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SOIL REPORT NO. 10

McLEAN COUNTY SOILS

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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, subsequent reports are sent only to those on the mailing list who are 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 in order to help the farmer and landowner 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.

McLEAN COUNTY SOILS

By CYRIL G. HOPKINS, J. G. MOSIER, E. VAN ALSTINE, AND F. W. GARRETT

McLean county is located in the central part of Illinois in the early Wisconsin glaciation. The general topography is undulating to slightly rolling, tho an area in the northwestern part of the county along the Mackinaw river is in part badly broken.

The difference in topography is due to two causes—glacial action and stream erosion. This county was covered by two ice sheets during the Glacial period. At that time snow and ice accumulated in the region of Labrador and to the west 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 clay, silt, sand, gravel, boulders, and even large masses of rock. Many of these were carried for hundreds of miles and rubbed against the surface rocks or against each other until ground into powder. When the limit of advance was reached by the melting of the ice, this material accumulated 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 this material deposited somewhat uniformly over the tract, marking the area previously covered by the ice sheet. Other advances occurred which built up other moraines. The intervening intermorainal tracts are occupied chiefly by level, undulating, or slightly rolling plains.

The material transported by the glacier varied with the character of the rocks over which it passed. Granites, limestones, sandstones, shales, et cetera, were mixed and ground up together. This mixture of all kinds of material—boulders, clay, silt, sand, and gravel—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 were changed entirely.

McLean county was first covered by the Illinois glacier, which did its share toward leveling the region and covering it with a deposit of boulder clay. After this a long period elapsed, during which a soil known as the Sangamon soil was formed from this glacial deposit. Then another advance occurred, known as the Iowan glacier. This glacier did not reach McLean county, but after its melting the state was covered with a deposit of wind-blown loess, which buried the old soil that was formed from the Illinois glacial drift. A new soil was formed from the loess, and after a long period had elapsed another ice advance occurred—the early Wisconsin glacier. This covered the entire county, bringing

with it immense quantities of the material which now covers the county to an average depth of 200 feet and in many places reaches a depth of 250 feet. The outer limit of this glaciation, known as the Shelbyville moraine, extends to the south-western corner of McLean county. (See the state soil map in Bulletin 123.)

The early Wisconsin glacier advanced and receded in this county at least three different times, building up terminal moraines with each advance. The largest of these is the Bloomington moraine, which in the western two-thirds of the county is made up of a double ridge, coalescing as it reaches the eastern part. This double ridge indicates two distinct glacial advances. Another moraine, known as the Cropsey ridge, occurs in the northeastern part of the county. A small spur from the Champaign moraine extends into the southeastern corner of the county, and it is likely that the extension of this was covered by the Bloomington moraine, which is about 100 feet higher than the area to the south. The intermorainal tracts are naturally poorly drained. They were formerly occupied by swamps, which have required much artificial drainage.

PHYSIOGRAPHY

The altitude of McLean county varies from 600 to about 900 feet above sea level, with an average of approximately 750 feet. The highest point, 920 feet, is on the Bloomington moraine near the center of Township 23 North, Range 4 East. The altitude of some of the points are as follows: Arrowsmith, 877 feet; Bellflower, 784; Bloomington, 821; Chenoa, 723; Colfax, 742; Cropsey, 802; Danvers, 808; Downs, 794; Ellsworth, 863; Funk's Grove, 694; Gillum, 820; Gridley, 752; Hudson, 768; Lexington, 746; Leroy, 780; McLean, 708; Normal, 790; Saybrook, 786; Weedman, 725.

The county is divided into four drainage areas: the Mackinaw in the north and northwest, the Sangamon in the east, Rooks creek, a branch of the Vermilion, in the northeast, and Sugar creek and its branches in the south and southwest. All these streams, however, flow into the Illinois river. Drainage is naturally well developed in the western half of the county.

SOIL MATERIAL AND SOIL TYPES

The early Wisconsin glacier left extensive deposits of boulder clay over the county, but the soils as a general rule are not formed from this material. After the Wisconsin glacier, the county was again covered by a deposit of fine wind-blown material, loessial in character, varying from 2 to 7 feet in depth, and it is from this loess that the soil has generally been formed. In very small areas on some of the more rolling parts, this fine material has been removed to such an extent that the exposed boulder clay may constitute the soil material.

The soils of the county are divided into four classes, as follows:

(a) 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 preserved them from complete decay.

(b) Upland timber soils, including those zones along stream courses over which for a long period of time forests once extended. These soils contain much

TABLE 1.—SOIL TYPES OF McLEAN COUNTY

Soil type No.	Name of type	Area in square miles	Area in acres	Percent of total area
	(a) Upland Prairie Soils (page 24)			
926 } 1126 {	Brown silt loam	847.38	542 323.2	72.602
1120	Black clay loam	168.69	107 961.6	14.474
1120.2	Gravelly black clay loam	4.04	2 585.6	.345
1128	Brown-gray silt loam on tight clay	2.42	1 548.8	.207
990 } 1190 {	Gravelly loam	.15	96.0	.012
	(b) Upland Timber Soils (page 29)			
934 } 1134 {	Yellow-gray silt loam	73.42	46 988.8	6.227
935 } 1135 {	Yellow silt loam	27.43	17 555.2	2.357
	(c) Terrace Soils (page 37)			
1527	Brown silt loam over gravel	.26	166.4	.002
1526.2	Brown silt loam on gravel	1.77	1 132.8	.152
1534.2	Yellow-gray silt loam on gravel	.97	620.8	.083
	(d) Swamp and Bottom-Land Soils (page 38)			
1401	Deep peat	.13	83.2	.011
1426	Deep brown silt loam	23.88	15 283.2	2.008
1454	Mixed loam	18.06	11 558.4	1.520
	Total	1 168.60	747 904.0	100.000

less organic matter, 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.

(c) Terrace soils. These have been formed by deposits from flooded streams overloaded with coarse sediment at the time of the melting of the glacier. Finer deposits which were later made upon the coarse gravelly material now constitute the soil.

(d) 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 72½ percent of the area consists of brown silt loam, 14½ percent of black clay loam, and 6 percent of yellow-gray silt loam, these three types covering 93 percent of the county. 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.

THE INVOICE AND INCREASE OF FERTILITY IN McLEAN 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 a 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.)

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 soil acidity as measured by the amount of limestone required to neutralize the acidity existing in the soil.

The soil to the depth indicated includes at least as much 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 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, for the weak, shallow-rooted plants will be unable to reach the supply of plant food in the subsoil. If, however, the fertility of the surface soil is maintained at a high point, then the plants,

with a vigorous start from the rich surface soil, can draw upon the subsurface and subsoil for a greater supply of plant food.

By easy computation it will be found that the most common prairie soil of McLean county does not contain more than enough total nitrogen in the plowed soil for the production of maximum crops for forty years, while the upland timber soils contain, as an average, much less nitrogen than the prairie land.

With respect to phosphorus, the condition differs only in degree, more than eight-tenths of the soil area of the county containing no more of that element than would be required for fifteen 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 with 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 28 centuries if only the grain is sold, or for 450 years even if the total crops should be removed and nothing returned. The corresponding figures are about 2,000 and 500 years for magnesium, and about 9,000 and 200 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 magnesium, and more especially with calcium, 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, and, with a population increasing by more than 20 percent each decade, the future needs of the

TABLE 2.—FERTILITY IN THE SOILS OF MCLEAN COUNTY, ILLINOIS

Average pounds per acre in 2 million pounds of surface soil (about 0 to 6⅔ inches)

Soil type No.	Soil type	Total organic carbon	Total nitrogen	Total phosphorus	Total potassium	Total magnesium	Total calcium	Limestone present	Soil acidity
	Upland Prairie Soils								
1126	Brown silt loam	57 410	4 870	1 120	36 640	8 350	9 560		60
1120	Black clay loam	91 370	8 160	2 000	34 210	16 580	31 240	Often	Rarely
1120.2	Gravelly black clay loam	65 180	6 020	1 620	32 520	23 920	74 740	170 760	
1128	Brown-gray silt loam on tight clay	47 880	4 200	1 380	36 220	6 780	7 300		120
1190	Gravelly loam	32 520	3 040	1 000	35 240	8 240	6 780		20
	Upland Timber Soils								
1134	Yellow-gray silt loam	33 670	2 940	1 050	35 910	6 220	7 820		60
1135	Yellow silt loam	17 780	1 650	750	35 440	7 330	6 420		150
	Terrace Soils								
1527	Brown silt loam over gravel	65 180	5 980	1 420	36 180	8 700	7 140		40
1526.2	Brown silt loam on gravel	41 930	3 770	1 080	38 430	8 050	7 480		40
1534.4	Yellow-gray silt loam on gravel	35 520	3 660	1 080	37 000	6 700	7 880		20
	Swamp and Bottom-Land Soils								
1401	Deep peat	318 850	29 530	2 710	6 240	5 610	33 460	3 930	
1426	Deep brown silt loam	79 940	6 620	2 120	38 980	11 260	16 500		60
1454	Mixed loam	65 760	5 980	1 760	42 620	14 080	20 100	8 120	

people dependent upon the corn belt are likely to be far greater than the requirements of the past, and soil fertility and crop yields should not decrease but increase.

In the production of general farm crops, McLean is now the leading county in the United States. The only rival counties for the position of greatest in agriculture are Los Angeles, Cal., and Lancaster, Pa. The crop values reported for these counties by the latest United States census (for 1909) are as follows:

County	Value of all crops	Value of all crops except tobacco, vegetables, fruits, and nuts
Los Angeles, California	$14 720 884	$6 734 259
Lancaster, Pennsylvania	13 059 588	8 617 170
McLean, Illinois	12 811 506	12 690 404

McLean county produced 16 million bushels of corn in 1909, while 8 million were produced in the six New England states, less than 10 million in the eleven Western states, 18 million in Maryland, 21 million in South Carolina, 39 million in Georgia, and 390 million in Illinois. And yet McLean county produced but little more than half a crop, measured by its normal climatic possibilities under rational systems of soil improvement. The ten-year average yield of corn for McLean county is 39 bushels per acre, according to the Statistical Reports of the Illinois State Board of Agriculture for the years 1905 to 1914. During the same ten years the average acre-yield was 78.3 bushels on the University of Illinois North Farm at Urbana, where organic manures, limestone, and phosphorus had been applied. (See records of Plots 6 and 7, Tables 3 and 4, pages 10 and 11.) Such results should induce careful study of the individual farm with its particular soil type or types, in order that the best methods may be adopted for soil improvement and preservation.

The variation among the different types of soil in McLean county with respect to their content of important plant-food elements is very marked. Thus the richest prairie land (black clay loam) contains from three to five times as much nitrogen and twice as much phosphorus as the common upland timber soils; and the deep peat soil contains eighteen times as much nitrogen but only one-sixth as much potassium as the yellow silt loam. The most significant facts revealed by the investigation of the McLean county soils are the lack of limestone and the low phosphorus content of the common prairie soil and of the most extensive timber type, which combined cover nearly 80 percent of the entire county. And yet both of these deficiencies can be overcome at relatively small expense by the application of ground limestone and fine-ground raw rock phosphate; and, after these are provided, clover can be grown with more certainty and in greater abundance, and nitrogen can thus be secured from the inexhaustible supply in the air. If the clover is then returned to the soil, either directly or in farm manure, the combined effect of limestone, phosphorus, and nitrogenous organic matter, with a good rotation of crops, will in time double the yield of corn and other crops on most farms.

Fortunately, some definite field experiments have already been conducted on brown silt loam, the most extensive type of soil in the early Wisconsin glaciation, as at Urbana in Champaign county, at Sibley in Ford county, and at Bloomington

in McLean county. Before considering in detail the individual soil types, it seems advisable to study some of the results already obtained where definite systems of soil improvement have been tried out on some of these experiment fields in different parts of central Illinois.

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 (Series 100), oats on another (Series 200), and oats, cowpeas, and corn on the third field (Series 300) until 1901.

From 1902 to 1910 the three-year rotation (with cowpeas in place of clover in 1902) was followed; the average yields are recorded in Table 3. A small crop of cowpeas in 1902 and a partial crop of clover in 1904 constituted all the hay harvested during the first rotation, mammoth clover grown in 1903 having lodged so that it was plowed under. (The yields were taken by carefully weighing the clover from small representative areas, but while the differences were thus ascertained and properly credited temporarily to the different soil treatments, they must ultimately reappear in subsequent crop yields, and consequently the 1903 clover crop is omitted from Table 3 in computing yields and values.) The average yields given represent one-third of the two small crops.

