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KANSAS STATE COLLEGE OF AGRICULTURE
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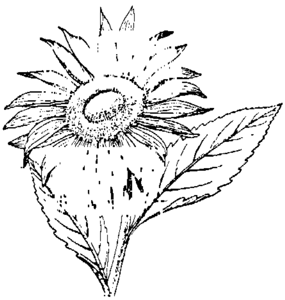
MANHATTAN, KANSAS

SOIL FERTILITY



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SOIL FERTILITY[1]

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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 the prairies were returned to the soil. This action built up a high content of organic matter and liberated plant nutrients. After the prairie sod was broken the productivity of the soil gradually decreased, because the supply of organic matter in which much of the available plant-food material is held was destroyed by cultivation. Erosion has been an important factor in many parts of the state in removing much of this organic matter as well as the fine silt particles of the surface soil. Little effort has been made to restore to the soil that which has been lost during the last fifty or sixty years. The system of farming, since the settlement of the state, has been a system of taking from the soil all that it would give and in most cases of returning little or nothing to help maintain the fertility. Most of the soils have been handled as though they were to be used for only a short period of time to supply food for mankind and little thought has been given to the condition in which they will be left to the next generation.

The soil is the most important source of wealth in an agricultural state. Its maintenance in a high state of productivity by good methods of soil management is essential to prosperity. If its fertility is wasted through poor methods of farming, the farmer, his community, and the state suffer.

It is important to become familiar with some of the more important groups of soils in Kansas, in order to understand better the methods of treatment that may be used in maintaining fertility under different conditions.

KANSAS SOILS

The soils of Kansas are so variable in age, origin, characteristics, requirements, and crop adaptation that a brief discussion of some major subdivisions will be helpful in understanding the problems in different parts of the state. The soil map of Kansas (fig. 1) shows the more important groups of soils. The areas indicated on this map must not be considered as having fixed boundaries, because the areas overlap somewhat. The soils within a given area are variable and the scale on which the map is made is so small that only the larger areas can be indicated. Because of the small scale, the bottom land or alluvial soils have not been outlined. Some of the more important soil regions of the state are the following:

1. Contribution No. 217 from the Department of Agronomy.

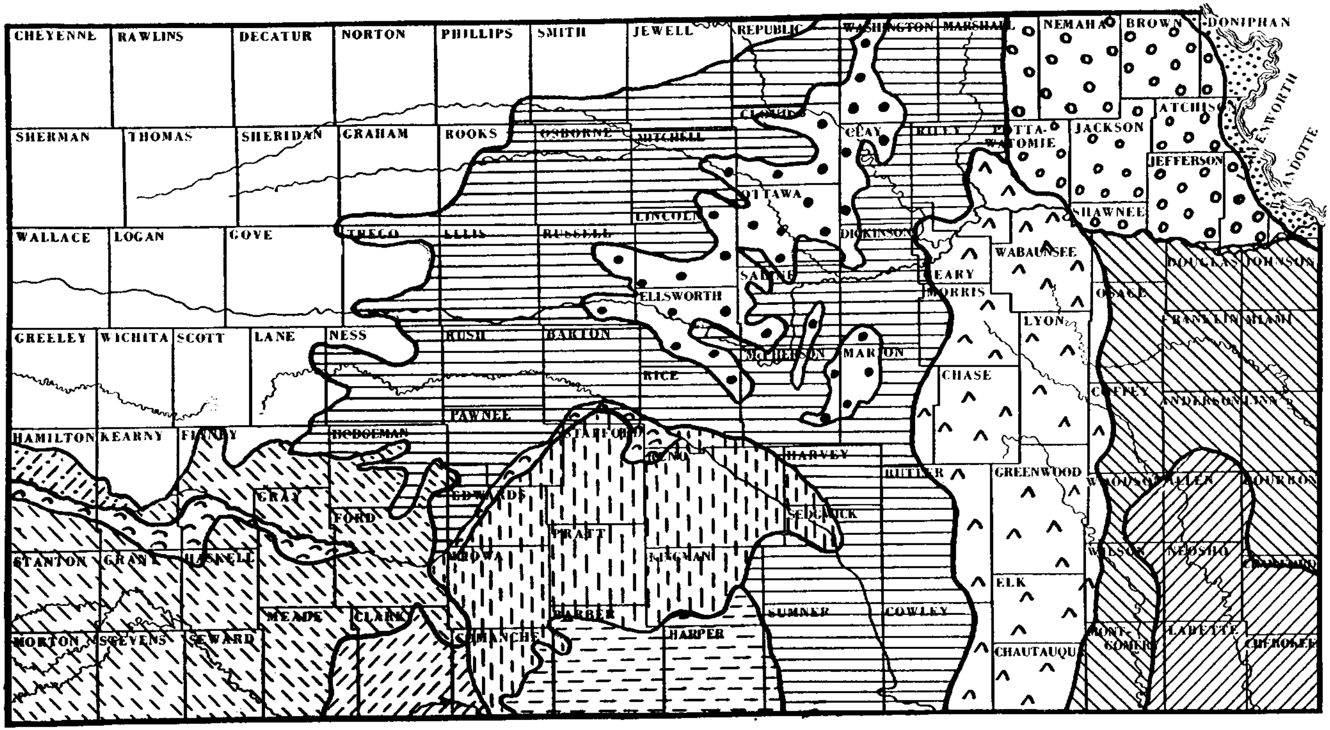
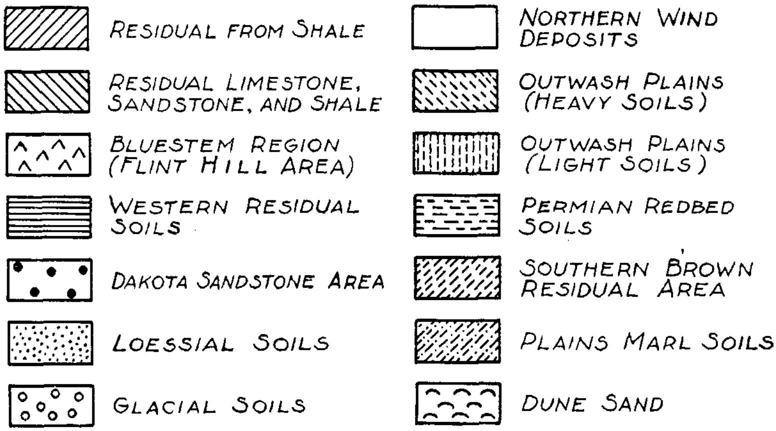


FIG. 1.—Map showing the more important soil regions of Kansas. (Key on opposite page.)



KEY TO SOIL REGIONS SHOWN IN FIGURE 1.

1. Residual Soils from Shale.--This area comprises mainly the soils of southeastern Kansas which are typically fairly old soils and have a distinct clay pan development in many places which occurs at depths varying from 6 to 18 inches. (Fig. 2.) The topography varies from level to gently rolling. Both surface and subsoil drainage are poor, especially on the more level areas. Most of these soils are gray to light brown in color. They have been subjected to leaching, and have therefore become low in lime and organic matter. They are also naturally low in phosphorus, and in most cases in nitrogen. There are, of course, areas of limestone and sandstone soils within the boundaries of this region, Some of these soils have more rolling topography, the soil layers are less badly leached, and the soils are better drained and more productive.

2. Residual Soils from Limestone, Sandstone, and Shale.-- The soils of this region comprise the upland group of east central Kansas. They vary in topography from level to rolling or gently hilly. They are relatively mature soils and have heavy clay subsoils except on the more rolling or hilly phases. In those portions of the region where limestone predominates, the topography is usually broken and limestone occurs near the surface. Large areas of this type are found in Bourbon county. In other areas, as in sections of Woodson, Wilson, and Montgomery counties, sandstone predominates in the parent material, and the soils are relatively low in fertility. The more broken areas in this particular section are limited to grazing and to a relatively scant growth of scrub oak. In the less broken areas the soils have been leached to such an extent that they are low in lime, organic matter, and nitrogen. Most of them are also low in phosphorus.

FIG. 2.—Soil profile of Cherokee silt loam. This is a level prairie type of soil and has a very tight clay pan layer in the subsoil.

3. Bluestem Region.--This region is perhaps more commonly known as the "Flint Hill" area of the state. The soils have been formed largely from limestone and are typically shallow. The topography varies from rolling to hilly. In local areas the soils are relatively level and well adapted to general farm crops. The region as a whole is adapted to the production of bluestem grasses which are used primarily for grazing purposes. The valleys throughout this region are fertile and capable of producing high yields of feed crops.

4. Western Residual Soils.--This region comprises the great general farm area throughout central Kansas. The soils have been formed from limestone, sandstone, and shale with limestone predominating in most of the area. Clay pans are not commonly developed in the soils of this region, because they are not so old as the soils farther east. The topography varies from level to rolling with occasional hills adjacent to the larger streams. The soils are typically rather deep and have a wide adaptation to general farm crops in so far as climatic conditions will permit. The more rolling of these soils have been severely injured by erosion and are deficient in nitrogen and organic matter. Lime and phosphorus are becoming deficient in many of the soils in the eastern part of the region.

5. Dakota Sandstone Area.--This region comprises those soils of central and north central Kansas that have been formed from Dakota sandstone. Most of them are relatively shallow, subject to erosion, and relatively low in plant-food materials. The topography varies from rolling to hilly. Although some of these soils are well adapted to general farm crops, the major portion of the area is suitable only for grazing purposes, partly because of the topography and low nutrient content of the soils, and also because of the droughty nature of the soils.

6. Loessial Soils.--The wind-deposited soils comprising the bluffs adjacent to the Missouri river valley are classed as brown loess. (Fig. 3, A.) These soils probably represent glacial material which has been reworked by the action of wind. They are typically deep, and have an open subsoil which permits of deep penetration of water and roots. The fertility is fairly high except in those areas where erosion has removed the surface soil. The topography varies from rolling to distinctly hilly. These soils are extremely subject to erosion and in some areas as much as 18 inches of the soil has been removed by the action of water since the land has been under cultivation. Because of the topographic features, the open subsoil, and general fertility of these soils, they are well adapted to the production of apples and other fruits, including the small fruits. Where topographic conditions permit they are adapted to corn, alfalfa, and other general farm crops. Farther back from the river the topography is less rugged and the dark surface soil is deeper. These soils form some of the most productive upland in the state. (Fig. 3, B.)

7. Glacial Soils.--These soils occupy most of the area of northeastern Kansas exclusive of the loessial region. They are variable in all features, but it is seldom that clay-pan horizons are found within this area. Along the southern and western margins, the topography is more broken, the soils are lighter in color, and lower in fertility. These soils are extremely subject to erosion, and in many cases fields have been practically ruined by gullies and sheet

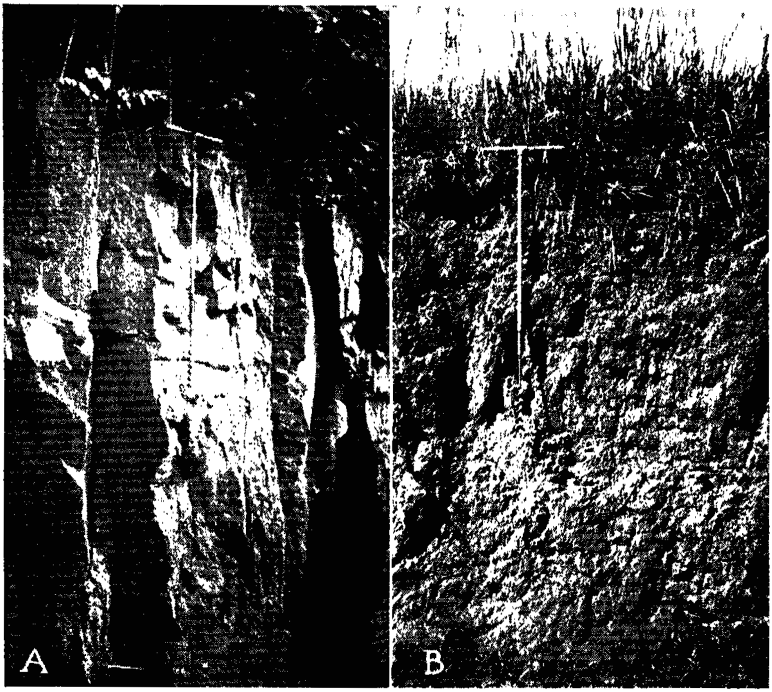


FIG. 3.—(A) Soil profile in brown loess. Note the uniform structure throughout the entire depth. Standing in vertical banks is characteristic of this soil. Because of the deep uniform condition it is well adapted to fruit trees.

(B) Marshall silt loam in northeastern Kansas. Note the deep, dark surface layer, and friable subsoil. This is one of the best upland corn soils in the corn belt.

erosion. If properly managed, they are productive, and are adapted to general farm crops, and in some sections to the production of apples. They are typically low in lime and phosphorus, and in the eroded areas organic matter and nitrogen are also deficient. Farther north in this area, as in sections of Brown, Doniphan, Atchison, Nemaha, and northern Jackson counties, where the topography is not so broken, the soils are darker in color and are much higher in plant-food materials. These darker soils are well adapted to the production of general farm crops and particularly to alfalfa and corn. These darker glacial soils are among the best of the upland soils in eastern Kansas.

8. Northern Wind Deposits.--The soils of northwestern Kansas comprise a great area of soils that have been formed from wind-deposited material. Except in the vicinity of streams, these soils are level to rolling, and are easily cultivated with power machinery. These soils are relatively young, do not have a clay-pan development, and have subsoils which are sufficiently open to a great depth. (Fig. 4.) These soils are high in plant-food materials, and when properly managed will successfully produce all general farm crops in so far as rainfall conditions will permit. There are many areas within this region adjacent to the streams where the wind-laid soils

FIG. 4.—Colby silt loam, northwestern Kansas. Note lime accumulations in subsoil. This is characteristic of soils developing under conditions of limited rainfall.

have been eroded away, the underlying rocks exposed, and residual soils formed. These wind-deposited soils are subject to erosion by both wind and water, and therefore must be handled with considerable care. There are many fairly large areas of these soils in the north central part of the state that have been severely injured by water erosion. There are also areas in the western section where erosion by wind has caused much damage.

