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HARDIN COUNTY SOILS

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

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*On leave.

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By Cyril G. Hopkins, J. G. Mosier, J. H. Pettit and J. E. Readhimer

Introduction

The counties of Hardin, Pope, Johnson, Union, Alexander, Pulaski and Massac include most of the unglaciated area of southern Illinois. The Ozark Hills extend across this area from west to east, and in places project into the next tier of counties on the north. The hill lands represent the most extensive soil types in these seven counties, altho the bottom lands are also very important, and quite extensive in the southern portion, including the Mississippi, Ohio, Cash and Big Bay bottoms.

Hardin county is representative of the unglaciated area in southern Illinois, but the information contained in this report on "Hardin County Soils" is applicable not only to the other counties in this area, but also to the hill lands in the lower Illinoisan glaciation lying between the Ozark Hills and the corn belt; and even in the corn-belt counties there are some hill lands, especially near the larger streams, whose chief difference from the Ozark Hills is the lower degree of acidity in the northern soils.

For information concerning the soils of the prairie counties of the wheat belt of Illinois, the reader is referred to Soil Report No. 1, "Clay County Soils"; and for information concerning most of the important soil types of the corn belt, he is referred to Soil Report No. 2, "Moultrie County Soils." In addition it may be stated that Bulletin 123, "The Fertility in Illinois Soils," shows the great soil areas of the state and gives the composition of the most important soil types in each area and much information relating to their improvement.

Soil Formation

Hardin county is situated in the southeastern part of the state on the Ohio river, entirely within the unglaciated area. The altitude above sea level varies from slightly over 300 feet to more than 800 feet, thus giving a relief of 500 feet in the county, the topography over almost the entire county being characterized by hills and valleys. As a result of the topography and of the somewhat heavy rainfall, water has been and is now a very active agent in soil formation or modification.

The chief material composing the soils of Hardin county is a wind-blown dust known as loess. Altho the county has never been glaciated it has no purely residual soil formed by the disintegration and partial decomposition of rocks in place, the residual material having been buried beneath the deposit of loess to a depth of 5 to 20 feet, altho on some of the stony slopes the soil is a mixture of residual and wind-blown material, and might properly be called residuo-loessial or residuo-aeolial soil.

The following table gives the soil types, the areas in acres and square miles, and the percentage of each type of total area in the county.

TABLE 1.—SOIL TYPES OF HARDIN COUNTY

Soil type No.	Names	Area in square miles	Area in acres	Percent of total
	(a) Upland Timber Soils (page 13)			
135	Yellow silt loam	120.15	76,896.0	70.56
134	Yellow-gray silt loam	10.50	6,720.0	6.17
864	Yellow fine sandy loam	.46	294.4	.27
198	Stony loam	17.05	10,912.0	10.01
199	Rock outcrop	3.58	2,291.2	2.10
	(b) Swamp and Bottom-land Soils (page 18)			
1323	Red-brown clay loam	3.16	2,022.4	1.86
1331	Deep gray silt loam	1.20	768.0	.66
1361.1	Mixed fine sandy loam	12.61	8,070.4	7.40
1380	River sand	.20	130.5	.12
	(c) Terrace Soils (page 20)			
1516	Gray clay	.31	195.8	.17
1530	Gray silt loam on tight clay	1.18	755.2	.68
	Totals	170.40	109,055.9	100.00

THE INVOICE AND INCREASE OF FERTILITY IN HARDIN COUNTY SOILS

SOIL ANALYSIS

To appreciate the value of the essential elements of fertility for crops, we should keep in mind that food for plants is just as important as food for animals. In the Appendix will be found a more comprehensive discussion of this general subject, which should be read and studied in advance by those who are not familiar with the fundamental principles involved; and in any case the reader should carry in mind the plant food requirements for crops and the loss of plant food from soils by leaching. (See Table A and the closing pages of the Appendix.)

In brief, all agricultural plants are composed of ten elements of plant food, of which two (carbon and oxygen) are secured from the air, one (hydrogen) from water, and seven (nitrogen, phosphorus, potassium, magnesium, calcium, iron, and sulfur) are taken from the soil. Legume crops, such as the clovers, peas, and beans, may, under suitable conditions, secure more or less of their nitrogen from the air in case the amount furnished by the soil is insufficient. The supply of iron in soils is so great that it need not be further considered, and so far as we know the supply of sulfur in the soil, supplemented by the sulfur brought to the soil in rain and otherwise, is sufficient to meet all requirements of common farm crops for that element.

