improved to such an extent by a crop of sweet clover that other more valuable crops like alfalfa can in a short time be successfully grown. A good plan is to seed sweet clover in late winter or early spring and to use it during the latter part of the first season and the first part of the second season for pasture. After the middle of July of the second year the clover should be allowed

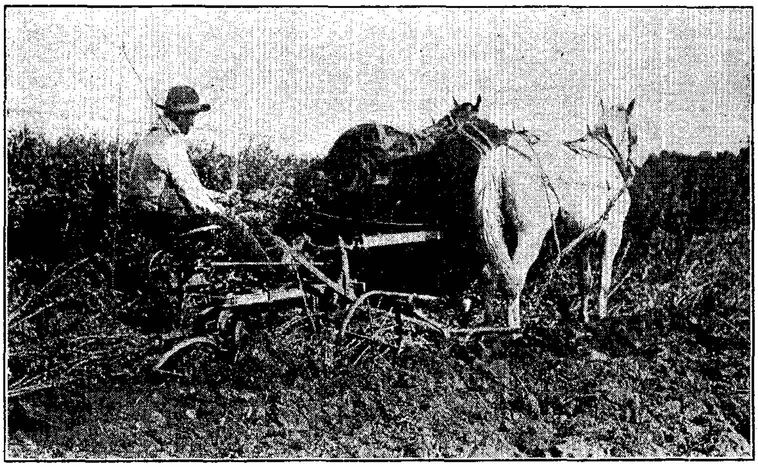

Fig. 4.—Plowing under sweet clover for green manure

to grow in order to make a rank growth of organic matter to plow under before frost in the fall. A rowed crop like kafir or cane should be planted the first season following sweet clover and small grain crops or alfalfa sown later.

In the western part of the state, where moisture is the limiting factor in crop production, it is not usually advisable to grow green-manuring crops because of the large amount of moisture they remove from the soil in their growth. In this section of the state all other sources of organic matter should be utilized before resorting to green-manuring crops.

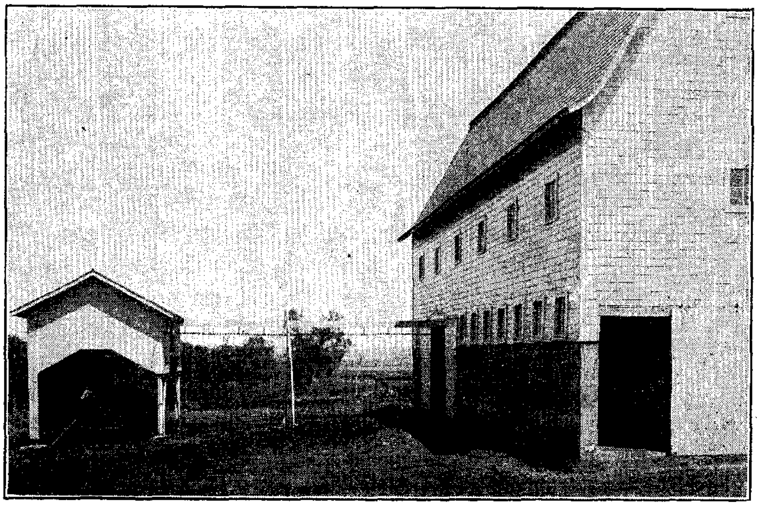

Fig. 5.—A good but inexpensive type of manure shed

THE CARE AND USE OF BARNYARD MANURE

Barnyard manure is the best form in which to supply organic matter to the soil. It is not only valuable for the plant food and organic matter that it supplies directly, but is equally valuable in aiding in the liberation of plant food. Kansas farmers need to appreciate more fully the value of manure. (Fig. 5.) As nearly as can be estimated, the manure produced annually in Kansas is worth more than ninety million dollars on the basis of the plant food that it contains, as much or more than the value of the average wheat crop of the state. It is also estimated that over one-half, or fully fifty million dollars' worth of manure is wasted annually. If the livestock farmer properly saves and utilizes his manure he can maintain his soil in a high state of productivity, but the livestock man who feeds his cattle in woodlots along the banks of streams, and so wastes his manure, usually depletes the fertility of his soil more rapidly than the man producing grain only. The feeding of livestock is of aid in maintaining the fertility of the soil only when the manure produced is properly saved and utilized.

Manure is of the greatest value when it is spread upon the cultivated fields as fast as it is produced. One of the most practical methods of handling manure is to feed stock, when weather conditions permit, on the cultivated fields. In this way, if care is taken in feeding, much of the manure may be scattered by the animals themselves and practically all of the plant food voided by the animals will be retained by the soil.