From 1902 to 1907 legume cover crops (Le), such as cowpeas and clover, were seeded in the corn at the last cultivation on Plots 2, 4, 6, and 8, but the growth was small and the effect, if any, was to decrease the returns from the regular crops. Since 1907 crop residues (R) have been returned to those plots. These consist of the stalks of corn, the straw of small grains, and all legumes except alfalfa hay and the seed of clover and soybeans.

On Plots 3, 5, 7, and 9, manure (M) was applied for corn at the rate of 6 tons per acre during the second rotation, and subsequently as many tons of manure have been applied as there were tons of air-dry produce harvested from the corresponding plots.

Lime (L) was applied on Plots 4 to 10 at the rate per acre of 250 pounds of air-slaked lime in 1902 and 600 pounds of limestone in 1903. Subsequently 2 tons per acre of limestone was applied to these plots on Series 100 in 1911, on Series 200 in 1912, on Series 300 in 1913, and on Series 400 in 1914; also 2½ tons per acre on Series 500 in 1911, two more fields having been brought into rotation, as explained on page 8.

Phosphorus (P) has been applied on Plots 6 to 9 at the rate of 25 pounds per acre per annum in 200 pounds of steamed bone meal; but beginning with 1908, one half of each phosphorus plot has received 600 pounds of rock phosphate in place of the 200 pounds of bone meal, the usual practice being to apply and plow under at one time all phosphorus and potassium required for the rotation.

Potassium (K=kalium) has been applied on Plots 8 and 9 at the yearly rate of 42 pounds per acre in 100 pounds of potassium sulfate, regularly in connection with the bone meal and rock phosphate.

On Plot 10 about five times as much manure and phosphorus are applied as on the other plots, but this "extra heavy" treatment was not begun until

1906, only the usual lime, phosphorus, and potassium having been applied in previous years. The purpose in making these heavy applications is to try to determine the climatic possibilities in crop yields by removing the limitations of inadequate fertility.

Series 400 and 500 were cropped in corn and oats from 1902 to 1910, but the corresponding plots were treated the same as in the three-year rotation. Beginning with 1911, the five series have been used for a combination rotation, wheat, corn, oats, and clover being rotated for five years on four fields, while alfalfa occupies the fifth field, which is then to be brought under the four-crop system to make place for alfalfa on one of the other fields for another five-year period, and so on. (See Table 4.)

From 1911 to 1914 soybeans were substituted three years because of clover failure; accordingly three-fourths of the soybeans and one-fourth of the clover are used to compute values. Alfalfa from the 1911 seeding so nearly failed that after cutting one crop in 1912 the field was plowed and reseeded. The average yield reported for alfalfa in Table 4 is one-fourth of the combined crops of 1912, 1913, and 1914.

The "higher prices" allowed for produce are $1 a bushel for wheat and soybeans, 50 cents for corn, 40 cents for oats, $10 for clover seed, and $10 a ton for hay; while the "lower prices" are 70 percent of these values, or 70 cents

PLATE 1.—CLOVER IN 1913 ON URBANA FIELD
FARM MANURE APPLIED
YIELD, 1.43 TONS PER ACRE

for wheat and soybeans, 35 cents for corn, 28 cents for oats, $7 for clover seed, and $7 a ton for hay. The double set of values is used to emphasize the fact that a given practice may or may not be profitable, depending upon the prices of farm produce. The lower prices are conservative, and unless otherwise stated, they are the values regularly used in the discussion of results. It should be understood that the increase produced by manures and fertilizers requires increased expense for binding twine, shocking, stacking, baling, threshing, hauling, storing, and marketing. Measured by the average Illinois prices for the past ten years, these lower values are high enough for farm crops standing in the field ready for the harvest.

The cost of limestone delivered at the farmers' railroad station in carload lots averages about $1.25 per ton. Steamed bone meal in carloads costs from $25 to $30 per ton. Fine-ground raw rock phosphate containing from 260 to 280 pounds of phosphorus, or as much as the bone meal contains, ton for ton, but in less readily available form, usually costs the farmer from $6.50 to $7.50 per ton in carloads. (Acid phosphate carrying half as much phosphorus, but in soluble form, commonly costs from $15 to $17 per ton delivered in carload lots in central Illinois.) Under normal conditions potassium costs about 6 cents a pound, or $2.50 per acre per annum for the amount applied in these experiments, the same as the cost of 200 pounds of steamed bone meal at $25 per ton.

Plate 2.—Clover in 1913 on Urbana Field
Farm Manure, Limestone, and Phosphorus Applied
Yield, 2.90 Tons per Acre

TABLE 3.—YIELDS PER ACRE, THREE-YEAR AVERAGES: URBANA FIELD
BROWN SILT LOAM PRAIRIE; EARLY WISCONSIN GLACIATION

Serial plot No.	First rotation, 1902-1904						Second rotation, 1905-1907						Third rotation, 1908-1910					
	Soil treatment	Corn, bu.	Oats, bu.	Hay, tons	Value of 3 crops		Soil treatment	Corn, bu.	Oats, bu.	Clover, tons	Value of 3 crops		Soil treatment	Corn, bu.	Oats, bu.	Clover, tons (bu.)	Value of 3 crops	
					Lower prices	Higher prices					Lower prices	Higher prices					Lower prices	Higher prices
1	0.....	75.4	48.8	.49	$43.48	$62.12	0.....	71.5	46.6	2.07	$52.56	$75.09	0.....	49.4	40.8	2.30	$44.81	$64.02
2	Le.....	77.4	45.1	.44	42.80	61.14	Le.....	68.5	52.0	1.83	51.34	73.35	R.....	51.5	43.4	(1.93)	43.69	62.41
3	0.....	75.3	50.4	.41	43.33	61.91	M.....	80.5	54.8	2.19	58.84	84.07	M.....	69.3	46.2	2.53	54.90	78.43
4	LeL.....	78.4	47.3	.42	43.62	62.32	LeL....	72.3	58.6	1.98	55.57	79.39	RL....	58.1	45.7	(2.02)	47.27	67.53
5	L.....	80.8	58.2	.44	47.66	68.08	ML....	84.8	59.8	2.46	63.64	90.92	ML....	74.9	47.5	2.94	60.09	85.85
6	LeLP....	88.0	52.5	.50	49.00	70.00	LeLP..	90.4	70.7	2.69	70.26	100.38	RLP...	83.8	54.5	(2.64)	63.07	90.10
7	LP.....	88.8	56.6	.98	53.79	76.84	MLP...	93.2	71.6	3.47	76.96	109.94	MLP...	86.6	55.4	4.17	75.01	107.16
8	LeLPK..	90.1	48.3	.64	49.53	70.77	LeLPK	93.8	71.7	3.06	74.32	106.18	RLPK	86.7	53.5	(1.99)	59.26	84.65
9	LPK....	90.5	54.3	1.34	56.26	80.37	MLPK	95.6	66.9	3.73	78.30	111.86	MLPK	90.9	53.6	3.90	74.12	105.89
10	LPK....	86.5	53.2	1.23	53.78	76.83	MxLPx	90.1	62.9	2.86	69.17	98.81	MxLPx	81.3	54.3	3.79	70.19	100.27

Le=legume cover crop; L=lime; P=phosphorus; K=potassium; M=manure; x=extra heavy applications of manure and phosphorus; R=crop residues (corn stalks, straw of wheat and oats, and all legumes except seed).

TABLE 4.—YIELDS PER ACRE, FOUR-YEAR AVERAGES, 1911-1914: URBANA FIELD BROWN SILT LOAM PRAIRIE; EARLY WISCONSIN GLACIATION

Serial plot No.	Soil treatment	Wheat, bu.	Corn, bu.	Oats, bu.	Soybeans–3, tons (bu.)	Clover–1, tons (bu.)	Alfalfa, tons	Value of 5 crops	
								Lower prices	Higher prices
1	0.....	18.3	50.8	39.8	1.60	1.70	1.70	$65.00	$92.87
2	R.....	19.7	53.8	40.6	(20.1)	(.74)	1.27	64.72	92.47
3	M.....	20.3	59.3	48.8	1.60	1.43	1.13	67.44	96.35
4	RL.....	22.3	55.7	42.8	(19.0)	(1.03)	1.19	67.20	96.00
5	ML.....	24.9	58.6	51.6	1.66	1.94	1.67	76.19	108.84
6	RLP....	37.4	62.2	58.7	(21.0)	(2.48)	2.69	98.58	140.83
7	MLP....	36.6	63.8	60.9	1.88	2.90	2.63	98.36	140.51
8	RLPK...	36.1	58.9	59.1	(22.2)	(1.41)	2.58	94.61	135.16
9	MLPK..	35.3	59.6	65.1	2.09	2.72	2.66	98.15	140.22
10	MxLPx..	43.5	55.7	67.2	2.14	2.94	2.84	105.02	150.03

To these cash investments must be added the expense of hauling and spreading the materials. This will vary with the distance from the farm to the railroad station, with the character of roads, and with the farm force and the immediate requirements of other lines of farm work. It is the part of wisdom to order such materials in advance to be shipped when specified, so that they may be received and applied when other farm work is not too pressing and, if possible, when the roads are likely to be in good condition.

The practice of seeding legume cover crops in the cornfield at the last cultivation where oats are to follow the next year has not been found profitable, as a rule, on good corn-belt soil; but the returning of the crop residues to the land may maintain the nitrogen and organic matter equally as well as the hauling and spreading of farm manure,—and this makes possible permanent systems of farming on grain farms as well as on live-stock farms, provided, of course, that other essentials are supplied. (Clover with oats or wheat, as a cover crop to be plowed under for corn, often gives good results.)

At the lower prices for produce, manure (6 tons per acre) was worth $1.05 a ton as an average for the first three years it was applied (1905 to 1907). The next rotation the average application of 10.21 tons per acre on Plot 3 was worth $10.09, or 99 cents a ton. The last four years, 1911 to 1914, the average amount applied (once for the rotation) on Plot 3 was 11.35 tons per acre, worth $6.42, or 57 cents a ton, as measured by its effect on the wheat, corn, oats, soybeans, and clover. Thus, as an average of the ten years' results, the farm manure applied to Plot 3 has been worth 84 cents a ton on common corn-belt prairie soil, with a good crop rotation including legumes. During the last rotation period moisture has been the limiting factor to such an extent as probably to lessen the effect of the manure.

Aside from the crop residues and manure, each addition affords a duplicate test as to its effect. Thus the effect of limestone is ascertained by comparing Plots 4 and 5, not with Plot 1, but with Plots 2 and 3; and the effect of phosphorus is ascertained by comparing Plots 6 and 7 with Plots 4 and 5, respectively.

As a general average, the plots receiving limestone have produced $1.22 an acre a year more than those without limestone, and this corresponds to more than $6 a ton for all of the limestone applied; but the amounts used before 1911 were so small and the results vary so greatly with the different plots, crops, and seasons that final conclusions cannot be drawn until further data are secured,

the first 2-ton applications having been completed only for 1914. However, all comparisons by rotation periods show some increase for limestone, varying from 82 cents on three acres (Plot 4) during the first rotation, to $8.75 on five acres (Plot 5) as an average of the last four years; and the need of limestone for best results and highest profits seems well established.

As an average of duplicate trials (Plots 6 and 7), phosphorus in bone meal produced increases valued at $1.92 per acre per annum for the first three years and at $4.67 for the next three; and the corresponding subsequent average increases from bone meal and raw phosphate (one-half plot of each) were $5.12 for the third rotation and $5.36 for the last four years, 1911 to 1914. The annual expense per acre for phosphorus is $2.80 in bone meal at $28 a ton, or $2.10 for rock phosphate at $7 a ton.

Potassium, applied at an estimated cost of $2.50 an acre a year, seemed to produce slight increases, as an average, during the first and second rotations; but subsequently those increases have been slightly more than lost in reduced average yields, the net result to date being an average loss of $2.53 per acre per annum, including the cost of the potassium.

Thus phosphorus nearly paid its cost during the first rotation, and has subsequently paid its annual cost and about 100 percent net profit; while potassium, as a general average, has produced no effect, and money spent for its applica-

PLATE 3.—CLOVER ON URBANA FIELD, SOUTH FARM
CROP RESIDUES PLOWED UNDER

tion has been lost. These field results are in harmony with what might well be expected on land naturally containing in the plowed soil of an acre only about 1,200 pounds of phosphorus and more than 36,000 pounds of potassium.

The total value of five average crops harvested from the untreated land during the last four years is $65. Where limestone and phosphorus have been used together with organic manures (either crop residues or farm manure), the corresponding value exceeds $98. Thus 200 acres of the properly treated land would produce as much in crops and in value as 300 acres of the untreated land.