We need to give special consideration to the five elements nitrogen, phosphorus, potassium, magnesium, and calcium, and in addition we should not only provide against soil acidity, but insure the presence of limestone.

In Table 1 are recorded the average amounts of these important elements per acre to a depth of 6⅔ inches for all of the different types of soil in Hardin county. The table also shows the amount of limestone, if present, or the amount of limestone required to neutralize or destroy the acidity present. The organic carbon is the best measure of the organic matter (partially decayed vegetable matter); and, as explained in the Appendix, the ratio of carbon to nitrogen gives some indication of the age or condition of the organic matter. Approximately one-half of the organic matter of the soil is carbon, so that 12,880 pounds of carbon, for example, correspond to about 12 tons per acre of organic matter.

Two million pounds per acre (about 6⅔ inches deep) represents at least as much soil as is ordinarily turned in plowing. This is the soil with which we finally incorporate the farm manure, phosphate, limestone, or other fertilizer applied to the soil; and this is the soil stratum upon which we must depend in large part to furnish the necessary plant food for the production of the common crops, as will be better understood from the information given in the Appendix. As there stated, even a rich subsoil has but little value if it lies beneath a worn-out surface. If, however, the surface soil is enriched, the strong, vigorous plants will have power to secure more plant food from the subsurface and subsoil than would be the case with weak, shallow-rooted plants.

TABLE 2.—FERTILITY IN THE SOILS OF HARDIN 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	Limestone required
				Upland Timber Soils					
135	Yellow silt loam	12880	1250	840	34200	7710	3980		2100
134	Yellow-gray silt loam	15600	1520	870	29150	5510	4390		40
864	Yellow fine sandy loam...	14180	1300	780	30760	5360	4620	500	
198	Stony loam (virgin).......	15600	840	480	25040	3420	4300		1520
				Swamp and Bottom-land Soils					
1323	Red-brown clay loam....	32320	3090	1830	41200	11780	6430	2390	
1331	Deep gray silt loam.....	12920	1100	580	26580	4860	5860	660	
1361.1	Mixed fine sandy loam...	13900	1290	650	29480	4990	4910	840	
1380	River sand.....	11100	520	920	18740	5720	10420	21620	
				Terrace Soils					
1516	Gray clay......	37160	3280	1260	39220	12560	11860	1020	
1530	Gray silt loam on tight clay.	39280	3360	1440	41860	11880	6360		260

By comparing the data in Table 1 with those in Table A in the Appendix, the relative supply of the different essential elements of plant food is very easily determined. Thus the surface soil of an acre of the yellow silt loam (the most extensive soil type in Hardin county, covering most of the ordinary hill land) contains only 1250 pounds of total nitrogen, while the grain crops suggested in Table A would remove from the soil 343 pounds during one rotation; and the total nitrogen in the plowed soil (if 6⅔ inches deep) would meet the requirements of only eight such crops of corn as ought to be grown under the average climatic conditions of southern Illinois. The ratio of carbon to nitrogen (about 10 to 1) shows that the organic matter is very inactive, and consequently that the liberation of nitrogen will not be rapid. The other upland soils of the county are not much better supplied with nitrogen; and too great emphasis cannot be laid upon the importance of growing legume crops, such as alfalfa, clover, cowpeas and soybeans, which if infected with the proper nitrogen-fixing bacteria have free access to the inexhaustible supply of nitrogen in the air.

On the other hand, there are some difficulties to be met and overcome if the most valuable legume crops are to be grown satisfactorily on these lands. Thus, all of these upland soils are markedly sour and consequently they not only contain no limestone, but require applications of that material to correct the acidity present.