9. Out wash Plains (Heavy Soils).--These heavier soils in the outwash plains group, comprising the southwest corner of the state, have been formed from a mixture of outwash material and the weathering of Plains marl. Where the marl is too close to the surface, the soils are not productive. Such areas, however, are not common except in the general vicinity of streams where erosion has removed much of the outwash material. These soils do not have a clay-pan development, but do have a deep subsoil which permits of deep penetration of moisture and plant roots. They have a high content of all plant-food materials, are never acid, but have occasional alkali spots which are not generally sufficiently extensive to become serious. Because of the relatively heavy surface-soil material, this area is well adapted to the production of wheat in so far as rainfall permits. These are the soils on which there has been an extensive expansion of the wheat industry during the last few years.

10. Out wash Plains (Light Soils).--These soils are of much the same origin as the heavy outwash soils, but occur farther east, have been weathered to a greater extent,, and are much more sandy in nature. They typically belong to the loam and sandy loam groups with occasional areas of sand. They have an open subsoil to a considerable depth, and are well adapted to general farm crops except where the sand content is too high. There are many local areas throughout this region where the soils are subject to blowing. These soils vary from acid to neutral in reaction. Some of them, as in sections of Reno, Harvey, Sedgwick, and Kingman counties, require lime for the best production of alfalfa and sweet clover. They are also becoming low in phosphorus, and in many areas the organic content has become deficient. The topography of these soils varies from level to gently rolling. Crop adaptation includes all general farm crops, but the region as a whole is adapted to the sorghums, corn, and alfalfa, rather than to wheat, to which the heavier soils of the same origin are better adapted.

11. Permian Redbed Soils.--These soils are representative of south central Kansas and have been formed from the weathering of Permian redbed materials. They vary from fairly fertile areas adapted to the production of wheat and other general farm crops, to sharply broken areas as in Barber county that are of very limited value, even for grazing purposes. They are subject to erosion, and where erosion has progressed to any great extent the soils are becoming deficient in organic matter, nitrogen, and available phosphorus. Many of the soils of this area require special attention to increasing the organic matter and preventing soil erosion.

12. Southern Brown Residual Area.--Most of the soils of this group occur in Clark county, are relatively level, fairly high in plant nutrients, and well adapted to the production of wheat and the sorghums. There are some shallow-water areas within the region where irrigation may be practiced. The more broken areas are suitable only for grazing purposes. There are also a few areas of sand dunes in the southern part of the region.

13. Plains Marl Soils.--These soils represent a long, narrow strip occupying the bluff north of the Arkansas river valley extending from the Colorado line east to Ford county. The band is narrow except in Hamilton and Kearny counties. The soils have been formed from the weathering of Plains marl, are typically droughty, shallow, and not well adapted to the production of cultivated crops. They are limited in value, even for grazing purposes.

14. Dune Sand.--The major area of dune sand occurs south of the Arkansas river from Ford county west, and in the Great Bend region. There are, however, many local areas of sand dunes throughout the entire southwestern portion of the state and extending as far east as Harvey and Reno counties. The sand dunes are naturally limited primarily to grazing purposes.

15. Bottom Land or Alluvial Soils.--The bottom land or alluvial soils comprise the areas that are subject to either frequent or occasional overflow. They make up an important group of soils that have a high agricultural value. These soils may best be described by their location as related to certain streams or sections of the state, but they have not been indicated on the map in figure 1.

The alluvial soils of southeastern and east central Kansas are typically heavy, dark in color, subject to frequent overflow, and poorly drained. On the higher areas and where protected from overflow, they have a fairly high productive capacity. Many large sections of these soils will be of limited value until they can be protected from overflow and are tile drained.

Along the streams of northeast Kansas the soils are subject to frequent overflow but otherwise they are productive. Drainage is poor in local areas, but most of these conditions could be improved by the use of open ditches.

The soils of the valley of the Kaw river and its larger tributaries comprise an important agricultural section. They vary from almost pure sands to heavy clays, but the loams and sandy loams predominate, thus giving good drainage. All general farm crops, in so far as climatic conditions will permit, are adapted to these soils. They also make up an important potato, truck, and nursery-stock section.

The valleys of the Arkansas and Cimarron rivers and their tributaries have soils that vary from some of the most productive areas of the state to areas that are practically barren. In some sections the valleys are broad, relatively high, and the soils are excellent loams and sandy loams. In other sections the water is practically at the surface of the land or within 2 or 3 feet of the surface. There are also local areas where alkali salts have accumulated to such an extent as to make the soils practically worthless. The soils of this region have an underlying bed of water-bearing sand and gravel at depths varying from 8 to 15 feet except on the shallow-water areas mentioned above. This water supply makes irrigation by pumping practical on many of the better soils along these streams, except perhaps in the eastern portion where the rainfall is heavier.

The bottom-land soils along the streams of central, north central, and northwestern Kansas are in general high above the stream bed and subject to only occasional overflow. They are deep, well-drained, high in plant-food materials, and offer an excellent reservoir for the storing of soil moisture. These soils are limited in their crop-producing capacity only by the amount of rainfall received.

TRENDS OF FERTILITY AND CROP YIELDS

That crop yields in Kansas have decreased materially since the state was settled is illustrated by the change which has taken place in the average yields of corn. (Fig. 5.)

The acre yield of corn has decreased rapidly during the past 60 years. There has also been a marked decline in the average yield of oats and wheat. The yield of corn has decreased consistently from 33.6 bushels per acre for the first 10-year period, 1865 to 1874, to 18.4 bushels for the 10-year period ending in 1924. This reduction in yield has taken place regardless of the fact that the varieties of corn grown during the last 30 years have been better adapted to the climatic conditions of the state than those grown during the first 30 years of the period.

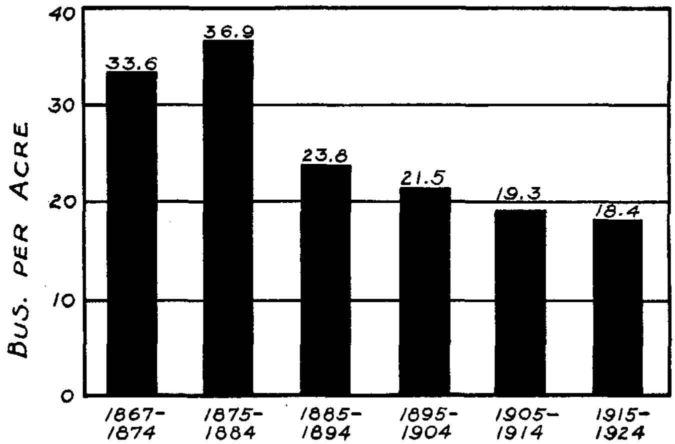


FIG. 5.—The average corn yields in Kansas by ten-year periods, 1865-1924.

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 that is not so well adapted to corn. A study of the acre yield of corn in eastern Kansas, however, shows that the decrease has been even more rapid in this section than for the state as a whole.

The decline in corn yields in Kansas correlates closely with the decline in nitrogen and organic matter in the soil. Table I gives the differences in nitrogen and organic matter of soils left in native sod as compared with the same kind of adjoining soils that have been under cultivation for several years. It will be seen from this table that soils which have been cultivated for about 30 years have lost from 25 to 30 per cent of their nitrogen and from 30 to 35 per cent of their organic matter. 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.

TABLE I.—DECREASE IN NITROGEN AND ORGANIC MATTER IN KANSAS SOILS DUE TO CULTIVATION. (a)

County and Soil Type.	Cropping system.	Pounds per acre.	
		Nitrogen.	Organic matter.
Riley, Oswego silt loam	Native meadow	4,980	122,400
	Wheat and corn 30 years	3,700	85,600
Brown, Marshall silt loam	Native meadow	5,480	139,200
	Average of six cultivated soils (corn, oats, and wheat)	4,240	106,800
Russell, Sedgwick clay loam	Native buffalo pasture	4,260	98,400
	Wheat 30 years	2,960	64,400
Allen, Oswego fine sandy loam	Native meadow	3,760	83,600
	Corn and broom corn	2,440	46,400
Butler, Sedgwick clay loam	Native pasture	4,280	106,400
	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
Average	Native	4,495	108,050
	Cultivated	3,108	69,500

(a) 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.

COMPOSITION OF THE SOIL

The soil is composed of broken and weathered pieces of rocks and minerals, together with varying amounts of decaying organic matter of both animal and vegetable origin. It is inhabited by great numbers of very small living organisms.

The soil is a complex mixture of material, which does not remain constant in composition for any length of time. Chemical changes are brought about by the products of decay, the action of water, oxygen, carbon dioxide, and various climatic changes. The work of microorganisms of both plant and animal types aids in bringing about, many of these changes. Changes are constantly taking place which affect the size, distribution, and arrangement of the soil particles. These facts make it possible to discuss the composition of the soil under three general heads, physical, chemical, and biological,

PHYSICAL COMPOSITION OF THE SOIL

Whenever a soil is examined, one of its most obvious characteristics is that it is made up of particles of different sizes. If the particles are coarse the soil is sandy, if very fine and sticky, the soil is called clay, while the particles intermediate in size are called silt.

In field soils the particles are never all of the same size, but usually vary in a given soil from gravel or sand to the very finest clay. Soils, therefore, are named upon the basis of the relative

FIG. 6.—Soils that contain much fine clay or colloidal material shrink upon drying. This causes the soil to crack. Cracking may occur at the surface as shown here, or it may occur in heavy clay layers in the subsoil.

amounts of coarse and fine particlee. Soils containing considerable amounts of all three grades of material, sand, silt, and clay, are called loam soils. If there is a slight preponderance of sand particles, it is designated as a sandy loam, or fine sandy loam if the sand grains are relatively small in size. If silt predominates, the soil is a silt loam. It is to this class that the greater number of agricultural soils belong. Soils having large amounts of clay are called clay loams, or soils like "gumbo" lands which are almost wholly made up of fine and very fine particles are called clap soils.

The very finest clay particles make up what is known as the "colloidal" material in the soil. This is the material which makes soils sticky, and may make up a considerable proportion of the soil. Cultivated soils range from about 5 to 60 per cent of material in the colloidal state.

When the soil is wet this colloidal material swells, making heavy soils very impervious to water or air. On the other hand, when soils become dry the colloidal material shrinks, pulling soils apart and forming the large cracks so common in many soils during dry weather. (Fig. 6.) It is also the cause of the formation of hard clods. Sandy soils do not exhibit these characteristics because they contain so little colloidal material.

After their formation from the decay of rocks, or after being deposited by wind or water, soils gradually undergo further development. The surface soil and subsoil become differentiated. Organic matter accumulates in the upper layers. Drainage water passing down through the soil carries the fine particles with it. These may accumulate in a layer or zone several inches below the surface, forming a heavy layer or clay pan. In this process soluble material is constantly being leached from the soil near the surface, which often may give the material a grayish appearance, particularly on level prairie lands where not much of the water runs off. Soils which have undergone these stages of development giving them a characteristic and well-defined profile, as those of eastern Kansas, are said to be mature or even old soils. Soils which have been subject to much leaching are usually lower in fertility than younger soils or those formed from more recent deposits and that have not yet developed characteristic zones in the soil profiles. In regions of relatively low rainfall accumulations of lime are often found in the upper subsoil. Where the rainfall is heavier the lime accumulation, if present, will be deeper.

CHEMICAL C0MPOSITION OF THE SOIL

Soil material may be divided chemically into two classes: (1) The inorganic compounds that are derived from the breaking down of rocks and minerals, and (2) the organic compounds that are derived from animal and vegetable materials present in the soil in varying stages of decay.

Of the inorganic constituents silica is the most abundant. It makes up most of the sand particles and enters into the composition of many of the soil-forming minerals. Other important soil-forming minerals are feldspar and iron. Upon weathering the feldspar forms much of the clay portion of the soil. The oxides of iron make up a considerable part of the soil and greatly affect the color of the soil and particularly the subsoil, giving the yellow, brown, and reddish colors. There are numerous other minerals that occur in the soil and supply various plant nutrients required by crops.

There are ten chemical elements that have been found to be necessary for the growth of plants. These are:

Hydrogen, Oxygen	Derived from water.
Carbon	Derived from carbon dioxide of air.
Nitrogen, Phosphorus, Calcium, Magnesium, Sulphur, Potassium, Iron	Derived from soil. (The nitrogen was originally from air, and some is utilized directly by legumes, through the activity of bacteria on the roots.)

It is now thought that in addition to these, very small amounts of manganese, boron, silica, and possibly other elements are beneficial to plant growth.

Almost all soils contain sufficient quantities of some of these elements to supply the needs of plants. Many soils, however, are deficient in one or more of the following: Nitrogen, phosphorus, potassium, and calcium.

PLANT-FOOD ELEMENTS IN KANSAS SOILS

Chemical analyses have been made of soils from various parts of Kansas[2] and the analyses of a few soils are given in Table II.

TABLE II.—QUANTITY OF PLANT-FOOD MATERIALS IN THE SURFACE 7-INCH LAYER OF TYPICAL KANSAS SOILS COMPARED WITH THE AMOUNTS CONSIDERED DESIRABLE FOR A VERY FERTILE SOIL.

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

2. Swanson, C. O. Chemical analyses of some Kansas soils. Kan. Agr. Expt. Sta. Bul. 199:633-715. 1914.

This table indicates that in general Kansas soils are low in nitrogen and phosphorus as compared with a very fertile soil. Most of them are high in potassium, while the calcium content varies widely. The practical management of these lands must take these factors into account if crops are to be produced most satisfactorily. It must be remembered, however, that the total plant-food content of a soil does not give complete proof of its crop-producing capacity.

AVAILABLE AND UNAVAILABLE MATERIAL FOR PLANTS

Plants take up food material from the soil for the most part after it has been dissolved in the soil water. Of the total amounts shown in Table II, only a small percentage of any of these elements is in solution at a given time. Crop growth, therefore, depends upon the amounts of the elements that are soluble or that may become soluble, rather than the total amount present in the soil. For this reason well-handled soils, even though they may be low in total fertility, sometimes produce as good crops as other soils with more total plant-food materials, but which have less of them in an available form.