The excessive applications on Plot 10 have usually produced rank growth of straw and stalk, with the result that oats have often lodged badly and corn has frequently suffered from drouth and eared poorly. Wheat, however, has as an average yielded best on this plot. The largest yield of corn on Plot 10 was 118 bushels per acre in 1907.

As an average of the results secured during the twelve years 1903 to 1914, on the University South Farm where fine-ground raw rock phosphate is applied at the rate of 500 pounds per acre per annum on the typical brown silt loam prairie soil, the return for each ton of phosphate[1] used has been $13.57 on Series

Plate 4.—Clover on Urbana Field, South Farm
Fine-Ground Rock Phosphate Plowed Under with Crop Residues

[1]During the first four years, Series 100 received only 1,500 pounds per acre of phosphate, and both series received also ½ ton per acre of limestone, the effect of which probably would be slight, as may be judged from the data secured later and reported herein.

100 and $12.07 on Series 200, with the "lower prices" allowed for produce, the rotation being wheat, corn, oats, and clover (or soybeans). This gives an average return of $12.82 for each ton of phosphate applied. Averages for each rotation period show the following value of increase per ton of phosphate used:

	Lower prices	Higher prices
First rotation, 1903 to 1906	$ 8.26	$11.80
Second rotation, 1907 to 1910	11.33	16.19
Third rotation, 1911 to 1914	18.88	26.97

Thus the rock phosphate paid back more than its cost during the first rotation, more than 1½ times its cost during the second rotation, and more than 2½ times its cost during the third rotation period.

One ton of fine-ground rock phosphate costs about the same as 500 pounds of steamed bone meal. Altho in less readily available form, the rock phosphate contains as much phosphorus, ton for ton, as the bone meal; and, when equal money values are applied in connection with liberal amounts of decaying organic matter, the natural rock may soon give as good results as the bone,—and, by supplying about four times as much phosphorus, the rock provides for greater durability.

The results just given represent averages covering the residue system and the live-stock system, both of which are represented in this crop rotation on the South Farm.

Ground limestone at the rate of 8 tons per acre was applied to the east half of these series of plots (excepting the check plots, which receive only residues or manure), beginning in 1910 on Series 200 and in 1911 on Series 100. Subsequent applications are made of 2 tons per acre each four years, beginning in 1914 on Series 200 and in 1915 on Series 100. As an average of results from both series, the crop values were increased during the third rotation, 1911-1914, as follows:

	Residue System		Live-Stock System	
	Lower prices	Higher prices	Lower prices	Higher prices
Gain for phosphate	$18.80	$26.86	$18.96	$27.09
Gain for limestone	2.31	3.30	2.55	3.64

Detailed records of these investigations are given in Tables 5 and 6, the data being reported by half-plots after 1910-1911. (Series 300 and 400, which are also used in this rotation, are located in part upon black clay loam and a heavy phase of brown silt loam. See discussion under "Black Clay Loam," page 26.)

Results of Experiments on Sibley Field

Table 7 gives the results obtained during twelve 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 the addition of phosphorus produced an increase of 8 bushels, nitrogen produced no increase, but nitrogen *and* phosphorus increased the yield by 15 bushels.

After six years of additional cropping, however, nitrogen appeared to be-

TABLE 5.—YIELDS AND VALUES IN SOIL EXPERIMENTS, UNIVERSITY SOUTH FARM
COMMON BROWN SILT LOAM PRAIRIE; EARLY WISCONSIN GLACIATION

Series 100		Corn 1903	Corn 1904	Oats 1905	Wheat 1906	Clover 1907	Corn 1908	Oats 1909	Clover 1910	Wheat[2] 1911	Corn 1912	Oats 1913	Soy-beans 1914	Value 1st four years		Value 2d four years		Value 3d four years	
Plot	Soil treatment applied	Bushels or tons per acre[1]												Lower prices	Higher prices	Lower prices	Higher prices	Lower prices	Higher prices
163	RP	45.1	54.1	57.5	39.8	(.83)	72.0	45.4	(.60)	46.85	74.9	26.8	(16.6)	$78.68	$112.40	$47.92	$68.46	$78.13	$111.62
166	RP	43.8	49.3	60.9	36.5	**(1.00)**	74.9	40.8	**(1.30)**	**53.40**	79.5	24.6	(17.5)	75.19	**107.41**	53.74	76.77	84.34	120.49
169	R	42.7	39.5	49.3	28.4	**(.90)**	65.0	39.9	(1.70)	36.71	67.9	19.1	(15.3)	**62.45**	89.22	52.12	74.46	65.52	93.60
170	M	41.8	38.7	52.2	26.2	2.56	69.6	40.1	2.87	35.85	76.7	22.5	1.09	61.13	87.33	73.60	105.14	65.87	94.10
173	MP	35.4	53.3	54.6	32.8	3.65	78.4	39.8	4.23	52.65	83.7	29.6	**1.45**	69.29	98.99	93.74	133.92	84.59	120.84
176	MP	39.3	58.1	61.9	38.8	3.74	79.5	40.0	4.23	51.03	85.6	32.1	**1.52**	78.58	112.26	94.81	135.45	85.30	121.87
163	RLP	.....								49.9	87.0	28.2	(18.1)	.....				85.94	122.78
166	RLP	.....								53.6	81.4	26.8	(18.0)	.....				86.11	123.02
169	R	.....								33.8	62.7	17.0	(15.2)	.....				61.00	87.15
170	M	.....								32.4	74.4	22.0	1.09	.....				**62.51**	89.30
173	MLP	.....								51.3	85.7	28.0	1.37	.....				83.33	119.05
176	MLP	.....								51.0	85.6	30.9	1.47	.....				84.60	120.86

[1]For legumes, figures in parentheses indicate bushels of seed; the others, tons of hay.
[2]From 1911 the acre-yields are based on half-plots, limestone having been applied to one half of plots indicated.

TABLE 6.—YIELDS AND VALUES IN SOIL EXPERIMENTS, UNIVERSITY SOUTH FARM
COMMON BROWN SILT LOAM PRAIRIE; EARLY WISCONSIN GLACIATION

Series 200		Oats 1903	Oats 1904	Wheat 1905	Clover 1906	Corn 1907	Oats 1908	Wheat 1909	Wheat[2] 1910	Corn 1911	Oats 1912	Soy-beans 1913	Wheat 1914	Value 1st four years		Value 2d four years		Value 3d four years	
Plot	Soil treatment applied	Bushels or tons per acre[1]												Lower prices	Higher prices	Lower prices	Higher prices	Lower prices	Higher prices
263	RP	24.7	25.7	32.1	.82	65.3	31.3	42.5	43.7	52.3	72.9	(13.7)	30.61	$42.32	$60.46	$91.96	$131.37	$69.73	$99.62
266	RP	23.1	24.5	29.3	.80	59.7	26.7	40.7	32.3	50.2	75.7	(12.3)	33.86	39.43	56.34	79.47	113.53	71.08	101.54
269	R	26.8	22.5	26.8	.86	57.9	31.5	39.4	25.3	35.5	61.9	(10.7)	16.11	38.58	55.12	74.38	106.25	48.52	69.32
270	M	22.0	21.5	24.0	.82	55.3	30.0	37.1	28.7	43.1	67.8	.84	17.40	34.72	49.60	73.81	105.45	52.12	74.47
273	MP	23.9	25.0	27.8	.77	62.5	29.5	43.4	43.7	38.6	69.4	1.17	37.16	38.54	55.06	91.10	130.15	67.14	95.92
276	MP	16.1	25.3	30.7	.68	58.0	27.9	44.1	38.2	48.0	68.6	1.34	41.98	37.84	54.06	85.72	122.46	74.77	106.82
263	RLP								49.0	50.3	78.9	(13.2)	40.36					77.19	110.27
266	RLP								45.2	47.1	78.7	(10.3)	36.01					70.93	101.34
269	R								35.3	45.3	68.4	(10.5)	20.71					56.85	81.22
270	M								33.3	45.2	73.2	1.12	20.06					58.20	83.14
273	MLP								46.2	53.7	69.0	1.27	46.23					79.37	113.38
279	MLP								39.5	50.6	69.5	1.24	48.98					80.13	114.48

[1]For legumes, figures in parentheses indicate bushels of seed; the others tons of hay.
[2]From 1910 the acre-yields are based on half-plots, limestone having been applied to one half of plots indicated.

come the most limiting element, the increase in the corn in 1907 being 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 apparently grew less productive, whereas, on land receiving both phosphorus and nitrogen, the yield 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.

TABLE 7.—CROP YIELDS IN SOIL EXPERIMENTS, SIBLEY FIELD

Brown silt loam prairie; early Wisconsin glaciation		Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Corn 1906	Corn 1907	Oats 1908	Wheat 1909	Corn 1910	Corn 1911	Oats 1912	Wheat 1913
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	5.5
102	Lime	60.0	54.0	74.7	31.7	39.2	38.9	24.7	28.8	34.0	22.2	85.6	6.8
103	Lime, nitro.	60.0	54.3	77.5	32.8	41.7	48.1	36.3	19.0	29.0	22.4	25.3	18.3
104	Lime, phos.	61.3	62.3	92.5	36.3	44.8	43.5	25.6	32.2	52.0	31.6	92.3	10.7
105	Lime, potas.	56.0	49.9	74.4	30.2	37.5	34.9	22.2	23.2	34.2	21.6	83.1	7.5
106	Lime, nitro., phos.	57.3	69.1	88.4	45.2	68.5	72.3	45.6	33.3	55.6	35.3	42.2	24.7
107	Lime, nitro., potas.	53.3	51.4	75.9	37.7	39.7	51.1	42.2	25.8	46.2	20.1	55.6	19.2
108	Lime, phos., potas.	58.7	60.9	80.0	39.8	41.5	39.8	27.2	28.5	43.0	31.8	79.7	11.8
109	Lime, nitro., phos., potas.	58.7	65.9	82.5	48.0	69.5	80.1	52.8	35.0	58.0	35.7	57.2	24.5
110	Nitro., phos., potas.	60.0	60.1	85.0	48.5	63.3	72.3	44.1	30.8	64.4	31.5	54.1	18.0
		Increase: Bushels per Acre											
For nitrogen		.0	.3	2.8	1.1	2.5	9.2	11.6	−9.8	−5.0	.2	−60.3	11.5
For phosphorus		1.3	8.3	17.8	4.6	5.6	4.6	.9	3.4	18.0	9.4	6.7	3.9
For potassium		−4.0	−4.1	−.3	−1.5	−1.7	−4.0	−2.5	−5.6	.2	−.6	−2.5	.7
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	14.0
For phos., nitro. over nitro		−2.7	14.8	10.9	12.4	24.8	24.2	9.3	14.3	26.6	12.9	16.9	6.4
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	−.2

Value of Crops per Acre in Twelve Years

Plot	Soil treatment applied	Total value of twelve crops	
		Lower prices	Higher prices
101	None	$172.89	$246.98
102	Lime	186.51	266.45
103	Lime, nitrogen	177.44	253.49
104	Lime, phosphorus	217.78	311.11
105	Lime, potassium	167.32	239.03
106	Lime, nitrogen, phosphorus	246.91	352.73
107	Lime, nitrogen, potassium	198.16	283.08
108	Lime, phosphorus, potassium	204.90	292.71
109	Lime, nitrogen, phosphorus, potassium	257.91	368.45
110	Nitrogen, phosphorus, potassium	242.47	346.38

Value of Increase per Acre in Twelve Years

For nitrogen	−$ 9.07	−$12.96
For phosphorus	31.27	44.66
For *nitrogen* and phosphorus over phosphorus	29.13	41.62
For *phosphorus* and nitrogen over nitrogen	69.47	99.24
For *potassium*, nitrogen, and phosphorus over nitrogen and phosphorus	11.00	15.72

Even in the unfavorable season of 1910 the yield of the highest producing plot exceeded the yield of the same plot in 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 was seen. Phosphorus appeared to be the first limiting element again in 1909, 1910, and 1911; while the lodging of oats, especially on the nitrogen plots, in the exceptionally favorable season of 1912, produced very irregular results. In 1913, wheat averaged 6.6 bushels without nitrogen or phosphorus (Plots 101, 102, 105) and 22.4 bushels where both nitrogen and phosphorus were added (Plots 106, 109, 110).