LOSS OF MANURE

Manure that accumulates in open feedyards loses value in three ways: (1) the seeping away of the liquid excrement; (2) leaching due to heavy rains; and (3) decay of the manure. Under average feedlot conditions most of the urine voided by the animals is lost. Urine contains about two-thirds of the nitrogen and four-fifths of the potassium in manure. This represents more than one-half of the plant food in the manure, and is the most valuable half because it is the part soluble in water and therefore the most readily available. When it is necessary to feed in the open,

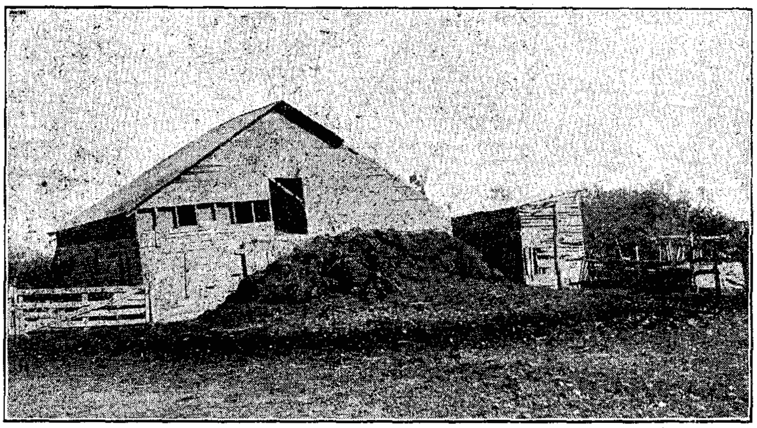

Fig. 6.—Manure stored in this way will soon lose more than three-fourths of its value

straw and waste feed should be utilized as much as possible as absorbing materials to retain the urine.

The loss of plant food from manure due to leaching by rain is also great when the manure is stored in piles in the open. (Fig. 6.) The loss from this source varies with weather conditions, and in our climate is greatest during the summer months. Manure that is stored in the open for a period of six months often loses one-half of its organic matter and about the same proportion of its plant food.

At this station in the spring of 1915, 1 ton of fresh cow manure was placed in a pile in the open in May and allowed to remain exposed to the weather for the following seven months. Samples of the manure were analyzed at the beginning and again at the end of the period, with the results shown in Table VIII.

TABLE VIII.— PLANT FOOD AND ORGANIC MATTER LOST FROM ONE TON OF MANURE DUE TO LEACHING FOR A PERIOD OF SEVEN MONTHS

TREATMENT	Pounds				Value per ton (a)
	Dry matter	Nitrogen	Phosphorus	Potassium	
Original	640.0	12.91	5.12	15.62	$4.30
Leached for seven months	276.5	4.20	1.14	6.53	1.47
Loss	363.5	8.71	3.98	9.09	2.83
Percent of loss	56.8	67.5	77.5	58.2	65.8

(a) The value of the manure was calculated on the following basis: Nitrogen, 20 cents per pound; potash, 6 cents; and phosphoric acid, 5 cents.

At the end of the period the original ton of manure weighed only 1,070 pounds. The value of the plant food lost was 65 percent of the original value. The greatest losses in plant food occurred in nitrogen and phosphorus, the elements most deficient in Kansas soils. In addition to the loss of plant food, the loss of organic matter was also great. The dry matter decreased from 640 pounds to 276.1 pounds, or more than 56 percent.

METHODS OF PREVENTING LOSS OF MANURE

In order to prevent such losses manure should be applied to the cultivated fields as soon as possible after it is produced. This usually means that the most of the manure should be applied during the late fall, the winter, and the early spring, when there is the least amount of team work on the farm. Manure can be applied at this season of the year the most economically both from the standpoint of labor and plant food loss.

The best results from the use of manure are obtained by applying it as a surface dressing on wheat, on ground to be seeded to alfalfa, or on fall plowed land that is to be planted to corn or kafir the following spring. The application should be uniform and not too heavy. Ten tons per acre is sufficient for practically all soils of the state. If the amount of manure available is limited, the application should be made as light as possible in order that a large area may be covered. It is more profitable to apply 100 tons of manure to 20 acres at the rate of 5 tons per acre than to apply it to 10 acres at the rate of 10 tons per acre.

VALUE OF MANURE AS A TOP DRESSING ON WHEAT

The value of barnyard manure when applied as a light top dressing on wheat in the winter has been well shown by experiments at this station where during the past seven years the manure has been applied at the rate of 2.5 tons to the acre annually on ground in wheat continuously. Table IX gives the results of this test.

Table IX.-THE EFFECT OF MANURE ON YIELD OF WHEAT

YEAR	Treatment		Increase due to manure
	2.5 tons manure per acre annually	No manure	
1911	29.4 bus.	25.8 bus.	3.6 bus.
1912	6.7 "	5.7 "	1.0 "
1913	28.4 "	17.6 "	10.8 "
1914	29.5 "	23.5 "	6.0 "
1915	21.9 "	12.7 "	9.2 "
1916	18.9 "	6.8 "	12.1 "
1917	20.5 "	11.9 "	8.6 "
Average	22.2 bus.	14.9 bus.	7.3 bus.

An application of 2.5 tons of manure annually has increased the average yield of wheat 7.3 bushels per acre during the past seven years. If wheat is given a value of $1 a bushel, the manure used in this test was worth $2.91 a ton.