The only exception to this is the small area of yellow fine sandy loam near Rosiclare, and even this is strongly acid in the subsurface and sub-

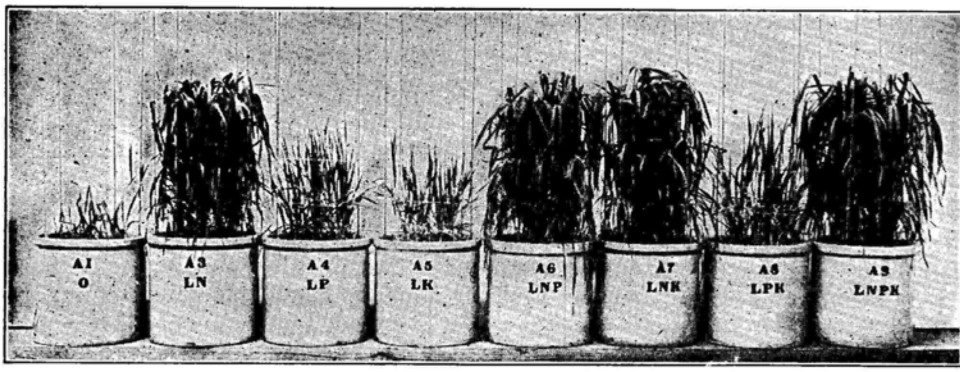

PLATE 1. WHEAT IN POT CULTURES; YELLOW SILT LOAM SOIL OF HILL LAND.

soil, the small amount of limestone in the surface soil probably being due to the recent additions of dust blown from the great area of river bed to the east and southwest, which is exposed to the action of the wind when the river is low, occasionally for weeks at a time. Even this soil should receive liberal applications of ground limestone.

RESULTS FROM POT-CULTURE EXPERIMENTS

The plant food element which limits the yield of cereal crops on the common upland soil is nitrogen. This fact is very strikingly illustrated by the results from pot-culture experiments reported in Table 3, and shown photographically in Plate 1.

A large quantity of the typical worn hill soil was collected from two different places. Each lot of soil was thoroly mixed and ten 4-gallon jars were filled with it. Ground limestone was added to all except the first and last jars in each set, those two being retained as control or check plots. The elements nitrogen, phosphorus, and potassium were added singly and in combination, as plainly indicated in Table 3.

TABLE 3.—CROP YIELDS IN POT-CULTURE EXPERIMENTS ON YELLOW SILT LOAM HILL LAND SOIL

Pot No.	Soil treatment applied	Wheat yields (grams per pot)	Oat yields (grams per pot)
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

As an average the nitrogen applied produced about eight times as much as the yield secured without the addition of nitrogen. While there are some variations in yield which are due, of course, to differences in the individuality of seed or other uncontrolled cause, yet there is no doubting the plain lesson taught by these actual trials with growing plants. Thus, both the soil analysis and the culture experiment agree in showing that the element nitrogen must be provided for the improvement of this soil.

The next question is, Where is the farmer to secure this much needed nitrogen? To purchase it in commercial fertilizer would cost too much. Indeed, the cost of the nitrogen in such fertilizers is greater than the value of the increase in crop yields, under average conditions. On the other hand, there is no need whatever to purchase it, because the air contains an inexhaustible supply of nitrogen, and under suitable conditions this can be obtained by the farmer direct from the air, not only without cost, but with profit in the getting; for clover, alfalfa, cowpeas and soybeans have power to secure atmospheric nitrogen, provided the soil contains limestone and the proper nitrogen-fixing bacteria; and these crops are worth raising for their own sake.

In order to get further information along this line an experiment with pot cultures was conducted for several years, with the results reported in Table 4, the same worn hill soil being used. To three of the pots (Nos. 3, 6 and 9) nitrogen was applied in commercial form, and 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 these were turned under before planting wheat or oats. Pots 1 and 8 serve for important comparisons.

After the second catch 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. These experiments confirm those reported in Table 3, in showing the very great need of nitrogen for the improvement of this soil; and they also show that the 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 legume crops could be fed to live stock and the resulting farm manure returned to the land; but this practice is not so good for the soil, altho it may sometimes be more profitable; and if sufficiently frequent crops of legumes are grown and if the farm manure produced is sufficiently abundant, and is saved and applied with care, this soil can be very markedly improved by live-stock farming, as well as by green manuring.

PLATE 2. WHEAT IN POT CULTURES; YELLOW SILT LOAM SOIL OF WORN HILL LAND.