In the lower part of Table 7 are shown the total values per acre of the twelve crops from each of the ten different plots, the amounts varying from $167.32 to $257.91, with corn valued at 35 cents a bushel, oats at 28 cents, and wheat at 70 cents. Phosphorus without nitrogen has produced $31.27 in addition to the increase by lime, but with nitrogen it has produced $69.47 above the crop values where only lime and nitrogen have been used. The results show that in 26 cases out of 48 the addition of potassium has decreased the crop yields. Even when applied in addition to phosphorus, and with no effort to liberate potassium from the soil by adding organic matter, potassium has produced no increase in crop values as an average of the results from Plots 108 and 109.

By comparing Plots 101 and 102, and also 109 and 110, it is seen that lime has produced an average increase of $14.53, or $1.21 an acre a year. This increase on these plots is practically the same as at Urbana, and it suggests that the time is here when limestone must be applied to some of these brown silt loam soils.

While nitrogen, on the whole, has produced an appreciable increase, especially on those plots to which phosphorus has also been added, it has cost, in commercial form, so much above the value of the increase produced that 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 Tables 8 and 9, giving all 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. This field is a part of the S. Noble King farm.

The general results of the thirteen years' work tell much the same story as those from the Sibley field. The rotations have differed since 1905 by the use of clover and the discontinuing of the use of commercial nitrogen,—in consequence of which phosphorus without commercial nitrogen, on the Bloomington field, has produced an even larger increase ($99.85) than has been produced by phosphorus and nitrogen over nitrogen on the Sibley field ($69.47).

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 8 are considered reliable. They not only

furnish much information in themselves, but they also offer instructive comparison with the Sibley field.

Wherever nitrogen has been provided, either by direct application or by the use of legume crops, the addition of the element phosphorus has produced very marked increases, the average yearly increase for the Bloomington field being worth $7.02 an acre. This is $4.52 above the cost of the phosphorus in 200 pounds of steamed bone meal, the form in which it is applied on the Sibley and the 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 nitrogen, a liberal use of clover or other legumes is suggested, the legume to be plowed 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 on the Bloomington field, 180 pounds per acre of phosphorus, as an average, has been removed in the thirteen crops. This is equal to 15 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 has been applied, the crops have removed only 120 pounds of phosphorus in the thirteen years, which is equivalent to only 10 percent of the total amount (1,200 pounds) present in the surface soil at the beginning of the experiment in 1902. The total phosphorus applied from 1902 to 1914, as an average of all plots where it has been used, has amounted to 325 pounds per acre and has cost $32.50.[1] This has paid back $97.20, or 300 percent on the invest-

Plate 5.—Corn in 1912 on Bloomington Field
On Left, Residues, Lime, and Potassium: Yield, 58.9 Bushels
On Right, Residues, Lime, and Phosphorus: Yield, 86.1 Bushels

[1]This is based on $25 a ton for steamed bone meal, but in recent years the price has been advanced generally to nearly $30.

TABLE 8.—CROP YIELDS IN SOIL EXPERIMENTS, BLOOMINGTON FIELD

Plot	Brown silt loam prairie; early Wisconsin glaciation — Soil treatment applied	Corn 1902	Corn 1903	Oats 1904	Wheat 1905	Clover 1906	Corn 1907	Corn 1908	Oats 1909	Clover[2] 1910	Wheat 1911	Corn 1912	Corn 1913	Oats 1914
		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	32.4	29.8
102	Lime	37.0	60.3	60.8	28.8	.58	63.1	35.3	53.6	1.09	22.5	47.9	30.0	40.6
103	Lime, crop residues[1]	35.1	59.5	69.8	30.5	.46	64.3	36.9	49.4	(.83)	25.6	62.5	37.5	30.8
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	44.1	45.0
105	Lime, potassium	37.7	56.4	62.5	33.2	.51	64.1	36.2	45.3	1.26	21.7	57.8	32.1	35.8
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	50.4	62.3
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	34.5	34.5
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	49.4	63.1
109	Lime, residues,[1] phosphorus, potassium	52.7	80.9	90.5	51.9	([3])	88.4	58.1	64.2	(.42)	60.4	83.4	49.0	54.4
110	Residues, phosphorus, potassium	52.3	73.1	71.4	51.1	([3])	78.0	51.4	55.3	(.60)	61.0	78.3	33.8	44.8
		Increase: Bushels or Tons per Acre												
	For residues	−1.9	−.8	9.0	1.7	−.12	1.2	1.6	−4.2		3.1	14.6	7.5	−9.8
	For phosphorus	4.7	12.7	11.9	10.4	1.07	19.0	12.2	10.2	3.12	35.1	26.6	14.1	4.4
	For potassium	.7	−3.9	1.7	4.4	−.07	1.0	.9	−8.3	.15	−.8	9.9	2.1	−4.8
	For residues, phosphorus over phosphorus	2.2	4.6	12.3	11.7	−1.65	−3.2	−1.7	8.7		2.6	11.6	6.3	17.3
	For phosphorus, residues over residues	8.8	18.1	15.5	20.4	−.46	14.6	8.9	23.1	(.84)	34.6	23.6	12.9	31.5
	For potassium, residues, phosphorus, over res., phos.	8.8	3.3	5.2	1.0	.00	9.5	12.3	−8.3	(−1.25)	.2	−2.7	−1.4	−7.9

[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.

Table 9.—Value of Crops per Acre in Thirteen Years, Bloomington Field

Plot	Soil treatment applied	Total value of thirteen crops	
		Lower prices	Higher prices
101	None	$186.83	$266.90
102	Lime	186.76	266.80
103	Lime, residues	193.83	276.90
104	Lime, phosphorus	286.61	409.45
105	Lime, potassium	190.53	272.19
106	Lime, residues, phosphorus	285.03	407.19
107	Lime, residues, potassium	191.10	273.00
108	Lime, phosphorus, potassium	294.91	421.31
109	Lime, residues, phosphorus, potassium	284.47	406.39
110	Residues, phosphorus, potassium	259.10	370.15
	Value of Increase per Acre in Thirteen Years		
	For residues	$ 7.07	$ 10.10
	For phosphorus	99.85	142.65
	For *residues* and phosphorus over phosphorus	−1.58	−2.26
	For *phosphorus* and residues over residues	91.20	130.29
	For *potassium*, residues, and phosphorus over residues and phosphorus	−.56	−.80

ment; whereas potassium, used in the same number of tests and at the same cost, has paid back only $2.20 per acre in the thirteen years, or less than 7 percent of its cost. Are not these results to be expected from the composition of such soil and the requirements of crops? (See Table 2; 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 cover 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 has been appreciable since 1910 (an average increase on Plots 106 and 109 of 4.5 bushels of wheat, 5.4 bushels of corn, and 4.3 bushels of oats) 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 thirteen years have drawn 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.

Plate 6 shows graphically the relative values of the thirteen 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. Plot 106, which receives the most practical treatment for permanent agriculture (RLP), has produced a total value in thirteen years only $1.58 below that from Plot 104 (LP). (See also table on last page of cover.)

THE SUBSURFACE AND SUBSOIL

In Tables 10 and 11 are recorded the amounts of plant food in the subsurface and the subsoil of the different types of soil in McLean county, 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 common prairie soil and the upland timber soils are from slightly to strongly acid in the subsurface and sometimes contain no limestone in the subsoil. This fact emphasizes 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. While the common brown silt loam prairie is usually slightly acid, the upland timber soils are, as a rule, more distinctly in need of

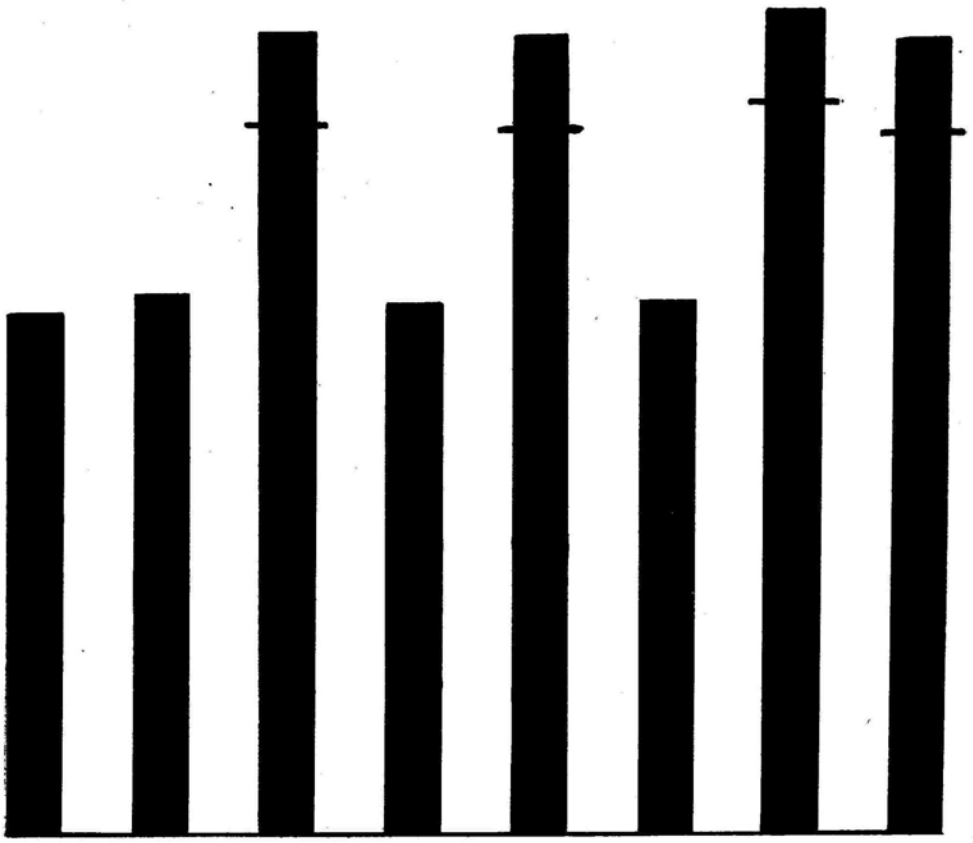

PLATE 6.—CROP VALUES FOR THIRTEEN YEARS, BLOOMINGTON EXPERIMENT FIELD
(R=residues; P=phosphorus; K=potassium, or kalium)

limestone, and as already explained, they are also more deficient in organic matter and nitrogen than the prairie soils, and thus more in need of growing clover.

TABLE 10.—FERTILITY IN THE SOILS OF McLEAN COUNTY, ILLINOIS

Average pounds per acre in 4 million pounds of subsurface soil (about 6⅔ to 20 inches)

Soil type No.	Soil type	Total organic carbon	Total nitrogen	Total phosphorus	Total potassium	Total magnesium	Total calcium	Limestone present	Soil acidity
	Upland Prairie Soils								
1126	Brown silt loam	74 530	6 660	1 870	73 230	19 520	17 850		110
1120	Black clay loam	91 180	8 130	3 150	70 760	33 150	57 190	Often	Rarely
1120.2	Gravelly black clay loam	65 200	6 240	2 600	67 880	46 640	106 200	252 200	
1128	Brown-gray silt loam on tight clay	27 720	3 200	2 160	78 960	17 640	12 040		880
1190	Gravelly loam	58 160	5 600	2 000	75 840	20 400	15 080		40
	Upland Timber Soils								
1134	Yellow-gray silt loam	24 490	2 710	1 490	74 230	16 390	13 980		2 350
1135	Yellow silt loam	15 280	2 020	1 540	72 000	24 620	14 620		3 660
	Terrace Soils								
1527	Brown silt loam over gravel	68 200	6 320	2 160	75 880	18 960	12 840		80
1526.2	Brown silt loam on gravel	55 320	5 160	1 640	83 780	22 600	14 340		100
1534.4	Yellow-gray silt loam on gravel	26 800	3 000	1 560	73 800	19 440	17 240		80
	Swamp and Bottom-Land Soils								
1401	Deep peat	608 090	52 420	4 610	14 160	11 080	63 270	Rarely	Often
1426	Deep brown silt loam	144 760	11 520	3 320	69 280	22 080	34 920	1 360	
1454	Mixed loam	112 560	11 080	3 080	83 320	28 960	37 000	3 160	

TABLE 11.—FERTILITY IN THE SOILS OF McLEAN COUNTY, ILLINOIS

Average pounds per acre in 6 million pounds 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	Soil acidity
	Upland Prairie Soils								
1126	Brown silt loam	32 310	3 620	2 350	114 870	48 600	46 360	Rarely	Often
1120	Black clay loam	35 480	3 450	3 410	111 560	58 820	80 450	Often	Rarely
1120.2	Gravelly black clay loam	47 760	4 140	3 120	104 220	54 540	119 520	279 300	
1128	Brown-gray silt loam on tight clay	21 900	3 120	3 540	120 600	36 240	19 500		840
1190	Gravelly loam	57 060	5 460	2 040	110 040	32 100	19 560		60
	Upland Timber Soils								
1134	Yellow-gray silt loam	21 380	2 840	4 040	114 270	42 060	31 590		Often
1135	Yellow silt loam	20 250	2 580	3 000	110 820	58 650	60 510		Often
	Terrace Soils								
1527	Brown silt loam over gravel	36 120	3 840	2 520	106 800	39 540	22 320		420
1526.2	Brown silt loam on gravel	42 690	4 470	2 130	113 040	37 380	24 300		Often
1534.4	Yellow-gray silt loam on gravel	28 800	3 180	2 700	103 620	30 360	27 180		420
	Swamp and Bottom-Land Soils								
1401	Deep peat	752 400	55 050	4 650	38 010	20 490	71 910		30
1426	Deep brown silt loam	86 880	5 640	3 180	108 600	27 720	47 220		120
1454	Mixed loam	101 280	9 900	3 120	123 900	43 320	49 200		60

INDIVIDUAL SOIL TYPES

(a) UPLAND PRAIRIE SOILS

The upland prairie soils of McLean county occupy 1,022.68 square miles, or 87.64 percent of the entire area of the county. They are black or brown in color, owing to their large content of organic matter.

