UNIVERSITY OF ILLINOIS

Agricultural Experiment Station

SOIL REPORT NO. 6

KNOX COUNTY SOILS

By CYRIL G. HOPKINS, J. G. MOSIER,
J. H. PETTIT, AND J. E. READHIMER

URBANA, ILLINOIS, AUGUST, 1913

STATE ADVISORY COMMITTEE ON SOIL INVESTIGATIONS

Ralph Allen, Delavan
A. N. Abbott, Morrison
F. I. Mann, Gilman
J. P. Mason, Elgin
C. V. Gregory, 538 S. Clark St., Chicago.

AGRICULTURAL EXPERIMENT STATION STAFF ON SOIL INVESTIGATIONS

Eugene Davenport, Director
Cyril G. Hopkins, Chief in Agronomy and Chemistry

Soil Analysis

J. H. Pettit, Chief
E. Van Alstine, Associate
J. P. Aumer, Associate
W. H. Sachs, First Assistant
Gertrude Niederman, Assistant
W. R. Leighty, Assistant
Oran Keller, Assistant
L. R. Binding, Assistant

Soil Experiment Fields—

J. E. Readhimer, Superintendent
Wm. G. Eckhardt,[1] Associate
O. S. Fisher, Associate
J. E. Whitchurch, Associate
E. E. Hoskins, Associate
F. C. Bauer, First Assistant
F. W. Garrett, Assistant

Soil Survey—

J. G. Mosier, Chief
A. F. Gustafson, Associate
S. V. Holt, Associate
H. W. Stewart, Associate
H. C. Wheeler, Associate
F. A. Fisher, Assistant
F. M. W. Wascher, Assistant
R. W. Dickenson, Assistant
John Woodard, Assistant

Soil Biology

A. L. Whiting, First Assistant

Soils Extension—

C. C. Logan, Associate

[1]On leave.

INTRODUCTORY NOTE

About two-thirds of Illinois lies in the corn belt, where most of the prairie lands are black or dark brown in color. In the southern third of the state, the prairie soils are largely of a gray color. This region is better known as the wheat belt, altho wheat is often grown in the corn belt and corn is also a common crop in the wheat belt.

Moultrie county, representing the corn belt; Clay county, which is fairly representative of the wheat belt; and Hardin county, which is taken to represent the unglaciated area of the extreme southern part of the state, were selected for the first Illinois Soil Reports by counties. While these three county soil reports were sent to the Station's entire mailing list within the state, Sangamon, La Salle, and other subsequent reports are sent only to the residents of the county concerned and to any one else upon request.

Each county report is intended to be as nearly complete in itself as it is practicable to make it, and, even at the expense of some repetition, each will contain a general discussion of important fundamental principles to help the farmer and landowner to understand the meaning of the soil fertility invoice for the lands in which he is interested. In Soil Report No. 1, "Clay County Soils," this discussion serves in part as an introduction, while in this and other reports it will be found in the Appendix, but if necessary it should be read and studied in advance of the report proper.

KNOX COUNTY SOILS

By CYRIL G. HOPKINS, J. G. MOSIER, J. H. PETTIT, AND J. E. READHIMER

Knox county lies in the upper Illinois glaciation and has an area of 720.69 square miles. The general topography of the northern and western half is undulating or slightly rolling, while the southern and southeastern portion is in part badly broken, especially along Spoon river and its tributaries. The upland prairie soils cover 57 percent of the county, the undulating timber lands about 14½ percent, the rough or rolling timber lands about 18½ percent, and the bottom lands nearly 10 percent.

The difference in topography is due to two causes—glacial action and stream erosion. Like most of the state, this county was covered by an ice sheet during the glacial period. During that time snow and ice accumulated in the region of Hudson Bay to such an amount that it pushed southward until a point was reached where the ice melted as rapidly as it advanced. In moving across the country, the ice gathered up all sorts and sizes of material, including pebbles, boulders, and even large masses of rock. Many of these were carried hundreds of miles and rubbed against the surface rocks or against each other until ground into powder. When the limit of advance was reached, where the ice largely melted, this material would accumulate in a broad undulating ridge, or moraine. When the ice melted away more rapidly than the glacier advanced, the terminus of the glacier would recede and leave a drift of boulder clay deposited somewhat uniformly, yet not entirely so, over the inter-morainal tract marking the area previously covered by the ice sheet. These intermorainal tracts are occupied chiefly by level, undulating, or rolling plains.

The material transported by the glacier varied with the character of the rocks over which it passed. Granites, limestones, sandstones, shales, etc., were mixed and ground up together. This mixture of all kinds of material, boulders, gravel, sand, silt, and clay, is called boulder clay, till, glacial drift, or simply drift. The grinding and denuding power of glaciers is enormous. A mass of ice 100 feet thick exerts a pressure of 40 pounds per square inch and this ice sheet may have been thousands of feet in thickness. The materials carried along in this mass of ice, especially the boulders and pebbles, became powerful agents for grinding and wearing away the surface over which the ice passed. Preglacial ridges and hills were rubbed down, valleys were filled with the debris, and the surface features changed entirely.

The depth of boulder clay over Knox county averages near 30 feet. No continuous morainal ridges occur; if they ever existed, they have been torn down thru erosion until now they are represented by a few high and somewhat isolated areas whose locations are shown upon the map by broken lines. These are also indicated by serial numbers 200 instead of 500. (See Bulletin 123, state map and pages 257 and 258.) There are two of these morainal areas in the county, one northwest and north of Oneida and the other southwest of Yates City. This latter was probably at one time a continuous ridge, but it has been cut in two by Spoon river and Willow creek.

PHYSIOGRAPHY AND ALTITUDE

The northwest quarter of the county drains into the Mississippi river; the rest drains principally thru Spoon river into the Illinois. The divide between the two rivers extends south and southwest from Section 2, Township 13 North, Range 2 East of the Fourth Principal Meridian, leaving the county in the northwest corner of Township 10 North, Range 1 East. The altitude of the divide varies from 770 to 840 feet above sea level. The average altitude of the county is 725 feet. The highest point, 859 feet, is in Section 10, Township 13 North, Range 4 East, while the lowest, about 536 feet, is where Spoon river leaves the county.

Spoon river and its tributaries have produced quite a variation in topography. The valleys of these streams are from 50 to 200 feet or more below the general level of the upland. This has permitted the small streams entering the river to do a large amount of erosion, and as a result the land adjacent to the bottom land of the larger streams is cut up into hills and valleys unsuited for ordinary agriculture. Before the land was put under cultivation, forests had extended their way up the streams and were slowly invading the adjoining prairies.

SOIL MATERIAL AND SOIL TYPES

The Illinois glacier covered Knox county and left a thick mantle of drift, completely burying the old soil that preceded it. After this a long period elapsed during which a deep soil, known as the old Sangamon soil,[1] was formed on the Illinois drift. Later, other ice invasions occurred, but they covered only the northern and northeastern parts of the state. (See state map in Bulletin 123, Iowan and Wisconsin glaciations.) These ice sheets did not reach Knox county, but finely-ground rock (rock flour) in immense quantities was carried south by the waters from the melting ice and deposited on the flooded plains, where it was picked up by the wind, carried farther, and finally deposited upon the surface, burying the drift material of the Illinois glaciation and the old Sangamon soil to a depth of 5 to 50 feet or more. This wind-blown material, called loess, represents a mixture of all kinds of material over which the glacier passed. The deeper deposit is nearer and on the east side of the larger stream courses and opposite the greatest width of bottom land. Its average depth in this county is about 15 feet. Soil has been formed from this comparatively new material.

The soils of Knox county are divided into three classes, as follows:

(1) Upland prairie soils, rich in organic matter. These were originally covered with wild prairie grasses, the partially decayed roots of which have been the source of the organic matter. The flat prairie land contains the higher amount of this constituent because the grasses and roots grew more luxuriantly there and the higher moisture content largely preserved them from decay.

(2) Upland timber soils, including those zones along stream courses over which forests once extended. These soils contain much less organic matter

[1]The Sangamon soil may sometimes be seen in cuts as a somewhat dark or bluish sticky clay or a weathered zone of yellowish or brownish clay.

because the large roots of dead trees and the surface accumulations of leaves, twigs, and fallen trees were burned by forest fires or suffered almost complete decay. The timber lands are divided chiefly into two classes—the undulating and the hilly areas.

(3) Swamp and bottom lands, which include the flood plains along streams and some small peaty swamp areas.

Table 1 gives the area of each type of soil in the county and its percentage of the total area. It will be observed that more than half the entire county is covered with the common prairie soil known as brown silt loam, and that about one-third consists of two upland timber types, the yellow silt loam (hilly) and the yellow-gray silt loam (undulating), the former occupying almost one-fifth of the entire county.

TABLE 1.—SOIL TYPES OF KNOX COUNTY

Soil type No. [1]	Name of type	Area in square miles	Area in acres	Percent of total area
	(a) Upland Prairie Soils (page 22)			
526	Brown silt loam	402.60	257 664	55.87
520	Black clay loam	8.31	5 318	1.15
528	Brown-gray silt loam on tight clay	.46	295	.06
	(b) Upland Timber Soils (page 26)			
534	Yellow-gray silt loam	104.43	66 836	14.48
535	Yellow silt loam	133.71	85 574	18.56
532	Light gray silt loam on tight clay	.02	12	.003
	(c) Swamp and Bottom-Land Soils (page 30)			
1326	Deep brown silt loam	71.09	45 498	9.86
1303	Shallow peat on clay	.03	19	.004
1301	Deep peat	.04	26	.006
	Total	720.69	461 242	100.00

[1]Soil types Nos. 226, 234, 235, and 232, as found on the maps, represent the same types as Nos. 526, 534, 535, and 532, except that the former are found on morainal areas.

The accompanying maps show the location and boundary lines of every type of soil in the county, even down to areas of a few acres; and in Table 2 are reported the amounts of organic carbon (the best measure of the organic matter) and the total amounts of the five important elements of plant food contained in 2 million pounds of the surface soil of each type (the plowed soil of an acre about 6⅔ inches deep). In addition, the table shows the amount of limestone present, if any, or the amount of limestone required to neutralize the acidity existing in the soil.[1]

[1]The figures given in Table 2 (and in the corresponding tables for subsurface and subsoil) are the averages for all determinations with some exceptions of limestone present or required. Some soil types, particularly those which are subject to erosion, may vary from acid to alkaline, especially in the subsurface or subsoil; and in such cases the word used in the table (see Table 11) is more useful than any average of figures involving both plus and minus quantities.

THE INVOICE AND INCREASE OF FERTILITY IN KNOX COUNTY SOILS

SOIL ANALYSIS

In order to avoid confusion in applying in a practical way the technical information contained in this report, the results are given in the most simplified form. The composition reported for a given soil type is, as a rule, the average of many analyses, which, like most things in nature, show more or less variation; but for all practical purposes the average is most trustworthy and sufficient. (See Bulletin 123, which reports the general soil survey of the state, together with many hundred individual analyses of soil samples representing twenty-five of the most important and most extensive soil types in the state.)

The chemical analysis of the soil gives the invoice of fertility actually present in the soil strata sampled and analyzed, but, as explained in the Appendix, the rate of liberation is governed by many factors. Also, as there stated, probably no agricultural fact is more generally known by farmers and landowners than that soils differ in productive power. Even tho plowed alike and at the same time, prepared the same way, planted the same day with the same kind of seed, and cultivated alike, watered by the same rains and warmed by the same sun, nevertheless the best acre may produce twice as large a crop as the poorest acre on the same farm, if not, indeed, in the same field; and the fact should be repeated and emphasized that the productive power of normal soil in humid sections depends upon the stock of plant food contained in the soil and upon the rate at which it is liberated.

The fact may be repeated, too, that crops are not made out of nothing. They are composed of ten different elements of plant food, every one of which is absolutely essential for the growth and formation of every agricultural plant. Of these ten elements of plant food, only two (carbon and oxygen) are secured from the air by all plants, only one (hydrogen) from water, while seven are secured from the soil. Nitrogen, one of these seven elements secured from the soil by all plants, may also be secured from the air by one class of plants (legumes) in case the amount liberated from the soil is insufficient. But even the leguminous plants (which include the clovers, peas, beans, alfalfa, and vetches), in common with other agricultural plants, secure from the soil alone six elements (phosphorus, potassium, magnesium, calcium, iron, and sulfur) and also utilize the soil nitrogen so far as it becomes soluble and available during their period of growth.

Table A in the Appendix shows the requirements of large crops for the five most important plant-food elements which the soil must furnish. (Iron and sulfur are supplied normally from natural sources in sufficient abundance compared with the amounts needed by plants, so that they are never known to limit the yield of common farm crops.)

As stated, the data in Table 2 represent the total amounts of plant-food elements found in 2 million pounds of surface soil,[1] which corresponds to an acre about 6⅔ inches deep. This includes at least as much soil as is ordinarily turned with the plow, and represents that part with which the farm manure, limestone, phosphate, or other fertilizer applied in soil improvement is incorporated. It is the soil stratum that must be depended upon

[1]The weight of peat is figured at ½ the weight of normal soils.

TABLE 2.—FERTILITY IN THE SOILS OF KNOX COUNTY

Average pounds per acre in 2 million pounds of surface soil[1] (about 0 to 6$\frac{2}{3}$ inches)

Soil type No.	Soil type	Total organic carbon	Total nitrogen	Total phosphorus	Total potassium	Total magnesium	Total calcium	Limestone present	Limestone requir'd
	Upland Prairie Soils								
526	Brown silt loam	65 750	5 150	1 200	32 730	9 670	12 400		70
520	Black clay loam	92 450	7 650	1 840	29 710	13 830	23 880		40
528	Brown-gray silt loam on tight clay	43 960	3 320	1 000	33 900	7 900	9 560		80
	Upland Timber Soils								
534	Yellow-gray silt loam	25 900	2 440	860	33 930	6 620	8 300		120
535	Yellow silt loam	25 420	2 330	820	36 100	7 090	7 930		60
532	Light gray silt loam on tight clay	26 480	2 020	980	36 020	6 500	9 160		80
	Swamp and Bottom Land Soils								
1326	Deep brown silt loam	60 790	4 910	1 790	36 190	10 250	12 130		50
1301	Deep peat	222 100	15 730	1 410	3 660	8 590	160 960	345 670	
1303	Shallow peat on clay	279 660	21 870	2 070	8 920	8 660	26 760	4 810	

[1] In 1 million pounds of peat (1301 and 1303).

in large part to furnish the necessary plant food for the production of crops, as will be seen from the information given in the Appendix. Even a rich subsoil has little or no value if it lies beneath a worn-out surface, but if the fertility of the surface soil is maintained at a high point, then the strong, vigorous plants will have power to secure more plant food from the subsurface and subsoil than would weak, shallow-rooted plants.

By easy computation it will be found that the most common prairie soil of Knox county does not contain more than enough total nitrogen in the plowed soil for the production of maximum crops for ten rotations (40 years); while the upland timber soils contain, as an average, less than one-half as much nitrogen as the prairie land.

With respect to phosphorus, the condition differs only in degree, nine-tenths of the soil area of the county containing no more of that element than would be required for sixteen crop rotations if such yields were secured as are suggested in Table A of the Appendix. It will be seen from the same table that in the case of the cereals about three-fourths of the phosphorus taken from the soil is deposited in the grain, while only one-fourth remains in the straw or stalks.

On the other hand, the potassium is sufficient for 25 centuries if only the grain is sold, or for 400 years even if the total crops should be removed and nothing returned. The corresponding figures are about 2500 and 600 years for magnesium, and about 15,000 and 300 years for calcium.

Thus, when measured by the actual crop requirements for plant food, potassium is no more limited than magnesium and calcium, and, as explained in the Appendix, with these elements we must also consider the fact that loss by leaching is far greater than by cropping.