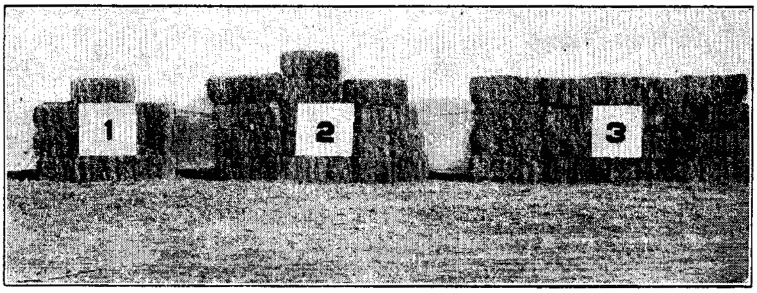

Fig. 7.—Alfalfa hay harvested from one-tenth acre plots having the following treatments:

1. No treatment
2. Manure, **2½** tons per acre annually
3. Manure, 5 tons per acre annually

USE OF MANURE ON ALFALFA

The effect of manure on alfalfa at this station has been even more pronounced than on wheat. (Fig. 7.) The alfalfa experiments were conducted on soil that had been eroded to some extent and was in a low state of fertility when the work was started. Alfalfa has since been grown continuously on manured and unmanured ground. Three different plots of ground have been manured, one plot at the rate of 2.5 tons per acre annually, another at the rate of 5 tons, and the third at the rate of 2.5 tons of manure and 380 pounds of raw rock phosphate per acre annually. Table X gives the yields of alfalfa on these plots for the last seven years.

TABLE X.—EFFECT OF MANURE ON YIELD OF ALFALFA

YEAR	Treatment			
	Manure, 2.5 tons per acre annually	Manure, 5 tons per acre annually	Manure 2.5 tons, and raw rock phosphate 380 lbs. per acre annually	No treatment
1911	3,659 lbs.	3,805 lbs.	4,649 lbs.	2,463 lbs.
1912	1,620 "	1,920 "	1,800 "	920 "
1913	3,041 "	4,366 "	3,724 "	1,901 "
1914	4,342 "	5,418 "	4,323 "	2,380 "
1915	11,110 "	13,250 "	11,530 "	5,570 "
1916	9,027 "	11,254 "	9,687 "	5,307 "
1917	7,160 "	10,170 "	7,470 "	4,780 "
Average	5,708 "	7,169 "	6,169 "	3,324 "

The average yield of alfalfa for the past seven years has been 3,324 pounds per acre on the unmanured ground, while ground manured at the rate of 5 tons annually produced an average yield of 7,169 pounds, an increase of about three-fourths of a ton per acre over the lighter application of manure. If alfalfa is given a value of $8 a ton, the manure applied at the rate of 2.5 tons to the acre was worth $3.81 a ton, and that applied at the rate of 5 tons to the acre was worth $3.08 a ton. Manure is always more valuable when used as a light application than when applied heavily. When the greatest possible return from manure is desired, it should be scattered over as large an area as possible. Heavy applications of manure should be made only when there is an abundance of it, and only in those sections of the state where there is sufficient moisture to rot the manure rapidly.

Raw rock phosphate applied with 2.5 tons of manure at the rate of 380 pounds per acre annually increased the yield of alfalfa 461 pounds per acre more than when manure was applied alone. The cost of the rock phosphate was a little less than $2 an acre. The increased yield very nearly paid for the cost of the fertilizer. On soils containing less available phosphorus, especially on those in the southeastern part of the state, an application of rock phosphate applied in this way would undoubtedly prove profitable.

THE USE OF MANURE IN CENTRAL AND WESTERN KANSAS

Many farmers in Central and Western Kansas are not using the barnyard manure produced on their farms. They feel that manure is not needed and that there is danger of reducing the yield of crops if it is used. In this section of Kansas it is necessary to use manure with greater caution than in the eastern section of the state. It should be applied in small quantities at a time, and usually as a top dressing so that it will not interfere with the moisture supply of the plants. Manure may be applied on ground that is to be listed to corn or kafir, or it may be applied as a top dressing on winter wheat in the fall or winter. The manure should be spread with a manure spreader, setting the spreader to make just as light an application as possible. If wheat can be top dressed in the fall or early winter the manure serves as a protection to the wheat against blowing and severe freezing, acts as a mulch to prevent evaporation of moisture, and later, when the manure is worked into the soil, it increases the supply of organic matter which enables the soil to hold more water. The supply of organic matter in the soils of Western Kansas must be conserved if they are to retain their present high state of productivity.

THE USE OF MANURE IN CENTRAL AND EASTERN KANSAS

In order to determine the comparative value of manure where it was applied in light applications as a top dressing on wheat, work was started in 1913 in cooperation with a number of farmers living in Eastern and Central Kansas.

Manure was applied in most cases as a top dressing in the fall or winter at the rate of from 5 to 10 tons per acre. The work has been done on different farms, or on different fields on the same farm, from season to season, so that the effect of the manure has not been accumulative. Undoubtedly the manure was of as much or greater benefit the second year following its application as it proved to be the first, but it has been impossible to secure information covering this point. As an average of 15 tests in the eastern one-fourth of Kansas, extending from 1914 to 1917, inclusive, manured wheat made an average yield of 23.2 bushels per acre, unmanured wheat, 17.4 bushels, a difference of 5.8 bushels per acre in favor of manured ground. In the central one-half of Kansas as an average of 11 tests for the same seasons manured wheat produced 24.4 bushels per acre, unmanured wheat 20.8 bushels, a difference of 3.6 bushels per acre in favor of manured ground. These tests show that manure, when properly applied as a top dressing on wheat, is of value in Central Kansas, as well as in eastern sections of the state. (Fig. 8.)