TABLE 4.—CROP YIELDS IN POT CULTURES, INCLUDING NITROGEN-FIXING GREEN MANURE CROPS: YELLOW SILT LOAM HILL LAND (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

RESULTS FROM FIELD EXPERIMENTS AT VIENNA

In 1902 a soil experiment field was established on the worn hill land of southern Illinois, near Vienna, in Johnson county; and the results of nine years' experiments under field conditions are reported in Table 5.

This field includes three divisions, or series, with five plots in each series. A three-year rotation of wheat, corn, and cowpeas was begun on this field, but because of local interest this was changed to corn, wheat, and clover. When the clover failed, which was frequent, cowpeas were substituted.

During the first three years the entire crop of cowpeas was plowed under, except on Plot 1, as indicated in Table 5. During the second three years all crops were removed; and during the third three-year period the pods of the compeas (small yields not threshed), and all grain were harvested and removed, while the pea vines or clover, and the wheat straw and corn stalks were returned to the land (except on Plot 1, from which all crops were removed and nothing returned). Thus, the "crop residues" were returned in part during the first period, not at all during the second period, and completely only during the third period; and the effect of plowing under all crop residues during one rotation upon the crop yields of the next rotation is not yet shown on this field.

If we pass over the first three years required to get the rotation and soil treatment underway, we still have the records of six years, during which time 6 crops of corn, 6 crops of wheat, and 1 crop of clover hay were harvested and weighed. A study of Table 5 will show that the land treated with ground limestone and some crop residues (Plot 3) produced, during the six years, 74 bushels more corn, 60 bushels more wheat, and 1¼ tons more hay than the untreated land.

It should be kept in mind that the figures showing increase in crop yields constitute the real data upon which all subsequent computations must be based. The work of the investigator is to conduct the experiment and secure the data; while the farmer and landowner has the right to use any prices he can justify for his locality and conditions, and these prices will vary greatly, not only in different years and seasons, but also in different localities. Thus the average price of corn in southern Illinois is probably 10 cents a bushel higher than in the corn belt, except in an occasional year when southern Illinois may produce an extra good crop and have a surplus to be shipped out.

As a rule the farmer is inclined to calculate the value of the increase in crop yields at the prevailing prices; while the computations usually made by the Experiment Station are much more conservative. At current prices for produce, say 60 cents a bushel for corn, 90 cents for wheat, and $15 a ton for hay, the increase in money value from the use of limestone on the Vienna field would amount to $117, which is $39 per acre for the six years, or $6.50 per acre per annum above the returns for the same crops from the untreated land.

By comparing Plots 2 and 3, it will be found that the land treated with limestone produced, during the same six years, 64 bushels more corn, 39 bushels more wheat, and 1.1 tons more harvested hay than the land otherwise treated the same. At the prices mentioned these increases amount to $90 from three acres, or $30 from one acre, which is $5.00 an acre for each year. This is about ten times the necessary average annual expense for ground limestone in permanent systems. Thus, long-continued investigations have shown that 800 pounds per acre is about the average annual loss of limestone. At $1.25 per ton, this would cost 50 cents per acre per annum.

These figures indicate a possible gross return of about $10 for every $1.00 necessarily invested in ground limestone for the improvement of this soil, which represents by far the most extensive soil type in the seven southernmost counties of Illinois. Some will probably insist that the prices and computations used above are reasonable and fair; and if present prices continue, it is possible that investment in ground limestone may ultimately pay such returns if the seed of the legume crops are harvested and if the full system of manuring with crop residues and catch crops is followed in the best crop rotation; but in Table 5 we have presented the more conservative figures.

In order to summarize the results of the nine years' experiments, the six grain crops from each series and the one crop of clover hay harvested from the 200 series (in 1907) are reduced to a money basis, in which corn is figured at 35 cents a bushel, oats at 30 cents, wheat at 70 cents, and hay at $6.00 a ton. These low prices are used in order to avoid any possible exaggeration of the value of the increase produced by the soil treatment applied. The prices are appreciably below the ten-year averages for Illinois, but it should be kept in mind that the increase produced by soil treatment is not delivered at the market by that treatment, but only ready for the harvest; and additional expense is required for harvesting, threshing, baling and storing or marketing. The yields are all given, and anyone can compute the value of the increase at any other prices, if desired.