These general statements relating to the total quantities of plant food in the plowed soil certainly emphasize the fact that the supplies of some of these necessary elements of fertility are extremely limited when measured by the needs of large crop yields for even one or two generations of people.

The variation among the different soil types with respect to their content of important plant-food elements is also very marked. Thus, the prairie soils contain two to three times as much nitrogen as the timber lands of the same topography; and the richest prairie land contains twice as much phosphorus as the common upland timber soils.

On the other hand, the most significant fact revealed by the investigation of the Knox county soils is the low phosphorus content of the common brown silt loam prairie, a type of soil which covers more than half the entire county. The market value of this land is about $200 an acre, and yet an application of forty dollars' worth of fine-ground raw rock phosphate

PLATE 1. WHEAT IN 1911 ON URBANA FIELD
COVER CROPS AND CROP RESIDUES PLOWED UNDER
AVERAGE YIELD, 35.2 BUSHELS PER ACRE

would double the phosphorus content of the plowed soil, and, if properly made, would in the near future double the yield of clover on the normal prairie soil and the undulating upland timber soils. If the clover was then returned to the soil, either directly or in farm manure, the combined effect of phosphorus and increased nitrogenous organic matter, with a good rotation of crops, would in time double the yield of corn on most farms.

With 5,000 pounds of nitrogen in the prairie soil and an inexhaustible supply in the air, with 33,000 pounds of potassium in the same soil and with practically no acidity, the economic loss in farming such land with only 1200 pounds of total phosphorus in the plowed soil can be appreciated only by the man who fully realizes that in less than one generation the crop yields could be doubled by adding phosphorus,—without change of seed or season and with very little more work than is now devoted to the fields.

Fortunately, some definite field experiments have already been conducted

PLATE 2. WHEAT IN 1911 ON URBANA FIELD
COVER CROPS AND CROP RESIDUES PLOWED UNDER
FINE-GROUND ROCK PHOSPHATE APPLIED
AVERAGE YIELD, 50.1 BUSHELS PER ACRE

on this most extensive type of soil, both in Knox county and on similar soil in several other counties, as at Urbana in Champaign county, at Sibley in Ford county, and at Bloomington in McLean county.

RESULTS OF FIELD EXPERIMENTS AT URBANA

A three-year rotation of corn, oats, and clover was begun on the North Farm at the University of Illinois in 1902, on three fields of typical brown silt loam prairie land which, after twenty years or more of pasturing, had grown corn in 1895, 1896, and 1897 (when careful records were kept of the yields produced) and had then been cropped with clover and grass on one field, oats on another, and oats, cowpeas, and corn on the third field, until 1901.

As an average of the first three years (1902-1904) phosphorus increased

PLATE 3. WHEAT IN 1911 ON URBANA FIELD
COVER CROPS AND FARM MANURE PLOWED UNDER
AVERAGE YIELD, 34.2 BUSHELS PER ACRE

TABLE 3.—EFFECT OF PHOSPHORUS ON BROWN SILT LOAM AT URBANA
(Average increase per acre)

Rotation	Years	Corn, bu.	Oats, bu.	Clover, tons	Value of increase[1]	Cost of treatment[1]
First..........	1902,-3,-4	8.8	1.9	.68	$ 7.73	$7.50
Second	1905,-6,-7	13.2	11.9	.79	12.93	7.50
Third..........	1908,-9,-10	18.7	8.4	1.05	15.37	7.17

[1]Prices used are 35 cents a bushel for corn, 30 cents for oats, $6 a ton for clover hay, 10 and 3 cents a pound, respectively, for phosphorus in bone meal and in rock phosphate.

the crop yields per acre by .68 ton of clover, 8.8 bushels of corn, and 1.9 bushels of oats. During the second three years (1905-1907) it produced average increases of .79 ton of clover, 13.2 bushels of corn, and 11.9 bushels of oats. During the third course of the rotation (1908-1910) it produced aver-

PLATE 4. WHEAT IN 1911 ON URBANA FIELD
COVER CROPS AND FARM MANURE PLOWED UNDER
FINE-GROUND ROCK PHOSPHATE APPLIED
AVERAGE YIELD, 51.8 BUSHELS PER ACRE

age increases of 1.05 tons of clover, 18.7 bushels of corn, and 8.4 bushels of oats. For convenient reference the results are summarized in Table 3.

Wheat is grown on the University South Farm in a rotation experiment started more recently. As an average of the four years 1908 to 1911, raw rock phosphate (with no previous application of bone meal) increased the yield of wheat by 10.3 bushels per acre. Here too, as an average of the four years, the phosphorus applied paid back about twice its cost.

In the grain system of farming, the yield of wheat in 1911 was 35.2 bushels per acre where cover crops and crop residues are plowed under without the use of phosphorus; but where rock phosphate is used the average yield was 50.1 bushels. (See Plates 1 and 2.)

In the live-stock system, the yield of wheat in 1911 was 34.2 bushels where manure and cover crops are used without phosphate, and 51.8 bushels, as an average, where rock phosphate is used in addition. (See Plates 3 and 4.)

These results emphasize the cumulative effect of permanent systems of soil improvement.

Wheat has also been grown on the North Farm during the last three years, and the average increase produced by phosphorus (part in bone meal and part in raw phosphate) has been 12.4 bushels per acre.

RESULTS OF EXPERIMENTS ON SIBLEY FIELD

Table 4 gives the results obtained during the past eleven years from the Sibley soil experiment field located in Ford county on the typical brown silt loam prairie of the Illinois corn belt.

Previous to 1902 this land had been cropped with corn and oats for many years under a system of tenant farming, and the soil had become somewhat deficient in active organic matter. While phosphorus was the limiting element of plant food, the supply of nitrogen becoming available annually was but little in excess of the phosphorus, as is well shown by the corn yields for 1903, when phosphorus produced an increase of 8 bushels, nitrogen without phosphorus produced no increase, but nitrogen and phosphorus together increased the yield by 15 bushels.

After six years of additional cropping, however, nitrogen appears to have become the most limiting element, the increase in the corn in 1907 having been 9 bushels from nitrogen and only 5 bushels from phosphorus, while both together produced an increase of 33 bushels. By comparing the corn yields for the four years 1902, 1903, 1906, and 1907, it will be seen that the untreated land has apparently grown less productive, whereas on land receiving both phosphorus and nitrogen the yield has appreciably increased, so that in 1907, when the untreated rotated land produced only 34 bushels of corn per acre, a yield of 72 bushels (more than twice as much) was produced where lime, nitrogen, and phosphorus had been applied, altho the two plots produced exactly the same yield (57.3 bushels) in 1902.

Even in the unfavorable season of 1910, the yield of the highest-producing plot exceeded that of 1902, while the untreated land produced less than half as much as it produced in 1902. The prolonged drouth of 1911 resulted in almost a failure of the corn crop, but nevertheless the effect of soil treatment is seen. Phosphorus appears to have been the first limiting element again in 1909, 1910, and 1911; while the lodging of oats, especially on the

TABLE 4.—CROP YIELDS IN SOIL EXPERIMENTS, SIBLEY FIELD

Brown silt loam prairie; early Wisconsin glacation		Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Corn 1906	Corn 1907	Oats 1908	Wheat 1909	Corn 1910	Corn 1911	Oats 1912
Plot	Soil treatment applied	Bushels per acre										
101	None	57.3	50.4	74.4	29.5	36.7	33.9	25.9	25.3	26.6	20.7	84.4
102	Lime	60.0	54.0	74.7	31.7	39.2	38.9	24.7	28.8	34.0	22.2	85.6
103	Lime, nitrogen	60.0	54.3	77.5	32.8	41.7	48.1	36.3	19.0	29.0	22.4	25.3
104	Lime, phosphorus	61.3	62.3	92.5	36.3	44.8	43.5	25.6	32.2	52.0	31.6	92.3
105	Lime, potassium	55.0	49.9	74.4	30.2	37.5	34.9	22.2	23.2	34.2	21.6	83.1
106	Lime, nitrogen, phosphorus	57.3	69.1	88.4	45.2	68.5	72.3	45.6	33.3	55.6	35.3	42.2
107	Lime, nitrogen, potassium	53.3	51.4	75.9	37.7	39.7	51.1	42.2	25.8	46.2	20.1	55.6
108	Lime, phosphorus, potassium	58.7	60.9	80.0	39.8	41.5	39.8	27.2	28.5	43.0	31.8	79.7
109	Lime, nitrogen, phos., potas.	58.7	65.9	82.5	48.0	69.5	80.1	52.8	35.0	58.0	35.7	57.2
110	Nitro., phos., potassium	60.0	60.1	85.0	48.5	63.3	72.3	44.1	30.8	64.4	31.5	54.1

Average Increase: Bushels per Acre

	Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Corn 1906	Corn 1907	Oats 1908	Wheat 1909	Corn 1910	Corn 1911	Oats 1912
For nitrogen	−1.7	3.4	.7	6.4	14.1	23.6	19.3	.1	6.4	1.6	−40.1
For phosphorus	1.7	12.1	10.7	9.2	16.5	15.7	6.4	8.1	16.3	12.0	5.4
For potassium	−3.0	−2.9	−5.1	2.4	−1.5	1.0	3.0	− .2	2.7	− .6	7.5
For nitro., phos., over phos.	−4.0	6.8	−4.1	8.9	23.7	28.8	20.0	1.1	3.6	3.7	−50.1
For phos., nitro. over nitro	−2.7	14.8	10.9	12.4	26.8	24.2	9.3	14.3	26.6	12.9	16.9
For potas., nitro., phos. over nitro., phos.	1.4	−3.2	−5.9	2.8	1.0	7.8	7.2	1.7	2.4	.4	15.0

Value of Crops per Acre in Eleven Years

Plot	Soil treatment applied	Total value of eleven crops	Value of increase
101	None	$ 172.73	
102	Lime	184.75	$ 12.02
103	Lime, nitrogen	167.42	— 5.31
104	Lime, phosphorus	214.50	41.77
105	Lime, potassium	173.22	.49
106	Lime, nitrogen, phosphorus	233.15	60.42
107	Lime, nitrogen, potassium	188.19	15.46
108	Lime, phosphorus, potassium	200.37	27.64
109	Lime, nitrogen, phosphorus, potassium	244.62	71.89
110	Nitrogen, phosphorus, potassium	233.51	60.81

Value of Increase per Acre in Eleven Years		Cost of increase
For nitrogen	$-17.33	$ 165.00
For phosphorus	29.75	27.50
For *nitrogen* and phosphorus over phosphorus	18.65	165.00
For *phosphorus* and nitrogen over nitrogen	65.73	27.50
For *potassium*, nitrogen, and phosphorus over nitrogen and phosphorus	11.47	27.50

nitrogen plots, in the exceptionally favorable season of 1912, produced very irregular results.

In the lower part of Table 4 are shown the total values per acre of the eleven crops from each of the ten different plots, the amounts varying from $167.42 to $244.62; also the value of the increase produced in crop yields above the value of the yields from the untreated land, corn being valued at 35 cents a bushel, oats at 30 cents, and wheat at 70 cents. Phosphorus without nitrogen produced $29.75 in addition to the increase by lime; but, with nitrogen, it produced $65.73 above the crop values where only lime and nitrogen were used. The results show that in 25 cases out of 44 the addition of potassium decreased the crop yields. Even under the most favorable conditions, and with no effort to liberate potassium from the soil by adding organic matter, potassium paid back less than half its cost.

By comparing Plots 101 and 102, and also 109 and 110, it will be seen that the average increase produced by lime was $11.55, or more than $1 an acre a year. Altho this increase may have been above normal on these plots because of the "condition" of the soil at the beginning, it suggests that the time is here when limestone must be applied to some of these brown silt loam soils. While nitrogen produced an appreciable increase, especially when phosphorus was provided, the only conclusion to be drawn, if we are to utilize this fact to advantage, is that the nitrogen must be secured from the air.

RESULTS OF EXPERIMENTS ON BLOOMINGTON FIELD

Space is taken to insert Table 5, giving all of the results thus far obtained from the Bloomington soil experiment field, which is also located on the brown silt loam prairie soil of the Illinois corn belt.

The general results of the eleven years' work on the Bloomington field tell much the same story as those from the Sibley field. The rotations differed by the use of clover and by discontinuing the use of commercial nitrogen on the Bloomington field after 1905, in consequence of which phosphorus without commercial nitrogen (Plot 104) produced an even larger increase ($89.92) than was produced by phosphorus over nitrogen ($65.73) on the Sibley field (see Plots 103 and 106).

It should be stated that a draw runs near Plot 110 on the Bloomington field, that the crops on that plot are sometimes damaged by overflow or imperfect drainage, and that Plot 101 occupies the lowest ground on the opposite side of the field. In part because of these irregularities and in part because only one small application has been made, no conclusions can be drawn in regard to lime. Otherwise all results reported in Table 5 are considered reliable. They not only furnish much information in themselves but they also offer instructive comparisons with the Sibley field.

Wherever nitrogen was provided, either by direct application or by the use of legume crops, the addition of the element phosphorus produced very marked increases, the average yearly increase for the Bloomington field being worth $7.11 an acre. This is $4.61 above the cost of the phosphorus in 200 pounds of steamed bone meal, the form in which it was applied to the Sibley and Bloomington fields. On the other hand, the use of phosphorus without nitrogen will not maintain the fertility of the soil (see Plots 104 and 106, Sibley field). As the only practical and profitable method of supplying the nitrogen, a liberal use of clover or other legumes is suggested, the legume to be plowed

TABLE 5.—CROP YIELDS IN SOIL EXPERIMENTS, BLOOMINGTON FIELD

Plot	Brown silt loam prairie; early Wisconsin glaciation	Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Clover 1906	Corn 1907	Corn 1908	Oats 1909	Clover[2] 1910	Wheat 1911	Corn 1912
Plot	Soil treatment applied	Bushels or tons per acre										
101	None	30.8	63.9	54.8	30.8	.39	60.8	40.3	46.4	1.56	22.5	55.2
102	Lime	37.0	60.3	60.8	28.8	.58	63.1	35.3	53.6	1.09	22.5	47.9
103	Lime, crop res.[1]	35.1	59.5	69.8	30.5	.46	64.3	36.9	49.4	(.83)	25.6	62.5
104	Lime, phosphorus	41.7	73.0	72.7	39.2	1.65	82.1	47.5	63.8	4.21	57.6	74.5
105	Lime, potassium	37.7	56.4	62.5	33.2	.51	64.1	36.2	45.3	1.26	21.7	57.8
106	Lime, residues,[1] phosphorus	43.9	77.6	85.3	50.9	[3]	78.9	45.8	72.5	(1.67)	60.2	86.1
107	Lime, residues,[1] potassium	40.4	58.9	66.4	29.5	.81	64.3	31.0	51.1	(.33)	27.3	58.9
108	Lime, phosphorus, potassium	50.1	74.8	70.3	37.8	2.36	81.4	57.2	59.5	3.27	54.0	79.2
109	Lime, res.,[1] phos., potassium	52.7	80.9	90.5	51.9	[3]	88.4	58.1	64.2	(.42)	60.4	83.4
110	Res., phosphorus, potassium	52.3	73.1	71.4	51.1	[3]	78.0	51.4	55.3	(.60)	61.0	78.3
	Average Increase: Bushels or Tons per Acre											
	For residues	1.4	3.1	11.4	5.9	−.96	1.3	−1.1	3.7	−1.64	4.4	7.9
	For phosphorus	9.5	17.8	14.8	14.4	.41	18.8	18.0	15.1	1.51	33.9	24.0
	For potassium	5.8	.2	.3	.7	.25	2.4	4.2	−4.8	−.63	−.6	2.1
	For res., phos. over phos.	2.2	4.6	12.6	11.7	−.65	−3.2	−1.7	8.7	−2.25	2.6	11.6
	For phos., res. over res.	8.8	18.1	15.5	20.4	−1.46	14.6	8.9	23.1	.84	34.6	23.6
	For potas., res., phos. over res., phos.	8.8	3.3	5.2	1.0	.00	9.5	12.3	−8.3	−1.25	.2	−2.7

Value of Crops per Acre in Eleven Years

Plot	Soil treatment applied	Total value of eleven crops	Value of increase
101	None	$167.22	
102	Lime	165.52	−$1.70
103	Lime, residues	173.17	5.95
104	Lime, phosphorus	255.44	88.22
105	Lime, potassium	169.66	2.44
106	Lime, residues, phosphorus	251.43	84.21
107	Lime, residues, potassium	170.57	3.35
108	Lime, phosphorus, potassium	256.92	89.70
109	Lime, residues, phosphorus, potassium	254.76	87.54
110	Residues, phosphorus, potassium	236.66	69.44

Value of Increase per Acre in Eleven Years		Cost of increase
For residues	$ 7.65	?
For phosphorus	89.92	$27.50
For *residues* and phosphorus over phosphorus	−4.01	?
For *phosphorus* and residues over residues	78.26	27.50
For *potassium*, residues, and phosphorus over residues and phosphorus	3.33	27.50

[1]Commercial nitrogen was used 1902–1905.
[2]The figures in parentheses mean bushels of seed; the others, tons of hay.
[3]Clover smothered by previous wheat crop.

under either directly or as manure, preferably in connection with the phosphorus applied, especially if raw rock phosphate is used.