The accumulation of organic matter in the prairie soils is due to the growth of prairie grasses 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 seven inches contained 13.5 tons of roots. Many of these roots died each year and by partial decay formed the humus of these dark prairie soils.

Brown Silt Loam (1126, *or* 926 *on moraines*)

Brown silt loam is the most important as well as the most extensive soil type in the county. It covers an area of 847.38 square miles (542,323 acres), or 72.6 percent of the entire county.

This type occupies the slightly undulating to rolling areas of the prairie land, much of which is well surface-drained, while many areas need artificial drainage. The morainal areas are sometimes sufficiently rolling to require considerable care in preventing erosion. Altho brown silt loam is normally a prairie soil, yet in some limited areas forests have recently invaded the dark soil. These forests consist quite largely of black walnut, 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 because of the fact that it still contains a large amount of organic matter, characteristic of prairie soils. After the growth of several generations of trees, the organic matter would become so reduced that the soil would then be classed as a timber type.

The surface soil, 0 to 6⅔ inches, is a brown silt loam, varying on the one hand to black as it grades into black clay loam (1120), and on the other hand to grayish brown or yellowish brown as it grades into the timber type, yellow-gray silt loam (1134 or 934). The physical composition varies to some extent, but it is normally a silt loam, containing from 65 to 80 percent of silt, together with some sand, and from 10 to 15 percent of clay. The amount of clay increases as the type approaches the black clay loam (1120), and becomes greatest in the level, poorly drained areas. The amount of sand varies from 10 to 20 percent.

The organic-matter content varies from 3.5 to 6.6 percent, with an average of 4.9 percent, or 49 tons per acre. The amount is less in the more rolling areas than in the low and poorly drained parts, owing to the fact not only that less vegetation grows on the drier, rolling areas, but that when incorporated with the soil much of it is removed by erosion and undergoes greater decomposition because of better aeration and less moisture. Where the type passes into the yellow-gray silt loam (1134 or 934), the organic-matter content becomes less, while in the low, swampy tracts where the grasses grew more luxuriantly and their

roots were more abundant, the large moisture content furnished conditions more favorable for the preservation of organic matter.

The natural subsurface is represented by a stratum varying from 6 to 16 inches in thickness, being thinner on the more rolling areas, while decidedly thicker and darker on the more 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, especially as it approaches the black clay loam type (1120). Both color and depth vary with the topography, the stratum being lighter in color as well as shallower on the more rolling areas and where the type grades into yellow-gray and yellow silt loam (1134 or 1135). The amount of organic matter varies with depth, but the average for this stratum (which is twice the thickness of the surface soil as it is sampled) is 3.2 percent, or 64 tons per acre.

The natural subsoil begins at 12 to 23 inches, and extends to an indefinite depth, but is sampled to 40 inches. It varies with the topography both in color and texture, and becomes slightly coarser with depth. It consists of a yellow or drabbish mottled yellow, clayey silt or silty clay, plastic when wet. Where the drainage has been good, it is of a bright to a pale yellow color. With poor drainage it approaches a drab or olive color with pale yellow mottlings or a yellow color with mottlings of drab. Each of the above strata is pervious to water, so that drainage takes place with little difficulty.

A phase of brown silt loam has been recognized in this county where, because of the removal of part of the fine loessial material by erosion, the glacial drift is encountered less than 30 inches from the surface. If the drift is quite compact, as is occasionally the case, this gives rise to a somewhat inferior subsoil, owing to its less pervious character. This condition, however, does not occur very generally nor over large areas, since most of the drift is pervious and some is quite gravelly. This phase is found mostly in Township 23 North, Range 6 East.

In the northeastern part of the county a slightly sandy phase of the type is found, but it is not sufficiently sandy to be classed as a loam. Small areas of sandy and gravelly loam, too small to be shown on the map, are common in the most rolling part of the morainal regions.

An abnormal phase of brown silt loam about 30 acres in extent is found in the northeast forty of Section 11, Township 22 North, Range 5 East. In spots this varies a great deal from the true type, being a sandy peat in some places, a marly peat in others, and in still others containing large amounts of brown iron oxid.

While the common brown silt loam is in fair physical condition, yet continuous cropping to corn, or corn and oats, with the burning of the stalks, is destroying the tilth; the soil is becoming more difficult to work; it runs together more; and aeration, granulation, and absorption of moisture do not take place as readily as formerly. This condition of poor tilth may become serious if the present methods of management continue; it is already one of the factors that limit the crop yields. The remedy is to increase the organic-matter content by plowing under farm manure and crop residues, such as corn stalks, straw, and clover.

The addition of fresh organic matter is not only of great value in improving the physical condition of this type of soil, but it 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 on brown silt loam, phosphorus should be applied liberally, and sufficient organic matter should be provided to furnish the necessary amount of nitrogen. On the ordinary type, limestone is already becoming deficient. 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 in the following spring for corn; and most of the crop residues, with all 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. In live-stock farming the regular rotation may be extended to five or six years by seeding both timothy and clover with the oats, and pasturing one or two years. Alsike and sweet clover may well replace red clover at times, in order to avoid clover sickness. (For results of field experiments on the brown silt loam prairie, see Tables 3 to 9.)

Black Clay Loam (1120)

Black clay loam represents the flat prairie and is sometimes called "gumbo" because of its sticky character. Its formation in flatter, poorly drained areas 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 occupies 168.69 square miles (17,961 acres), or 14.47 percent of the entire area of the county. It is so flat that proper drainage is one of the most difficult problems in its management.

The surface soil, 0 to 6⅔ inches, is a black granular clay loam, varying locally to a black clayey silt loam on the large flat areas. It contains, on an average, 7.6 percent of organic matter, or 76 tons per acre, varying from 65 to 98 tons. In physical composition it varies somewhat as it grades into other types. As it passes toward the brown silt loam, which nearly always surrounds it, it becomes more silty. Where it merges into the gravelly black clay loam (1120.2), it sometimes contains considerable quantities of sand and fine or medium gravel.

The subsurface stratum has a thickness of 10 to 16 inches and varies from a black to a brownish gray clay loam, usually somewhat heavier than the surface soil. The average amount of organic matter is 4 percent, or 80 tons per acre. The lower part of this stratum frequently is a drab or yellowish drab silty clay. The stratum is quite pervious to water, owing to jointing or checking from shrinkage in times of drouth.

The subsoil to a depth of 40 inches varies from a drab to a yellowish drab silty clay. As a rule, the iron is not highly oxidized, because of poor drainage and lack of aeration. Concretions of carbonate of lime are frequently found. The perviousness of the subsoil is about the same as the subsurface and is due to the same cause. When thrown out on the surface where wetting and drying may take place, it soon breaks into small cubical masses. Gravel is frequently present.

Black clay loam presents many variations. Here, as elsewhere, the boundary lines between it and the brown silt loam are not always distinct. In some cases topography is a great help in locating the boundary, but in other cases there may be an intermediate zone of greater or less width. The washing in of silty

material from the surrounding higher lands, especially near the edges of the areas, modifies the character of the soil, giving the surface a silty character. This change is taking place more rapidly now, with the annual cultivation of the soil, than formerly, when washing was largely prevented by prairie grasses.

Drainage is the first requirement in the management of this type; altho it usually has but little slope, yet because of its perviousness it is easily tile-drained. 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 as a consequence it becomes more difficult to work. Both organic matter and limestone tend to develop granulation. The former should be maintained by turning under manure or such crop residues as corn stalks and straw, and by the use of clover and pasture in rotations. Ground limestone should be applied when needed to keep the soil sweet. It should be remembered that the difficulty of working clay soils is in proportion to their deficiency in organic matter.

While black clay loam is one of the best soils in the state, yet the clay and humus which it contains 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, they shrink. This results in the formation of cracks, sometimes as much as two or more inches in width and extending with lessening width to two or three feet in depth. During the drouth of 1914, the cracks were so large and deep that in many cases a one-inch auger could be forced into them, without turning, to a depth of more than two feet. These cracks allow the soil strata to dry out rapidly, and as a result the crop is injured thru lack of moisture. They may do considerable damage by "blocking out" hills of corn and severing the roots. While cracking may not be prevented entirely, good tilth with a soil mulch will do much toward that end. Both for aeration and for producing a mulch for conserving moisture, cultivation is more essential on this type than on the brown silt loam. It must be remembered, however, that cultivation should be as shallow as possible, in order to prevent injury to the roots of the corn.

This type is fairly well supplied with plant food, which is usually liberated with sufficient rapidity by a good rotation and by 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. Altho the addition of phosphorus is not expected to produce marked profit, 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.

At Urbana, on the South Farm of the University of Illinois, a series of plots devoted chiefly to variety tests and other crop-production experiments extends across an area of black clay loam. Where rock phosphate has been applied at the rate of 500 pounds an acre a year in connection with crop residues, in a four-year rotation of wheat, corn, oats, and clover (or soybeans), the value of the increase produced per ton of phosphate used in three successive rotation periods, has been $2.13, $4.70, and $6.48, respectively, at the "lower prices," or $3.04, $6.71, and $9.26, respectively, at the "higher prices" for produce. In the live-stock system, the phosphorus naturally supplied in the manure, supple-

mented by that liberated from this fertile soil, has thus far been nearly sufficient to meet the crop requirements; the increase in crop values per ton of phosphate applied having been, as an average for the twelve years, only $2.26 at the "lower prices," or $3.26 at the "higher prices." These returns are less than half the cost of the phosphorus applied, and some seasons no benefit appears.

This type is rich in magnesium and calcium, and in the Wisconsin glaciation it usually contains plenty of carbonates. With continued cropping and leaching, applications of limestone will ultimately be needed.

Gravelly Black Clay Loam (1120.2)

Gravelly black clay loam occurs in the poorly drained areas in the eastern and northeastern part of the county in the large sloughs that, during parts of the year, were once covered with streams whose currents were sufficiently strong to carry and deposit considerable quantities of sand and small gravel. These materials have become mixed with the fine material and form a distinct phase of black clay loam.

The surface soil, 0 to 6⅔ inches, varies from 15 to 40 percent in the amount of gravel it contains, the gravel itself being mostly fine. The organic-matter content is not quite so high as in the black clay loam, being about 6.4 percent, or 64 tons per acre.

The subsurface, extending from 6⅔ to 18 or 20 inches, is a brown gravelly clay loam, containing about 3.2 percent of organic matter and passing at the lower limit into a less gravelly and much lighter colored clay loam.

The subsoil varies from a drab to a pale yellowish drab, indicating poor oxidation. It does not usually contain as much gravel as either the surface or subsurface. Limestone concretions are frequently found.

The management of this type is not different from that of the black clay loam, altho there may be a greater necessity for maintaining the supply of organic matter because of the lower content of this constituent naturally in the soil. The presence of gravel affects the working of the soil only to a slight extent, since clay possesses such distinctive properties that it takes a large amount of gravel and sand to overcome its effects. Hence this type works very little differently from the ordinary black clay loam.

Brown-Gray Silt Loam on Tight Clay (1128)

Brown-gray silt loam on tight clay occurs in numerous small areas thruout the county, principally in Township 23 North, Ranges 1 West and 1 East; also in the southwestern part of Township 24 North, Range 1 West. The total area occupied by this type is 2.42 square miles (1,549 acres), or .2 percent of the area of the county. While not of great importance from the standpoint of area, yet it is interesting to note that the tight clay soils, or so-called hardpan, have developed under certain conditions even in the early Wisconsin glaciation. The topography is flat and naturally poorly drained.