In order to produce good crops, particularly on thin soils, it is necessary to give special attention to providing a supply of available plant-food material for each crop. This must be provided at such time that it will be available when needed by the growing crop. Plants absorb large amounts of most of the plant-food elements during the early stages of growth. It is therefore advisable to make sure of a supply of available plant food at the time of seeding or shortly thereafter.

CHEMICAL ANALYSIS OF THE SOIL

A chemical analysis of a soil is useful in determining the total amounts of the various essential elements that are present. It thus gives an idea of the total potential fertility of one soil as compared with another. Such an analysis for specific types of soil or for the soils of a given region is of much value in determining what general systems of soil management or soil treatment should be followed.

On the other hand, there has been a somewhat general idea that if a chemical analysis of a soil were made the fertilizer requirements of that soil and its crop adaptation could readily be determined. Many attempts have been made to determine by chemical tests the available nutrients and hence the fertilizer requirements of a soil. Some tests are in use which give some information regarding the need for phosphorus and lime, and a careful observation of conditions may reveal the need for nitrogen, but none of these tests is absolutely reliable in all cases.

Owing to the fact that a chemical analysis usually includes a determination of total elements present, it does not give the amounts of plant-food materials the plants will be able to obtain from the soil. Since it is not possible to determine the rate at which the plant-food elements will be made available, it is impossible from the chemical analysis of the total plant food to determine the kind or how much of a given fertilizer should be added unless there is an obvious deficiency even in the total amount of an element present. In addition to this the physical and chemical properties of a soil, particularly its acidity, as well as its supply of microorganisms and also the climatic factors, will greatly alter the supply of available plant-food material during a given season. These factors combine to limit the practical application of a soil analysis.

It should be said here, however, that it is often possible for the Agricultural Experiment Station to give farmers much valuable information regarding the use of fertilizers or the kind of crops to be grown. This advice is based not only upon a chemical examination of the soil and an examination of its texture, but also upon the results of field experiments that may have been carried out on the same or similar soil types in the region under consideration.

BIOLOGICAL INHABITANTS OF THE SOIL

The soil may have the appearance of an inert lifeless material. Instead of being in this condition it is inhabited with myriads of plant and animal forms which can be seen only with the aid of a powerful microscope. The most important of these soil organisms seem to be the bacteria and fungi. The organisms bring about many important reactions of the soil, such as decay, oxidation, nitrification, and nitrogen-fixation. Their activities are not all beneficial, for certain groups may bring about denitrification and others may cause plant diseases.

In addition to the microscopic forms of life in the soil there exists a host of larger forms which materially affect the fertility. Many insects live in the soil or pass certain stages of their life cycle below the surface of the ground. These often may be harmful to crops, but their burrowing in the soil has a beneficial effect upon its tilth. Earthworms work over the soil a great deal and not only affect the tilth, but the openings which they make allow greater penetration of the rainfall and air. Crawfish, gophers, moles, squirrels, and many other animals greatly affect the condition of the soil when all their activities are considered.

HOW SOILS LOSE FERTILITY

When soils are broken out of native sod or timber land and planted to cultivated crops they usually decrease in fertility rapidly. This loss is due to (1) removal of plant food in the crops, (2) loss of soil by erosion, (3) removal of soluble material through leaching, and (4) loss of particles by blowing.

LOSS THROUGH CROPS

When crops or live stock are sold from the land, large quantities of plant food may be taken from the farm. This is one of the important ways by which the fertility of soils has been reduced. The approximate amounts of the different plant-food elements contained in various farm products are shown in Table III. It will be seen from this table that the grains are relatively high in nitrogen and phosphorus, while the straw or stover is relatively high in potassium and calcium.

TABLE III.—AMOUNTS OF VARIOUS PLANT-FOOD ELEMENTS CONTAINED IN CROPS AND IN ANIMAL PRODUCTS.

CROP AND ANIMAL PRODUCTS.	Pounds of plant-food elements.			
	Nitrogen.	Phosphorus.	Potassium.	Calcium.
Corn, grain, 50 bus	50.0	9.5	9.0	0.5
Corn stover, 1.75 T	28.0	3.5	30.3	10.0
Oats, grain, 40 bus	24.0	4.0	4.6	.8
Oats, straw, 1.2 T	14.2	1.8	24.0	7.2
Wheat, grain, 25 bus	30.0	3.7	6.6	.5
Wheat, straw, 1 T	10.0	2.0	18.3	4.0
Alfalfa, hay, 4 T	200.0	18.0	96.0	145.0
Sweet clover, 2.5 T	113.5	9.5	96.0	52.6
Red or alsike clover, 2 T	80.0	10.0	60.0	58.0
Soy beans, grain, 10 bus	31.0	5.2	10.0	.7
Soy beans, hay, 2 T	106.0	14.0	49.0	....
Sorghum, kafir, grain, 40 bus	37.5	12.0	6.5	1.1
Sorghum, stover, 3 T	49.2	16.2	20.6	....
Potatoes, tubers, 100 bus	21.0	4.3	30.0	1.2
Apples, 300 bus	23.5	2.5	28.5	1.6
Fat cattle, 1,000 lbs	25.0	7.0	1.0	11.8
Fat hogs, 1,000 lbs	18.0	3.0	1.0	4.5
Milk, 1,000 lbs	5.1	1.9	1.8	1.3
Butter fat, 1,000 lbs	1.2	.4	.4	.2

The legume hays contain large quantities of all the plant-food elements. When such crops are sold from the farm, the mineral fertility elements are removed at a rapid rate. However, the nitrogen of legumes is taken from the air by the plants and the amount of this element in such crops is therefore not lost from the soil. It should be remembered, however, that legumes must be inoculated or they do not take nitrogen from the air, but really draw upon the soil nitrogen under such conditions.

It may also be noted that in the sale of live stock considerable quantities of fertility are removed. The carcass of a 1,000-pound steer would contain approximately the same amount of plant-food material as 40 bushels of oats. In the sale of milk or butter fat, very little soil fertility is removed.

SOil EROSION BY WATER

One of the most important sources of loss of fertility from cropped land has been through the soil's being carried away by water. Many of the older soils of the world have been almost devastated by this process. The results of experiments carried on in recent years show that the loss may be extremely rapid from cultivated land. (Fig. 7.) In the humid sections of the country practically every hillside affords an example of this destructiveness of soil erosion. It is undoubtedly depleting the fertility of rolling land at a more rapid rate than is the removal of crops or other farm products.

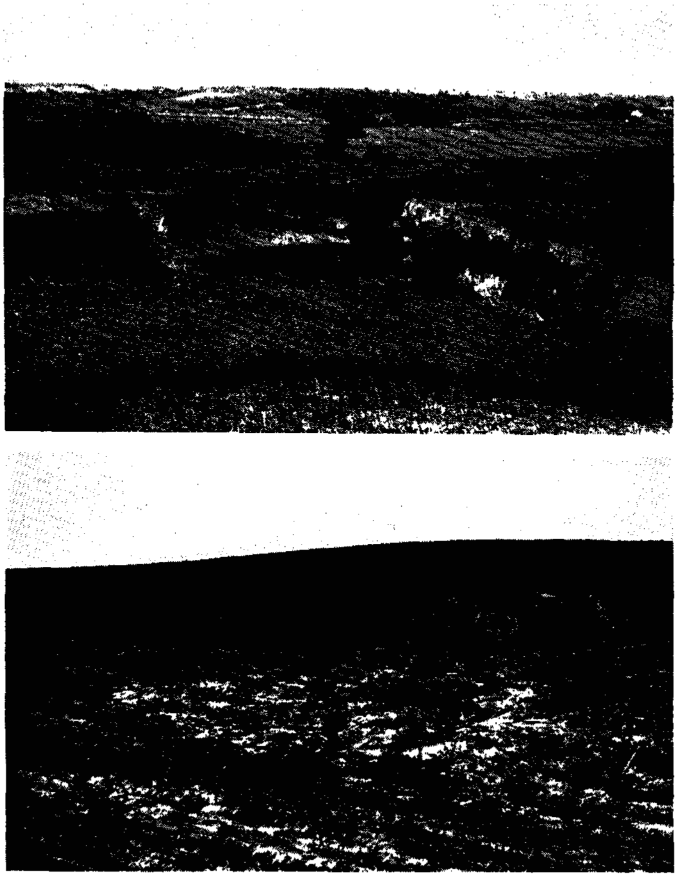


FIG. 7.—Ditches allow the water to run away quickly, give little time for absorption, and add greatly to the total volume of flood water. They reduce the usefulness and the market value of the land.

EROSION BY WIND-BLOWING

In many places in the light-rainfall region and in certain other regions the wind may transport dust and fine soil particles in great quantities and for long distances. Under such conditions soils in local areas may suffer severe losses of fertility. The loss occurs when the land has relatively little or no crop cover during periods of heavy winds. During severe storms small plants may be blown out as the surface soil is removed. The soil is sometimes deposited in low or protected places as snow is drifted by the wind. The amount of loss due to this means has never been measured accurately. An idea of the damage sometimes occurring may be gained from figure 8.

FIG. 8.—Wind erosion. Anything which checks the wind will cause soil to lodge and form drifts in regions subject to soil blowing.

LEACHING

When water passes down through the soil it dissolves some of the plant-food material and carries it away in the drainage water. This process acts slowly but its action is so continuous in regions of high rainfall that it may be the cause of enormous losses.

Excessive leaching can be largely controlled by keeping the land covered with a crop as much of the time as possible. The plants draw much water and food material from the soil, thus preventing it from leaching away. A crop like alfalfa may use so much water that the subsoil is seldom filled with water. Since the soil is thus dried out it is therefore in condition to receive the next rain without permitting a great amount of leaching.

In the cooler sections of the country where evaporation is low there is more continuous leaching than in warmer regions. Under climatic conditions such as prevail in Kansas, leaching is relatively a small factor in soil depletion except in the eastern part of the state where the annual rainfall is between 30 and 40 inches and where in many places the land is of fairly level topography.

HOW SOILS GAIN FERTILITY

In the foregoing discussion it has been pointed out how soils may lose fertility. There are certain ways in which soils may gain fertility and these tend to offset the losses.

Much of the soil material eroded from upland may be caught at the foot of slopes or deposited on overflow land during times of floods. Since it is largely the richer surface material that is lost from soil by erosion, this material may greatly enrich the land where it is deposited. However, since these lowland soils are usually fertile already, the gain in fertility does not offset the loss from the upland soils. There are some cases, however, where sandy or other infertile soil material may wash out of gullies and be deposited on lower land. In such cases the bottom-land soil may be lowered in productiveness rather than increased.

Some soils have been formed largely by wind-deposited material. These loessial soils of the United States and other countries are among the best in the world. They have been gradually enriched by deposits being blown in from other regions. Wind-deposited soils are found over much of northwestern Kansas as well as in extensive deposits in the northeastern part of the state along the Missouri and Kansas rivers. This type of gain in fertility in one locality is usually at the sacrifice of fertility in some other locality.

The return of the plant nutrients contained in the crop in the form of manure from animals, as well as the return of crop residues, aids in maintaining the fertility of soils.

Soils gain much in their nitrogen content due to the activities of microörganisms. Legume plants have the power of fixing nitrogen from the atmosphere by means of the bacteria which live in the nodules on the roots. This tends to increase the nitrogen content of the soil. In addition to this method of fixation another type of bacteria known as Azotobacter and some other forms living in the soil on the decaying organic matter take their nitrogen from the air. These two groups of soil organisms do much to maintain or even increase the nitrogen content of the soils of some sections of the state.

Another means of adding fertility to the soil is through the use of commercial fertilizers. Although fertilizers are used chiefly for improving the growth of the immediate crop, in many cases an excess over crop needs may be applied which tends to raise the total fertility of the land. The supply of phosphorus or lime in the soil may be increased without great difficulty through the use of chemical materials.

MAINTAINING SOIL FERTILITY

Since new lands suitable for crops have already been largely put under cultivation it is becoming more necessary to give attention to keeping up the fertility of older soils. As economic conditions become more tense it becomes necessary to make each acre produce more profitably. This cannot be done on relatively unproductive soil, and it is therefore becoming more necessary to maintain the soil in a fairly high state of fertility. This practice will not only be a benefit to the farmers of the present day, but will leave the soil in more productive condition for those who farm the land in the future.

SOIL EROSION CONTROL

One of the more important things that can be done in keeping up the fertility of the soil is to reduce the losses of soil through erosion. Soil erosion is of two types: (1) Gullying and (2) sheet erosion, or the loss of soil from the entire surface due to heavy rains.

Gullying.--Gullies are most easily controlled by keeping most of the water out of them. This can be done most effectively by means

FIG. 9.—A rock dam across a broad ditch has caused a large amount of soil to be deposited. This has tended to level the field somewhat and has prevented the loss of a large amount of fertile soil.

of cover crops, or sod crops, or by the use of terraces. Putting obstructions in the deep ditches is in many cases advisable. This is best done by putting in brush and straw and tying it down with stakes or in many cases coarse material like corn or kafir stalks may be used effectively in ditches to catch the soil.

After these obstructions have caught some soil this new deposit should be seeded with some quick-growing crop such as oats, sorghum, or grass, which is simply allowed to fall down, and will hold the soil and aid in catching more. Willows or other perennial plants or trees should be started in large ditches to form permanent obstructions. These may often be cut over and allowed to fall down in the ditch. They then collect debris and soil until the ditch may be practically eliminated.

The soil-saving dam has been used particularly in filling rather large ditches that do not have too much fall where considerable fill can be accomplished by one dam. These dams may be constructed of soil, rock, or concrete. (Fig. 9.) A large tile passing underneath the dam is usually used as an overflow. As the water collects and stands above the dam, the soil material settles out and soon fills the ditch. The use of a soil-saving dam of this type has been limited because of the expense of construction. The use of a larger number of small, cheaply constructed dams or obstructions in ditches is in most cases the more practical, particularly if they are combined with sod crops or quick-growing crops seeded in the ditches to catch and hold the eroded material.

Ditches having vertical banks should sometimes have the sides plowed down and seeded to grass, after the dams have been constructed, to prevent excessive loss of soil and water. The more gradual slope of the sides of the ditch will hold the grass and prevent further cutting of the banks.