From the soil of the best treated plots, 160 pounds per acre of phosphorus, as an average, were removed in the eleven crops. This is equal to more than 13 percent of the total phosphorus contained in the surface soil of an acre of the untreated land. In other words, if such crops could be grown for eighty years, they would require as much phosphorus as the total supply in the ordinary plowed soil. The results plainly show, however, that without the addition of phosphorus such crops cannot be grown year after year. Where no phosphorus was applied, the crops removed only 107 pounds of phosphorus in the eleven years, which is equivalent to only 9 percent of the total amount (1,200 pounds) in the surface soil at the beginning (1902). The total phosphorus applied from 1902 to 1912, as an average of all plots where it was used, amounted to 275 pounds per acre and cost $27.50. This paid back $84.91, or 300 percent on the investment; whereas potassium, used in the same number of tests and at the same cost, paid back only $1.59 per acre in the eleven years, or less than 6 percent of its cost. Are not these results to be expected from the composition of the soil and the requirements of crops? (See Table 2, page 7, and also Table A in the Appendix.)

Nitrogen was applied to this field in commercial form only, from 1902 to 1905; but clover was grown in 1906 and 1910, and a catch crop of cowpeas after the clover in 1906. The cowpeas were plowed under on all plots, and the 1910 clover (except the seed) was plowed under on five plots (103, 106, 107, 109, and 110). Straw and corn stalks have also been returned to these plots in recent years. The effect of returning these residues to the soil is already appreciable (an average increase of 4.4 bushels of wheat in 1911 and 7.9 bushels of corn in 1912) and probably will be more marked on subsequent crops. Indeed, the large crops of corn, oats, and wheat grown on Plots 104 and 108 during the eleven years drew their nitrogen very largely from the natural supply in the organic matter of the soil.

The roots and stubble of clover contain no more nitrogen than the entire plant takes from the soil alone, but they decay rapidly in contact with the soil and probably hasten the decomposition of the soil humus and the consequent liberation of the soil nitrogen. But of course there is a limit to the reserve stock of humus and nitrogen remaining in the soil, and the future years will undoubtedly witness a gradually increasing difference between Plots 104 and 106 and between Plots 108 and 109, in the yields of grain crops.

In Plate 5 are shown graphically the relative values of the eleven crops for the eight comparable plots, Nos. 102 to 109. The cost of the phosphorus is indicated by that part of the diagram above the short crossbars. It should be kept in mind that no value is assigned to clover plowed under except as it reappears in the increase of subsequent crops. Plots 106 and 109 are heavily handicapped because of the clover failure on those plots in 1906 and the poor yield of clover seed in 1910, whereas Plots 104 and 108 produced a fair crop in 1906 and a very large crop in 1910. As an average, Plots 106 and 109 are only $3.09 behind Plots 104 and 108 in the value of the eleven crops harvested, and this would have been covered by about ½ bushel more clover seed in 1906 or 1910, or it may be covered by 10 bushels more corn in 1913. The values from Plots 103 and 107 average $4.28 more than the values from Plots 102 and 105. (See also table on last page of cover.)

(R stands for residues; P, for phosphorus, and K, for potassium Kalium.)

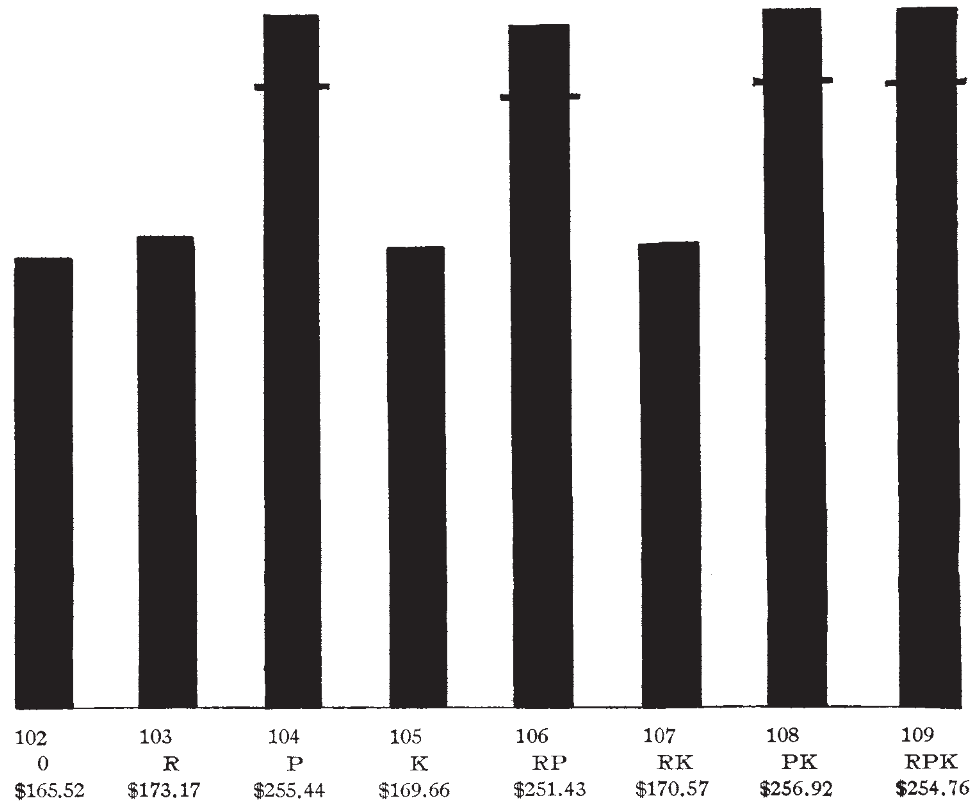

PLATE 5. CROP VALUES FOR ELEVEN YEARS,
BLOOMINGTON EXPERIMENT FIELD

RESULTS OF FIELD EXPERIMENTS AT GALESBURG

In Tables 6, 7, and 8 are reported in detail the results obtained from the University of Illinois soil experiment field near Galesburg, on the line between Knox and Warren counties, on the brown silt loam prairie soil of the upper Illinois glaciation.

A six-year rotation has been practiced on this field since 1904. During the first six years the order of cropping was corn, corn, oats, wheat, followed by two years of clover and timothy. Since then the rotation has been corn, corn, oats, clover, wheat, clover. There are only three independent series of plots, so that while corn is grown every year the other crops are harvested only in alternate years, altho clover should be on the field every year, either in the stubble of the oats and wheat or as a regular crop.

Each series contains twenty individual fifth-acre plots 2 rods wide and 16 rods long, with half-rod division strips cultivated and cropped between the plots, a quarter-rod border cultivated and cropped surrounding each series, and grass strips about two rods wide between the series and surrounding the experiment field. The soil treatment for the individual plots is indicated in Tables 6, 7, and 8.

Limestone was applied in small amount (1300 pounds per acre) to the first fifteen plots in each series in 1904. No further application was made until the spring of 1912, when 4 tons per acre was applied to Plots 1 to 15 of Series

TABLE 6.—CROP YIELDS IN SOIL EXPERIMENTS, GALESBURG FIELD: SERIES 100

Plot	Brown silt loam prairie; upper Illinois glaciation	Corn 1904	Corn 1905	Oats 1906	Wheat 1907	Clover[1] 1908	Timothy[1] 1909	Corn 1910	Corn 1911	Oats 1912
Plot	Soil treatment applied	Bushels or tons per acre								
101	Lime	63.8	52.5	53.8	34.0	2.71	2.04	59.8	66.5	53.3
102	Residues, lime	67.3	49.8	53.6	41.4	(.96)	(3.83)	72.6	75.1	56.9
103	Manure, lime	64.7	48.1	50.3	31.6	2.59	1.83	77.6	81.0	60.0
104	Cover crop, manure, lime	65.3	46.5	46.7	32.8	2.61	1.70	77.9	78.9	70.2
105	Lime	74.7	54.9	52.3	35.1	2.80	2.05	66.2	67.4	60.8
106	Lime, phosphorus	78.2	66.1	53.9	41.9	3.18	2.58	72.4	79.4	68.6
107	Residues, lime, phosphorus	75.9	63.1	55.0	41.3	(.67)	(4.92)	78.0	83.8	65.2
108	Manure, lime, phosphorus	72.6	61.1	54.2	37.9	3.18	2.36	74.6	79.8	77.3
109	Cover crop, manure, lime, phosphorus	74.1	60.0	54.2	40.0	3.15	2.33	74.0	79.1	74.4
110	Lime	72.4	58.8	50.5	32.7	2.65	1.74	61.5	59.2	54.5
111	Lime, phosphorus, potassium	81.2	72.3	53.9	36.6	3.21	2.42	74.5	81.1	70.9
112	Residues, lime, phosphorus, potassium	82.3	71.0	59.4	41.1	(.58)	(5.00)	81.9	83.7	59.5
113	Manure, lime, phosphorus, potassium	77.1	72.2	52.8	36.1	3.45	2.49	77.6	82.4	74.4
114	Cover crop, manure, lime, phos., potassium	89.4	69.9	54.5	38.7	3.36	2.55	75.9	85.0	70.0
115	Lime	81.2	68.1	62.8	36.8	2.99	2.19	59.4	67.3	53.0
116	Residues	77.1	61.8	57.3	38.2	(1.17)	(5.33)	70.6	68.9	52.0
117	Residues, phosphorus	79.4	64.2	60.0	36.2	(1.25)	(5.50)	75.0	77.5	66.1
118	Residues, phosphorus, potassium	82.3	70.8	52.0	40.9	(1.38)	(4.75)	78.3	78.4	68.1
119	Residues, lime, nitrogen, phos., potassium	87.1	76.3	66.2	46.0	(1.08)	(5.00)	74.8	79.3	67.3
120	None	82.9	65.1	65.3	45.8	3.04	2.82	72.7	67.4	70.2
	Increase for residues					—2.19	—.89	5.9	4.3	—7.3
	Increase for manure							7.7	5.4	6.3
	Increase for phosphorus	6.2	10.7	3.4	3.6	.26	.42	1.8	5.7	10.3
	Increase for potassium	6.4	8.3	—.9	—.8	.11	—.01	2.8	2.2	—1.7
	Increase for nitrogen	4.8	5.5	14.2	5.1	—(.30)	(.25)	—3.5	.9	—.8

[1]The figures in parentheses in these columns represent bushels of seed; the others, tons of hay.

300. Thus far no apparent effect has been produced, but further experiment with liberal applications may show results. Plots 1 to 15 in Series 100 and 200 were given 4 tons per acre in the spring of 1913.

The "residues" include the straw and corn stalks, all clover except the seed, and legume cover crops, such as cowpeas, soybeans, or vetch, seeded in the corn at the last cultivation. They are returned to certain plots to supply nitrogen and organic matter in a system of grain farming. This system was not fully under way on all series until 1911, as may be seen from the lower parts of Tables 6, 7, and 8, so that as yet no conclusions regarding this treatment are justified, except that an abundance of organic matter is thus provided. Whether the value of the clover plowed under will ultimately reappear in subsequent yields of grain and seed, must be determined by the further accumulation of data.[1]

[1]Alsike clover promises to yield the better returns in seed, altho in some cases seed has been threshed from both the first and second cuttings of the red clover. It is quite possible that better average results would be secured by regularly removing the first cutting of red clover, with the purpose of threshing it for seed, as well as the second cutting if found

TABLE 7.—CROP YIELDS IN SOIL EXPERIMENTS, GALESBURG FIELD: SERIES 200

Brown silt loam prairie; upper Illinois glaciation		Oats 1904	Wheat 1905	Clover 1906	Timothy 1907	Corn 1908	Corn 1909	Oats 1910	Clover 1911	Wheat 1912
Plot	Soil treatment applied	Bushels or tons per acre								
201	Lime	57.5	40.5	.72	2.30	79.8	54.1	48.0	1.39	17.5
202	Residues, lime	55.0	40.0	.63	1.31	78.8	51.9	43.3		21.1
203	Manure, lime	52.5	38.5	.57	2.55	101.3	65.6	50.6	2.64	21.7
204	Cover crop, manure, lime	55.0	40.2	.63	2.73	102.7	66.8	53.0	2.32	19.6
205	Lime	67.5	42.2	1.22	2.84	86.3	54.4	44.4	2.29	18.2
206	Lime, phosphorus	62.5	41.3	1.36	3.27	99.6	59.1	55.5	2.42	27.3
207	Residues, lime, phosphorus	57.5	42.2	.90	1.79	105.6	49.4	48.6		27.3
208	Manure, lime, phosphorus	60.0	40.0	.91	3.18	106.6	69.8	58.6	2.30	27.3
209	Cover crop, manure, lime, phos.	50.0	39.0	.91	3.16	105.8	75.7	60.3	2.03	27.8
210	Lime	57.5	37.5	.69	2.46	84.5	57.8	42.3	1.14	12.2
211	Lime, phosphorus, potassium	55.0	38.7	1.31	3.38	95.7	67.0	55.3	2.01	28.2
212	Residues, lime, phosphorus, potassium	65.0	39.3	1.40	2.15	103.3	57.5	53.8		28.3
213	Manure, lime, phosphorus, potassium	65.0	41.5	1.79	3.62	98.1	69.8	58.3	2.55	25.9
214	Cover crop, manure, lime, phos., potas.	62.5	40.7	1.51	3.48	102.8	73.3	62.8	2.46	25.3
215	Lime	60.0	35.5	.83	2.33	84.1	58.2	41.6	.98	8.8
216	Residues	72.5	37.0	.82	1.37	87.3	54.8	38.6		11.8
217	Residues, phosphorus	57.5	38.7	.85	1.44	98.6	49.6	43.4		22.1
218	Residues, phosphorus, potassium	50.0	40.7	1.51	2.17	99.0	43.0	46.3		28.3
219	Residues, lime, nitrogen, phos., potas.	57.5	37.7	1.21	1.98	109.6	47.2	57.2		27.3
220	None	55.0	39.5	.71	2.49	88.3	49.5	38.1	1.00	15.6
Increase for residues								—3.1	—1.70	0.0
Increase for manure						7.7	8.3	2.9	.56	.6
Increase for phosphorus		—3.0	.7	.21	.41	12.0	2.0	7.3	—.17	7.7
Increase for potassium		2.0	—.1	.52	.39	—3.5	1.4	2.0	.09	.8
Increase for nitrogen		7.5	—3.0	—.30	—.19	10.6	4.2	10.9		—1.0

Farm manure is applied to certain plots (see tables) in proportion to their previous average crop yields, that is, as many tons of manure are applied to each plot as there were tons of average air-dry produce removed from the corresponding plots during the previous rotation; but no manure was used until crops had been grown for four years and the data had been thus accumulated from which to compute the proper applications of manure. The live-stock system was not fully under way on all series until 1912 (see lower parts of tables), when the average increase from the manure varied from ½ bushel of wheat to nearly 17 bushels of corn.