The surface soil, 0 to 6⅔ inches, consists of a brown or grayish brown silt loam, containing some fine sand and coarse silt, which give it a peculiar, mealy feel but excellent texture. It contains about 4 percent of organic matter, or 40 tons per acre, and is somewhat richer in this constituent than the corresponding

type in southern Illinois. The organic-matter content varies with its relation to other types, being greater where it approaches brown silt loam (1126) and less where it passes into yellow-gray silt loam (1134). As a rule, the surface soil is not so granular as the ordinary brown silt loam.

The subsurface is represented by a stratum 10 to 12 inches thick. The color varies from a brown to a gray or grayish brown, the upper part of the stratum usually being brown, while the lower part is decidedly gray or grayish brown. It differs from the surface soil principally in the amount of organic matter it contains, having 1.2 percent as compared with 4 percent in the top stratum.

The natural subsoil begins at a depth of 16 to 18 inches, as a yellowish, almost impervious, silty clay, and has a thickness of 10 to 15 inches. It is usually underlain by a rather pervious silt. This tight clay layer obstructs drainage to such an extent that percolation is not very rapid, hence the soil dries very slowly. The land should be tiled thoroly, unless surface drainage is sufficient. In order to do this, the lines of tile should be placed not over four rods apart.

Care should be taken, on this type, to maintain or increase the amount of organic matter by the proper rotation of crops and the turning under of crop residues and farm manures. Deep-rooting crops, such as red, mammoth, and sweet clover, should be grown so as to render the tight clay more permeable to air and water.

From Table 2 it will be seen that the surface soil contains only 4,200 pounds of nitrogen and 1,380 pounds of phosphorus per acre. To increase these amounts, liberal applications of fine-ground rock phosphate should be made in connection with decaying organic matter, as on the brown silt loam. This type is distinctly acid in surface, subsurface, and subsoil. Limestone should be applied at the rate of 2 to 3 tons per acre every four to six years. The initial applications may well be 1 ton of phosphate and 4 tons of limestone.

Gravelly Loam (1190 *or* 990)

Gravelly loam occupies many areas on the upland but covers a total of only 96 acres. These areas are small and isolated, representing small gravel ridges recently covered by fine wind-blown material.

The organic matter of the soil should be maintained, and in other respects the treatment should be the same as for the brown silt loam, except that phosphorus need not be added, because of the deep feeding range afforded plant roots.

(b) Upland Timber Soils

The upland timber soils occur along streams, or, in some cases, on or near somewhat steep morainal ridges. They are characterized by a yellow, yellowish gray, or gray color, due to their low organic-matter content. This lack of organic matter has been caused by the long-continued growth of forest trees. As the forests invaded the prairies, two effects were produced: (1) the shading of the trees prevented the growth of prairie grasses, the roots of which are mainly responsible for the large amount of organic matter in prairie soils; (2) the trees themselves added very little organic matter to the soil, for the leaves and branches either decayed completely or were burned by forest fires. As a result the organic-matter content of the upland timber soils has been reduced until in some parts of the state a low condition of apparent equilibrium has been reached.

Yellow-Gray Silt Loam (1134 *or* 934)

Yellow-gray silt loam occurs in the outer timber belts along streams and in the less rolling of the timbered morainal areas. The type covers 73.42 square miles (46,989 acres), or 6.23 percent of the entire area of the 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 yellow, yellowish gray, gray, or brownish gray silt loam, incoherent but not granular. The more nearly level areas are gray in color, while the more rolling phase of the type has a yellow or brownish yellow color. As the type approaches the brown silt loam, it becomes decidedly darker. The organic-matter content averages 2.9 percent, or 29 tons per acre, but it varies considerably with topography. As the type approaches the brown silt loam, the organic matter amounts to as much as 3.8 percent, while as it approaches the yellow silt loam, it diminishes to as low as 2.3 percent. In some cases it is extremely difficult to draw the line between the long-cultivated brown silt loam and the yellow-gray silt loam, because of the gradation between the types.

The subsurface stratum varies from 3 to 10 inches in thickness, erosion having reduced its thickness on the more rolling areas. It is usually a gray, grayish yellow, or yellow silt loam, somewhat pulverulent, but becoming more coherent and plastic with depth. The amount of organic matter is about 1 percent, or 20 tons per acre in the four million pounds of soil.

The subsoil is a yellow or mottled grayish yellow, clayey silt or silty clay, somewhat plastic when wet, but friable when only moist, and pervious to water. Glacial drift is sometimes encountered at a depth of less than 40 inches. This is due to the removal by erosion of part of the loessial material. The glacial drift may be locally a very gravelly deposit, but usually it is a slightly gravelly clay and in some places is lacking in permeability. Otherwise, each stratum of this type is quite pervious to water, except in the level gray areas, where the tight and more or less compact clayey layer has been formed at a depth of 18 to 24 inches. Small areas of light gray silt loam on tight clay are found in the county, but none large enough to be shown on the map.

In the management of this type one of the most essential things is the maintaining or the increasing of organic matter. This is necessary in order to supply nitrogen and liberate mineral plant food, to give better tilth, to prevent "running together," and on some of the more rolling phases, to prevent washing.

Another essential is the neutralization of the acidity of the soil by the application of ground limestone, so that clover, alfalfa, and other legumes may be grown more successfully. The initial application may well be 4 or 5 tons per acre, after which 2 tons per acre every four or five years will be sufficient. Since the soil is poor in phosphorus, this element should be applied, preferably in connection with farm manure or clover plowed under. In permanent systems of farming, fine-ground natural rock phosphate will be found the most economical form in which to supply the phosphorus, altho steamed bone meal or acid phosphate may well be used temporarily until plenty of decaying organic matter can be provided.

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 duplicate trials each year for the four years 1911 to 1914, the crop values from four acres were $16.44 from untreated land, $18.22 where organic manures were applied in proportion to the amount of crops produced, and $33.58 where 6 tons per acre of limestone and the organic manures were applied,—the wheat, corn, oats, and clover (or cowpeas or soybeans) grown in the rotation being valued at the "lower prices" heretofore mentioned. Owing to the low supply of organic matter, phosphorus produced almost no benefit, as an average, during the first two years; but with increasing applications of organic matter, the effect of phosphorus is becoming more apparent in subsequent crops. Of course the full benefit of a four-year rotation cannot be realized during the first four years. The farm manure was applied to one field each year, and the fourth field received no manure until the fourth year. Likewise, crop residues plowed under during the first rotation may not be fully recovered in subsequent increased yields until the second or third rotation period.

While limestone is the material first needed for the economic improvement of the more acid soils of southern Illinois, with organic manures and phosphorus to follow in order, the less acid soils of the central part of the state are first in need of phosphorus, altho limestone and organic matter must also be provided for permanent and best results.

Table 12 shows in detail thirteen 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 McLean 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 early Wisconsin glaciation, in which McLean county is situated.

The Antioch field was started in order to learn as quickly as possible what effect would be produced by the addition to this type of soil, of nitrogen, phosphorus, and potassium, singly and in combination. These elements were all added in commercial form until 1911, after which the use of commercial nitrogen was discontinued and crop residues were substituted in its place. (See report of Urbana field for further explanations, page 7.) Only a small amount of lime was applied at the beginning, in harmony with the teaching which was common at that time; furthermore, Plot 101 proved to be abnormal, so that no conclusions can be drawn regarding the effect of lime. In order to ascertain the effect produced by additions of the different elements singly, Plot 102 must be regarded as the check plot. Three other comparisons are also possible to determine the effect of each element under different conditions.

As an average of 40 tests (4 each year for ten years), liberal applications of commercial nitrogen produced a slight decrease in crop values; but as an average of thirteen years each dollar invested in phosphorus paid back $2.54 (Plot 104), while potassium applied in addition to phosphorus (Plot 108) produced no increase, the crops being valued at the lower prices used in the tabular statement. 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 com-

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

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	Clover 1913[2]	Wheat 1914
Plot	Soil treatment applied[1]	Bushels or tons per acre												
101	None	44.8	36.6	17.8	18.5	35.9	12.4	65.6	12.2	5.2	34.4	21.3	.50	30.8
102	Lime	45.1	38.9	12.8	10.3	31.5	9.5	61.6	11.7	3.0	24.6	17.5	.60	30.0
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	([3])	40.8
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	1.32	54.2
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	.72	34.0
106	Lime, nitrogen, phosphorus	56.6	62.7	15.9	15.2	59.3	20.9	49.1	33.8	6.0	37.0	46.9	([3])	41.3
107	Lime, nitrogen, potassium	52.1	54.9	10.3	11.8	39.0	11.1	52.6	21.0	1.6	7.0	16.9	([3])	43.2
108	Lime, phosphorus, potassium	60.7	66.0	19.7	28.7	59.1	18.3	59.4	26.2	3.2	42.2	35.9	1.60	46.0
109	Lime, nitrogen, phosphorus, potassium	61.2	69.1	31.9	18.0	65.9	31.4	51.9	30.5	3.0	44.2	31.9	([3])	41.0
110	Nitrogen, phosphorus, potassium	59.7	71.8	37.2	16.3	66.3	28.8	55.9	34.5	4.0	49.0	38.1	([3])	37.8
		Increase: Bushels or Tons per Acre												
For nitrogen		1.2	1.9	−10.0	7.5	6.3	−3.1	−1.3	1.3	−1.6	−14.2	6.9		10.8
For phosphorus		5.0	14.7	−.3	25.5	25.9	3.9	9.3	11.6	3.8	12.8	31.6	.72	24.2
For potassium		3.1	11.3	−3.1	11.4	3.4	3.4	.9	1.8	1.6	−4.2	1.3	.12	4.0
For nitrogen, phosphorus over phosphorus		6.5	9.1	3.4	−20.6	1.9	7.5	−21.8	10.5	−.8	−.4	2.2		−12.9
For phosphorus, nitrogen over nitrogen		10.3	21.9	13.1	−2.6	21.5	14.3	−11.2	20.8	4.6	26.6	22.5		.5
For postassium, nitrogen, phosphorus over nitrogen, phosphorus		4.6	6.4	16.0	2.8	6.6	10.5	2.8	−3.3	−3.0	7.2	−15.0		−.3

[1]Crop residues in place of commercial nitrogen after 1911.
[2]Figures in parentheses indicate bushels of seed; the others, tons of hay.
[3]No seed produced: clover plowed under on these plots.

TABLE 13.—VALUE OF CROPS PER ACRE IN THIRTEEN YEARS, ANTIOCH FIELD

Plot	Soil treatment applied	Total value of thirteen crops	
		Lower prices[1]	Higher prices[2]
101	None	$135.12	$193.03
102	Lime	119.74	171.06
103	Lime, nitrogen	124.70	178.15
104	Lime, phosphorus	202.20	288.85
105	Lime, potassium	138.88	198.40
106	Lime, nitrogen, phosphorus	179.41	256.31
107	Lime, nitrogen, potassium	133.54	190.77
108	Nitrogen, phosphorus, potassium	201.35	287.65
109	Lime, nitrogen, phosphorus, potassium	191.22	273.18
110	Nitrogen, phosphorus, potassium	[illegible]	[illegible]
	Value of Increase per Acre in Thirteen Years	196.62	[illegible]
	For nitrogen	$ 4.96	$ 7.09
	For phosphorus	82.46	117.79
	For *nitrogen* and phosphorus over phosphorus	−22.79	−32.54
	For *phosphorus* and nitrogen over nitrogen	54.71	78.16
	For *potassium*, nitrogen, and phosphorus over nitrogen and phosphorus	11.81	16.87

[1]Wheat at 70 cents a bushel, corn at 35 cents, oats at 28 cents, hay at $7 a ton.
[2]Wheat at $1 a bushel, corn at 50 cents, oats at 40 cents, hay at $10 a ton.

mercial nitrogen damaged the small grains by causing the crop to lodge; but in those years when a corn yield of 40 bushels or more was secured by the application of phosphorus either alone or with potassium, then the addition of nitrogen produced an increase.