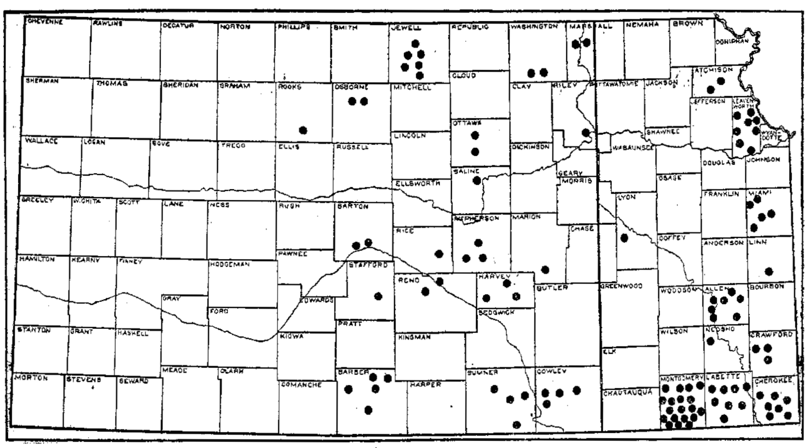

Fig. 8.—Map of Kansas showing location of cooperative experiments in which manure has been applied to wheat as a top dressing

TABLE XI.—THE EFFECT OF MANURE APPLIED AS A TOP DRESSING ON WHEAT IN EASTERN AND CENTRAL KANSAS

Year	Number of tests	Yield in bushels per acre		
		Manured	Unmanured	Difference in favor of manuring
		Eastern one-fourth of Kansas		
1914	14	31.2	25.9	5.3
1915	13	20.0	15.5	4.5
1916	17	18.7	12.0	6.7
1917	18	22.9	16.2	6.7
Average 1914-1917		23.2	17.4	5.8
		Central one-half of Kansas		
1914	15	28.3	26.5	1.8
1915	9	20.6	17.8	2.8
1916	11	22.6	17.3	5.3
1917	8	26.2	21.8	4.4
Average 1914-1917		24.4	20.8	3.6
Grand average		23.8	19.2	4.6

COMMERCIAL FERTILIZERS

On many farms barnyard manure is not produced in sufficient amounts to maintain the fertility of the soil. Under such conditions the question is commonly asked, can commercial fertilizers be used in place of manure? In order to answer the question it is necessary to consider the nature of commercial fertilizers. A commercial fertilizer is a material containing available nitrogen, phosphorus, or potassium in concentrated form. It may contain any or all of these elements. If it contains all, as most fertilizers found on the market do, it is called a complete fertilizer. While commercial fertilizers supply plant food in a form much more concentrated than barnyard manure, unlike barnyard manure they do not supply organic matter, which has already been shown to be deficient in old cultivated soils, and to be absolutely necessary to supply plant food, to preserve good tilth, and to retain water in the soil. Because commercial fertilizers do not add any appreciable amount of organic matter, they cannot be expected to replace manure in soil improvement, but should be used, where they can be used profitably, in addition to barnyard manure and other forms of organic matter.

DO COMMERCIAL FERTILIZERS IMPOVERISH THE SOIL?

Do commercial fertilizers impoverish the soil? If once used, must they be used continuously? These are questions commonly asked by farmers contemplating using fertilizers.

Instances in eastern states are often cited where it was found impossible to discontinue, without great reduction in soil productivity, the use of commercial fertilizers after they had been used for several seasons. It should be remembered in this connection that, as stated heretofore, commercial fertilizers do not supply organic matter. It is by means of organic matter in the soil that most of the plant food is liberated from season to season. When organic matter is not added, the supply of material from which plant food can be liberated from the soil itself gradually grows smaller. Under such conditions the productivity of the soil might be maintained by increasing quantities of commercial fertilizer that would supply available plant food, but should the fertilizer be discontinued, the production of the soil would suddenly decrease. This loss in yield, however, would only represent the decrease, due to the gradual exhaustion of the organic matter of the soil, that would have taken place gradually if commercial fertilizers had not been used. Commercial fertilizers are not crop stimulants—they contain nothing that can in any way injure the soil, but they cannot in themselves be expected to maintain the fertility of the soil. They should, therefore, be used only when a good rotation of crops is practiced, and when organic matter is supplied systematically.