On Plots 4, 9, and 14 cover crops are grown as indicated in the tables, but the results thus far secured do not justify advising this practice, as may be seen by comparing these plots with Plots 3, 8, and 13, respectively.

advisable. Some splendid seed crops have been secured from the second cutting when the first was clipped and left on the land, but under other seasonal conditions the second crop has been a failure. In such cases, altho the apparent effect is a total loss of the clover crop, at least part of this apparent loss is recovered in subsequent crops of grain. It should never be forgotten that the purpose of this system is to enable the grain farmer to maintain the fertility of his soil, even tho some other system which he may not be prepard to adopt might be more profitable.

TABLE 8.—CROP YIELDS IN SOIL EXPERIMENTS, GALESBURG FIELD: SERIES 300

Brown silt loam prairie; upper Illinois glaciation		Timothy 1904	Timothy 1905	Corn 1906	Corn 1907	Oats 1908	Wheat 1909	Wheat 1910	Clover 1911	Corn 1912
Plot	Soil treatment applied	Bushels or tons per acre								
301	Lime	1.36	1.54	66.8	75.9	28.6	31.7	16.2	2.17	70.8
302	Residues, lime	1.38	1.59	68.6	77.7	26.6	33.8	19.4		89.6
303	Manure, lime	1.30	1.92	72.0	80.3	28.3	36.3	19.6	2.57	104.3
304	Cover crop, manure, lime	1.38	2.02	75.6	83.1	26.1	40.4	22.3	2.03	103.3
305	Lime	1.20	1.75	70.5	78.3	22.5	36.6	21.2	1.83	92.1
306	Lime, phosphorus	1.21	1.65	69.7	84.4	32.7	40.6	22.2	2.64	98.2
307	Res., lime, phosphorus	1.16	1.55	74.0	84.1	27.5	41.2	24.1		103.2
308	Manure, lime, phosphorus	1.25	1.63	73.9	86.1	33.9	39.7	21.6	3.25	107.9
309	Cover crop, manure, lime, phosphorus	1.55	2.03	83.9	87.8	28.9	44.9	24.9	3.13	106.0
310	Lime	1.75	2.25	84.3	85.6	31.6	39.8	22.4	2.74	93.0
311	Lime, phosphorus, potassium	2.10	2.41	86.9	87.8	32.3	44.3	24.5	3.59	101.9
312	Residues, lime, phosphorus, potassium	1.55	1.91	75.8	81.2	25.9	41.8	23.2		98.4
313	Manure, lime, phosphorus, potassium	1.16	1.53	68.4	77.9	31.3	35.8	23.0	3.28	108.8
314	Cover crop, manure, lime, phos., potas.	1.50	1.52	70.6	81.7	27.7	42.0	23.1	3.57	106.9
315	Lime	1.90	1.97	74.1	85.1	30.6	36.8	21.6	2.47	90.6
316	Residues	1.82	1.82	67.7	80.6	26.7	34.2	22.9		82.1
317	Residues, phosphorus	1.95	2.00	59.1	83.3	31.1	44.9	27.0		99.2
318	Residues, phosphorus, potassium	2.65	2.18	66.8	73.6	25.8	43.3	29.1		113.2
319	Residues, lime, nitrogen, phos., potas.	4.15	2.37	71.2	84.7	32.7	43.8	24.9		104.1
320	None	1.46	1.56	59.6	72.8	31.3	28.5	15.8	1.46	79.1
Increase for residues									—2.46	5.8
Increase for manure										16.7
Increase for phosphorus		.01	—.05	1.2	5.1	4.8	6.0	2.9	.86	8.6
Increase for potassium		.37	.14	1.6	—4.7	—2.2	—.8	.6	.47	2.9
Increase for nitrogen		1.50	.19	4.4	11.1	6.9	.5	—4.2		—9.1

At the beginning of this experiment this field was all in timothy sod. Series 300 was not broken during the first two years, but ½ ton of raw rock phosphate per acre was applied as top-dressings. This produced practically no effect,—a result to be expected. A ton of phosphate per acre applied to Series 200 produced no effect on the oats seeded on timothy sod in 1904 and but little effect on the wheat which followed in 1905. Beginning with Series 100 in 1904, Series 300 in 1906, and Series 200 in 1908, the regular plan has been to apply 1½ tons of raw rock phosphate (375 pounds of phosphorus) per acre every six years before plowing for corn, in addition to the partial applications made as stated above. This plan has been followed essentially, and will be continued until the phosphorus content of the plowed soil is at least doubled, but ultimately the amounts applied for each rotation will be reduced to supply only about as much as is removed in the crops grown, and of course the annual expense for this element will then decrease accordingly.

Potassium is applied in the form of potassium sulfate, 100 pounds per acre of the sulfate (containing 42 pounds of potassium) being used for each year in the rotation. The application is made only in connection with the phosphate in order to ascertain whether its use in this way is profitable, there being no doubt that it would be unprofitable if used alone.

In order to help settle the question whether commercial nitrogen could be used with profit, Plot 19 has received nitrogen at the rate of 25 pounds per acre per annum. Nearly the total amount for the first four years was applied in 1904, but since 1907 the applications have been made annually. The nitrogen has been applied in addition to crop residues, phosphorus, and potassium, but without limestone.

TABLE 9.—GALESBURG EXPERIMENT FIELD: FINANCIAL STATEMENT
(Value of increase from three acres)

Series 100..... Series 200..... Series 300..... Years.........	Corn Oats Grass 1904	Corn Wheat Grass 1905	Oats Clover Corn 1906	Wheat Grass Corn 1907	Clover Corn Oats 1908	Grass Corn Wheat 1909	Corn Oats Wheat 1910	Corn Clover Clover 1911	Oats Wheat Corn 1912	Average 1907 to 1912
For residues..					$13.14[1]	$-5.34[1]	$ 1.13[2]	$23.46	$ -.16	
For manure...					2.70[1]	2.90[1]	3.57[2]	5.25[2]	8.16	
For phosph'r's	$ 1.33	$ 3.93	$2.70	$6.77	7.20	7.42	4.85	6.14	11.49	$7.31
For potassium	5.06	3.67	3.41	.14	-1.22	-.13	2.00	4.13	1.06	1.00
For nitrogen..	12.93	.97	4.00	6.31	3.98	3.32	-.90	.31	-4.12	1.48

[1]One crop only.
[2]Two crops only.

In Table 9 is given a financial summary of the results thus far secured from the Galesburg field. Three facts are clearly brought out by the data:

First.—Commercial nitrogen at 15 cents a pound has never paid its cost, and as the system of providing "home-grown" nitrogen in crop residues has developed, the effect of commercial nitrogen has decreased, so that as an average of the last five years it has paid back only 4 percent of its annual cost.

Second.—Potassium, likewise, has never paid its cost, but during the early years, when no adequate provision was made for decaying organic matter, the soluble potassium salt produced a very marked effect, due in part no doubt to the fact that it helped to dissolve and make available the raw phosphate always applied with it. With the subsequent increase in decaying organic matter, the effect of potassium was greatly reduced. As an average of the last six years, potassium costing $7.50 has paid back only $1.

Third.—Phosphorus applied in fine-ground natural rock phosphate in part as top-dressing, and with no adequate provision for decaying organic matter, paid only 47 percent on the investment as an average of the first three years. But it should be kept in mind that the word *investment* is here used in its proper sense, for the phosphorus removed in the increase produced was less than 2 percent of the amount applied, and that removed in the total crops, less than one-third. During the last six years, however, the phosphorus has paid 130 percent on the investment, even tho two-thirds of the application remains to positively enrich the soil.

The results from the Galesburg experiment field furnish some interesting and valuable illustrations of the danger of drawing incorrect conclusions from field-culture experiments conducted for a short time only and without comprehensive knowledge of the factors involved. Thus, the first year the effect of potassium ($5.06) was four times, and that of nitrogen ($12.93) ten times as great as the effect of phosphorus ($1.33); whereas in the last year the effect of phosphorus ($11.49) was eleven times that of potassium ($1.06), while commercial nitrogen applied in addition to the crop residues appears to have been detrimental. These facts only support the following statement quoted on page 208 of Bulletin 123, "The Fertility in Illinois Soils":

"In considering the general subject of culture experiments for determining fertilizer needs, emphasis must be laid on the fact that such experiments should never be accepted as the sole guide in determining future agricultural practice. If the culture experiments and the ultimate chemical analysis of the soil agree in the deficiency of any plant-food element, then the information is conclusive and final; but if these two sources of information disagree, then the culture experiments should be considered as tentative and likely to give way with increasing knowledge and improved methods to the information based on chemical analysis, which is absolute."[1]

THE SUBSURFACE AND SUBSOIL

In Tables 10 and 11 are recorded the amounts of plant food in the subsurface and the subsoil, but it should be remembered that these supplies are of little value unless the top soil is kept rich. Probably the most important information contained in these tables is that the most valuable upland timber soil (yellow-gray silt loam) is usually more strongly acid in the subsurface and the subsoil than in the surface, thus emphasizing the importance of having plenty of limestone in the surface soil to neutralize the acid moisture which rises from the lower strata by capillary action during times of partial drouth, which are critical periods in the life of such plants as clover. Thus, while the common brown silt loam prairie soil is practically neutral, the upland timber soil of similar topography is already in need of limestone; and, as already explained, it is much more deficient in phosphorus and nitrogen than is the common prairie soil.

[1]Taken from "Culture Experiments for Determining Fertilizer Needs," by C. G. H. in Cyclopedia of American Agriculture, Volume I, page 475.

TABLE 10.—FERTILITY IN THE SOILS OF KNOX COUNTY

Average pounds per acre in 4 million pounds[1] of subsurface (about $6\frac{2}{3}$ to 20 inches)

Soil type No.	Soil type	Total organic carbon	Total nitrogen	Total phosphorus	Total potassium	Total magnesium	Total calcium	Limestone present	Limestone requir'd
	Upland Prairie Soils								
526	Brown silt loam	82 720	6 900	1 960	66 060	22 590	22 880		120
520	Black clay loam	87 220	7 240	2 680	61 960	29 040	41 760		40
528	Brown gray silt loam on tight clay....	39 720	3 320	1 480	71 280	22 080	18 360		440
	Upland Timber Soils								
534	Yellow-gray silt loam	16 830	2 210	1 420	6 7550	18 740	14 650		2 240
535	Yellow silt loam	16 900	1 870	1 610	7 4860	23 140	14 340		1 300
532	Light gray silt loam on tight clay ...	20 400	1 920	1 920	7 4760	23 920	17 360		720
	Swamp and Bottom-Land Soils								
1326	Deep brown silt loam..	81 370	6 390	2 720	73 150	21 730	22 470		90
1301	Deep peat.....	511 440	38 420	2 480	3 200	14 260	362 920	777 780	
1303	Shallow peat on clay.......	238 180	22 180	4 100	23 900	20 740	57 100	31 140	

[1]In 2 million pounds of peat (1301 and 1303).

TABLE 11.—FERTILITY IN THE SOILS OF KNOX COUNTY

Average pounds per acre in 6 million pounds[1] of subsoil (about 20 to 40 inches)

Soil type No.	Soil type	Total organic carbon	Total nitrogen	Total phosphorus	Total potassium	Total magnesium	Total calcium	Limestone present	Lime stone requir'd
	Upland Prairie Soils								
526	Brown silt loam	35 160	3 630	2 490	99 890	47 110	35 510		250
520	Black clay loam	25 410	2 490	4 050	100 200	51 690	58 290	19 290	
528	Brown-gray silt loam on tight clay..........	39 000	3 300	2 820	104 820	52 980	32 340		300
	Upland Timber Soils								
534	Yellow-gray silt loam.. ...	16 040	2 580	3 110	101 100	47 980	30 480		1960
535	Yellow silt loam	17 570	2 150	2 780	108 580	44 440	28 940	rarely	often
532	Light gray silt loam on tight clay...........	28 080	2 460	3 720	112 440	48 600	34 920		720
	Swamp and Bottom-Land Soils								
1326	Deep brown silt loam..	51 080	4 180	3 520	110 860	37 740	29 500		140
1301	Deep peat	608 520	45 420	4 980	7 470	22 380	592 020	1287 750	
1303	Shallow peat on clay..........	174 420	10 440	6 720	93 540	69 180	384 540	724 020	

[1]In 3 million pounds of deep peat (1301).

INDIVIDUAL SOIL TYPES

(a) UPLAND PRAIRIE SOILS

The soils of this class comprise 411.37 square miles, or 57 percent of the entire county. They are usually dark in color owing to their large organic-matter content.

The accumulation of organic matter in the prairie soils is due to the growth of prairie grasses that once covered them, and whose network of roots was protected from complete decay by imperfect aeration due to the covering of fine soil material and the moisture it contained. On the native prairies the tops of these grasses were usually burned or became almost completely decayed. From a sample of virgin sod of "blue stem," one of the most common prairie grasses, it has been determined that an acre of this soil to a depth of 7 inches contained 13½ tons of roots. Many of these roots died each year and by partial decay formed the humus of these dark prairie soils. In upland forests no such quantity of roots is found in the soil. The vegetable material consists of leaves and twigs, which fall upon the surface and either are burned by forest fires or undergo almost complete decay. There is very little chance for these to become mixed with the soil. As a result the organic-matter content has been lowered by the growth of forests until in some parts of the state a low condition of apparent equilibrium has been reached.

Brown Silt Loam (526 *or* 226)

This is the most important as well as the most extensive type of soil in the county. It covers an area of 402.6 square miles (257,664 acres), or 55.87 percent of the entire county.

This type is generally sufficiently rolling for fair natural surface drainage, altho tile drainage is often needed and there are some exceptions where the land is so flat as to require artificial surface drainage. Some few areas along streams are so rolling that in order to prevent washing they should be cropped only with the utmost care.

Altho the brown silt loam is normally a prairie soil, in some limited areas forests have recently extended over the dark soil. These forests consist quite largely of black walnut, with such other trees as wild cherry, hackberry, ash, hard maple, and elm. A black-walnut soil is recognized generally by farmers as being one of the best timber soils. As a rule it still contains a large amount of the organic matter that accumulated from the prairie grasses.

The surface soil, 0 to 6⅔ inches, is a brown silt loam, varying from a yellowish brown on the more rolling areas to a dark brown or black on the more nearly level or originally poorly-drained areas. The physical composition varies to some extent, but is normally a silt loam containing from 70 to 85 percent of the different grades of silt together with some sand and clay. The amount of clay usually varies from 8 to 12 percent; it increases as the type approaches the black clay loam (520) and becomes greatest in the poorly-drained level areas. The amount of sand varies from 7 to 15 percent and increases as the bottom land of the large streams is approached.

The organic-matter content varies from 3.8 to 7.25 percent in the surface soil, or from 38 to 72.5 tons per acre,—about 56 tons as an average. Where this type passes into the brown-gray silt loam on tight clay (528) or into the yellow-gray silt loam (534), the percentage of organic matter becomes lower, but where it passes into the black clay loam it becomes higher.

The natural subsurface is represented by a stratum varying from 5 to 16 inches in thickness, being thinner on the more rolling areas and thicker on the level areas. Its physical composition varies in the same way as that of the surface soil, but it usually contains a slightly larger amount of clay. Locally it may become quite heavy, as where the type grades into black clay loam. In color it varies from a dark brown or almost black to a light brown or yellowish brown, but as a rule it becomes lighter with depth and passes gradually into the yellow subsoil. The color is due to the presence of organic matter and to the oxidation of the iron. The organic-matter content averages 3.5 percent.