Terraces can also be used effectively in keeping much of the run-off water out of the main ditch while it is being plowed in and the banks seeded to grass. The water may be carried off the field at a slow rate through the terraces and do little cutting.

Sheet Erosion.--The loss of soil fertility due to sheet erosion is probably far greater than from gullying. Through sheet erosion a thin layer of the most fertile soil is removed from the surface with each heavy rain. Because the material is thus removed gradually and because subsequent cultivation destroys all evidence of the erosion, the ill effects often go more or less unnoticed until after much damage has been done.

TABLE IV.—PER CENT OF RAINFALL IN RUN-OFF, AND RATE SOIL IS LOST BY SHEET EROSION FROM LAND UNDER DIFFERENT SYSTEMS OF MANAGEMENT. (*a*)

TREATMENT.	Per cent of rainfall in run-off.	Tons of soil eroded per A. in six years.	Years necessary to erode 7 inches of soil.
Not cultivated—no crop	48.9	207	29
Plowed 4 ins. deep. Fallowed. No crop	31.3	247	24
Plowed 8 ins. deep. Fallowed. No crop	28.4	214	28
Corn annually	27.4	106	56
Wheat annually	25.2	39	150
Rotation—corn, wheat, clover	14.1	13	437
Sod—blue grass	11.5	1.7	2,547

(*a*) Duley, F. L., and Miller, M. F. Erosion and surface run-off under different soil conditions. Mo. Agr. Expt. Sta. Res. Bul. 63:1-50. 1923.

It has been shown by experiments (Table IV) that sheet erosion is greatly reduced when the land is kept covered with a crop as much of the time as possible. By using a cropping system that provides for a crop on the land most of the time, or at least during the seasons when the greatest erosion is likely to occur, much can be done to reduce the disastrous effects of sheet erosion. Cropping systems differ widely as to the time the land is covered with a crop. This difference is shown in Table V.

TABLE V.—TIME DIFFERENT CROPPING SYSTEMS KEEP LAND COVERED WITH A GROWING CROP.

CROPPING SYSTEM.	Months in one rotation.	Months land is in a growing crop.	Per cent of time land is in a growing crop or sod.
Corn continuously	12	4	33
Wheat continuously	12	9	75
Corn, oats, soy beans	36	16	44
Corn, wheat, red clover	36	34	94

It should also be noted that some crops give more effective protection than others. (Fig, 10.) Small grain crops hold the soil far better than corn or other cultivated crops. Red clover forms a sod and protects the land much more effectively than a crop like soy beans. Furthermore, the red clover occupies the land much longer than soy beans and thus gives not only more efficient but more extended protection from washing. Sweet clover or alfalfa used in the cropping system gives much the same protection as red clover.

On steepest lands, permanent grass pastures or meadows should be

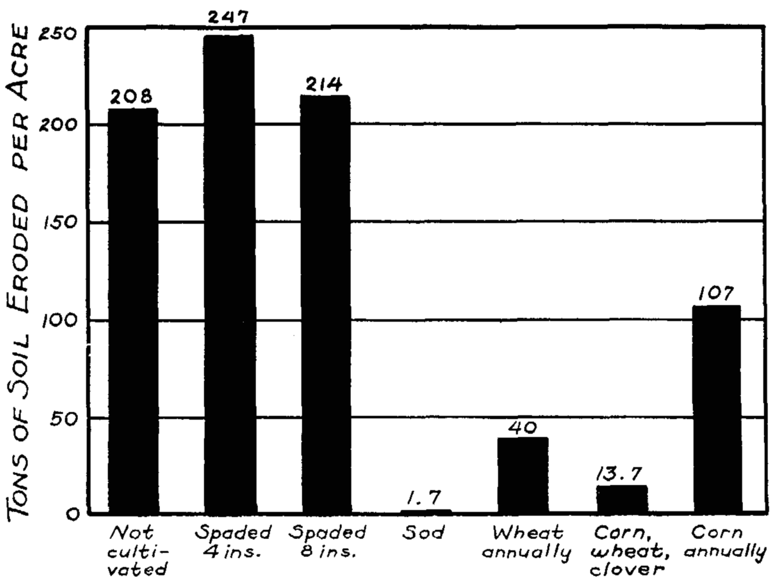


FIG. 10.—Graphs showing amount of soil eroded per acre annually under various soil treatments.

used as much as possible since they form the most effective protection against erosion. The less sloping ground should be grown to small grain or kept in such rotations that the land will be protected by a crop at least three-fourths of the time. It is only on relatively level upland or bottom lands that cultivated crops can be grown more or less constantly without serious loss from erosion. Even in such cases the land should be rotated with other crops since continuous cropping is seldom the best practice on any soil.

Terracing.--Where it is necessary to grow cultivated crops, or to use rotations including cultivated crops, on rolling land, the use of a system of broad ridge terraces will aid greatly in protecting the land from erosion.

Terraces control erosion because they intercept the water at

FIG. 11.—The construction of terraces across the slopes is an effective method of reducing the amount of erosion.

regular intervals on the slope, slow up the rate of flow, and prevent it from accumulating in large volume. This greatly reduces the amount of cutting that the water can do. Gullies are prevented, and if the proper system of cropping and cultivation is used sheet erosion may be greatly reduced.

The broad ridge terrace, sometimes called Mangun terrace or broad base terrace, is the only type of terrace adapted to general farm conditions in Kansas for controlling sheet erosion. These terraces are constructed by throwing up a ridge similar to a graded roadbed around the hill. (Fig. 11.) They are built almost on the contour, but usually have a slope of 2 to 6 inches per 100 feet toward one end which serves as an outlet for the excess water. Where the principal purpose of the terrace is to save water, the terrace may be constructed on the contour, when they are known as "level terraces." Such terraces hold the water on the land and in regions of low rainfall may aid in the conservation of moisture.

The terrace ridge together with the ditch on the upper side should be 18 to 25 feet wide when complete. A broad ridge is much easier than a narrow one to cross with farming implements and harvesting machinery, In addition to this it is less likely to be destroyed during excessive rains.

Terraces may also be used to fill ditches as well as to prevent their formation. If it becomes necessary to cross a small ditch with a terrace a heavy fill is made at this point, and as the water collects above during rains much soil material will be deposited. This will soon fill the ditch to a point where it can be crossed with machinery. Further cutting in the old ditch is avoided, because the water is carried off by the terraces.

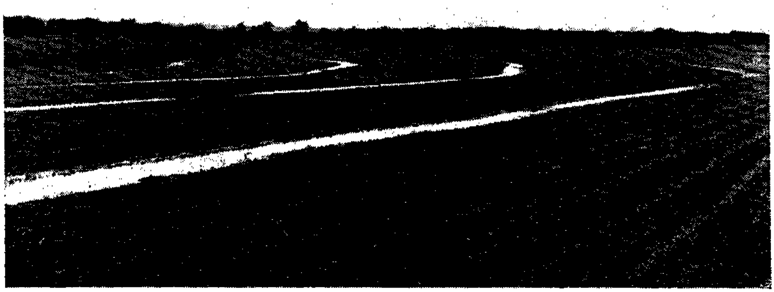


FIG. 12.—A system of terraces prevents the formation of gullies in the field. Note that the sorghum rows run parallel with the terraces. This is the proper method of handling row crops on terraced land.

Terraced land that is to be grown to row crops will be further protected from erosion if the rows are put approximately parallel with the terraces. (Fig. 12.) This may be done by making the first row approximately parallel with the middle terrace on the hillside. Then if the planting proceeds in each direction from this, the rows will usually be near enough on the contour to prevent serious washing in the row, and a minimum number of point rows will be required. When row crops are planted in this way it will be found that young plants do not wash out during heavy rains.

CONTROL OF SOIL BLOWING

It is usually much easier to prevent soil blowing than to check it after the soil has started to move. The preventive measures consist in keeping the surface of the soil somewhat rough or of having it covered with a crop during the period when blowing occurs. A rough condition may be secured by cultivating the soil when it is damp, by the use of shovel type of cultivators rather than the disk, and by leaving much of the stubble and straw on and near the surface of the soil. Any system of cultivation that makes the soil very fine will make it more subject to blowing. On some soils, blowing has been held in check by growing corn or one of the sorghums in wide rows, drilling a small grain crop between these rows, and then leaving the stalks standing on the field in the spring until after danger of blowing is over. Applying straw or manure to the field and disking it in lightly will often aid in preventing soil blowing. When the soil is in such condition that there is danger of its blowing, steps should be taken at once to prevent it by cultivating or listing strips through the field.

After soil starts to blow it may usually be checked by cultivating with a shovel cultivator, strips of land across the field at right angles to the direction of the wind. After the blowing has become severe the cultivator will not be effective and the lister should be used instead. Beginning on the windward side of the field a series of three or four furrows should be made at right angles to the direction of the wind. The distance between the listed strips may vary from one to four rods, depending on the severity of the wind.

CROP ROTATIONS

One of the oldest known methods of keeping soils productive is by growing different crops on a piece of land rather than growing the same crop year after year. Rotation of crops when properly planned helps eradicate weeds, control insects, control plant diseases, increase the productiveness of the soil, and distribute the farm labor. To be most successful the rotation must be planned to suit conditions on the individual farm. In planning a rotation the kind and amount of live stock must be considered as well as the soil condition.

The effect of crop rotation in increasing the yield of crops is shown in Table VI and figure 13, giving the results from the soil-fertility experiments at Manhattan.

It will be seen from this table that the crops grown in rotation have given decidedly higher yields than the crops grown on the same

TABLE VI.—EFFECT OF CROP ROTATION ON YIELDS OF CROPS.
Manhattan, Kan., 1911 to 1930.

CROP.	Crop yields per acre.		Increase with rotation.
	Continuous cropping.	Rotation—alfalfa, corn, wheat.	
Corn	19.4 bus.	33.6 bus.	14.2 bus.
Wheat	15.3 bus.	21.1 bus.	5.8 bus.
Alfalfa	2,683 lbs.	4,793 lbs.	2,110 lbs.

land continuously. To be of value in improving the soil or maintaining the crop yields, a rotation should contain a legume crop such as alfalfa, sweet clover, red clover, soy beans, or some other if better adapted. In the western part of Kansas where the rainfall

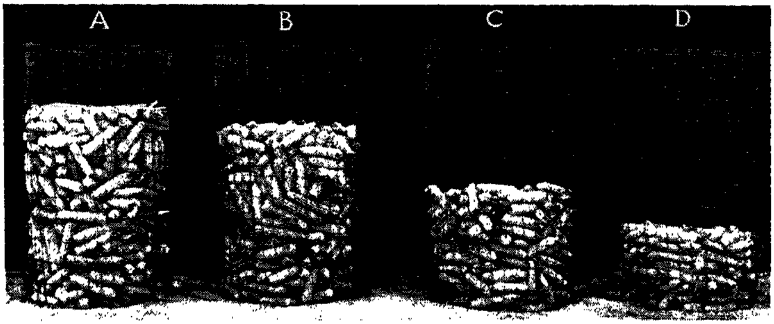


FIG. 13.—Effect of rotation on yields of corn during a good corn year, 1928, Manhattan, Kan. (A) Sixteen-year rotation including alfalfa; (B) three-year rotation including cowpeas; (C) three-year rotation, corn, corn, wheat (no legume); (D) corn continuously.

is light, it is sometimes desirable to include a year of fallow in the rotation. (Table VII.) This allows time for the soil to accumulate moisture and available plant-food material which may have considerable influence on the crop yields for one or more years.

TABLE VII.—THE EFFECT OF FALLOW ON THE YIELDS OF WHEAT, FORT HAYS AND GARDEN CITY BRANCH STATIONS. (*a*)

METHOD OF SEEDBED PREPARATION.	Fort Hays, 1907 to 1931.		Garden City, 1914 to 1930.	
	Average yield per acre.	Number of failures in 24 yrs. (*b*)	Average yield per acre.	Number of failures in 16 yrs. (*b*)
	Bus.		*Bus.*	
Late plowing	10.9	11	4.6	10
Early plowing	16.5	6	6.9	9
Early listing	18.8	4	7.5	9
Summer fallow (alternate years)	23.5	3	11.8	5

(*a*) These results were secured in coöperation with the Division of Dry Land Agriculture, United States Department of Agriculture.
(*b*) Yields of less than 5 bushels per acre.

The use of a fallow not only increases the yield of grain the following years, but it greatly reduces the frequency of crop failure. Experimental results secured at the Fort Hays Branch Agricultural Experiment Station show that one year of fallow will influence the yields of wheat, for more than one year and that it is not necessary to fallow every other year. Where conditions correspond to those at the Fort Hays station a year of fallow may advantageously be followed by three years of wheat. Farther west, where rainfall is much less, not more than two years of wheat should follow a year of fallow.

TABLE VIII.—EFFECT OF FALLOW ON FOLLOWING CROPS OF WHEAT. FORT HAYS STATION, 1918 TO 1931.
Hays, Kan.

SEEDBED.	Average yield, bushels per acre.
Wheat first year after fallow	28.2
Wheat second year after fallow	24.7
Wheat third year after fallow	23.1
Wheat continuously	21.1

MAINTAINING THE NITROGEN AND ORGANIC MATTER IN THE SOIL

Since most of the soil nitrogen is contained in the organic matter, nitrogen and organic matter may to a large extent be considered together. If a soil is to be productive it must contain an ample supply of available nitrogen. This is most easily supplied when the soil contains a plentiful supply of total nitrogen. There are a number of ways in which the supply of nitrogen in the soil may be maintained. The growing of legumes, the use of manures and green manures, and in some cases even the use of commercial fertilizers, will help keep up the supply of total nitrogen in the soil.

Organic matter decays rapidly in a cultivated soil. The more frequently a soil is plowed and the more intensively 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 grains; while soils seeded down to alfalfa or grass crops may increase in organic content.

It is important to keep a soil well supplied with organic matter because of its nitrogen content and because of its value, particularly following sod crops, in absorbing water and in keeping the soil in good tilth. Organic matter is also the principal food of the bacteria which make plant-food materials available. The growing of legumes in the rotation, the application of manure, the return of all crop residues to the soil, and the growing of green-manure crops are the methods of maintaining or increasing the nitrogen content of the soil, and particularly the available nitrogen.