Commercial fertilizers should be used only when necessary to supply an element of plant food that is deficient in the soil. As has already been shown, potassium is present in Kansas soils in liberal quantities. It is, therefore, very seldom that potassium can be supplied in commercial form with profit. Phosphorus and nitrogen are found in much smaller quantities, and in the more humid sections of the state may often be the limiting factors in crop yields. Nitrogen is so high in price that it is unprofitable to purchase it in large quantities. Since it can be secured from the air by leguminous plants, the deficiency of this element can best be made up in that way. Phosphorus is the one element which is deficient in the soil and for which there is no ready source of supply. It is true that the supply of phosphorus can be conserved in the surface soil by growing deep-rooted crops, by feeding on the farm the crops grown thereon, but even when these practices are followed there are soils in the state that will be greatly benefited by an added supply.

It was shown in Table III that the soils of Eastern and Southeastern Kansas have a lower phosphorus content than any others in the state. Fertilizer experiments have also demonstrated that in this section of the state, especially on residual soils derived from sandstone and shale, a commercial fertilizer supplying phosphorus can frequently be used with profit, and that such fertilizers could be used with profit much more extensively than they are used at the present time.

Figure 9 shows areas where cooperative experiments have been conducted with fertilizers on wheat and where they did and did not give paying returns.

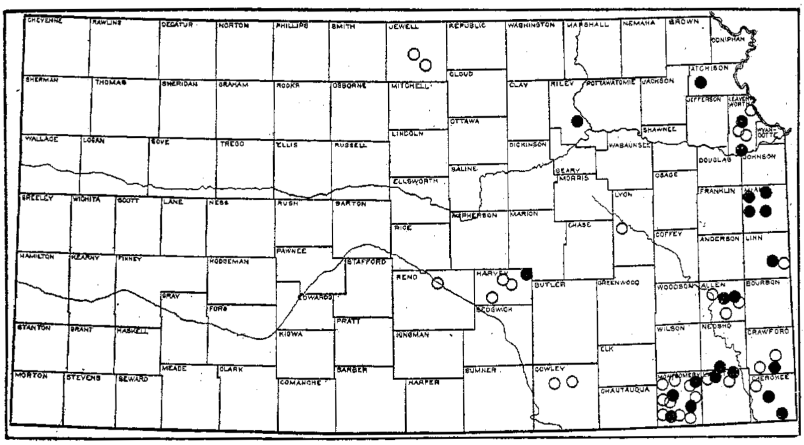

Fig. 9.—Map of Kansas showing location of cooperative experiments in which commercial fertilizers have been used on wheat. The dots represent experiments in which they were profitable, the circles experiments in which they were used at a loss

It will be seen from a study of the map that fertilizers have generally given paying returns on wheat only in the two or three eastern tiers of counties in the state. Better returns have been secured in the southern portion of this area than in the northern portion, and in the southern portion the best returns have been secured on the sandstone and shale soils.

FERTILIZERS FOR SOUTHEASTERN KANSAS

A good example of the results secured in Southeastern Kansas is shown in Table XII, which gives the results of tests conducted in Cherokee County.

TABLE XII.—RESULTS OF FERTILIZER TESTS ON SHALE SOILS IN SOUTHEASTERN KANSAS

TREATMENT	Yield of wheat per acre							
	1912	1913	1914	1915	1916	Average	Average cost of fertilizer	Value less cost of fertilizer
No treatment	10.3	5.6	16.3	2.5	6.3	8.2	$0.00	$8.20
Potassium	10.0	......	15.3	2.1	4.7	*a*8.0	1.00	7.00
Phosphorus	22.0	10.3	31.0	16.2	11.7	18.2	3.63	14.57
Potassium and phosphorus	24.3	11.8	31.0	21.7	12.3	20.2	4.63	15.57
Potassium, phosphorus, and nitrogen	16.0	13.6	32.3	23.5	13.0	19.9	5.83	14.07

(*a*) Average of four seasons only.

The test was conducted in 1912 and 1913 on the farm of O. A. Rhoades, and in 1914, 1915, and 1916 on the farm of C. W. Karsten. The soil upon which the test was conducted was the Bates silt loam, a residual soil derived from the decay of shale rock and sandstone. Five plots, differently treated, were compared in the test. On one plot potash in the form of sulphate of potassium was applied at the rate of 40 pounds per acre; on another plot phosphorus in the form of steamed bone meal was applied at the rate of 250 pounds per acre; on a third plot a combination of phosphorus and potassium was applied in the form and amount used on the plots receiving but one element; on a fourth plot nitrogen in the form of dried blood was applied at the rate of 40 pounds per acre, in addition to potassium and phosphorus; a fifth plot was unfertilized. The quantity of fertilizer applied to the acre was much heavier than is ordinarily applied in practice in this state, especially when a combination of the different elements is used. The object, however, was not to determine the proper rate of applying fertilizers, but to determine which, if any, of the elements of plant food it was profitable to supply.

The plot receiving potassium alone was, through accident, omitted in 1913. As an average of the four years in which this treatment was used, the yield of the plot receiving potassium was 8 bushels per acre, while for the same seasons the unfertilized plot produced 8.6 bushels per acre. Potassium used alone did not increase the yield of wheat, although the potassium cost on an average $1 per acre.