The natural subsoil begins 12 to 23 inches beneath the surface and extends to an indefinite depth, but it is usually sampled to 40 inches. It varies from a yellow to a drabbish-yellow clayey silt. In the level or nearly level areas it is of a drab color mottled with yellow blotches, while in the more rolling areas better drainage has allowed higher oxidation of the iron to take place, giving the yellow to brownish-yellow color. The upper 8 to 12 inches of the subsoil usually contains more clay than the lower part, the coarser material consisting of coarse silt or fine sand. The subsoil contains about 1 percent of organic matter, and is generally pervious to water, permitting good underdrainage.

While most of this type is in fair physical condition, yet the continuous growing of corn, or corn and oats, with the burning of the corn stalks and possibly the oat stubble is reducing the organic-matter content and destroying the tilth. The soil is becoming more difficult to work; it runs together more; and aeration, granulation, absorption, and moisture movement are interfered with.

This condition of poor tilth is becoming very serious on many farms and is one of the factors that limit crop yields. The remedy is to increase the organic-matter content by plowing under crop residues, such as corn stalks, straw, clover, etc., instead of selling them from the farm or burning them, as is often done at present. The stalks should be thoroly cut up with a sharp disk or stalk cutter and turned under. Likewise the straw should be put back on the land in some practical way, either directly or in the form of manure. Clover should be one of the crops grown in the rotation, and it should be plowed under directly or as manure instead of being sold as hay, except where manure can be brought back.

The addition of fresh organic matter is of even greater importance, because of its nitrogen content and because of its power as it decays to liberate potassium from the inexhaustible supply in the soil and phosphorus from the phosphate contained in or applied to the soil.

For permanent profitable systems of farming, phosphorus should be applied liberally, and sufficient organic matter should be provided to furnish nitrogen. On the ordinary brown silt loam, limestone is already becoming deficient, but this is not always the case on the heavier phase, which is usually found near draws or in low-lying areas. In live-stock farming an application of two tons of limestone and one-half ton of fine-ground rock phosphate per acre every four years, with the return to the soil of all manure made from a rotation of corn, corn, oats, and clover, will maintain the fertility of this type, altho heavier applications of phosphate may well be made during the first two or three rotations. If grain farming is practiced, the rotation may be wheat, corn, oats, and clover, with an extra seeding of clover as a cover crop in the wheat, to be plowed under late in the fall or the following spring for corn; and most of the crop residues, with all the clover except the seed, should also be plowed under. In either system alfalfa may be grown on a fifth field and moved every five years, the hay being fed or sold. (For results of field experiments on the brown silt loam prairie, see Tables 3 to 9.)

Black Clay Loam (520)

This type of soil represents the flat prairie (the naturally poorly-drained areas of the upper Illinois glaciation) and is sometimes called "gumbo" because of its sticky character. Its formation in these places is due to the accumulation of organic matter and to the washing in of clay and fine silt from the slightly higher adjoining lands. This type is not extensive; it occupies only 8.31 square miles (5,318 acres), or 1.15 percent of the entire area of the county. In topography it is so flat that proper drainage is one of the most difficult problems in its management.

The surface stratum is a black, granular clay loam with 7 to 8½ percent of organic matter, or an average of 78 tons per acre. The wet condition of the soil has allowed a greater accumulation of organic matter in this than in any other type of upland soil in the county.

The property of granulation is important to all soils, but it is especially so to heavy ones or those containing considerable clay, since it is by granulation that the soil is kept mellow and rendered pervious to air and water. If the granules are destroyed by puddling (as by the tramping of stock while the ground is wet), they will be formed again by freezing and thawing or by wetting and drying. These natural agencies produce "slacking," as the process is usually termed. If, however, the organic-matter or lime content becomes low, this tendency to granulate grows less and the soil becomes more difficult to work.

The subsurface stratum extends to a depth of 10 to 16 inches below the surface stratum. It differs from the surface in color, becoming lighter with depth, the lower part of the stratum passing into a drab or yellowish silty clay, and it also contains a higher percentage of clay. It is quite pervious to water, due to jointing or checking from shrinkage in times of drouth. The amount of organic matter varies from 3 to 4 percent, with an average of 3.75 percent.

The subsoil is usually a drab or dull yellow silty clay but locally it may be a yellow or clayey silt. As a rule the iron is not highly oxidized because of poor drainage and lack of aeration. The subsoil is checked and jointed, making it pervious to water and consequently easy to drain.

This type presents some variations. Here as elsewhere the boundary lines between different soil types are not always distinct, but types frequently pass from one to the other very gradually, thus giving an intermediate zone of greater or less width. Gradations between brown silt loam (526) and black clay loam (520) are very likely to occur since they are usually adjoining types. This gives a lighter phase of the black clay loam, with a smaller organic-matter content than the average, and a heavier phase of the brown silt loam, with a larger amount of organic matter than usual.

Drainage is the first requirement for this type, and because of its perviousness it underdrains well. Keeping the soil in good physical condition is very essential, and thoro drainage helps to do this to a great extent. As the organic matter is destroyed by cultivation and nitrification and as the limestone is removed by cropping and leaching, the physical condition of the soil becomes poorer, and consequently it becomes more difficult to work. Both organic matter and lime tend to develop granulation. The former should be maintained by turning under manure, clover, and crop residues, such as cornstalks and straw, instead of burning them as is so commonly practiced. Ground limestone should be applied when needed to keep the soil sweet.

While this type of soil is one of the best in the state, yet the clay and humus contained in it give it the property of shrinkage and expansion to such a degree as to be somewhat objectionable at times, especially during drouth. When the soil is wet these constituents expand, and when the moisture evaporates or is used by crops, the soil shrinks. The result is the formation of cracks up to two inches or more in width and extending with lessening width a foot or more in depth. These cracks permit the excessive loss of moisture from the surface, subsurface, and subsoil. They also sometimes "block out" the hills of corn, tearing the roots and doing considerable damage to the crop. While cracking may not be prevented entirely, yet good tilth with a soil mulch will do much toward that end.

This type is well supplied with plant food, which is usually liberated with sufficient rapidity by a good rotation and the addition of moderate amounts of organic matter. The amount of organic matter added must be increased, of course, with continued farming until the nitrogen supplied is equal to that removed. While no marked profit is to be expected from the addition of phosphorus, it is likely to pay its cost in the second or third rotation, and even by maintaining the productive power of the land the capital invested is protected. This soil is rich in magnesium and calcium, and the subsoil usually contains plenty of carbonates. With continued cropping and leaching, the addition of limestone will be necessary. (No field experiments have been conducted as yet on this type of soil.)

Brown-Gray Silt Loam on Tight Clay (528)

This type occupies only .46 square mile (295 acres), or only .06 percent of the area of the county. It occurs almost entirely in areas intermediate between the prairie brown silt loam (526) and the timber yellow-gray silt loam (5.34). In topography it is usually flat.

The surface soil, 0 to 6⅔ inches, is a light brown to a grayish-brown silt loam, containing some fine sand and coarse silt that gives it a peculiar mealy "feel." The organic matter varies from 3½ to 4 percent according to the relation of this type to other types, being greater where it approaches brown silt loam and less where it passes into yellow-gray silt loam (534).

The subsurface is represented by a stratum of silt loam 10 to 12 inches thick, which varies in color from brown to gray, usually from the upper to the lower parts of the stratum. It differs from the surface in containing less organic matter, the average percentage being but 1.7.

The subsoil is a yellowish clay, beginning 16 to 18 inches beneath the surface. This clay stratum is not so nearly impervious as that of the corresponding type in southern Illinois.

This type should be drained where necessary. Care should be taken to increase the nitrogen and the organic-matter content by proper rotation and by turning under crop residues, clover, or farm manure. Phosphorus should be used liberally in connection with the decaying organic matter, as on the brown silt loam, and limestone should also be applied at the rate of 2 to 3 tons per acre every four to six years.

(b) UPLAND TIMBER SOILS

Yellow-Gray Silt Loam (534 *or* 234)

This type occurs in the outer timber belts along the streams and covers 104.44 square miles (66,842 acres), or 14½ percent of the entire county. In topography it is sufficiently rolling for good surface drainage without much tendency to wash if proper care is taken.

The surface soil, 0 to 6⅔ inches, is a gray to yellowish-gray silt loam, incoherent and mealy, but not granular. The amount of organic matter averages about 2.2 percent, or 22 tons per acre.

The subsurface stratum varies from 3 to 10 inches in thickness. The greatest variation is due to topography, the thinner subsurface being on the more rolling land. It is a silt loam, gray, grayish-yellow, or yellow in color, somewhat mealy but becoming more coherent and clayey with depth, and containing only .72 percent of organic matter.

The subsoil is a yellow or grayish-yellow mottled clayey silt or silty clay, somewhat plastic when wet but friable when moist, and pervious to water.

This type is quite variable in texture because of the fact that it grades into so many different types, the transition zone between two types showing a likeness to each.

Agriculturally, the yellow-gray silt loam in Knox county is second in importance, but with the improvements easily possible its value per acre may become equal to that of the brown silt loam. In the management of this type, one of the first essentials is the maintenance or increase of the organic matter in order to give better tilth, to supply nitrogen and liberate mineral plant food, to prevent running together, and in some of the more rolling phases to prevent washing. Another essential is the application of ground limestone, especially in order that clover, alfalfa, and other legumes may be grown more successfully. Liberal use should also be made of phosphorus, since in the surface stratum of this type there is less than 900 pounds to an acre. (See Table 2, page 5.)

For definite results from the most practical field experiments upon typical yellow-gray silt loam, we must go down into "Egypt," where the people of Saline county, especially those in the vicinity of Raleigh and Galatia, have provided the University with a very suitable tract of this type of soil for a permanent experiment field. There, as an average of triplicate tests each year, the yield of corn on untreated land was 25.3 bushels in 1910, 23.6 bushels in 1911, and 22 bushels in 1912; while the corresponding averages from land treated with heavy applications of limestone and a limited amount of organic manures were 41.4 bushels in 1910, 41.3 bushels in 1911, and 50.1 bushels in 1912, the corn being grown on a different series of plots every year in a four-year rotation of wheat, corn, oats, and clover. About the same proportionate increases were produced in wheat and hay, and the effect on oats was also marked.

Owing to the low supply of organic matter and limestone, phosphorus produced no benefit, as an average, during the first two years, but with increasing supplies of organic matter the effect of phosphorus is seen in the crops of 1912 and 1913. Of course, a single four-year rotation cannot be practiced in less than four years, and the full benefit of the system of rotation and soil treatment is not to be expected before the third or fourth four-year period.

While limestone is the material first needed for the economic improvement of the more acid soil of southern Illinois, with organic manures and phosphorus to follow in order, the less acid soils of the central and northern parts of the state are frequently most deficient, relatively, in phosphorus and organic matter.

Table 12 shows in detail eleven years' results secured from the Antioch soil experiment field located in Lake county on the yellow-gray silt loam of the late Wisconsin glaciation. In acidity, this type in Knox county is intermediate between the similar soils in Saline and Lake counties, but no experiment field has been conducted on this important soil type in the upper Illinois glaciation.

The Antioch field was started in order to learn as quickly as possible just what effect would be produced by the addition of nitrogen, phosphorus, and potassium, singly and in combination. These elements have all been added in commercial form. Only a small amount of lime was applied at the beginning, and with the abnormality of Plot 1 and with an abundance of limestone in the subsoil (a common condition in the late Wisconsin glaciation), no conclusions can be drawn regarding the effect of lime.

As an average of 44 tests (4 each year for 11 years), liberal applications of commercial nitrogen produced a slight decrease in crop values, phosphorus paid back 200 percent of its cost, while each dollar invested in potassium brought back only 34 cents (a net loss of 66 percent). Thus, while the detailed data show great variation, owing both to some irregularity of soil and to some very abnormal seasons, with three almost complete crop failures (1904, 1907, and 1910), yet the general summary strongly confirms the analytical data in showing the need of applying phosphorus and the profit from its use, and the loss in adding potassium. In most cases commercial nitrogen damaged the small grains by causing the crop to lodge; but whenever a corn yield of 40 bushels or more was secured where phosphorus had been applied either alone or with potassium, then the addition of nitrogen produced an increase. From a comparison of the results from the Sibley and the Bloomington fields, we must conclude that better yields are to be secured by providing nitrogen by means of legume crops grown in the rotation rather than by the use of commercial nitrogen, which is evidently too readily available, causing too rapid growth and consequent weakness of straw; and of course the atmosphere is the most economic source of nitrogen where that element is needed for soil improvement in general farming. (See Appendix for detailed discussion of "Permanent Soil Improvement.")

Yellow Silt Loam (535 *or* 235)

This type covers about 133.71 square miles (85,574 acres), or 18.56 percent of the entire county. It occurs as the hilly and badly eroded lands on the inner timber belts along streams, usually only in narrow, irregular strips with arms extending up the small streams. In topography it is very rolling and so badly broken that as a rule it should not be cultivated because of the danger of injury from washing.

The surface soil, 0 to 6⅔ inches, is a yellow or grayish-yellow mealy silt loam. It varies a great deal because of recent washing; in some places the real subsoil may be exposed. The amount of organic matter varies from 1.5 to 3 percent depending upon the extent of the washing, but it averages about 2.2 percent, or 22 tons per acre.

TABLE 12.—CROP YIELDS IN SOIL EXPERIMENTS, ANTIOCH FIELD

Plot	Yellow-gray silt loam, undulating timberland; late Wisconsin glaciation	Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Corn 1906	Corn 1907	Oats 1908	Wheat 1909	Corn 1910	Corn 1911	Oats 1912
Plot	Soil treatment applied	Bushels per acre										
101	None[1]	44.8	36.6	17.8	18.5	35.9	12.4	65.6	12.2	5.2	34.4	21.3
102	Lime	45.1	38.9	12.8	10.3	31.5	9.5	61.6	11.7	3.0	24.6	17.5
103	Lime, nitrogen	46.3	40.8	2.8	17.8	37.8	6.4	60.3	13.0	1.4	10.4	24.4
104	Lime, phosphorus	50.1	53.6	12.5	35.8	57.4	13.4	70.9	23.3	6.8	37.4	49.1
105	Lime, potassium	48.2	50.2	9.7	21.7	34.9	12.9	62.5	13.5	4.6	20.4	18.8
106	Lime, nitro., phos.	56.6	62.7	15.9	15.2	59.3	20.9	49.1	33.8	6.0	37.0	46.9
107	Lime, nitro., potas.	52.1	54.9	10 3	11.8	39.0	11.1	52.6	21.0	1.6	7.0	16.9
108	Lime, phos., potas.	60.7	66.0	19.7	28.7	59.1	18.3	59.4	26.2	3.2	42.2	35.9
109	Lime, nitro., phos. potas.	61.2	69.1	31.9	18.0	65.9	31.4	51.9	30.5	3.0	44.2	31.9
110	Nitro., phos., potas.	59.7	71.8	37.2	16.3	66.3	28.8	55.9	34.5	4.0	49.0	38.1

Average Increase: Bushels per Acre

	Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Corn 1906	Corn 1907	Oats 1908	Wheat 1909	Corn 1910	Corn 1911	Oats 1912
For nitrogen	3.0	4.7	1.6	−8.4	4.8	3.9	−10.1	5.9	−1.4	−6.5	−.3
For phosphorus	9.2	16.7	11.1	9.0	24.6	11.0	−1.4	13.7	2.1	24.6	21.6
For potassium	6.0	11.0	6.9	.3	3.2	5.9	−3.9	2.3	−1.2	1.1	−8.6
For nitro., phos. over phos.	6.5	9.1	3.4	−20.6	1.9	7.5	−21.8	10.5	−.8	−.4	2.2
For phos., nitro. over nitro.	10.3	21.9	13.1	−2.6	21.5	14.5	−11.2	20.8	4.6	26.6	22.5
For potas., nitro., phos. over nitro., phos.	4.6	6.4	16.0	2.8	6.6	10.5	2.8	−3.3	−3.0	7.2	−15.0

Value of Crops per Acre in Eleven Years

Plot	Soil treatment applied	Total value of eleven crops	Value of increase
101	None	$112.16	
102	Lime	96.38	$−15.78
103	Lime, nitrogen	97.89	—14.27
104	Lime, phosphorus	157.67	45.51
105	Lime, potassium	111.86	−.30
106	Lime, nitrogen, phosphorus	152.75	40.59
107	Lime, nitrogen, potassium	104.89	−7.27
108	Lime, phosphorus, potassium	160.25	48.09
109	Lime, nitrogen, phosphorus, potassium	164.83	52.67
110	Nitrogen, phosphorus, potassium	172.78	60.62

Value of Increase per Acre in Eleven Years		Cost of increase
For nitrogen	$1.51	$165.00
For phosphorus	61.29	27.50
For *nitrogen* and phosphorus over phosphorus	−4.92	165.00
For *phosphorus* and nitrogen over nitrogen	54.86	27.50
For *potassium*, nitrogen, and phosphorus over nitrogen and phosphorus	12.08	27.50

[1]Plot 101, the check plot, is the lowest ground but it is well drained and is appreciably better land than the rest of the field. Plot 102 is a more trustworthy check plot.