Legumes.--The growing of legume crops that are able to take free nitrogen from the air by means of bacteria living in the nodules on the roots (fig. 14) affords the most natural and practical method of maintaining the nitrogen supply of the soil. Some of the nitrogen collected by legume plants is stored in the nodules of the roots and in the roots themselves, while a large part of it is used in building up the protein material in the leaves, stems, and seeds. In fact the top part of the plant contains from two to six times as much nitrogen as the roots, the amount varying greatly with the stage of development of the plant and with different legumes.

It is evident, therefore, that if the top part of the plant is removed from the soil much nitrogen and organic matter are removed also. On the other hand, if the crop is fed to live stock a large part

FIG. 14.—Well-inoculated soy-bean plants.

of the nitrogen and much of the organic matter will be returned to the soil in the manure. If the greatest benefit is to be obtained from growing legumes use must be made not only of the nitrogen and organic matter in the roots of the plants, but also of the fertility contained in the tops of the plants, in so far as possible, by returning to the soil this part of the plant in the form of green manures or the manure from live stock.

Green Manures.--On many farms only a small number of live stock are kept and it is impossible to produce manure from all the legumes that should be grown as a means of keeping up the nitrogen content of the soil. Under such conditions a green-manure crop may be used to advantage to maintain the supply of nitrogen and organic matter. This system has much to recommend it in so far as the soil is concerned, though it has certain practical disadvantages which are difficult to overcome. The use of large quantities of water in growing the green-manure crop is often a disadvantage under Kansas conditions. Because of the expense of growing green-manure crops all crop residues and stable manure should be used first and green manure should be used only as a last resort, except in cases where the green manure can be produced with but little extra expense.

In the past no legume that was adapted for a green-manure crop under a wide variety of conditions and that did not require the use of the land for an entire growing season was available. This has been a serious handicap to green manuring since it is seldom that a farmer feels he can lose the use of his land for a full season for the purpose of growing a crop to plow under. Recently, however, certain crops that occupy the land for only a part of the year and permit the regular crops in the rotation to be produced have been used for green manure with considerable success. The more popular of these green-manure crops in Kansas are sweet clover, cowpeas, soy beans, vetch, and rye.

Sweet clover is rapidly gaining in popularity as a green-manure crop because it can be seeded alone in the spring or with a small grain and allowed to grow in the fall, producing a pasture or hay crop after the grain crop is removed. The following spring it makes an early growth which permits it to be plowed under for green manure before a summer crop like corn or sorghum is planted. This system, however, is adapted only to the more humid sections of the state. Care must be taken during dry springs that the green-manure crop does not remain on the land too long and remove so much water from the soil that it will deprive the following crop of moisture.

On the more droughty soils and in the lighter rainfall sections it is not advisable to plow the sweet clover under in the spring and then attempt to grow a crop. Under such conditions it is more practical to permit the plants to continue growing until they come into bloom and then plow the crop under and use the land for wheat that fall; or the crop may be pastured during the summer and plowed in the fall or early spring for some row crop the following year.

Soy beans and cowpeas have been used to some extent as green-manure crops by seeding at the rate of 1 bushel per acre on disked ground immediately after harvesting a crop of oats or wheat. The soy beans or cowpeas will make considerable growth during the summer and can be plowed under just before frost. This practice has not been widely used since it usually can be carried out only in the more humid sections and in regions where the season is long enough after harvest to permit the production of considerable growth of cowpeas or soy beans.

The practice of seeding cowpeas or soy beans in corn after the last cultivation has not proved profitable under Kansas conditions because the crops will seldom make a satisfactory growth. Soils that are extremely low in organic matter and nitrogen may be greatly improved by seeding cowpeas or soy beans at the usual time in the spring and then plowing the entire crop under in midsummer for green manure, though the cost of this method has prevented it from becoming a general practice.

Some potato growers seed cowpeas, turnips, soy beans, rye, or rye and vetch after removing potatoes, and plow these crops under in the late fall or early spring before time for planting the next crop. Some orchardists have found rye, or rye and vetch seeded together, to be valuable as a green-manure crop and also to prevent winter and early spring erosion in orchards that must be clean cultivated during the summer.

If satisfactory green-manure crops can be found that will work well into the rotation, for many farmers green manuring may be a practical method of keeping a supply of available plant food in the soil. The practice is particularly advisable where the number of live stock on the farm is limited.

In the Great Plains region of the United States, where the rainfall is light, no very satisfactory system of green manuring has been worked out. The effect which these crops have in using moisture may offset any value in adding organic matter or available plant food. Further investigations, however, may possibly disclose some system of green manuring adapted to this region.

PROVIDING AVAILABLE NITROGEN

In order for crops to make satisfactory growth an ample supply of available plant-food material must be present in the soil. The supply of available nitrogen can be affected greatly by the system of soil management used. Rapidly decaying organic material in the soil releases soluble nitrogen in the form of nitrates which are readily assimilated by the crop plants. The addition of manures, crop residues, or green manure in this way adds much to the supply of available nitrogen.

Weeds growing on the land take out nitrates and thus deprive the crop of this valuable plant food. Weeds may also absorb the soluble nitrogen until the next crop will be greatly delayed in starting. For this reason fallow land or land to be seeded soon to a crop should be kept free of weeds. The weeds also reduce the moisture as well as the nitrate content of the soil.

Much of the advantage gained by early plowing and early preparation of the ground for wheat and alfalfa is due to the destruction of weeds. Thus they do not rob the soil of moisture or plant-food materials that are made available during this period of soil preparation by soil microorganisms.

On many infertile soils even good methods of crop rotation and cultivation may not be sufficient to keep the soluble nitrogen content as high as is desirable. In such cases nitrogenous fertilizers such as ammonium sulphate, sodium nitrate, or others may be used.

Legume crops adapted to such soils may also be made to supply available nitrogen to the land.

The proper attention in providing an ample supply of available nitrogen not only aids in giving higher yields of crops, but helps in producing crops of better quality. The protein content of wheat, for example, depends largely upon the supply of available nitrogen. It may usually be increased by increasing the supply of available nitrogen in the soil. This is illustrated in Table IX.

TABLE IX.—RELATION OF SEEDBED PREPARATION TO YIELD AND PROTEIN CONTENT OF WHEAT.

Manhattan, Kan., 1911 to 1920.

METHOD OF SEEDBED PREPARATION.	Nitrates in soil at seeding time, p. p. m.	Average yield, bushels per acre.	Per cent protein.
Disked at seeding time	6.7	7.7	12.11
Plowed September 15, 3 ins. deep	8.7	12.3	12.15
Plowed August 15, 7 ins. deep	18.5	19.0	13.33
Plowed July 15, 7 ins. deep	27.6	20.7	13.93

Inoculation for Legumes.--Legume plants do not take nitrogen from the air and produce large yields of high-protein crops unless they are supplied with the bacteria that are necessary to produce nodules on the roots. The bacteria for some legumes such as cowpeas, white clover, vetch, and Japan clover are widely distributed and will be found in most soils. The bacteria which inoculate alfalfa, sweet clover, soy beans, and some other legumes are less widely distributed and often have to be added to the soil artificially.

Artificial inoculation may be accomplished by taking inoculated soil from a field where the crop has been grown or directly from around inoculated plants. This soil may then either be sown on the field to be inoculated and worked into the ground or, if more convenient, applied to the seed directly as a dust, or it may be mixed with water and sprinkled over the seed. The damp seed should be dried for a brief period before being sown.

During recent years inoculating material for legumes has been produced by growing the bacteria in pure cultures. The organisms are then sprinkled over the seed just before seeding. After the seed germinates the young roots are soon infected by the legume organisms and, if conditions are favorable, the seedlings will show the presence of nodules when only a few weeks old. Due to the greater convenience of using artificial inoculation this method is gaining in popularity. The material can be purchased at reasonable prices from commercial companies.

When a legume is grown on a given field for some time the soil becomes inoculated with the bacteria for that crop and further artificial inoculation is unnecessary.

There are certain groups of legume bacteria which may inoculate several different legumes, while others cross-inoculate with only one or two legumes, and some like the soy bean are not known to cross-inoculate with any other plant. The most important of these groups which cross-inoculate[3] are as follows:

1. Red, alsike, white, crimson, and mammoth clovers.
2. Alfalfa, sweet, clover, bur clover, yellow trefoil.
3. Cowpea, partridge pea, peanut, velvet bean, lima bean, Japan clover, Korean lespedeza.
4. Garden peas, field peas, sweet peas, vetches, broad beans.
5. Garden beans, scarlet runner beans.
6. Soy beans.
7. Black locust.

BARNYARD MANURE

One of the oldest and best-known methods of maintaining soil fertility is by the use of animal manures. The value of these materials is recognized by farmers everywhere. In spite of this fact, however, far too little attention is given to the production and care of this valuable by-product of the farm. Large quantities are allowed to lie around barns or in exposed lots where they deteriorate rapidly or are washed away by the rains.

As soils get older, farmers give more attention to the care of manure since it becomes more essential for profitable crop production. As the value of land increases and more attention is given to acre yields, farmers naturally give more attention to the manure production of the farm.

The value derived from manure depends to a great extent upon what crops it is used and also upon the character of the manure. The results of using manure in different cropping systems show a decided difference in the value of crop increases obtained from a ton of manure. Table X shows the results of such experiments at the Kansas station.

TABLE X.—VALUE OF CROP INCREASE PER TON OF MANURE USED IN DIFFERENT CROPPING SYSTEMS.

Kan. Agr. Expt. Sta., 1911 to 1927.

CROPPING SYSTEM.	Rate of application.	Increase per ton of manure.
Corn continuously	2.5 T. annually	$1.57
Three-year rotation—corn, cowpeas, wheat	5 T. every 3 years	1.78
Wheat continuously	2.5 T. annually	2.65
Sixteen-year rotation—alfalfa, corn, wheat, wheat	5 T. every 3 years	3.03
Alfalfa continuously	5 T. annually	3.58
Alfalfa continuously	2.5 T. annually	4.53

Crop Prices.—Corn, 60 cents a bushel; wheat, $1 a bushel; alfalfa, $12 a ton; cowpea hay, $10 a ton.

3. Waksman, S. A. Principles of soil microbiology. pp. 136-137. 1927.

Manure in light applications gives greater increases per ton used than where it is applied more heavily, but the acre increase may be much less. This is illustrated in the case of a 2½-ton application on alfalfa as compared with the 5-ton application. It is evident, therefore, that where the supply is limited manure should be spread in fairly light applications and as many acres covered as possible if the greatest total profit is to be realized. Some farmers such as market gardeners desire high yields per acre. It is often to their advantage to apply large amounts of manure per acre in order to secure high yields of crops that have a high acre value.

Methods of Handling Manure.--In order to prevent excessive loss of plant-food material from manure it should be applied to the land as soon as possible. Experiments have shown that manure exposed to the weather from three to five months will lose from one-third to one-half of its plant-food value. Well-rotted manure is often recommended for garden crops, but this is because the material is in better physical condition and the plant-food material is more available. In the process of rotting, manure always loses much of its plant-food elements as well as organic matter.

A manure spreader is the most convenient and satisfactory method of applying barnyard manure to the land. It is often good farm practice to pasture certain crops in the field or to do a considerable portion of the feeding in temporary feed yards in fields. If this is done the animals scatter the manure and thus the necessity for hauling and spreading is eliminated. The advantage of such a practice is not entirely in the elimination of handling, but there is no loss of manure due to scattering about the lots or to fermentation and leaching. Another advantage in feeding on a cultivated field is that most of the liquid manure will go back on the land, whereas a large part of it is lost when other feeding methods are followed. The importance of this is obvious when it is realized that approximately 40 per cent of the total value of animal manure is in the liquid portion.

Reinforcing Manure.--Owing to the fact that manure is relatively low in the element phosphorus, as compared with the other plant-food elements, it is often desirable to add some phosphorus to the manure. This may be done by applying 20 to 40 pounds of superphosphate or raw rock phosphate over each load of manure. In this way the phosphorus is distributed as the manure is unloaded. Another method of accomplishing this result is to apply the two materials at different times in the rotation. For example, the manure may be applied to the land before corn or sorghum, and the phosphorus applied with the wheat or alfalfa. In this way the maximum benefit from the two materials probably will be obtained.

COMMERCIAL FERTILIZERS

Commercial fertilizers are concentrated plant-food materials. They are used very extensively throughout Europe and eastern and southern United States for practically all crops, including the grasses. As a general rule the use of commercial fertilizer increases as the agriculture of a country becomes older, because the soils become lower in plant-food materials and it becomes necessary to use commercial fertilizer to secure economic returns.

Kansas farmers have been using commercial fertilizers for only about 35 years, and now use only a relatively small quantity. They could be used economically much more extensively than at the present time, especially in the eastern portion of the state on the eroded soils and on the relatively thin soils. Many soils formed from sandstone and shale and some of limestone origin are in need of additional plant-food materials in the form of phosphatic and nitrogenous fertilizers or legume residues. The use of commercial fertilizers at the present time is limited to the heavier rainfall sections of Kansas because in the central and western portions of the state crop yields are more frequently limited by a lack of moisture than a lack of available plant-food material. The use of commercial fertilizers in the lighter rainfall sections frequently results in a decrease in the yield of grain crops because they stimulate early growth, which uses an excessive quantity of moisture, thus reducing the quantity available to mature the crop. This lack of moisture and the more tender vegetation resulting from the rapid growth make the plants more susceptible to "firing." The same condition may result from the use of excessive quantities of fertilizer in the more humid sections.

COMMERCIAL FERTILIZERS VERSUS BARNYARD MANURE

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 do that are found on the market, it is called a complete fertilizer. Barnyard manure carries large amounts of plant-food material and is usually the cheapest source of plant food on the farm. Since it is essentially a by-product of the farm the complete utilization of this material should be a part of every good system of soil management. When this fails to supply sufficient plant food or does not supply the different materials in proper proportion, manure should be supplemented by commercial plant foods.