Phosphorus applied alone produced as an average of the five seasons 18.2 bushels per acre, while the unfertilized plot for the same seasons produced but 8.2 bushels. Thus an average application of $3.63 worth of phosphorus in the form of steamed bone meal increased the yield of wheat 10 bushels per acre. At an average price of $1 per bushel for wheat, the value of the crop, after paying for the cost of the fertilizer on the plot receiving phosphorus, would have amounted to $14.57 per acre, or $6.37 more than the unfertilized plot.

The plot on which potassium was applied in addition to phosphorus produced, as an average, 20.2 bushels per acre, 2 bushels more than the plot receiving phosphorus alone. The increased yield was a little more than sufficient to pay for the potassium applied. The plot receiving all three elements of plant food, nitrogen in addition to phosphorus and potassium, produced an average yield of 19.9 bushels per acre, slightly less than the plot receiving phosphorus and potassium only. The lower average yield was due to the poor crop produced in 1912, when the plot which received nitrogen lodged. In every other season nitrogen slightly increased the yield, but not sufficiently to pay for the cost of the nitrogen applied.

The results of this test seem to show that phosphorus is the element of plant food that is deficient in this soil. While potassium and nitrogen slightly increased the yield most seasons, the increase in yield was only about sufficient to pay for the cost of these fertilizers. It is evident that if a complete fertilizer is used on wheat on this soil, it should be very rich in phosphorus and low in both nitrogen and potassium. When the ground has been well prepared for the crop, a fertilizer supplying phosphorus only will undoubtedly be the most profitably to apply.

THE FORM OF PHOSPHORUS TO APPLY

There are a number of forms in which phosphorus can be purchased—raw bone meal, special or steamed bone meal, acid phosphate, and raw rock phosphate being the most common. Raw bone meal is made of finely pulverized bones and carries a small percent of nitrogen, while steamed or special bone meal is more finely ground and contains less nitrogen but more phosphorus. Acid phosphate may be made from bones or from phosphate rock by treating them with acid to make the plant food more readily available. Raw rock phosphate is a phosphate bearing rock that has been finely pulverized. The phosphorus in this material is not readily available, and it must, therefore, be applied in connection with manure or some other form of organic matter in order to make the phosphorus available to plants. In the few tests conducted with raw rock phosphate in this state, it has not given as promising results as other more avirailable forms of phosphatic fertilizers. The best phosphatic fertilizer to use will usually be the one in which the largest quantity of available phosphorus can be purchased for a dollar. Ordinarily this will be either acid phosphate or steamed bone meal.

THE AMOUNT OF FERTILIZER TO APPLY

In the experiment just described phosphorus was applied at a rate in excess of that which is ordinarily applied in farm practice. In order to determine the amount of fertilizer that it would pay to apply on the type of soil on which the experiment was conducted work was started in 1914 and has been continued to date on the farm of O. A. Rhoades. The same soil type on which the fertilizer tests were conducted on Mr. Rhoades' farm in 1912 and 1913 was employed.

TABLE XIII.-RATE-OF-APPLICATION TEST OF STEAMED BONE MEAL ON WHEAT

Pounds of bone meal per acre	Yield in bushels per acre					Cost of fertilizer per acre	Value of crop less cost of fertilizer (a)	Increase due to fertilizer
	1914	1915	1916	1917	Average			
No fertilizer	15.2	5.4	5.7	15.9	10.6	....	$10.60	....
60	(b)24.5	14.4	8.5	21.0	17.1	$0.87	16.23	$5.63
90	29.9	15.6	8.9	21.6	19.0	1.31	17.69	7.09
120	30.8	16.1	9.3	22.1	19.6	1.74	17.86	7.26
150	32.3	15.4	8.9	22.2	19.7	2.18	17.52	6.92
180	31.9	17.5	9.5	21.9	20.2	2.61	17.59	6.99
300	......	17.1	......	......	....	4.35	12.75	2.15

(a) Wheat valued at $1 per bushel; steamed bone valued at $29 per ton.
(b) Eighty pounds applied in 1914.

A series of plots were used on which steamed bone meal was applied on wheat at varying rates, from a check plot that received none up to a maximum application of 180 pounds per acre in each season and of 300 pounds per acre one season. The results of the test are shown in Table XIII. The average yield of wheat on the unfertilized plot was 10.6 bushels per acre; on the plot receiving a 68-pound application of steamed bone meal, 17.1 bushels per acre; on the plot receiving 120 pounds, the yield was 19.6 bushels; and on the plot receiving 180 pounds it was 20.2 bushels. The first 60 pounds of bone per acre produced an increase of 6.5 bushels; the second 60 pounds an increase of 2.5 bushels; and the third 60-pound application an increase of 0.6 bushel. While the increase in yield was sufficient to pay for the cost of the fertilizer up to and including the 180-pound application, it is doubtful if it would be good farm practice to apply more than 100 to 120 pounds per acre, and for the money invested greater returns were obtained with even smaller applications. If acid phosphate instead- of steamed bone meal is used, a larger quantity is required to supply the same amount of phosphorus.

THE CROPS TO FERTILIZE

Crops differ in their fertilizer requirements and in the way in which they respond to the application of fertilizers.