The subsurface varies from 0 to 12 inches in thickness on account of the removal of part or all of the surface and subsurface by washing.

The subsoil is a compact yellow clayey silt which in some places may consist of glacial drift brought near the surface by erosion.

In the management of this type, the most important thing is to prevent general surface washing and gullying. If it is cropped at all, a rotation should be practiced that will require a cultivated crop as little as possible and allow pasture and meadow most of the time. If tilled, the land should be plowed deeply, and contours should be followed as nearly as possibly both in plowing and in planting. Furrows should not be made extending up and down the slope, and the land should be cultivated in the same direction in which it is plowed. Every means should be employed to maintain and to increase the organic-matter content in order to supply nitrogen and to help hold the soil and keep it in good physical condition so that it will absorb a large amount of water and thus diminish the run-off. (See Circular 119.)

Additional treatment recommended is the liberal use of ground limestone. This is advised only where surface erosion has not occurred to too great an extent, and chiefly for such crops as clover and alfalfa, which can often be produced successfully with plenty of limestone (5 tons per acre), thoro inoculation, and about 10 tons of farm manure to give the young alfalfa a good start, after which its extensive root system makes the plant almost independent of the surface soil, except for limestone. An initial application of 500 pounds per acre of steamed bone meal or acid phosphate is often helpful in starting alfalfa, especially where manure is not available.

Light Gray Silt Loam on Tight Clay (532)

Only two very small areas of this type, aggregating but 12 acres, are shown on the map. Many others occur, but they are too small to be represented on a map of this scale.

The surface soil is a white or light gray silt loam, incoherent, mealy, and porous. Spherical iron concretions are usually present. The organic-matter content is low, amounting to only about 2.2 percent, or 22 tons per acre.

The subsurface is a light gray silt extending to a depth of 14 to 18 inches, becoming more clayey with depth and containing only .7 percent of organic matter.

The subsoil is a tight, compact, plastic, clayey silt, yellow with gray mottlings.

Besides being deficient in organic matter, this type is lacking in limestone and is consequently in poor physical condition. It runs together badly and, owing to the strong capillarity in the surface and subsurface strata, it does not hold moisture well. In the management of this soil, ground limestone should be used liberally, rock phosphate should be added, and the organic-matter content increased in every practical way. Deep-rooting crops, such as red, mammoth, or sweet clover, would loosen the tight clay subsoil as well as supply the soil with organic matter and nitrogen. Crop residues or farm manure should be plowed under to bring the soil into better tilth.

(c) SWAMP AND BOTTOM-LAND SOILS

Deep Brown Silt Loam (1326)

The bottom-land soil is derived from material washed from the upland, and must therefore have some relation to the upland soils. It differs in being more variable in physical composition than any single upland type, and the brown color extends into it to greater depth. The bottoms along the streams of the county vary from a few rods to a mile or more in width. These lands occupy 71.09 square miles (45,498 acres), and constitute 9.86 percent of the entire area of the county. In topography they are flat or have very slight undulations that represent old stream or overflow channels. Better drainage is needed in much of this area.

The surface soil, 0 to 6⅔ inches, is usually a brown silt loam containing from 3.5 to 5.3 percent of organic matter, the average being 4.4 percent, or 44 tons per acre. It is probably easier to maintain the fertility and the organic matter in this type than in the upland types, because of occasional overflow and the consequent deposition of material rich in humus and plant food. In physical composition this soil varies from a clay loam to a sandy loam, but the areas of these extreme types, especially of the sandy loam, are so small and so changeable that it is impracticable to try to show them on the map, as the next flood may change their boundaries.

The subsurface is brown silt loam, becoming lighter in color and frequently in texture with depth. It contains an average of 3.2 percent of organic matter.

The subsoil is a yellowish-drab silt loam varying in physical composition either to a clayey silt or to a sandy loam, or even to a sand in the lower subsoil. Because of the way in which this type was formed, the different strata necessarily vary greatly.

Where proper drainage is secured the type is quite productive. As a rule, where it is subject to frequent overflow nothing is needed except good farming. Even the systematic rotation of crops is not so important where the land is subject to occasional overflows, but where it lies high or is protected from overflow a rotation including legume crops should be practiced, and ultimately provision should be made for the enrichment of such protected land in both phosphorus and organic matter, and if necessary in limestone.

Deep Peat (1301)

A small area of deep peat, covering about 26 acres, is found in Section 1, Township 9 North, Range 3 East. This area needs drainage first of all. The surface soil, 0 to 6⅔ inches, is a brown somewhat marly peat, varying in composition because of silts carried in and deposited by water. Both subsurface and subsoil are brown peat mixed with shells.

The samples collected and analyzed show great deficiency in potassium and only moderate amounts of phosphorus. The addition of 100 to 200 pounds per acre of potassium chlorid (often erroneously called "muriate" of potash) is almost certain to produce very marked benefit; and where this is done, phosphorus is likely to prove profitable in the future. When manure is applied, it will furnish potassium and produce increased crops, as a rule, but if the supply of manure is limited, it may be a better plan to use it on other land, and improve this with commercial materials. (See also Bulletin 157, "Peaty Swamp Lands; Sand and 'Alkali' Soils.")

Shallow Peat on Clay (1303)

This type occupies an area of about 19 acres in the southwest quarter of Section 7, Township 9 North, Range 3 East, on the edge of the bottom land. It includes some medium peat, but shallow peat predominates.

The surface soil, 0 to 6⅔ inches, is a brown peat containing some shells.

The subsurface consists of a stratum of brown peat varying from 4 to 10 inches in thickness underlain by a drab clay that constitutes the subsoil.

Aside from drainage, very deep plowing, which will mix some of the clay with the peaty stratum, is the only special treatment recommended. (See Bulletin 157 for results of such plowing on similar land.)

APPENDIX

A study of the soil map and the tabular statements concerning crop requirements, the plant-food content of the different soil types, and the actual results secured from definite field trials with different methods or systems of soil improvement, and a careful study of the discussion of general principles and of the descriptions of individual soil types, will furnish the most necessary and useful information for the practical improvement and permanent preservation of the productive power of every kind of soil on every farm in the county.

More complete information concerning the most extensive and important soil types in the great soil areas in all parts of Illinois is contained in Bulletin 123, "The Fertility in Illinois Soils," which contains a colored general survey soil map of the entire state.

Other publications of general interest are:

Bulletin No. 76, "Alfalfa on Illinois Soils"
Bulletin No. 94, "Nitrogen Bacteria and Legumes"
Bulletin No. 115, "Soil Improvement for the Worn Hill Lands of Illinois"
Bulletin No. 125, "Thirty Years of Crop Rotation on the Common Prairie Lands of Illinois"
Circular No. 110, "Ground Limestone for Acid Soils"
Circular No. 127, "Shall we use Natural Rock Phosphate or Manufactured Acid Phosphate for the Permanent Improvement of Illinois Soils?"
Circular No. 129, "The Use of Commercial Fertilizers"
Circular No. 149, "Some Results of Scientific Soil Treatment" and "Methods and Results of Ten Years' Soil Investigation in Illinois"
Circular No. 165, "Shall we use 'Complete' Commercial Fertilizers in the Corn Belt?"

NOTE.—Information as to where to obtain limestone, phosphate, bone meal, and potassium salts, methods of application, etc., will also be found in Circulars 110 and 165.

SOIL SURVEY METHODS

The detail soil survey of a county consists essentially of indicating on a map the location and extent of the different soil types; and, since the value of the survey depends upon its accuracy, every reasonable means is employed to make it trustworthy. To accomplish this object three things are essential: first, careful, well-trained men to do the work; second, an accurate base map upon which to show the results of their work; and, third, the means necessary to enable the men to place the soil-type boundaries, streams, etc., accurately upon the map.

The men selected for the work must be able to keep their location exactly and to recognize the different soil types, with their principal variations and limits, and they must show these upon the maps correctly. A definite system is employed in checking up this work. As an illustration, one soil expert will survey and map a strip 80 rods or 160 rods wide and any convenient length, while his associate will work independently on another strip adjoining this area, and, if the work is correctly done, the soil type boundaries will match up on the line between the two strips.

An accurate base map for field use is absolutely necessary for soil mapping. The base maps are made on a scale of one inch to the mile. The official data of the original or subsequent land survey are used as a basis in the construction of these maps, while the most trustworthy county map available is used in locating temporarily the streams, roads, and railroads. Since the best of these published maps have some inaccuracies, the location of every road, stream, and railroad must be verified by the soil surveyors, and corrected if wrongly located. In order to make these verifications and corrections, each survey party is provided with an odometer for measuring distances, and a plane table for determining directions of roads, railroads, etc.

Each surveyor is provided with a base map of the proper scale, which is carried with him in the field; and the soil-type boundaries, additional streams, and necessary corrections are placed in their proper locations upon the map while the mapper is on the area. Each section, or square mile, is divided into 40-acre plots on the map, and the surveyor must inspect every ten acres and determine the type or types of soil composing it. The different types are indicated on the map by different colors, pencils for this purpose being carried in the field.

A small auger 40 inches long forms for each man an invaluable tool with which he can quickly secure samples of the different strata for inspection. An extension for making the auger 80 inches long is taken by each party, so that any peculiarity of the deeper subsoil layers may be studied. Each man carries a compass to aid in keeping directions. Distances along roads are measured by an odometer attached to the axle of the vehicle, while distances in the field off the roads are determined by pacing, an art in which the men become expert by practice. The soil boundaries can thus be located with as high a degree of accuracy as can be indicated by pencil on the scale of one inch to the mile.

SOIL CHARACTERISTICS

The unit in the soil survey is the soil type, and each type possesses more or less definite characteristics. The line of separation between adjoining types is usually distinct, but sometimes one type grades into another so gradually that it is very difficult to draw the line between them. In such exceptional cases, some slight variation in the location of soil-type boundaries is unavoidable.

Several factors must be taken into account in establishing soil types. These are (1) the geological origin of the soil, whether residual, glacial, loessial, alluvial, colluvial, or cumulose; (2) the topography, or lay of the land; (3) the native vegetation, as forest or prairie grasses; (4) the structure, or the depth and character of the surface, subsurface, and subsoil; (5) the physical, or mechanical, composition of the different strata composing the soil, as the percentages of gravel, sand, silt, clay, and organic matter which they contain; (6) the texture, or porosity, granulation, friability, plasticity, etc.; (7) the color of the strata; (8) the natural drainage; (9) agricultural value, based upon its natural productiveness; (10) the ultimate chemical composition and reaction.

The common soil constituents are indicated in the following outline:

CONSTITUENTS OF SOILS

Soil Constituents	Organic Matter	Comprising undecomposed and partially decayed vegetable material	
	Inorganic Matter	Clay	.001 mm.[1] and less
		Silt	.001 mm. to .03 mm.
		Sand	.03 mm. to 1. mm.
		Gravel	1. mm. to 32 mm.
		Stones	32. mm. and over

[1]25 millimeters equal 1 inch.

Further discussion of these constituents is given in Circular 82.

GROUPS OF SOIL TYPES

The following gives the different general groups of soils:

Peats—Consisting of 35 percent or more of organic matter, sometimes mixed with more or less sand or silt.

Peaty loams—15 to 35 percent of organic matter mixed with much sand and silt and a little clay.

Mucks—15 to 35 percent of partly decomposed organic matter mixed with much clay and some silt.

Clays—Soils with more than 25 percent of clay, usually mixed with much silt.

Clay loams—Soils with from 15 to 25 percent of clay, usually mixed with much silt and some sand.

Silt loams—Soils with more than 50 percent of silt and less than 15 percent of clay, mixed with some sand.

Loams—Soils with from 30 to 50 percent of sand mixed with much silt and a little clay.

Sandy loams—Soils with from 50 to 75 percent of sand.

Fine sandy loams—Soils with from 50 to 75 percent of fine sand mixed with much silt and little clay.

Sands—Soils with more than 75 percent of sand.

Gravelly loams—Soils with 15 to 50 percent of gravel with much sand and some silt.

Gravels—Soils with more than 50 percent of gravel.

Stony loams—Soils containing a considerable number of stones over one inch in diameter.

Rock outcrop—Usually ledges of rock having no agricultural value.

More or less organic matter is found in nearly all the above classes.

SUPPLY AND LIBERATION OF PLANT FOOD

The productive capacity of land in humid sections depends almost wholly upon the power of the soil to feed the crop; and this, in turn, depends both upon the stock of plant food contained in the soil and upon the rate at which this is liberated, or rendered soluble and available for use in plant growth. Protection from weeds, insects, and fungous diseases, tho exceedingly important, is not a positive but a negative factor in crop production.

The chemical analysis of the soil gives the invoice of fertility actually present in the soil strata sampled and analyzed, but the rate of liberation is governed by many factors, some of which may be controlled by the farmer, while others are largely beyond his control. Chief among the important controllable factors which influence the liberation of plant food are limestone and decaying organic matter, which may be added to the soil by direct application of ground limestone and farm manure. Organic matter may be supplied also by green-manure crops and crop residues, such as clover, cowpeas, straw, and cornstalks. The rate of decay of organic matter depends largely upon its age and origin, and it may be hastened by tillage. The chemical analysis shows correctly the total organic carbon, which represents, as a rule, but little more than half the organic matter; so that 20,000 pounds of organic carbon in the plowed soil of an acre correspond to nearly

20 tons of organic matter. But this organic matter consists largely of the old organic residues that have accumulated during the past centuries because they were resistant to decay, and 2 tons of clover or cowpeas plowed under may have greater power to liberate plant food than the 20 tons of old, inactive organic matter. The recent history of the individual farm or field must be depended upon for information concerning recent additions of active organic matter, whether in applications of farm manure, in legume crops, or in grass-root sods of old pastures.

Probably no agricultural fact is more generally known by farmers and landowners than that soils differ in productive power. Even tho plowed alike and at the same time, prepared the same way, planted the same day with the same kind of seed, and cultivated alike, watered by the same rains and warmed by the same sun, nevertheless the best acre may produce twice as large a crop as the poorest acre on the same farm, if not, indeed, in the same field; and the fact should be repeated and emphasized that with the normal rainfall of Illinois the productive power of the land depends primarily upon the stock of plant food contained in the soil and upon the rate at which it is liberated, just as the success of the merchant depends primarily upon his stock of goods and the rapidity of sales. In both cases the stock of any commodity must be increased or renewed whenever the supply of such commodity becomes so depleted as to limit the success of the business, whether on the farm or in the store.

As the organic matter decays, certain decomposition products are formed, including much carbonic acid, some nitric acid, and various organic acids, and these have power to act upon the soil and dissolve the essential mineral plant foods, thus furnishing soluble phosphates, nitrates, and other salts of potassium, magnesium, calcium, etc., for the use of the growing crop.