DO COMMERCIAL FERTILIZERS INJURE 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, and in most cases carry only small amounts of nitrogen. It is by means of organic matter in the soil that most of the plant food is liberated from season to season and it is in this material that the nitrogen is held. When organic matter is not added, the supply of material that aids in liberating plant-food materials from the soil, as well as the total nitrogen 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 including plenty of available nitrogen, but should the fertilizer be discontinued the productivity 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 and certain nutrients 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 when a good rotation of crops is practiced, and when organic matter is supplied systematically.

FERTILIZER MATERIALS

There are many different fertilizer materials that carry nitrogen, phosphorus, and potassium. Only a few of the more common of these will be mentioned here.

Nitrogenous fertilizers are grouped into organic and inorganic materials. Of the organic group, cottonseed meal and some of the by-products of the packing houses, such as tankage and dried blood, have been used extensively in the past, but their use is decreasing because they are being used in feeds for live stock. Dried pulverized manure and phosphated manure are coming into common use, especially for lawn and garden purposes.

The inorganic nitrogenous fertilizers are used much more extensively than the organic and include Chilean nitrate of soda, by-product ammonium sulphate, and several synthetic forms such as calcium nitrate, urea, and also synthetic ammonium sulphate and sodium nitrate. (Fig. 15.) Sodium nitrate and ammonium sulphate are used more extensively than the other forms, but the other synthetic materials are gradually becoming more popular. The inorganic nitrogenous fertilizers are more quickly available than the organic.

Phosphatic Fertilizers.--There are three common fertilizer materials which carry phosphorus. These are: Superphosphate, bone meal, and raw rock phosphate. The superphosphate is made by treating the phosphate rock with sulphuric acid to make the phosphorus available more readily. Superphosphates vary from 16 to 45 per cent in the amount of phosphoric acid *(P2O5)* which they carry.

Contrary to common belief, this fertilizer will not make the soil acid. Bone meal is a by-product of the meat-packing industry and carries about 1 per cent nitrogen and 30 per cent phosphoric acid. The bones are treated with steam to remove some of the organic materials, and are then ground. Raw rock phosphate is a phosphate rock that has been finely pulverized. The phosphoric acid content is about 30 per cent, but in this material it is not so readily available as in the other phosphates. It is therefore usually applied in larger amounts, but the applications are less frequent. It is frequently applied in connection with manure or some green-manure crop with the intention of making the phosphorus available to plants. The best phosphatic fertilizer to use will usually be the one

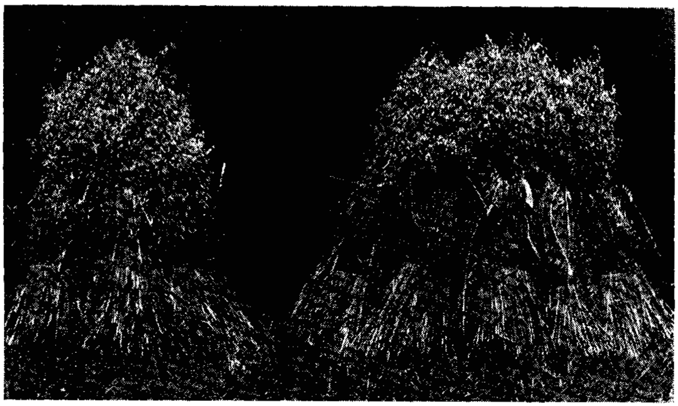


FIG. 15.—Effect of nitrogenous fertilizer on oats following sorghum. Left—no treatment. Right—sodium nitrate, 100 pounds per acre.

in which the largest quantity of available phosphorus can be purchased for a dollar. Ordinarily on most Kansas farms this will be either superphosphate or bone meal.

Potash Fertilizers.--Potassium sulphate and potassium chloride are the most common carriers of potash. They are of almost equal value as a fertilizer for all farm crops with the exception of tobacco, potatoes, and sugar beets. Potassium sulphate is preferable for these crops because the chloride form gives rise to a product of lower quality.

Mixed Fertilizers.--A mixed fertilizer is one that carries two or more of the fertilizer elements. The material is manufactured by fertilizer companies and is sold on the basis of its composition as determined by analyses. When a fertilizer carrying more than one element is needed it is preferable to purchase a mixed fertilizer because it is difficult for the farmer to secure separate ingredients and mix them properly. Of the three elements, nitrogen, phosphorus. and potassium, which may occur in mixed fertilizers. the nitrogen is the most expensive and, as has already been stated, should usually be secured through the use of manure and legume crops.

Since most Kansas soils are well supplied with potassium, it is not necessary in most places to purchase this element. Because of these facts it is only in special cases that Kansas farmers need to purchase mixed fertilizers. When it is considered advisable to use mixed fertilizers, it is usually more economical to purchase high-grade mixtures or those carrying more than a total of 14 per cent of available plant-food materials such as a 4-16-0 or a 4-16-4. In these statements the first figure refers to the percentage of nitrogen, the second to the percentage of phosphorus expressed as phosphoric acid (P205), and the third to potassium expressed as potash (K20).

PHOSPHORUS, THE ELEMENT MOST COMMONLY NEEDED IN FERTILIZERS IN KANSAS

As has already been stated in Table II, Kansas soils as a rule are quite well supplied with potassium. It is very seldom, therefore, that applications of this plant-food material in the form of a fertilizer will result in a profitable increase in the yield of the crop. On some soils, however, it will increase the yield of alfalfa to some extent if used in connection with phosphorus.

It has also been pointed out that the most practical method of solving the nitrogen problem is through the production of legumes in the crop rotation, the return of all manure and crop residues to the soil, and the use of green-manure crops where necessary.

Table XI emphasizes the importance of phosphorus as a fertilizer element in the production of wheat. It will be seen that the average yield of wheat following the use of phosphorus alone has been almost as high as when nitrogen and phosphorus were used together or following the use of all three fertilizer elements. In the production of alfalfa at Manhattan, phosphorus has had more influence on the yields of hay than has potassium or nitrogen, as is shown by Table XII.

TABLE XI.—THE EFFECT OF FERTILIZERS ON THE YIELD OF WHEAT IN COÖPERATIVE TESTS WITH FARMERS IN SOUTHEASTERN KANSAS, 1912 TO 1930.

TREATMENT.	Number of tests.	Average yield in bushels per acre.
None	....	16.9
Phosphorus	147	21.4
Phosphorus and nitrogen	139	22.2
Phosphorus, nitrogen, and potassium	146	22.0

TABLE XII.—EFFECT OF FERTILIZERS ON THE YIELD OF ALFALFA.

Twenty-year average, 1911 to 1930, Manhattan, Kan.

TREATMENT.	Average yield in pounds per acre.	
	Alfalfa continuously.	Alfalfa in rotation.
None	2,683	4,793
Phosphorus	3,374	5,321
Potassium	2,637	....
Phosphorus and potassium	3,575	5,962
Phosphorus, potassium, and nitrogen	3,779	6,178

CROPS TO FERTILIZE

The profitable use of commercial fertilizer in Kansas varies with the crop grown, the section of the state, and soil conditions. For these reasons it is advisable to discuss the use of fertilizers with respect to each crop.

FERTILIZERS FOR WHEAT

Wheat is one of the most commonly fertilized crops in the state because it usually has a relatively high market value, and a small increase in yield will result in a profit from the use of the fertilizer. It grows through the season of the year when plant food is liberated from the soil in the smallest quantities, and it is a crop that is usually benefited by a vigorous early growth.

In general it is not profitable to use commercial fertilizers on wheat in Kansas except in the eastern one-fourth of the state. Farther west the yields are usually limited by climatic conditions. At the Fort Hays branch station it has not been profitable to use fertilizer for this crop. (Table XIII.) It is true that phosphorus has shown a slight increase in yield, but this increase is not significant and is not sufficient to justify the use of the material.

TABLE XIII.—EFFECT OF FERTILIZER ON THE YIELD OF WHEAT AT THE FORT HAYS STATION, 1920 TO 1929.

Hays, Kan.

TREATMENT.	Average yield, bushels per acre.
None	23.2
Phosphorus	24.6
Phosphorus and nitrogen	23.4

In the production of wheat on the more fertile upland and on the bottom-land soils of eastern Kansas it is not generally economical to use fertilizer. On soils of medium or low fertility, however, it may be used with profit. (Fig. 16.) The best materials to use on such soils are superphosphate, bone meal, or a mixed fertilizer, On the less fertile soils and on land that has been plowed late, it will be advisable to use a fertilizer carrying some nitrogen, as the 4-16-0. Under other conditions bone meal or superphosphate may be used

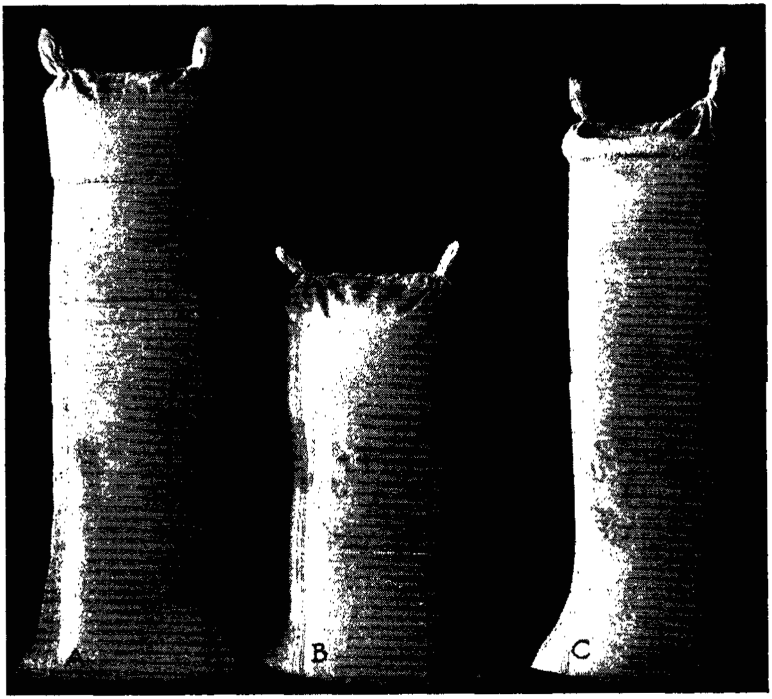


FIG. 16.—Effect of soil treatment on yields of wheat in the 3-year rotation, Manhattan, Kan. (A) Complete fertilizer. (B) No treatment. (C) Manure. Average yield for 20 years: (A) 24.5 bushels per acre; (B) 17.3 bushels; (C) 21.5 bushels.

more economically, and tests have shown that one is about as effective as the other when equal quantities of phosphorus are applied. In a total of 48 tests conducted in 14 counties in southeastern Kansas, from 1912 to 1928, the average yield of wheat was 18.4 bushels per acre with the use of each of these carriers of phosphorus.

The application of fertilizer for wheat should preferably be made at the time of seeding with a combination grain and fertilizer drill. The rate of application should be 100 to 125 pounds of bone meal, or 125 to 150 pounds of 16 or 18 per cent superphosphate, or of a mixed fertilizer of approximately 4-16-0 composition. Heavier ap-

TABLE XIV.—EFFECTS OF BONE MEAL AND SUPERPHOSPHATE ON WHEAT YIELDS.

Cherokee county, Kansas.

Bone meal.		Superphosphate.	
Rate of application in pounds per acre.	Average yield in bushels per acre, 1919 to 1928.	Rate of application in pounds per acre.	Average yield in bushels per acre, 1918 to 1928.
None	18.7	None	16.6
60	23.4	50	22.4
90	22.9	100	21.5
120	23.7	150	20.9
150	24.1	200	21.3
180	23.4	250	20.6
210	24.2		

plications are usually not advisable, since the greatest increase per pound of fertilizer is obtained with the lighter applications, and extremely heavy applications may reduce the yield of grain during dry seasons.

The results given in Table XIV were secured in Cherokee county, Kansas. In studying these results it must be remembered that the applications of fertilizers were made every year and that there was undoubtedly some residual effect. These figures indicate that when wheat is being grown continuously on the same land and when the crop is fertilized each year, the rate of applications of either bone meal or superphosphate may be greatly reduced. However, when wheat is grown in rotation with other crops which are not fertilized, the rates of application previously suggested will be usually more profitable.

Spring applications of superphosphate to fall-seeded wheat have not given profitable returns. In extreme cases when the soil is very low in nitrogen and the wheat plants are yellow and growth is retarded, it is advisable to use a readily soluble nitrogenous fertilizer such as ammonium sulphate or sodium nitrate at the rate of about 100 pounds per acre. It should be applied as a surface dressing after the plants are 4 to 6 inches high, since at this stage they will show the lack of available nitrogen if it is deficient. It is very doubtful, however, if this practice will be profitable where the seedbed has been properly prepared, and especially for central or western Kansas because of the limited rainfall in those regions.

Methods of Applying Fertilizers for Wheat.--The most practical method of applying fertilizer to wheat land is to make the application at the time of seeding the grain with the combination grain and fertilizer drill. Experimental results secured on the Agronomy farm at Manhattan comparing the yields of wheat when the fertilizer was drilled with the grain and when the fertilizer was applied broadcast and harrowed in previous to seeding, show the importance of planting the seed and applying the fertilizer with the combination drill. The results of this experiment are given in figures 17 and 18.