Wheat.—Wheat is usually one of the most profitable crops to fertilize because it has a high market value and therefore requires but a small increase in yield to pay for the fertilizer applied. It also grows through the season of the year when plant food is liberated from the soil in the smallest amounts, and is a crop that is benefited by a vigorous early growth.

Corn.—It seldom pays to fertilize corn, even in the section of the state where fertilizers give their best results on wheat. Corn grows through the warmest period of the year when plant food is liberated the most rapidly, and consequently has the best opportunity to secure an abundance of plant food from the soil itself. It is also a crop that should make a slow growth in the early period of its development. One of the advantages of listing corn is the slow development that listed corn makes during its early stage of growth, which results in a smaller stalk and a larger root development in proportion to the leaf area. Commercial fertilizer applied before or at the time of planting corn produces a more rapid early growth of the plant and makes it less able to withstand periods of dry weather to which it is likely to be subjected later in the season. Thus in dry, unfavorable seasons commercial fertilizer may actually reduce the yield of grain.

Kafir.—All sorghum crops naturally make a very slow early, growth. They are not as easily injured by dry weather as corn and require a longer time than corn to mature. Anything that hastens their early growth is usually beneficial, consequently commercial fertilizer often gives paying returns on kafir and other sorghums, and frequently increases the growth of kafir sufficiently to mature the crop under conditions where it would otherwise fail to mature.

Alfalfa, Clover, and Grass.—Forage crops respond readily to applications of fertilizer. Commercial fertilizer applied to wheat with which clover and timothy is seeded is frequently as valuable for the grass crops seeded with the wheat as for the wheat itself. An application of fertilizer is often the deciding factor in securing a stand of grass on those soils in the eastern part of the state. Commercial fertilizer can often be used with profit at the time of seeding alfalfa on the thinner types of soil in Eastern Kansas. It is not as satisfactory for this purpose as barnyard manure, but where manure is not available it may be used in the place of manure.

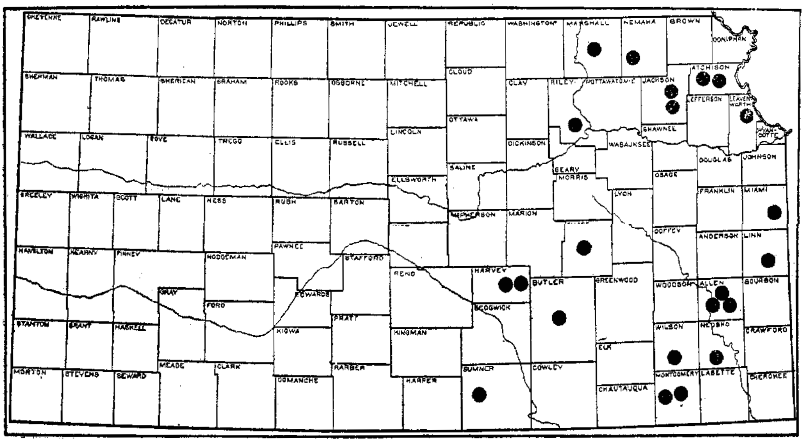

Fig. 10.—Map of Kansas showing location of cooperative experiments in which phosphorus has increased the yield of alfalfa

Commercial fertilizers, especially those high in phosphorus, such as steamed bone meal and acid phosphate, are often as profitable to use on old stands of alfalfa as barnyard manure. (Fig, 10.) This is particularly the case on farms where manure is not abundant. On such farms it is more profitable to apply the small amount of manure produced on the farm to the cultivated crops such as corn and wheat, and to purchase a phosphatic fertilizer for the alfalfa.

Old alfalfa secures from the air the nitrogen it needs for growth, potassium is secured by it in abundance from the soil, and it is not benefited by the organic matter supplied in the manure to the extent that cultivated crops like corn, kafir, and wheat are benefited. It is also difficult to prevent grass and.weeds starting in old alfalfa fields that are manured, because most manure contains seeds of these plants. For these reasons it has been found in Eastern Kansas that phosphatic fertilizer can be used very satisfactorily in place of manure for fertilizing alfalfa.

LIME

Lime is not a fertilizer in the same sense as are the substances that have been discussed as commercial fertilizers. While it is an indispensable element in plant tissue, it is generally present in all cultivated soils in sufficient quantity to supply fully the needs of the plant. Yet even where this is the case, the soil may be greatly in need of liming. Lime is used, therefore, as a soil amendment not so much for its effect directly on the plant as for its effect on the soil which indirectly affects the plant. Soils that are low in lime are said to be sour. This means that they give an acid reaction. Plants differ in their ability to grow in sour soils. Some plants, such as corn, wheat, timothy, and oats, are affected but little by soil acidity. Other plants, such as clover, alfalfa, and sweet clover, are very sensitive to acid conditions, and either fail to grow or make an unsatisfactory growth.

The soils of Kansas vary greatly in their content of lime. Those in the western part of the state, where rainfall is light and where there has not been much leaching, have a very high lime content.