As already explained, fresh organic matter decomposes much more rapidly than the old humus, which represents the organic residues most resistant to decay and which consequently has accumulated in the soil during the past centuries. The decay of this old humus can be hastened both by tillage, which maintains a porous condition and thus permits the oxygen of the air to enter the soil more freely and to effect the more rapid oxidation of the organic matter, and also by incorporating with the old, resistant residues some fresh organic matter, such as farm manure, clover roots, etc., which decay rapidly and thus furnish or liberate organic matter and inorganic food for bacteria, the bacteria, under such favorable conditions, appearing to have power to attack and decompose the old humus. It is probably for this reason that peat, a very inactive and inefficient fertilizer when used by itself, becomes much more effective when incorporated with fresh farm manure; so that, when used together, two tons of the mixture may be worth as much as two tons of manure, but if applied separately, the peat has little value. Bacterial action is also promoted by the presence of limestone.

The condition of the organic matter of the soil is indicated more or less definitely by the ratio of carbon to nitrogen. As an average, the fresh organic matter incorporated with soils contains about twenty times as much carbon as nitrogen, but the carbohydrates ferment and decompose much more rapidly than the nitrogenous matter; and the old resistant organic residues, such as are found in normal subsoils, commonly contain only five or six times as much carbon as nitrogen. Soils of normal physical composition, such as loam, clay loam, silt loam, and fine sandy loam, when in good productive condition, contain about twelve to fourteen times as much carbon as nitrogen in the surface soil; while in old, worn soils that are greatly in need of fresh, active, organic manures, the ratio is narrower, sometimes falling below ten of carbon to one of nitrogen. (Except in newly made alluvial soils, the ratio is usually narrower in the subsurface and subsoil than in the surface stratum.)

It should be kept in mind that crops are not made out of nothing. They are composed of ten different elements of plant food, every one of which is absolutely essential for the growth and formation of every agricultural plant. Of these ten elements of plant food, only two (carbon and oxygen) are secured from the air by all agricultural plants, only one (hydrogen) from water, and seven from the soil. Nitrogen, one of these seven elements secured from the soil by all plants, may also be secured from the air by one class of plants (legumes), in case the amount liberated from the soil is insufficient; but even these plants (which include only the clovers, peas, beans, and vetches, among our common agricultural plants) secure from the soil alone six elements (phosphorus, potassium, magnesium, calcium, iron and sulfur), and also utilize the soil nitrogen so far as it becomes soluble and available during their period of growth.

Plants are made of plant-food elements in just the same sense that a building is made of wood and iron, brick, stone, and mortar. Without materials, nothing material can be made. The normal temperature, sunshine, rainfall, and length of season in central Illinois are sufficient to produce 50 bushels of wheat per acre, 100 bushels of corn, 100 bushels of oats, and 4 tons of clover hay; and, where the land is properly drained and properly tilled, such crops would frequently be secured *if the plant foods were present in sufficient amounts and liberated at a sufficiently rapid rate to meet the absolute needs of the crops.*

CROP REQUIREMENTS

The accompanying table shows the requirements of such crops for the five most important plant-food elements which the soil must furnish. (Iron and sulfur are supplied normally in sufficient abundance compared with the amounts needed by plants, so that they are not known ever to limit the yield of general farm crops grown under normal conditions.)

TABLE A.—PLANT FOOD IN WHEAT, CORN, OATS, AND CLOVER

Produce		Nitrogen, pounds	Phosphorus, pounds	Potassium, pounds	Magnesium, pounds	Calcium, pounds
Kind	Amount					
Wheat, grain	50 bu.	71	12	13	4	1
Wheat straw	2½ tons	25	4	45	4	10
Corn, grain	100 bu.	100	17	19	7	1
Corn stover	3 tons	48	6	52	10	21
Corn cobs	½ ton	2		2		
Oats, grain	100 bu.	66	11	16	4	2
Oat straw	2½ tons	31	5	52	7	15
Clover seed	4 bu.	7	2	3	1	1
Clover hay	4 tons	160	20	120	31	117
Total in grain and seed		244[1]	42	51	16	4
Total in four crops		510[1]	77	322	68	168

[1]These amounts include the nitrogen contained in the clover seed or hay, which, however, may be secured from the air.

To be sure, these are large yields, but shall we try to make possible the production of yields only half or a quarter as large as these, or shall we set as our ideal this higher mark, and then approach it as nearly as possible with profit? Among the four crops, corn is the largest, with a total yield of more than six tons per acre; and yet the 100-bushel crop of corn is often produced on rich pieces of land in good seasons. In very practical and profitable systems of farming, the Illinois Experiment Station has produced, as an average of the six years 1905 to 1910, a yield of 87 bushels of corn per acre in grain farming (with limestone and phosphorus applied, and with crop residues and legume crops turned under), and 90 bushels per acre in live-stock farming (with limestone, phosphorus, and manure).

The importance of maintaining a rich surface soil cannot be too strongly emphasized. This is well illustrated by data from the Rothamsted Experiment Station, the oldest in the world. Thus on Broadbalk field, where wheat has been grown since 1844, the average yields for the ten years 1892 to 1901 were 12.3 bushels per acre on Plot 3 (unfertilized) and 31.8 bushels on Plot 7 (well fertilized), but the amounts of both nitrogen and phosphorus in the subsoil (9 to 27 inches) were distinctly greater in Plot 3 than in Plot 7, thus showing that the higher yields from Plot 7 were due to the fact that the plowed soil had been enriched. In 1893 Plot 7 contained per acre in the surface soil (0 to 9 inches) about 600 pounds more nitrogen and 900 pounds more phosphorus than Plot 3. Even a rich subsoil has little value if it lies beneath a worn-out surface.

METHODS OF LIBERATING PLANT FOOD

Limestone and decaying organic matter are the principal materials the farmer can utilize most profitably to bring about the liberation of plant food.

The limestone corrects the acidity of the soil and thus encourages the development not only of the nitrogen-gathering bacteria which live in the nodules on the roots of clover, cowpeas, and other legumes, but also the nitrifying bacteria, which have power to transform the insoluble and unavailable organic nitrogen into soluble and available nitrate nitrogen.

At the same time, the products of this decomposition have power to dissolve the minerals contained in the soil, such as potassium and magnesium, and also to dissolve the insoluble phosphate and limestone which may be applied in low-priced forms.

Tillage, or cultivation, also hastens the liberation of plant food by permitting the air to enter the soil and burn out the organic matter; but it should never be forgotten that tillage is wholly destructive, that it adds nothing whatever to the soil, but always leaves the soil poorer. Tillage should be practiced so far as is necessary to prepare a suitable seed-bed for root development and also for the purpose of killing weeds, but more than this is unnecessary and unprofitable in seasons of normal rainfall; and it is much better actually to enrich the soil by proper applications or additions, including limestone and organic matter (both of which have power to improve the physical condition as well as to liberate plant food) than merely to hasten soil depletion by means of excessive cultivation.

PERMANENT SOIL IMPROVEMENT

The best and most profitable methods for the permanent improvement of the common soils of Illinois are as follows:

(1) If the soil is acid, apply at least two tons per acre of ground limestone, preferably at times magnesian limestone ($CaCO_3MgCO_3$), which contains both calcium and magnesium and has slightly greater power to correct soil acidity, ton for ton, than the ordinary calcium limestone ($CaCO_3$); and continue to apply about two tons per acre of ground limestone every four or five years. On strongly acid soils, or in preparing the land for alfalfa, five tons per acre of ground limestone may well be used for the first application.

(2) Adopt a good rotation of crops, including a liberal use of legumes, and increase the organic matter of the soil either by plowing under the legume crops and other crop residues (straw and corn stalks), or by using for feed and bedding practically all the crops raised and returning the manure to the land with the least possible loss. No one can say in advance what will prove to be the best rotation of crops, because of variation in farms and farmers, and in prices for produce, but the following are suggested to serve as models or outlines:

First year, corn.
Second year, corn.
Third year, wheat or oats (with clover or clover and grass).
Fourth year, clover or clover and grass.
Fifth year, wheat and clover or grass and clover.
Sixth year, clover or clover and grass.

Of course there should be as many fields as there are years in the rotation. In grain farming, with small grain grown the third and fifth years, most of the coarse products should be returned to the soil, and the clover may be clipped and left on the land (only the clover seed being sold the fourth and sixth years); or, in live-stock farming, the field may be used three years for timothy and clover pasture and meadow if desired. The system may be reduced to a five-year rotation by cutting out either the second or the sixth year, and to a four-year system by omitting the fifth and sixth years.

With two years of corn, followed by oats with clover-seeding the third year, and by clover the fourth year, all produce can be used for feed and bedding if other land is available for permanent pasture. Alfalfa may be grown on a fifth field for four or eight years, which is to be alternated with one of the four; or the alfalfa may be moved every five years, and thus rotated over all five fields every twenty-five years.

Other four-year rotations more suitable for grain farming are:

Wheat (and clover), corn, oats, and clover; or corn (and clover), cowpeas, wheat, and clover. (Alfalfa may be grown on a fifth field and rotated every five years, the hay being sold.)

Good three-year rotations are:

Corn, oats, and clover; corn, wheat, and clover; or wheat (and clover), corn (and clover), and cowpeas, in which two cover crops and one regular crop of legumes are grown in three years.

A five-year rotation of (1) corn (and clover), (2) cowpeas, (3) wheat, (4) clover, and (5) wheat (and clover) allows legumes to be seeded four times, and alfalfa may be grown on a sixth field for five or six years in the combination rotation, alternating between two fields every five years, or rotating over all the fields if moved every six years.

To avoid clover sickness it may sometimes be necessary to substitute sweet clover or alsike for red clover in about every third rotation, and at the same time to discontinue its use in the cover-crop mixture. If the corn crop is not too rank, cowpeas or soybeans may also be used as a cover crop (seeded at the last cultivation) in the southern part of the state, and, if necessary to avoid disease, these may well alternate in successive rotations.

For easy figuring it may well be kept in mind that the following amounts of nitrogen are required for the produce named:

1 bushel of oats (grain and straw) requires 1 pound of nitrogen.
1 bushel of corn (grain and stalks) requires 1½ pounds of nitrogen.
1 bushel of wheat (grain and straw) requires 2 pounds of nitrogen.
1 ton of timothy requires 24 pounds of nitrogen.
1 ton of clover contains 40 pounds of nitrogen.
1 ton of cowpeas contains 43 pounds of nitrogen.
1 ton of average manure contains 10 pounds of nitrogen.

The roots of clover contain about half as much nitrogen as the tops, and the roots of cowpeas contain about one-tenth as much as the tops.

Soils of moderate productive power will furnish as much nitrogen to clover (and two or three times as much to cowpeas) as will be left in the roots and stubble. For grain crops, such as wheat, corn, and oats, about two-thirds of the nitrogen is contained in the grain and one-third in the straw or stalks. (See also discussion of "The Potassium Problem," on pages below.)

(3) On all lands deficient in phosphorus (except on those susceptible to serious erosion by surface washing or gullying) apply that element in considerably larger amounts than are required to meet the actual needs of the crops desired to be produced. The abundant information thus far secured shows positively that fine-ground natural rock phosphate can be used successfully and very profitably, and clearly indicates that this material will be the most economical form of phosphorus to use in all ordinary systems of permanent, profitable soil improvement. The first application may well be one ton per acre, and subsequently about one-half ton per acre every four or five years should be applied, at least until the phosphorus content of the plowed soil reaches 2,000 pounds per acre, which may require a total application of from three to five or six tons per acre of raw phosphate containing 12½ percent of the element phosphorus.

Steamed bone meal and even acid phosphate may be used in emergencies, but it should always be kept in mind that phosphorus delivered in Illinois costs about 3 cents a pound in raw phosphate (direct from the mine in carload lots), but 10 cents a pound in steamed bone meal, and about 12 cents a pound in acid phosphate, both of which cost too much per ton to permit their common purchase by farmers in carload lots, which is not the case with limestone or raw phosphate.

Phosphorus once applied to the soil remains in it until removed in crops, unless carried away mechanically by soil erosion. (The loss by leaching is only about 1½ pounds per acre per annum, so that more than 150 years would be required to leach away the phosphorus applied in one ton of raw phosphate.)

The phosphate and limestone may be applied at any time during the rotation, but a good method is to apply the limestone after plowing and work it into the surface soil in preparing the seed bed for wheat, oats, rye, or barley, where clover is to be seeded; while phosphate is best plowed under with farm manure, clover, or other green manures, which serve to liberate the phosphorus.

(4) Until the supply of decaying organic matter has been made adequate, on the poorer types of upland timber and gray prairie soils some temporary benefit may be derived from the use of a soluble salt or mixture of salts, such as kainit, which contains both potassium and magnesium in soluble form and also some common salt (sodium chlorid). About 600 pounds per acre of kainit applied and turned under with the raw phosphate will help to dissolve the phosphorus as well as to furnish available potassium and magnesium, and for a few years such use of kainit will no doubt be profitable on lands deficient in organic matter, but the evidence thus far secured indicates that its use is not absolutely necessary and that it will not be profitable after adequate provision is made for decaying organic matter, since this will necessitate returning to the soil either all produce except the grain (in grain farming) or the manure produced in live-stock farming. (Where hay or straw is sold, manure should be bought.)

On soils which are subject to surface washing, including especially the yellow silt loam of the upland timber area, and to some extent the yellow-gray silt loam, and other more rolling areas, the supply of minerals in the subsurface and subsoil (which gradually renew the surface soil) tends to provide for a low-grade system of permanent agriculture if some use is made of legume plants, as in long rotations with much pasture, because both the minerals and nitrogen are thus provided in some amount almost permanently; but where such lands are farmed under such a system, not more than two or three grain crops should be grown during a period of ten or twelve years, the land being kept in pasture most of the time; and where the soil is acid a liberal use of limestone, as top-dressings if necessary, and occasional reseeding with clovers will benefit both the pasture and indirectly the grain crops.

ADVANTAGE OF CROP ROTATION AND PERMANENT SYSTEMS

It should be noted that clover is not likely to be well infected with the clover bacteria during the first rotation on a given farm or field where it has not been grown before within recent years; but even a partial stand of clover the first time will probably provide a thousand times as many bacteria for the next clover crop as one could afford to apply in artificial inoculation, for a single root-tubercle may contain a million bacteria developed from one during the season's growth.

This is only one of several advantages of the second course of the rotation over the first course. Thus the mere practice of crop rotation is an advantage, especially in helping to rid the land of insects and foul grass and weeds. The deep-rooting clover crop is an advantage to subsequent crops because of that characteristic. The larger applications of organic manures (made possible by the larger crops) are a great advantage; and in systems of permanent soil improvement, such as are here advised and illustrated, more limestone and more phosphorus are provided than are needed for the meager or moderate crops produced during the first rotation, and consequently the crops in the second rotation have the advantage of such accumulated residues (well incorporated with the plowed soil) in addition to the regular applications made during the second rotation.

This means that these systems tend positively toward the making of richer lands. The ultimate analyses recorded in the tables give the absolute invoice of these Illinois soils. They show that most of them are positively deficient only in limestone, phosphorus, and nitrogenous organic matter; and the accumulated information from careful and long-continued investigations in different parts of the United States clearly establishes the fact that in general farming these essentials can be supplied with greatest economy and profit by the use of ground natural limestone, very finely ground natural rock phosphate, and legume crops to be plowed under directly or in farm manure. On normal soils no other applications are absolutely necessary, but, as already explained, the addition of some soluble salt in the beginning of a system of improvement on some of these soils produces temporary benefit, and if some inexpensive salt, such as kainit, is used, it may produce sufficient increase to more than pay the added cost.