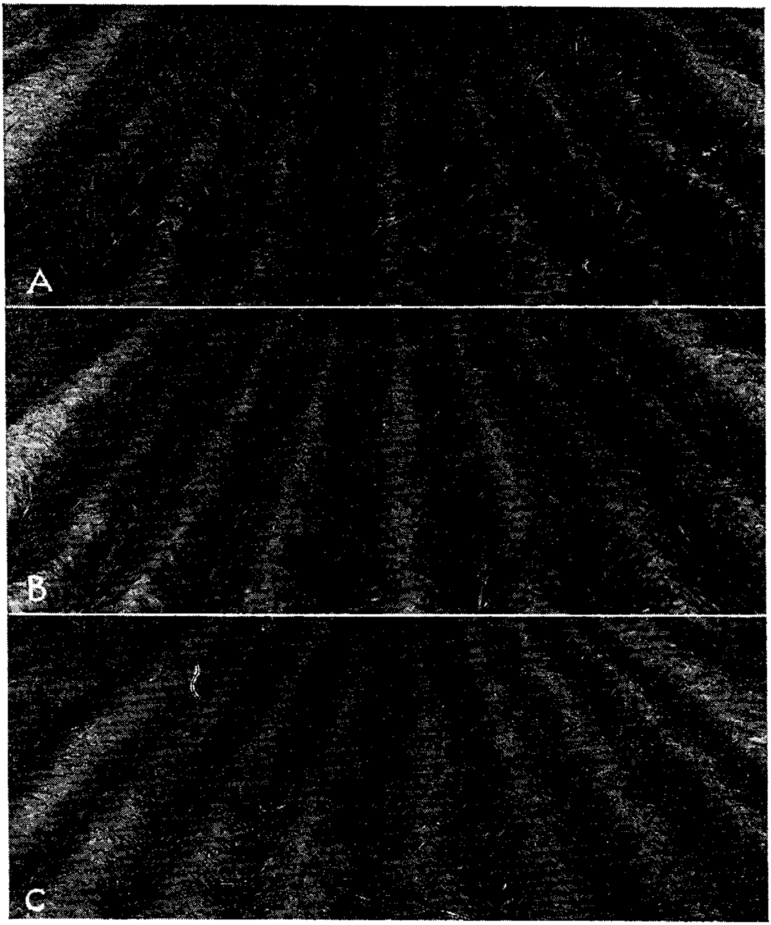


FIG. 17.—Effect of different methods of applying fertilizer on early growth of wheat. (A) Superphosphate applied in drill row with wheat. (B) Superphosphate applied broadcast. (C) No fertilizer.

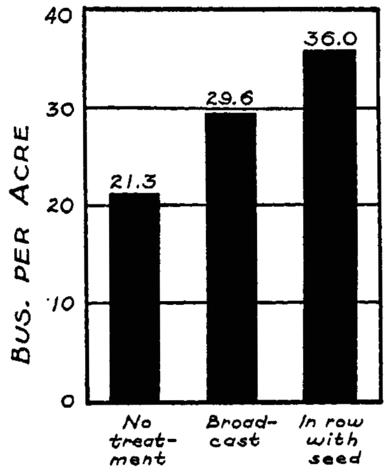


FIG. 18.—Graphs showing effect on yield of wheat of applying superphosphate broadcast and in the row with the seed.

FERTILIZERS FOR ALFALFA

The statement that alfalfa enriches the soil is made so often that it is a common belief that a field well established in alfalfa will take care of itself as far as plant-food material is concerned. This is not the case, because alfalfa, like every other crop, secures a large part of its plant-food material from the soil.

Fortunately the soils of Kansas are well supplied with potassium, but many are low in phosphorus, and since alfalfa requires this element in fairly large quantities, it is not surprising that applications of phosphatic fertilizers greatly increase the yield. Some of the soils in the state are already so low in this element that alfalfa makes a poor, sickly growth on them, and is unable to compete with weeds and grass.

Where Fertilizers Are Needed.--During the last 17 years a large number of experiments have been conducted in Kansas to determine the fertilizer requirements of alfalfa. These experiments have extended from Garden City on the west to the eastern border of the state. Fertilizers have had no appreciable influence on the yields of alfalfa in central and western Kansas (Table XV), but experiments in eastern Kansas have shown very profitable returns, especially from the use of phosphorus.

TABLE XV.—INFLUENCE OF COMMERCIAL FERTILIZERS ON THE YIELDS OF ALFALFA HAY AT THE FORT HAYS BRANCH STATION.

Hays, Kan., 1920 to 1928.

TREATMENT.	Average yield, tons per acre.
None	4.2
Superphosphate, 150 pounds annually	4.4
Manure, 5 tons every 2 years, and 150 pounds of superphosphate annually	4.5
Superphosphate, 150 pounds, and sulphate of potash, 50 pounds annually	4.1

The experiments at Hays were conducted on bottom-land soils and it is quite evident that none of the treatments was profitable. At the Garden City branch station results secured from irrigated alfalfa for a period of nine years showed no benefits from the use of commercial fertilizers. The plot receiving superphosphate produced the highest yield, 6.3 tons per acre, but the adjoining untreated plot produced an average of 6.16 tons per acre.

Experiments conducted on the five experiment fields in southeastern Kansas (Table XVI and fig. 19) show quite conclusively that phosphorus is a very essential fertilizer element for alfalfa in southeastern Kansas. It will be noted that the use of superphosphate in addition to lime resulted in an average annual yield of almost 1 ton per acre over the use of lime alone. This means that the phosphorus aided very materially in helping maintain the stand of alfalfa at a fairly high rate of production. The yields from all plots were low in 1929 because of severe injury to the crop by bacterial wilt of alfalfa, and in 1930 yields were low because of drought.

TABLE XVI.—EFFECT OF SOIL TREATMENTS ON ALFALFA YIELDS.

Southeastern Kansas experiment fields.

TREATMENT.	Tons per acre.					Av., all fields.	
	Columbus, 4 yrs.	Fort Scott, 3 yrs.	Moran, 5 yrs.	Parsons, 5 yrs.	Rest, 5 yrs.	Yield.	Increase from treatment.
No treatment	0.77	1.69	1.37	0.94	1.84	1.32	....
Lime	1.79	1.77	2.23	1.60	2.11	1.90	0.58
Lime, superphosphate	2.12	2.75	3.31	1.93	2.74	2.57	1.25
Lime, manure	2.31	2.29	2.82	2.32	2.79	2.51	1.19
Lime, manure, superphosphate	2.24	3.36	3.62	2.55	3.41	3.04	1.72
Lime, manure, rock phosphate	2.47	3.47	3.49	2.48	3.29	3.04	1.72

That these results are not limited to local conditions is well illustrated by the data presented in Table XVII. The cost of the fertilizer applied in the tests was about $1.85 per acre. Each dollar expended for fertilizer resulted in an increased return varying from $2 to $7. In addition to the increased yields, the phosphorus aided materially in maintaining the stands against weeds and grass.

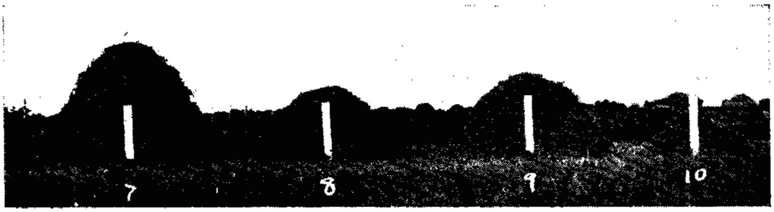


FIG. 19.--Alfalfa. on experiment field at Parsons, Kan. Treatments: (7) Lime, manure, rock phosphate; *(8)* lime; (9) manure; (10) no treatment.

Where to Use Phosphorus.--Phosphorus can be used profitably in alfalfa production on most of the soils in the eastern two-fifths of the state as is shown in Table XVII. On many of these soils alfalfa can be grown without phosphorus, but on these soils it will increase the yields and will help maintain the stands. The poorer upland

TABLE XVII.—EFFECT OF PHOSPHORUS ON THE YIELD OF ALFALFA HAY IN DIFFERENT SECTIONS OF KANSAS.

COUNTY.	Duration of experiment in years.	Yield in pounds per acre.		
		No phosphate.	Super-phosphate.	Average annual increase from the use of phosphorus.
Riley	19	4,875	5,445	570
Allen (Carlyle)	9	3,736	5,584	1,848
Butler (upland)	8	5,042	6,062	1,020
Butler (bottom land)	5	6,411	8,512	2,101
Allen (Moran)	4	5,200	7,480	2,280
Greenwood	5	6,519	8,129	1,610
Labette	5	3,961	6,009	2,048
Morris	3	4,507	5,913	1,406
Wilson	4	5,200	6,640	1,440
Bourbon	3	3,540	5,500	1,960
Cherokee	3	4,520	5,500	980
Jackson	2	2,917	4,109	1,192

soils and many of the bottom-land soils that have previously grown alfalfa for many years, will not produce profitable crops without the aid of phosphorus. When the soil is low in nitrogen and manure cannot be applied previous to seeding, it is advisable to use a fertilizer containing some nitrogen as well as phosphorus, such as a 4-16-0, at seeding time. Careful preparation of the seedbed well in advance of seeding will also help provide a supply of available nitrogen for the young plants.

Applying Fertilizers to Alfalfa.--For a new stand of alfalfa, superphosphate should be applied just previous to seeding or at the time of seeding and annually thereafter at the rate of about 150 pounds per acre for 16 to 18 per cent material. Fertilizer such as 4-16-0 and bone meal should be applied at about the same rate as superphosphate, but if rock phosphate is used the material should be applied at the rate of about 1,000 pounds per acre and should be thoroughly incorporated in the soil.

The application may be made with a fertilizer drill, a combination grain and fertilizer drill, a lime sower, or an old grain drill. After the first year only superphosphate is satisfactory as a top dressing for alfalfa because the other phosphate carriers are relatively insoluble. Superphosphate may be applied to best advantage as a surface dressing in the spring just before growth starts. If desirable, the rate of application of superphosphate may be doubled and the fertilizer applied every second year. If a heavy application of rock phosphate is made at the start, later applications are not necessary.

FERTILIZERS FOR CLOVER

Where red and alsike clover are grown in eastern Kansas they will respond to the use of commercial fertilizer in much the same manner as alfalfa. The fertilizer requirements are the same as for alfalfa and the application should be made at or before the time of seeding.

FERTILIZERS FOR GRAIN SORGHUMS

Since the grain sorghums usually will produce a more profitable yield than corn on thin soils, it is commonly assumed that they will not respond to increased soil fertility. This idea is without foundation because the grain sorghums are capable of a ready response to an increased fertility of the soil.

Commercial fertilizers cannot be used successfully for the grain sorghums in central and western Kansas, but they can be used with profit on many of the upland soils in the eastern part of the state. The grain sorghums in eastern Kansas are commonly planted on the thinner upland soils and consequently on soils which are low in organic matter, nitrogen, and available phosphorus.

The rate of applying fertilizers for the grain sorghums is 75 to 100 pounds per acre. The fertilizer may be used to best advantage by putting it in the row with the seed by use of the combination planter and fertilizer drill. The fertilizer used should be superphosphate or approximately a 4-16-0 mixture.

FERTILIZERS FOR CORN

Commercial fertilizers have not in general been used successfully in the production of corn in Kansas. The materials stimulate the early growth of the plant and thus produce a larger plant which will require more moisture for its development. The heavy removal of moisture takes place in the early part of the season and depletes the amount remaining to mature the crop, consequently when the corn plant is most in need of moisture the supply will be low, the plant will have a tendency to "fire," and lower yields may result. Further, it is apparent that corn yields are dependent upon climatic conditions and general fertility of the soil rather than upon a high content of available plant-food material at the time the crop is planted. Fair increases have been obtained, however, by the use of fertilizer for corn on medium to thin lands. This is particularly true where it is properly used in a rotation.

In tests carried out on experiment fields in southeastern Kansas corn was grown in a rotation that was treated with lime and superphosphate and other soil treatments. The other crops in the rotation, particularly alfalfa, were increased by the treatment. When the land was planted to corn the yield was increased materially through the effect of lime and phosphate. A summary of the yields for the Moran field in Allen county with different treatments is given in Table XVIII. The rotation used was corn, corn, oats, wheat, clover. One crop of corn came immediately after the clover and the second crop followed corn. When clover failed cowpeas were substituted and plowed under for green manure.

TABLE XVIII.—SUMMARY OF CORRECTED YIELDS OF CORN ON SOUTHEASTERN KANSAS EXPERIMENT FIELDS.

Moran, Kan., 1925 to 1930.

TREATMENT.	Average yield of corn, bushels per acre.		Increase for treatment.		Increase for clover and green manure.
	After corn.	After clover or green manure. (a)	After corn.	After clover or green manure.	
No treatment	27.44	37.69	....	....	10.25
Lime	33.66	42.82	6.22	5.13	9.16
Manure	29.37	38.57	1.93	.88	9.20
Lime and manure	35.55	43.44	8.11	5.75	7.89
Lime and superphosphate	35.01	50.31	7.57	12.62	15.30
Lime, manure, and superphosphate	35.99	46.99	8.55	9.30	11.00
Lime, manure, and rock phosphate	34.47	48.82	7.03	11.13	14.35
No legume, no treatment	28.77	35.28	1.33	—2.41	6.51
Lime, potash, and superphosphate	35.71	44.49	8.27	6.80	8.78

(a) In 1925 and 1927 corn was grown after cowpeas had been turned under for green manure. On the other years corn followed clover, except 1930, when it followed alfalfa.

FERTILIZERS FOR SPECIAL CROPS

There are a few special crops or conditions where fertilizers may be used to advantage. These include especially potatoes, apples, and lawns.

Potatoes.--Commercial fertilizers have not been used commonly in the production of potatoes in Kansas and the experimental evidence regarding their use on this crop is meager. Some people in the southeastern part of the state have been using phosphatic and mixed fertilizers on potatoes with a considerable degree of success for several years. The limited information available indicates that commercial fertilizers which are high in nitrogen and phosphorus may be used successfully at the rate of about 300 pounds per acre in the potato section of the Kaw valley and in other sections of eastern Kansas. Present indications are that potash fertilizers cannot be used with profit on potatoes.

Apple Trees.--Commercial fertilizers were not used on the orchard lands in Kansas until about six years ago. During the last few years, however, the use of ammonium sulphate on the apple orchards of northeastern Kansas has become common. The fertilizing method which is meeting with success is the application of ammonium sulphate at the rate of about 5 pounds per tree for an orchard in bearing. The fertilizer is applied about two weeks before the trees come into bloom as a surface dressing around the tree and extending 2 feet beyond the spread of the branches. On larger trees the rate may safely be increased to 7 pounds per tree, and on smaller trees it may be reduced. The fertilizer will influence the thrift of the tree the first year, but will not have much influence on the yield of fruit until the following season.