From a comparison of the results from the Urbana, Sibley, and Bloomington fields, we must conclude that better yields are to be secured by providing nitrogen by means of farm manure or legume crops grown in the rotation 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 (1135 *or* 935)

Yellow silt loam covers 27.43 square miles (17,555 acres) and constitutes 2.36 percent of the entire area of the county. It occurs as the hilly and badly eroded land on the inner timber belts adjacent to the streams, usually only in narrow, irregular strips with arms extending up the small valleys. In topography it is very rolling, and in most places so badly broken that 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, pulverulent silt loam. It varies greatly in color and texture, owing to recent washing. In places the natural subsoil may be exposed. This exposure gives it a decidedly yellow color. The soil freshly plowed appears yellow or brownish yellow, but when it becomes dry after a rain, it is of a grayish color. In some places the surface soil is formed from glacial drift, but this is only on very limited areas and on the steepest slopes. The organic-matter content is the lowest of any type in the county, being only 1.5 percent, or 15 tons per acre. It varies, however, from 1.2 to 1.8 percent.

The subsurface varies from a yellow silt loam to a yellow clayey silt loam, and on the steepest slopes may consist of weathered glacial drift. The thickness of the stratum varies from 5 to 12 inches, depending on the amount of recent erosion. The organic-matter content amounts to only 12 tons per acre.

The subsoil consists normally of a yellow clayey silt, but in some areas may be composed entirely of glacial drift.

The first and most important thing in the management of this type is to prevent general surface washing and gullying. If the land 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 possible in plowing, planting, and cultivating. Furrows should not be made up and down the slopes. Every means should be employed to maintain and increase the organic-matter content. This will 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, "Washing of Soils and Methods of Prevention.")

Additional treatment recommended for this yellow silt loam is the liberal use of limestone wherever cropping is practiced. This type is quite acid and very deficient in nitrogen; and the limestone, by correcting the acidity of the soil, is especially beneficial to the clover grown to increase the supply of nitrogen. Where this soil has been long cultivated and thus exposed to surface washing, it is particularly deficient in nitrogen; indeed, on such lands the low supply of nitrogen is the factor that first limits the growth of grain crops. This fact is very strikingly illustrated by the results from two pot-culture experiments reported in Tables 14 and 15, and shown photographically in Plates 7 and 8.

In one experiment, a large quantity of the typical worn hill soil was collected from two different places.[1] Each lot of soil was thoroly mixed and put in ten four-gallon jars. Ground limestone was added to all the jars except the first and last in each set, those two being retained as control or check pots. The elements nitrogen, phosphorus, and potassium were added singly and in combination, as shown in Table 14.

As an average, the nitrogen applied produced a yield about eight times as large as that secured without the addition of nitrogen. While some variations in yield are to be expected, because of differences in the individuality of seed or other uncontrolled causes, yet there is no doubting the plain lesson taught by these actual trials with growing plants.

The question arises next, Where is the farmer to secure this much-needed nitrogen? To purchase it in commercial fertilizers would cost too much; indeed, under average conditions the cost of the nitrogen in such fertilizers is greater than the value of the increase in crop yields.

But there is no need whatever to purchase nitrogen, for the air contains an inexhaustible supply of it, which, under suitable conditions, the farmer can draw upon, not only without cost, but with profit in the getting. Clover, alfalfa, cowpeas, and soybeans are not only worth raising for their own sake, but they have the power to secure nitrogen from the atmosphere if the soil contains limestone and the proper nitrogen-fixing bacteria.

[1]Soil for wheat pots from loess-covered unglaciated area, and that for oat pots from upper Illinois glaciation.

To secure further information along this line, another experiment with pot cultures was conducted for several years with the same type of worn hill soil as that used for wheat in the former experiment. The results are reported in Table 15.

To three pots (Nos. 3, 6, and 9) nitrogen was applied in commercial form, at an expense amounting to more than the total value of the crops produced. In three other pots (Nos. 2, 11, and 12) a crop of cowpeas was grown during the late summer and fall and turned under before the wheat or oats were planted. Pots 1 and 8 served for important comparisons. After the second cover crop of cowpeas had been turned under, the yield from Pot 2 exceeded that from Pot 3; and in the subsequent years the legume green manures produced, as an average, rather better results than the commercial nitrogen. This experiment confirms that reported in Table 14, in showing the very great need of nitrogen for the improvement of this type of soil, and it also shows that nitrogen need not be purchased but that it can be obtained from the air by growing legume crops and plowing them under as green manure. Of course the soil can be very markedly improved by feeding the legume crops to live stock and returning the resulting

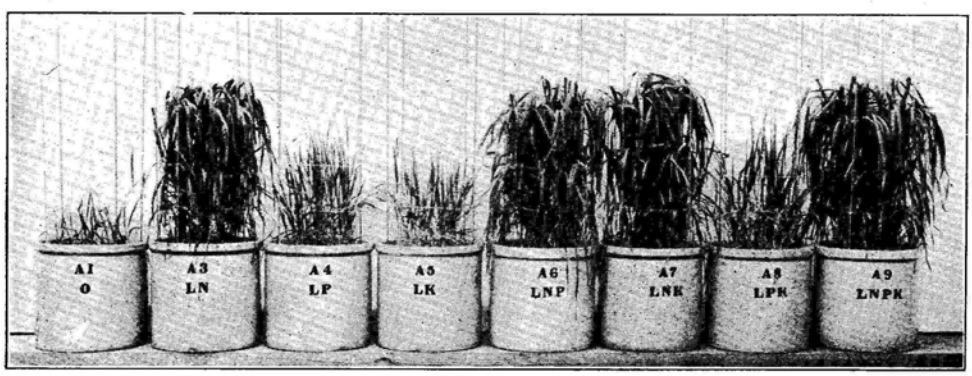

PLATE 7.—WHEAT IN POT-CULTURE EXPERIMENT WITH YELLOW SILT LOAM OF WORN HILL LAND
(See Table 14)

TABLE 14.—CROP YIELDS IN POT-CULTURE EXPERIMENT WITH YELLOW SILT LOAM OF WORN HILL LAND

(Grams per pot)

Pot No.	Soil treatment applied	Wheat	Oats
1	None	3	5
2	Limestone	4	4
3	Limestone, nitrogen	26	45
4	Limestone, phosphorus	3	6
5	Limestone, potassium	3	5
6	Limestone, nitrogen, phosphorus	34	38
7	Limestone, nitrogen, potassium	33	46
8	Limestone, phosphorus, potassium	2	5
9	Limestone, nitrogen, phosphorus, potassium	34	38
10	None	3	5
Average yield with nitrogen		32	42
Average yield without nitrogen		3	5
Average gain for nitrogen		29	37

farm manure to the land, if legumes are grown frequently enough and if the farm manure produced is sufficiently abundant and is saved and applied with care.

As a rule, it is not advisable to try to enrich this type of soil in phosphorus, for with the erosion that is sure to occur to some extent the phosphorus supply will be renewed from the subsoil.

Probably the best legumes for this type of soil are sweet clover and alfalfa. On soil deficient in organic matter sweet clover grows better than almost any other legume, and the fact that it is a very deep-rooting plant makes it of value in increasing organic matter and preventing washing. Worthless slopes that have been ruined by washing may be made profitable as pasture by growing sweet clover. The blue grass of pastures may well be supplemented by sweet clover and alfalfa, and a larger growth obtained, because the legumes provide the necessary nitrogen for the blue grass.

To get alfalfa well started requires the liberal use of limestone, thoro inoculation with nitrogen-fixing bacteria, and a moderate application of farm manure. If manure is not available, it is well to apply about 500 pounds per acre of acid phosphate, or steamed bone meal, mix it with the soil, by disking if possible, and then plow it under. The limestone (about 5 tons) should be applied after plowing and should be mixed with the surface soil in the preparation of the seed bed. The special purpose of this treatment is to give the alfalfa a quick start in order that it may grow rapidly and thus protect the soil from washing.

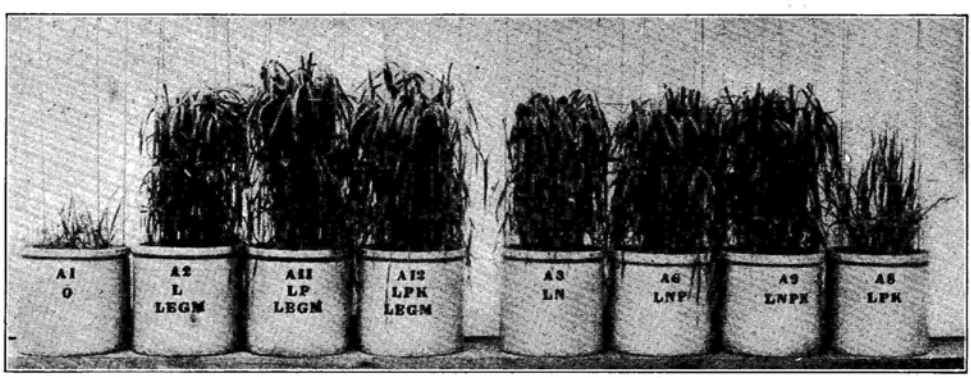

PLATE 8.—WHEAT IN POT-CULTURE EXPERIMENT WITH YELLOW SILT LOAM OF WORN HILL LAND (See Table 15)

TABLE 15.—CROP YIELDS IN POT-CULTURE EXPERIMENT WITH YELLOW SILT LOAM OF WORN HILL LAND AND NITROGEN-FIXING GREEN MANURE CROPS

(Grams per pot)

Pot No.	Soil treatment	1903 Wheat	1904 Wheat	1905 Wheat	1906 Wheat	1907 Oats
1	None	5	4	4	4	6
2	Limestone, legume	10	17	26	19	37
11	Limestone, legume, phosphorus	14	19	20	18	27
12	Limestone, legume, phosphorus, potassium	16	20	21	19	30
3	Limestone, nitrogen	17	14	15	9	28
6	Limestone, nitrogen, phosphorus	26	20	18	18	30
9	Limestone, nitrogen, phosphorus, potassium	31	34	21	20	26
8	Limestone, phosphorus, potassium	3	3	5	3	7

(c) TERRACE SOILS

Terrace soils were formed on terraces or old fills in valleys. The terraces owe their formation generally to the deposition of material from an overloaded and flooded stream during the melting of the glaciers. The material varied from fine to coarse. These valleys were sometimes filled almost to the height of the upland. Later the streams cut down thru these fills and developed new bottom lands, or flood plains, at a lower level, leaving part of the old fill as a terrace. The lowest and most recently formed bottom land is called first bottom. The higher land no longer flooded (or very rarely, at most) is generally designated as second bottom. Finer material later deposited on this sand and gravel of the fill now constitutes the soil. The terraces occur along the Mackinaw and Sangamon rivers.

Brown Silt Loam over Gravel (1527)

Brown silt loam over gravel occurs along the Sangamon river in very limited areas. The total area is only 166 acres.

The surface soil, 0 to 6⅔ inches, is a brown to a dark brown silt loam, containing some sand and 5.7 percent of organic matter, or 57 tons per acre. The topography is slightly undulating.

The subsurface soil varies from a brown to a yellowish brown or yellowish drab silt loam, and the lower part of the stratum at a depth of 16 to 18 inches contains fragments of sand and gravel.

The subsoil is a yellowish or drab-colored silt or clayey silt, which becomes quite gravelly at 35 to 48 inches and passes into rather a pure gravel.

This type, as a rule, is well drained, because of the pervious character of the subsoil. The treatment should be the same as for brown silt loam, except that the addition of phosphorus is not likely to be profitable, because of the deep feeding range afforded plant roots.

Brown Silt Loam on Gravel (1526.2)

Brown silt loam on gravel covers an area of 1.77 square miles (1,132 acres), or only .15 percent of the total area of the county. It differs from the brown silt loam over gravel only in the fact that gravel is within 30 inches of the surface. Because of the nearness of the gravel the type is more susceptible to drouth than if this stratum were deeper.

The treatment for this type should be practically the same as for the preceding. There is, however, a greater necessity for increasing the organic matter, because the soil contains less of that constituent.

Yellow-Gray Silt Loam on Gravel (1534.2)

Yellow-gray silt loam on gravel is found along both the Mackinaw and Sangamon rivers. It represents the terrace soil that has been covered by a growth of trees and is consequently low in organic matter. The total area is 621 acres.

The surface soil, 0 to 6⅔ inches, is a yellow or yellowish gray silt loam with an organic-matter content of 3.1 percent, or 31 tons per acre.

The subsurface is a yellow silt loam containing a perceptible amount of sand.

The subsoil is a yellow silt or clayey silt, passing into the gravel at a depth of 12 to 30 inches. Local borings are obtained where the gravel layer may be slightly below 30 inches.

This soil needs nitrogen and organic matter as the most essential things in its improvement.

(d) SWAMP AND BOTTOM-LAND SOILS

Deep Peat (1401)

A few small areas of deep peat, aggregating 83 acres, are mapped in this county. They occur in low, poorly drained places in bottom land or swamps.