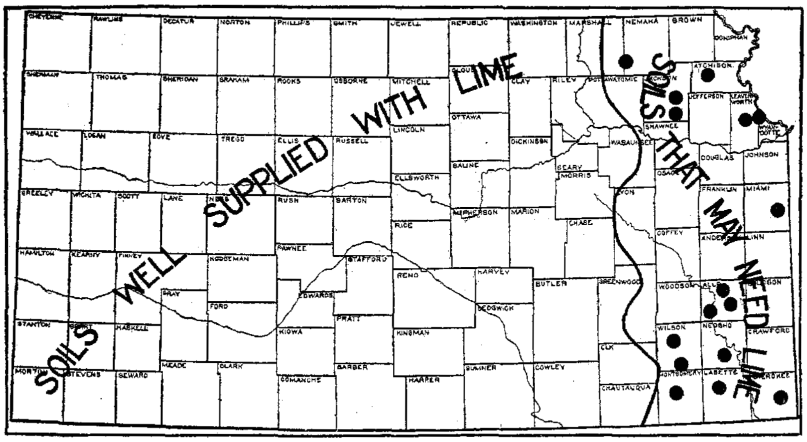

Fig. 11.—Map of Kansas showing the portion of the state that is well supplied with lime, and the portion in which it may be necessary to apply lime. The dots represent cooperative experiments in which applications of lime have increased the yield of alfalfa or clover

In Eastern Kansas, where the rainfall is high, much more leaching has occurred and acid soils have developed. (Fig. 11.) As is to be expected, the acid soil is the most common where the rainfall is the heaviest and where the soil has been formed from sandstone and shale rocks. Not all the soils in the area where lime is generally deficient are in need of lime. Some soils, especially those formed from limestone, have sufficient lime for the present needs of all crops. There may also be areas west of the area indicated on the map as needing lime where lime will be needed for alfalfa. But such areas will be rare and of limited extent, consisting largely of sandy soil or soil that has been subjected to excessive leaching.

FORM OF LIME TO USE

There are several forms in which lime may be purchased for agricultural purposes. The chief of these are ground lime rock or crushed limestone, quick or burned lime, hydrated lime, and air-slaked lime.

Most lime comes originally from limestone rock and is known chemically as carbonate of lime. The active element in this material is calcium. The composition of limestone is usually expressed as calcium oxide. Pure limestone contains approximately 56 percent of calcium oxide. Limestone rock is sometimes finely ground and used for liming soils. In this form it is known as ground lime rock or crushed limestone. The value of ground lime rock depends upon its fineness—the finer it is ground the more valuable it becomes. This form of lime has also been recommended because it has no injurious effect on the soil as is the case with some other forms.

Quick lime or burned lime is in the form of calcium oxide and is often called caustic lime. It is made by burning limestone to a red heat. This is the most active form of lime andshould not be applied to the soil without being slaked, as it will tend to destroy the organic matter. As much calcium oxide is contained in 100 pounds of quick lime as in 178 pounds of pure limestone.

Hydrated lime is quick lime to which water has been added. The water and calcium oxide combine chemically and slaked lime or hydrated lime results. If the proper amount of water is added the hydrated lime will be a fine, dry powder. As much calcium oxide is contained in 100 pounds of quick lime as in 132 pounds of hydrated lime.

Air-slaked lime is formed when caustic lime is exposed to the air, because carbonic acid is absorbed from the atmosphere. Air-slaked lime is usually very fine and is not injurious to the soil.

The kind of lime to use is usually that which is cheapest. In Kansas, ground or crushed limestone is usually the least expensive to apply. It can be obtained at reasonably low rates from several companies[1] in the eastern part of the state.

THE QUANTITY OF LIME TO APPLY

On most soils that are in need of lime at least 2 tons of ground limestone to the acre should be used at the first application, to be followed by an application of 1 to 2 tons once in a rotation of five to six years. It may be necessary to make the first application heavier than this on soils that are very acid and on which alfalfa or clover is to be grown. If burned lime or quick lime is to be used the application should be about one-half that required when crushed limestone is used.

TIME AND METHOD OF APPLICATION

The time to apply lime depends somewhat on the farming system, but, as a rule, it is best to make the application on plowed soil so that it can be worked into the soil thoroughly without plowing under. Although autumn is the best time to make the application, there is no serious objection to applying lime at any time when the soil is not occupied by a crop. If a field requiring lime is to be seeded to alfalfa or clover the application should be made six months or a year before seeding the crop, in order that the lime may have time to become thoroughly incorporated with the soil and correct the acid condition.

Lime may be scattered over the surface of the soil by the use of a lime spreader[2] or by hand from a wagon. The first method is preferable, as the lime may be applied more evenly in this way.

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1. The names of companies having lime for sale will be furnished on application to the Department of Agronomy, Agricultural Experiment Station, Manhattan, Kan.

2. Lime spreaders are manufactured by the following companies:
   Peoria Drill Company, Peoria, Ill.
   Empire Drill Company, Shotsville, N. Y.
   International Harvester Company, Chicago, Ill.
   Champion Drill Company, Avon, N. Y.
   Crown Manufacturing Company, Phelps, N. Y.
   Sterling Manufacturing Company, Sterling, Ill.
   Keystone Farm Machine Company, York, Pa.
   Parlin & Orendorff Plow Company, Kansas City, Mo