Lawns.--Most lawns in eastern Kansas can be improved materially by the proper use of a nitrogenous fertilizer. Such fertilizer will cause a thicker and more luxuriant growth of grass of darker green color. Under most conditions it is not advisable to use commercial fertilizers on lawns in the central and western portions of the state, unless thorough and consistent irrigation is practiced.

One of the best lawn fertilizers is ammonium sulphate, which carries a high percentage of nitrogen. (Fig. 20.) The application should be made at three different times during the season, the first one being made in the spring just before the grass starts to grow, the second one during the latter part of May or first of June, and the third in the early fall when the heavier fall growth starts. The material should be applied uniformly over the area at the rate of about 2 pounds per 500 square feet of lawn at each period. Slightly heavier applications may be made, but great care must be exercised to secure uniform distribution of the fertilizer. The application should be made when the grass is dry. It is desirable to water the lawn lightly just after applying the fertilizer.

FIG. 20.—Effect of nitrogenous fertilizers on growth of blue grass in a lawn at Manhattan. Grass harvested from 10-foot-square areas. Soil treatments: (A) No fertilizer; (B) sodium nitrate; (C) ammonium sulphate.

USE OF LIME

Lime is not a fertilizer in the same sense as are the substances that have been discussed as commercial fertilizers. While calcium, the active ingredient of lime, is an indispensable element in plant growth, it is usually present in sufficient quantities in most Kansas soils to supply the needs of the plant, except perhaps in the case of some legumes such as alfalfa and sweet clover. (Fig. 21.) Yet

FIG. 21.—Sweet clover on Cherokee silt loam. On many soils in eastern Kansas sweet clover cannot be grown successfully without the use of lime. Superphosphate also greatly increases the yield. Left—no treatment. Right—lime and superphosphate.

even where this is the case, the soil may be greatly in need of liming, not only for supplying calcium to the plants, but also as a soil amendment for its beneficial effect on many soil properties which indirectly affect the plant. Soils that are low in lime are frequently sour or acid. This condition exists because the lime has been leached out and this has been accompanied by an accumulation of acids in the soil. Some soils may show considerable acidity and still have a fair supply of lime in available form. In such cases, which usually occur on fertile soils, crops may often be grown without liming because the plants are able to get the calcium needed for their growth.

Plants differ widely in their ability to grow on acid or low-lime soils. Some plants such as corn, wheat, oats, and the sorghums are affected very little by soil acidity, while other plants such as alfalfa, sweet clover, and red clover are very sensitive to acid conditions and either fail or make an unsatisfactory growth when there is a deficiency of lime. There are some plants such as berries that do best on soils that are acid and low in lime.

SOILS THAT NEED LIME

Lime is lost from the soil primarily by leaching processes, although some is withdrawn by plants. This means that the soils of porous structure, such as the sands, are more likely to be acid than heavy soils existing under the same conditions. Contrary to popular opinion, bottom-land soils that are poorly drained and subject to frequent overflow are not likely to be acid.

The soils of Kansas vary greatly in their lime content. Those in the western part of the state, where rainfall is light and where there has not been much leaching, have a high lime content. In eastern Kansas, where the rainfall is high, much more leaching has occurred and acid soils have developed. Acid soils are most common where the rainfall is heaviest and where the soils have been formed from sandstone and shale rocks. However, soils formed from limestone are frequently acid in the heavier rainfall areas. The level prairie soils of eastern and southeastern Kansas are low in lime because of the excessive leaching that has taken place.

FORMS OF LIME TO USE

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

Most lime comes originally from limestone rock, where it occurs as calcium carbonate. The active element in the limestone is the calcium, and the lime content of the rock may be expressed as calcium carbonate or calcium oxide. Pure limestone contains 100 per cent calcium carbonate, which is equivalent to approximately 56 per cent of calcium oxide. When limestone is pulverized for agricultural purposes, its value depends upon the purity and fineness of the material. The finer the rock is ground the more effective it becomes. It should be sufficiently fine for all of the material to pass through a 10-mesh sieve and for 40 per cent of it to pass through a 100-mesh sieve.

Quicklime or burned lime is in the form of calcium oxide and is oftener called caustic lime. It is made by burning limestone. This is the most active form of lime, but is usually too expensive to use for agricultural purposes. As much calcium oxide is contained in 100 pounds of pure quicklime as in 178 pounds of pure limestone.

Hydrated lime is quicklime to which water has been added. The water and calcium oxide combine chemically and slaked lime or hydrated lime results. As much calcium oxide is contained in 100 pounds of pure quicklime as in 132 pounds of hydrated lime.

Air-slaked lime is formed when caustic lime or hydrated lime is exposed to the air, because carbon dioxide is absorbed from the atmosphere. Air-slaked lime is usually very fine.

The form of lime to use is usually that which will furnish the equivalent of a pound of calcium at the cheapest price. In Kansas crushed limestone is usually the least expensive to apply. It should be ground fine for best results.

THE QUANTITY OF LIME TO APPLY

There is no accurate method of determining the exact amount of lime to apply per acre. Certain chemical tests give an indication of the amount that should be used, but the results of these tests are not absolute. The rate will vary with the reaction of the soil, the kind of soil, the crop to be grown, and the rotation being followed. It is usually best to apply the lime at that rate which has been found to be best for a given type of soil or to make the tests for lime requirement and base the rate of application upon these tests and the factors mentioned above. Under Kansas conditions the most common rate of application is 2 tons of finely ground limestone per acre. If burned lime or quicklime is used the application should be about one-half that required when crushed limestone is used.

TIME AND METHOD OF APPLICATION

Lime should preferably be applied several weeks before seeding the crop that is to benefit from the treatment. It is a good practice to plow the soil as early as possible for the crop, disk once to level the soil to some extent, and then apply the lime. The lime should then be thoroughly incorporated into the surface soil. Lime should not be plowed under and only in exceptional cases is it practical to make applications to established stands of alfalfa and clover.

The most practical method of applying lime is with a lime spreader. The finest forms may be applied with some types of fertilizer drills. It is sometimes applied with a manure spreader or by hand with a shovel, but it is difficult to make an even distribution of the material by either method.

The limited experimental information available in the state at this time indicates that much lighter rates of application of lime may be used successfully in the production of such crops as sweet clover, if the lime is very fine and is drilled in the row with the seed. An application of 200 to 300 pounds per acre applied in this manner has apparently been as effective in sweet clover production on the acid soils of southeastern Kansas as have applications of as much as 2 tons per acre applied broadcast and harrowed in before seeding.

BUILDING UP RUN-DOWN LAND

Land that has been badly depleted in fertility, because of continuous cropping to grain or other cultivated crops and of the loss of surface soil by erosion, may often be brought back into a condition where profitable crops can be grown. It is not an easy matter to increase the total amount of plant food in an acre of wornout land, but the land can be so managed that larger crops can be grown. This can be done by providing a good physical condition in the soil and an abundant supply of available plant-food material.

There are several fundamental principles that should be observed in the proper management of poor land. One of the first things that should be done is to work out a cropping system that will aid in providing available nutrients, that will add some nitrogen to the soil, and supply the needs of the live stock to be kept. For a farm in the humid region some legume crop should always be included. This should occupy from one-fourth to one-third of the cultivated acreage.

In order to grow these legume crops most successfully, especially alfalfa and clovers, it will be necessary in most cases to add lime and some commercial fertilizer to the land. Phosphates such as superphosphate, bone meal, or rock phosphate are the fertilizers most commonly used. By the addition of these phosphates larger crops of legumes may be grown and consequently larger amounts of nitrogen may be fixed from the air. This in turn will enrich the soil in total nitrogen, provide larger supplies of available nitrogen for the needs of the following crops, and thus greatly stimulate the growth of other crops in the rotation.

When the growth of grain crops is thus enhanced by the use of legumes combined with phosphatic fertilizers, not only will the immediate profit from the farm usually be increased, but if the crops are fed to live stock the amount of manure produced on the farm will be increased. This additional amount of manure can be returned to the soil with a resulting further increase in the productivity of the land.

Many run-down soils have been reduced in productiveness because of soil erosion. In fact this is one of the most common causes of really exhausted soils. In such cases every practical precaution should be taken against further loss of fertility in this way. A cropping system should be adopted that will keep the land covered with a crop as much of the time as possible, and especially during seasons of the year when heavy rains are most likely to occur. The construction of a system of terraces (see “Terracing,” page 28) will immediately check serious erosion on gentle slopes. Contour plowing or planting will also aid materially in reducing erosion when row crops are grown. The steep slopes should be kept in permanent sod most of the time. If these sod lands are reinforced with some legume such as white clover, Korean lespedeza, or sweet clover, the productivity of the pasture will not only be increased but the future productivity of the land will be improved.

In considering the improvement of run-down land it should be remembered that where the farmer must make a living from the land the first thing to do is to produce satisfactory yields. The yields must be increased before the farmer will be in financial condition to strive for permanently richer soil. This increase in yields can be brought about by the use of commercial fertilizers, lime, and crop rotation, as well as by the careful selection of the crops to be grown combined with the best methods of cultivating and handling the land. Later increases may be obtained from a more extensive use of manure, or manure combined with the other soil treatments named. These statements concerning the use of fertilizers must be taken to apply only to the regions where soils have been shown to respond to fertilizer treatment.

DRAINAGE

Where land does not have sufficient drainage it is often unproductive, even though the soil has a high percentage of nutrient elements. In many cases the wise use of surface ditches will remove the water so that the land can be farmed without difficulty. In other cases it may be necessary to install a system of tile drainage. In most cases surface drainage should be used as far as possible, since this is less expensive than tile drainage. Tile drains are a permanent improvement in wet soils and when once properly installed require very little attention. They are much more satisfactory than surface ditches because they require but little attention and do not interfere with cultivation.

Owing to the high cost of installing tile and also to the recent decrease in land values, very little tile drainage has been done during recent years. Anyone contemplating the use of tile should secure the advice of one experienced in this work before spending money on such a project.

IRRIGATION

Many Kansas soils are reduced in their productiveness because of an insufficient supply of moisture. There are several million acres in the state that have possibilities for irrigation. That is, water is available either from surface streams or from underground flow for purposes of irrigation. At present only a very small percentage of the irrigation possibilities of the state are being utilized.

The possibilities for making irrigation profitable are best on crops that make much of their growth during midsummer. Alfalfa, sugar beets, grain sorghums, corn, and truck crops often give greatly increased yields from irrigation. At the Garden City station large increases have been obtained by irrigation on grain sorghums. Some of these results are shown in Table XIX.

TABLE XIX.—EFFECT OF IRRIGATION ON YIELD OF CROPS AT THE GARDEN CITY BRANCH STATION.

Nine-year average, 1921 to 1929.

CROP.	Yield, bus. per acre.	
	Not irrigated.	Winter irrigated.
Dwarf Yellow milo........	24.9	46.9
Blackhull White kafir......	14.2	40.7
Pink kafir...............	17.6	38.6
Sudan grass..............	4.6	10.0

The alfalfa yields under irrigation at Garden City have averaged 6.77 tons per acre, whereas the crop cannot be produced satisfactorily there under dry-land conditions. Irrigation water is usually applied during the growing season, but good results have been obtained at Garden City by applying the irrigation water in the late winter or early spring.

In the use of irrigation water some care must be exercised to see that the water does not contain too much soluble salt. Water containing as much as 1,000 parts per million of soluble salt is usually of doubtful value and in many cases should not be used. The amount of salt contained is, however, of no more importance than the kind of salts present in irrigation water. It is important that the ratio of equivalent quantities of calcium and sodium be at least 1 to 1 and preferably the proportion of calcium salts should be even higher. If sodium salts are too high an unfavorable condition may develop for the growth of plants and the physical condition of the soil may be injured.

ALKALI SPOTS

In many places throughout Kansas small unproductive areas known as "alkali spots" or sometimes as "slick spots" are found. These may occur on hillsides, where they are the result of seepage water coming to the surface. As the water evaporates the dissolved salts are left at the surface of the ground. This concentration of salts hinders or may completely prevent the growth of plants. These seeps usually appear at the surface because of a heavy layer of clay in the subsoil. Consequently these spots are usually hard and difficult to work. The salts may also be of such a nature as to cause deflocculation of the clay. This makes it still more impervious to water.

In other cases the "alkali spots" occur on level areas or bottom lands. In such cases the subsoil is usually so heavy as to prevent good drainage. The water therefore evaporates from the surface and leaves the salt deposits. This is true especially where the spots occur in small depressions. In other cases the alkali soil is due to a high water table along streams. The water rises by capillarity through the soil and evaporates, leaving the salt at the surface. There are many such areas along the Arkansas river and its tributaries. These areas usually grow salt grass and are known as "salt-grass lands."

Another cause of alkali soils in some places is the use of irrigation water that is highly contaminated with soluble salts. Most of the water now being used for irrigation in Kansas probably is not high enough in salt content to be injurious to the soil. There are, however, certain well waters and also certain streams in Kansas that carry so high a concentration of soluble salts that they should not be used for irrigation purposes. It is advisable, therefore, to have a careful study made of water that is to be used for irrigation, before any large projects are begun.

The principal salts that are causing alkali trouble in Kansas are sodium chloride (common salt), sodium sulphate, and sodium bicarbonate. There are also salts of calcium and magnesium in certain places that may be sufficiently highly concentrated to be harmful. In most cases, however, the presence of these latter salts will tend to counteract the harmful action of the sodium salts.

Not much experimental work has as yet been done in Kansas to determine the best treatments for these various alkali conditions. There are, however, certain things that can be done to improve such lands. Good drainage should be provided in all cases. In practically all alkali conditions, lack of adequate drainage is one of the primary causes. If this is improved, other treatments will be more effective. In many cases improving the drainage conditions will be sufficient to eliminate serious trouble. The drainage may in some cases be accomplished by means of surface ditches. In others tile drains will be needed.

Heavy applications of manure and phosphate are usually of some benefit. Deep plowing immediately before seeding will mix the salt, with a considerable layer of soil and thus permit seeds to germinate and get started before the salt again concentrates at the surface in amounts sufficient to prevent growth. There are certain other chemical treatments sometimes used for alkali soils, but not enough experimental work has been done with these to justify their general recommendation at the present time. On many of these spots, growing sweet clover will improve the soil.