The surface soil, 0 to 6⅔ inches, is black, generally well decomposed, and contains about 55 percent of organic matter. The subsurface is very similar to the surface, but the organic-matter content is not so high, being about 50 percent. The subsoil is quite variable; in some places it passes into a drab silty clay and in others it is peaty to a depth of 40 inches. It frequently contains shells mingling with the organic matter.

Drainage is of course the first essential for this type. If it does not produce well when drained, trials should be made with potassium. (See Bulletin 157.)

Deep Brown Silt Loam (Bottom Land) (1426)

Deep brown silt loam occurs along the streams, chiefly in the southwestern part of the county. It aggregates 23.88 square miles, or 2 percent of the county.

The surface soil, 0 to 6⅔ inches, is a brown silt loam containing from 5 to 8 percent of organic matter. It varies somewhat in physical composition from a heavy phase to one containing sand in sufficient amounts to be called a sandy loam. This latter, however, does not occur in areas large enough to be mapped.

The subsurface soil is similar to the surface except that the organic-matter content is slightly lower, varying from 4 to 7 percent, and consequently the soil is a little lighter in color. The subsoil is not so dark as the surface and contains local areas of coarse material.

Where proper drainage is secured, this type is very productive. As a rule, where it is subject to frequent overflow nothing else is needed except good farming. Even the systematic rotation of crops is not so important where the land is subject to occasional overflow; but where it lies high or is protected from overflow by dikes, 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 acid, in limestone.

Mixed Loam (Bottom Land) (1454)

Mixed loam occurs chiefly north of the Bloomington moraine. It aggregates 18 square miles, or 1.5 percent of the county. It varies quite widely in its physical composition, including sand, sandy loam, silt loam, and possibly some clay loam. Its character changes more or less with each flood; hence it is impracticable to attempt to separate it into distinct types. The amount of organic matter in the surface soil is about 5.5 percent, which is equivalent to 55 tons per acre.

The subsurface is a dark soil, varying in physical composition from a sandy loam to a clay loam. The organic-matter content is about 4.6 percent.

The subsoil is slightly lighter in color than the subsurface, with a variable composition similar to that of the other strata.

This type is fertile, and no treatment is suggested beyond that mentioned for the preceding type, deep brown silt loam.

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 soil-survey 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. 82, "Physical Improvement of Soils"
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, "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?"
Circular No. 167, "The Illinois System of Permanent Fertility"

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 ascertaining, and 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 the 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 must 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 angling 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, ditches, 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 carried 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) the agricultural value, based upon its natural productiveness; (10) the ultimate chemical composition and reaction.

The common soil constituents are indicated in the following outline:

Soil constituents	Organic matter	Comprising undecomposed and partially decayed vegetable or organic material
	Inorganic matter	Clay.....001 mm.[1] and less
		Silt.....001 mm. to .03 mm.
		Sands.....03 mm. to 1. mm.
		Gravel.....1. mm. to 32 mm.
		Stones.....32. mm. and over

Further discussion of these constituents is given in Circular 82.

[1]25 millimeters equal 1 inch.

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. Some silt and a little clay may be present.

Mucks—15 to 35 percent of partly decomposed organic matter mixed with much clay and 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 25 to 50 percent of gravel with much sand and some silt.

Gravels—Soils with more than 50 percent of gravel and much sand.

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

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

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

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 it 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 corn stalks. 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 land- than that soils differ in productive power. Even tho plowed alike and ne time, prepared the same way, planted the same day with the same eed, and cultivated alike, watered by the same rains and warmed by sun, nevertheless the best acre may produce twice as large a crop as 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 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 composted with fresh farm manure; so that two tons of the compost[1] 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

[1]In his book, "Fertilizers," published in 1839, Cuthbert W. Johnson reported such compost to have been much used in England and to be valued as highly, "weight for weight, as farm-yard dung."

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. Soils of cut-over or burnt-over timber lands sometimes contain so much partially decayed wood or charcoal as to destroy the value of the nitrogen-carbon ratio for the purpose indicated. (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 wheat, corn, oats, and clover 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 never known to limit the yield of general farm crops grown under normal conditions.)

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

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

Produce		Nitrogen	Phosphorus	Potassium	Magnesium	Calcium
Kind	Amount					
		lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*
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.

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. 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 which 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 what-

ever to the soil, but always leaves it 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 on land being prepared 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. 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. In 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 following.)

(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 a 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 may 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 supplying decaying organic matter, since this will necessitate returning to the soil the potassium contained in the crop residues from grain farming or the manure produced in live-stock farming, and will also provide for the liberating of potassium from the soil. (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 clover crop is an advantage to subsequent crops because of its deep-rooting char-

acteristic. 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 was 12.7 bushels on untreated land and 23.3 bushels where 86 pounds of nitrogen and 29 pounds of phosphorus per acre per annum were applied. 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 wheat crop removed annually an average of 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) was 14.2 bushels on untreated land, 38.1 bushels where 43 pounds of nitrogen and 29 pounds of phosphorus were 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. Where only 70 pounds of sodium were applied in addition to the nitrogen and phosphorus, the average was 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 the wheat straw, which contains more than three-fourths of the potassium removed in the wheat crop (see Table A), were returned to the soil, the necessity of purchasing potassium in a good system of farming on such land would be at least very remote, for the supply would be adequately maintained by the actual amount returned in the straw, together with the additional amount which would be liberated from the soil by the action of decomposition products.

While about half the potassium, nitrogen, and organic matter, and about one-fourth the phosphorus contained in manure is 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 in average live-stock farming the animals destroy two-thirds of the organic matter and retain one-fourth of the nitrogen and phosphorus from the food they consume, they retain less than one-tenth of the potassium; 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) will 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 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, gave an increase of 10.7 bushels. Thus, at 40 cents a bushel for corn, the kainit 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 included an equally complete test with potassium sulfate and kainit on land to which 8 tons per acre of farm manure

were 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 by chemical analysis that potassium salts and most other soluble salts increase the solubility of the phosphorus in soil and in rock phosphate; 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 they consume, it it 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, farmers following this practice 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. Practically the same amount of calcium was found, by analyses, in the Rothamsted drainage waters.

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

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.

Physical Improvement of Soils

In the management of most soil types, one very important thing, aside from proper fertilization, tillage, and drainage, is to keep the soil in good physical condition, or good tilth. The constituent most important for this purpose is organic matter. Not only does it impart good tilth to the soil, but it prevents much loss by washing on rolling land, warms the soil by absorption of heat, retains moisture during drouth and prevents the soil from running together badly; and, as it decays, it furnishes nitrogen for the crop and aids in the liberation of mineral plant food. This constituent must be supplied to the soil in every practical way, so that the amount may be maintained or even increased. It is being broken down during a large part of the year, and the nitrates produced are used for plant growth. This decomposition is necessary, but it is also quite necessary that the supply be maintained.

The physical effect of organic matter in the soil is to produce a granulation, or mellowness, very favorable for tillage and the development of plant roots. If continuous cropping takes place, accompanied with the removal or the destruction of the corn stalks and straw, the amount of organic matter is gradually diminished and a condition of poor tilth will ultimately follow. In many cases this already limits the crop yields. The remedy is to increase the organic-matter content by plowing under manure or crop residues, such as corn stalks, straw, and clover. Selling these products from the farm, burning them, or feeding them and not returning the manure, or allowing a very large part of the manure to be lost before it is returned to the land, all represent bad practice.

One of the chief sources of loss of organic matter in the corn belt is the practice of burning the corn stalks. Could the farmers be made to realize how great a loss this entails, they would certainly discontinue the practice. Probably no form of organic matter acts more beneficially in producing good tilth than corn stalks. It is true that they decay rather slowly, but it is also true that their

durability in the soil after partial decomposition is exactly what is needed in the maintenance of an adequate supply of humus.

The nitrogen in a ton of corn stalks is 1½ times that in a ton of manure, and a ton of dry corn stalks incorporated with the soil will ultimately furnish as much humus as 4 tons of average farm manure; but when burned, both the humus-making material and the nitrogen which these stalks contain are destroyed and lost to the soil.

The objection is often raised that when stalks are plowed under they interfere very seriously in the cultivation of corn, and thus indirectly destroy a great deal of corn. If corn stalks are well cut up and then turned under to a depth of 5½ to 6 inches when the ground is plowed in the spring, very little trouble will result.

Where corn follows corn, the stalks, if not needed for feeding purposes, should be thoroly cut up with a sharp disk or stalk cutter and turned under. Likewise, the straw should be returned to the land in some practical way, either directly or as 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 when manure can be brought back.

It must be remembered, however, that in the feeding of hay, or straw, or corn stalks, a great destruction of organic matter takes place, so that even if the fresh manure were returned to the soil, there would still be a loss of 50 to 70 percent owing to the destruction of organic matter by the animal. If manure is allowed to lie in the farmyard for a few weeks or months, there is an additional loss which amounts to from one-third to two-thirds of the manure recovered from the animal. This is well shown by the results of an experiment conducted by the Maryland Experiment Station, where 80 tons of manure were allowed to lie for a year in the farmyard and at the end of that time but 27 tons remained, entailing a loss of about 66 percent of the manure. Most of this loss occurs within the first three or four months, when fermentation, or "heating," is most active. Two tons of manure were exposed from April 29 to August 29, by the Canadian Experiment Station at Ottawa. During these four months the organic matter was reduced from 1,938 pounds to 655 pounds. To obtain the greatest value from the manure, it should be applied to the soil as soon as possible after it is produced.

It is a common practice in the corn belt to pasture the corn stalks during the winter and often rather late in the spring after the frost is out of the ground. This tramping of stock sometimes puts the soil in bad condition for working. It becomes partially puddled and will be cloddy as a result. If tramped too late in the spring, the natural agencies of freezing and thawing, and wetting and drying, with the aid of ordinary tillage, fail to produce good tilth before the crop is to be planted. Whether the crop is corn or oats, it necessarily suffers, and if the season is dry, much damage may result. If the field is put in corn, a poor stand is likely to follow, and if put in oats, a compact soil is formed which is unfavorable for their growth. Sometimes the soil is worked when too wet. This also produces a partial puddling which is unfavorable to physical, chemical, and biological processes. The bad effect will be greater if cropping has reduced the organic matter below the amount necessary to maintain good tilth.

PUBLICATIONS RELATING TO ILLINOIS SOIL INVESTIGATIONS

Bulletins

No.

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 (2d 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 (2d edition, 1912).
157 Peaty Swamp Lands; Sand and "Alkali" Soils, 1912.
177 Radium as a Fertilizer, 1915.
181 Soil Moisture and Tillage for Corn, 1915.

Circulars

*64 Investigations of Illinois Soils, 1903.
*68 Methods of Maintaining the Productive Capacity of Illinois Soils, 1903 (2d edition, 1905).
*70 Infected Alfalfa Soil, 1903.
*72 Present Status of Soil Investigation, 1903 (2d edition, 1904).
82 The Physical Improvement of Soils, 1904 (3d edition, 1912).
86 Science and Sense in the Inoculation of Legumes, 1905 (2d 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 (2d 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 (2d 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 (3d edition, 1912).
*116 Phosphorus and Humus in Relation to Illinois Soils, 1908.
119 Washing of Soils and Methods of Prevention, 1908 (2d 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 (3d 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 (2d 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 (2d 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.
168 Bread from Stones, 1913.
181 How Not to Treat Illinois Soils, 1915.

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.
7 McDonough County Soils, 1913.
8 Bond County Soils, 1913.
9 Lake County Soils, 1915.
10 McLean County Soils, 1915.

*Out of print.

THIRTEEN 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	3.33
1905	Wheat, bu.	28.8	39.2	10.4	7.28
1906	Clover, tons	.58	1.65	1.07	7.49
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	2.86
1910	Clover, tons	1.09	4.21	3.12	21.85
1911	Wheat, bu.	22.5	57.6	35.1	24.58
1912	Corn, bu.	47.9	74.5	26.6	9.30
1913	Corn, bu.	30.0	44.1	14.1	4.93
1914	Oats, bu.	40.6	45.0	4.4	1.23

Total value of increase in thirteen years	$99.85
Total cost of phosphorus in thirteen years	32.50
Net profit in thirteen years	$67.35

After the first year the phosphorus began to more than pay its annual cost; and during the second five-year period the increase produced by the phosphorus was worth almost as much as the total crops produced on the land not receiving phosphorus. In later years the need of organic manures with phosphorus has become apparent. (See pages 18 to 22 for more complete details.)

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