THE POTASSIUM PROBLEM

As reported in Illinois Bulletin 123, where wheat has been grown every year for more than half a century at Rothamsted, England, exactly the same increase was produced (5.6 bushels per acre), as an average of the first 24 years, whether potassium, magnesium, or sodium was applied, the rate of application per annum being 200 pounds of potassium sulfate and molecular equivalents of magnesium sulfate and sodium sulfate. As an average of 60 years (1852 to 1911), the yield of wheat has been 12.7 bushels on untreated land, 23.3 bushels where 86 pounds of nitrogen and 29 pounds of phosphorus per acre per annum were applied; and, as further additions, 85 pounds of potassium raised the yield to 31.3 bushels; 52 pounds of magnesium raised it to 29.2 bushels; and 50 pounds of sodium raised it to 29.5 bushels. Where potassium was applied, the average wheat crop removed 40 pounds of that element in the grain and straw, or three times as much as would be removed in the grain only for such crops as are suggested in Table A. The Rothamsted soil contained an abundance of limestone, but no organic matter was provided except the little in the stubble and roots of the wheat plants.

On another field at Rothamsted the average yield of barley for 60 years (1852 to 1911) has been 14.2 bushels on untreated land, 38.1 bushels where 43 pounds of nitrogen and 29 pounds of phosphorus have been applied per acre per annum; while the further addition of 85 pounds of potassium, 19 pounds of magnesium, and 14 pounds of sodium (all in sulfates) raised the average yield to 41.5 bushels, but, where only 70 pounds of sodium were applied in addition to the nitrogen and phosphorus, the average has been 43.0 bushels. Thus, as an average of 60 years, the use of sodium produced 1.8 bushels less wheat and 1.5 bushels more barley than the use of potassium, with both grain and straw removed and no organic manures returned.

In recent years the effect of potassium is becoming much more marked than that of sodium or magnesium, on the wheat crop; but this must be expected to occur in time where no potassium is returned in straw or manure, and no provision made for liberating potassium from the supply still remaining in the soil. If more than three-fourths of the potassium removed were returned in the straw (see Table A), and if the decomposition products of the straw have power to liberate additional amounts of potassium from the soil, the necessity of purchasing potassium in a good system of farming on such land is very remote.

While about half the potassium, nitrogen, and organic matter, and about one-fourth the phosphorus contained in manure will be lost by three or four months' exposure in the ordinary pile in the barn yard, there is practically no loss if plenty of absorbent bedding is used on cement floors, and if the manure is hauled to the field and spread within a day or two after it is produced. Again, while the animals destroy two-thirds of the organic matter and retain one-fourth of the nitrogen and phosphorus in average live-stock farming, they retain less than one-tenth of the potassium, from the food consumed; so that the actual loss of potassium in the products sold from the farm, either in grain farming or in live-stock farming, is wholly negligible on land containing 25,000 pounds or more of potassium in the surface 6⅔ inches.

The removal of one inch of soil per century by surface washing (which is likely to occur wherever there is satisfactory surface drainage and frequent cultivation) would permanently maintain the potassium in grain farming by renewal from the subsoil, provided one-third of the potassium is removed by cropping before the soil is carried away.

From all of these facts it will be seen that the potassium problem is not one of addition but of liberation; and the Rothamsted records show that for many years other soluble salts have practically the same power as potassium to increase crop yields in the absence of sufficient decaying organic matter. Whether this action relates to supplying or liberating potassium for its own sake, or to the power of the soluble salt to increase the availability of phosphorus or other elements, is not known, but where much potassium is removed, as in the entire crops at Rothamsted, with no return of organic residues, probably the soluble salt functions in both ways.

As an average of 112 separate tests conducted in 1907, 1908, 1909, and 1910 on the Fairfield experiment field, an application of 200 pounds of potassium sulfate, containing 85 pounds of potassium and costing $5.10, increased the yield of corn by 9.3 bushels per acre; while 600 pounds of kainit, containing only 60 pounds of potassium and costing $4.00, gave an increase of 10.7 bushels. Thus, at 40 cents a bushel for corn, the kainit has paid for itself; but these results, like those at Rothamsted, were secured where no adequate provision had been made for decaying organic matter.

Additional experiments at Fairfield include an equally complete test with potassium sulfate and kainit on land to which 8 tons per acre of farm manure had been applied. As an average of 112 tests with each material, the 200 pounds of potassium sulfate increased the yield of corn by 1.7 bushels, while the 600 pounds of kainit also gave an increase of 1.7 bushels. Thus, where organic manure was supplied, very little effect was produced by the addition of either potassium sulfate or kainit; in part perhaps because the potassium removed in the crops is mostly returned in the manure if properly cared for, and perhaps in larger part because the decaying organic matter helps to liberate and hold in solution other plant-food elements, especially phosphorus.

In laboratory experiments at the Illinois Experiment Station, it has been shown that potassium salts and most other soluble salts increase the solubility of the phosphorus in soil and in rock phosphate as determined by chemical analysis; also that the addition of glucose with rock phosphate in pot-culture experiments increases the availability of the phosphorus, as measured by plant growth, altho the glucose consists only of carbon, hydrogen, and oxygen, and thus contains no plant food of value.

If we remember that, as an average, live stock destroy two-thirds of the organic matter of the food consumed, it is easy to determine from Table A that more organic matter will be supplied in a proper grain system than in a strictly live-stock system; and the evidence thus far secured from older experiments at the University and at other places in the state indicates that if the corn stalks, straw, clover, etc., are incorporated with the soil as soon as practicable after they are produced (which can usually be done in the late fall or early spring), there is little or no difficulty in securing sufficient decomposition in our humid climate to avoid serious interference with the capillary movement of the soil moisture, a common danger from plowing under too much coarse manure of any kind in the late spring of a dry year.

If, however, the entire produce of the land is sold from the farm, as in hay farming, or when both grain and straw are sold, of course the draft on potassium will then be so great that in time it must be renewed by some sort of application. As a rule, such farmers ought to secure manure from town, since they furnish the bulk of the material out of which manure is produced.

CALCIUM AND MAGNESIUM

When measured by the actual crop requirements for plant food, magnesium and calcium are more limited in some Illinois soils than potassium. But with these elements we must also consider the loss by leaching. As an average of 90 analyses[1] of Illinois well-waters drawn chiefly from glacial sands, gravels, or till, 3 million pounds of water (about the average annual drainage per acre for Illinois) contained 11 pounds of potassium, 130 of magnesium, and 330 of calcium. These figures are very significant, and it may be stated that if the plowed soil is well supplied with the carbonates of magnesium and calcium, then a very considerable proportion of these amounts will be leached from that stratum. Thus the loss of calcium from the plowed soil of an acre at Rothamsted, England, where the soil contains plenty of limestone, has averaged more than 300 pounds a year as determined by analyzing the soil in 1865 and again in 1905. And practically the same amount of calcium was found by analyzing the Rothamsted drainage waters.

Common limestone, which is calcium carbonate ($CaCO_3$), contains, when pure, 40 percent of calcium, so that 800 pounds of limestone are equivalent to 320 pounds of calcium. Where 10 tons per acre of ground limestone were applied at Edgewood, Illinois, the average annual loss during the next ten years amounted to 790 pounds per acre. The definite data from careful investigations seem to be ample to justify the conclusion that where limestone is needed at least 2 tons per acre should be applied every 4 or 5 years.

It is of interest to note that thirty crops of clover of four tons each would require 3,510 pounds of calcium, while the most common prairie land of southern Illinois contains only 3,420 pounds of total calcium in the plowed soil of an acre. (See Soil Report No. 1.) Thus limestone has a positive value on some soils for the plant food which it supplies, in addition to its value in correcting soil acidity and in improving the physical condition of the soil. Ordinary limestone (abundant in the southern and western parts of the state) contains nearly 800 pounds of calcium per ton; while a good grade of dolomitic limestone (the more common limestone of northern Illinois) contains about 400 pounds of calcium and 300 pounds of magnesium per ton. Both of these elements are furnished in readily available form in ground dolomitic limestone.

---

[1]Reported by Doctor Bartow and associates, of the Illinois State Water Survey.

PUBLICATIONS RELATING TO ILLINOIS SOIL INVESTIGATIONS

No.

BULLETINS

76 Alfalfa on Illinois Soil, 1902 (5th edition, 1913).
*86 Climate of Illinois, 1903.
*88 Soil Treatment for Wheat in Rotation, with Special Reference to Southern Illinois, 1903.
*93 Soil Treatment for Peaty Swamp Lands, Including Reference to Sand and "Alkali" Soils, 1904. (See No. 157.)
94 Nitrogen Bacteria and Legumes, 1904 (4th edition, 1912).
*99 Soil Treatment for the Lower Illinois Glaciation, 1905.
115 Soil Improvement for the Worn Hill Lands of Illinois, 1907.
123 The Fertility in Illinois Soils, 1908 (2nd edition 1911).
125 Thirty Years of Crop Rotations on the Common Prairie Soil of Illinois, 1908.
145 Quantitative Relationships of Carbon, Phosphorus, and Nitrogen in Soils, 1910 (2nd edition, 1912).
157 Peaty Swamp Lands; Sand and "Alkali" Soils, 1912.

CIRCULARS

*64 Investigations of Illinois Soils, 1903.
*68 Methods of Maintaining the Productive Capacity of Illinois Soils, 1903 (2nd edition, 1905).
*70 Infected Alfalfa Soil, 1903.
*72 Present Status of Soil Investigation, 1903. (2nd edition, 1904).
82 The Physical Improvement of Soils, 1904 (3rd edition, 1912).
86 Science and Sense in the Inoculation of Legumes, 1905 (2nd edition, 1913).
*87 Factors in Crop Production, with Special Reference to Permanent Agriculture in Illinois, 1905.
*96 Soil Improvement for the Illinois Corn Belt 1905 (2nd edition, 1906).
*97 Soil Treatment for Wheat on the Poorer Lands of the Illinois Wheat Belt, 1905.
*99 The "Gist" of Four Years' Soil Investigations in the Illinois Wheat Belt, 1905.
*100 The "Gist" of Four Years' Soil Investigations in the Illinois Corn Belt, 1905.
105 The Duty of Chemistry to Agriculture, 1906 (2nd edition, 1913).
108 Illinois Soils in Relation to Systems of Permanent Agriculture, 1907.
109 Improvement of Upland Timber Soils of Illinois, 1907.
110 Ground Limestone for Acid Soils, 1907 (3rd edition, 1912).
*116 Phosphorus and Humus in Relation to Illinois Soils, 1908.
119 Washing of Soils and Methods of Prevention, 1908 (2nd edition, 1912).
*122 Seven Years' Soil Investigation in Southern Illinois, 1908.
123 The Status of Soil Fertility Investigations, 1908.
124 Chemical Principles of Soil Fertility, 1908.
127 Shall We Use Natural Rock Phosphate or Manufactured Acid Phosphate for the Permanent Improvement of Illinois Soils? 1909 (3rd edition, 1912).
129 The Use of Commercial Fertilizers, 1909.
130 A Phosphate Problem for Illinois Land Owners 1909.
141 Crop Rotation for Illinois Soils, 1910 (2nd edition, 1913).
142 European Practice and American Theory Concerning Soil Fertility, 1910.
145 The Story of a King and Queen, 1910.
149 Results of Scientific Soil Treatment; and Methods and Results of Ten Years' Soil Investigation in Illinois, 1911.
150 Collecting and Testing Soil Samples, 1911 (2nd edition, 1912).
155 Plant Food in Relation to Soil Fertility, 1912.
157 Illinois Conditions, Needs, and Future Prospects, 1912.
165 Shall we Use "Complete" Commercial Fertilizers in the Corn Belt? 1912 (4th edition, 1913).
167 The Illinois System of Permanent Fertility, 1913.

SOIL REPORTS

1 Clay County Soils, 1911.
2 Moultrie County Soils, 1911.
3 Hardin County Soils, 1912.
4 Sangamon County Soils, 1912.
5 La Salle County Soils, 1913.
6 Knox County Soils, 1913.

*Out of print.

ELEVEN YEARS' RESULTS WITH PHOSPHORUS ON THE UNIVERSITY OF ILLINOIS SOIL EXPERIMENT FIELD AT BLOOMINGTON, ON THE TYPICAL PRAIRIE LAND OF THE ILLINOIS CORN BELT

Year	Crop grown	Yield without phosphorus	Yield with phosphorus	Increase for phosphorus	Value of increase per acre
1902	Corn, bu.	37.0	41.7	4.7	$ 1.64
1903	Corn, bu.	60.3	73.0	12.7	4.44
1904	Oats, bu.	60.8	72.7	11.9	3.57
1905	Wheat, bu.	28.8	39.2	10.4	7.28
1906	Clover, tons	.58	1.65	1.07	6.42
1907	Corn, bu.	63.1	82.1	19.0	6.65
1908	Corn, bu.	35.3	47.5	12.2	4.27
1909	Oats, bu.	53.6	63.8	10.2	3.06
1910	Clover, tons	1.09	4.21	3.12	18.72
1911	Wheat, bu.	22.5	57.6	35.1	24.57
1912	Corn, bu.	47.9	74.5	26.6	9.30
	Total value of increase in eleven years				$ 89.92
	Total cost of phosphorus in eleven years				27.50
	Net profit in eleven years				$ 62.42

After the first year the phosphorus never failed to more than pay its annual cost; and, as an average of the last four years, the increase produced by the phosphorus is worth as much as the total crops produced on the land not receiving phosphorus. (See pages 12 to 15 for more complete details.)

Accessibility Statement

The Natural Resources Conservation Service (NRCS) is committed to making its information accessible to all of its customers and employees. If you are experiencing accessibility issues and need assistance, please contact our Helpdesk by phone at (800) 457-3642 or by e-mail at ServiceDesk-FTC@ftc.usda.gov. For assistance with publications that include maps, graphs, or similar forms of information, you may also wish to contact our State or local office. You can locate the correct office and phone number at http://offices.sc.egov.usda.gov/locator/app.

The USDA Target Center can convert USDA information and documents into alternative formats, including Braille, large print, video description, diskette, and audiotape. For more information, visit the TARGET Center's Web site (http://www.targetcenter.dm.usda.gov/) or call (202) 720-2600 (Voice/TTY).

Nondiscrimination Policy

The U.S. Department of Agriculture (USDA) prohibits discrimination against its customers, employees, and applicants for employment on the basis of race, color, national origin, age, disability, sex, gender identity, religion, reprisal, and where applicable, political beliefs, marital status, familial or parental status, sexual orientation, whether all or part of an individual's income is derived from any public assistance program, or protected genetic information. The Department prohibits discrimination in employment or in any program or activity conducted or funded by the Department. (Not all prohibited bases apply to all programs and/or employment activities.)

To File an Employment Complaint

If you wish to file an employment complaint, you must contact your agency's EEO Counselor (http://directives.sc.egov.usda.gov/33081.wba) within 45 days of the date of the alleged discriminatory act, event, or personnel action. Additional information can be found online at http://www.ascr.usda.gov/complaint_filing_file.html.

To File a Program Complaint

If you wish to file a Civil Rights program complaint of discrimination, complete the USDA Program Discrimination Complaint Form, found online at http://www.ascr.usda.gov/complaint_filing_cust.html or at any USDA office, or call (866) 632-9992 to request the form. You may also write a letter containing all of the information requested in the form. Send your completed complaint form or letter by mail to U.S. Department of Agriculture; Director, Office of Adjudication; 1400 Independence Avenue, S.W.; Washington, D.C. 20250-9419; by fax to (202) 690-7442; or by email to program.intake@usda.gov.

Persons with Disabilities

If you are deaf, are hard of hearing, or have speech disabilities and you wish to file either an EEO or program complaint, please contact USDA through the Federal Relay Service at (800) 877-8339 or (800) 845-6136 (in Spanish).

If you have other disabilities and wish to file a program complaint, please see the contact information above. If you require alternative means of communication for program information (e.g., Braille, large print, audiotape, etc.), please contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).