About 9 tons per acre of ground limestone were applied in 1902. The cost of this is figured at $1.25 per ton. This is somewhat above the average cost in southern Illinois.

The phosphorus was supplied at the rate of 25 pounds per acre per annum in 200 pounds of steamed bone meal, applied at the rate of 600 pounds every three years. It is figured at 10 cents a pound for phosphorus, or at $25 a ton for steamed bone. The average cost of steamed bone is now somewhat higher; and where farm manure or green manure is available we advise using raw rock phosphate in place of steamed bone, the raw phosphate being just as rich in phosphorus and costing in southern Illinois less than $8.00 per ton in carload lots.

The potassium was applied at the rate of 42 pounds per acre per annum in 100 pounds of potassium sulfate. The potassium sulfate is figured at $50 per ton, or potassium at 6 cents a pound. As shown in Table 2, this common upland contains, as an average, more than 30,000 pounds of potassium in the plowed soil of an acre (6⅔ inches deep), and the subsurface and subsoil are still richer, so that the potassium problem is not one of addition but of liberation; and, if potassium salts are applied at all or temporarily, until more vegetable matter can be grown and plowed under, then we would recommend the use of kainit in larger amounts and at less expense, rather than potassium sulfate, for reasons explained in the Appendix.

It should be understood that when these field experiments were begun, we had but very little information concerning the composition or requirements of Illinois soils. We used steam bone meal and potassium sulfate to find out if the soil needed phosphorus or potassium. It was known that these materials furnish those elements in good form. On many experiment fields established more recently we are now using fine-ground rock phosphate with very good results, and in some cases we are also making trials with kainit. (See Soil Reports Nos. 1 and 2 and Circulars 116, 127, 149, and 157.)

Taking into account the entire period of nine years, it will be seen that, at most conservative prices, the ground limestone has already paid back nearly twice its actual cost, and the equivalent of about one-half of the limestone still remains in the soil for the benefit of future crops.* It is

*On the Edgewood experiment field in Effingham county 10 tons per acre of ground limestone were applied in 1902. At the end of ten years the analysis of the soil showed that 8,370 pounds of limestone still remained in the surface stratum, as the average of eight treated plots; while the acidity of the subsurface of the same plots averaged 2770 pounds less (in terms of limestone required to neutralize it) than the average of eight untreated half plots, and the acidity in the surface soil of the untreated land corresponded to 1070 pounds of limestone required. Thus the total difference at the end of ten years is equivalent to 6.1 tons of calcium carbonate, and the net loss has been 3.9 tons of limestone, or 780 pounds per acre per annum. (These averages are based upon analyses involving twenty-four determinations, which were made by Mr. C. F. Ferris, B.S., as part of his work for the degree of Master of Science in Agronomy, 1912.)

TABLE 5.—CROP YIELDS PER ACRE ON VIENNA EXPERIMENT FIELD, ON COMMON WORN HILL LAND: YELLOW SILT LOAM, UNGLACIATED

Soil treatment	None (except rotation)	Crop residues	Crop residues and limestone	Crop residues, limestone, phosphorus	Residues, limestone, phosphorus, potassium
Plot No	101	102	103	104	105
1902 Corn, bu	15.5	13.3	14.9	12.5	19.9
1903 Corn, bu	9.3	5.0	8.3	7.4	11.6
1904 Cowpeas	removed	turned	turned	turned	turned
1905 Wheat, bu	1.3	10.8	18.2	25.6	30.0
1906 Cowpeas	removed	removed	removed	removed	removed
1907 Corn, bu	16.7	17.8	30.3	37.1	38.1
1908 Wheat, bu	0	0	4.5	8.3	9.8
1909 Cowpeas	removed	turned	turned	turned	turned
1910 Corn, bu	33.5	35.4	44.7	46.6	58.3
Value of six crops	$27.16	$32.59	$50.26	$59.99	$72.63
Increase over Plot 2			$17.67	$27.40	$40.04
Plot No.	201	202	203	204	205
1902 Oats, bu	19.1	18.8	19.8	20.0	31.7
1903 Cowpeas	removed	turned	turned	turned	turned
1904 Wheat, bu	6.7	7.1	10.0	14.8	17.5
1905 Corn, bu	37.5	42.9	61.9	57.2	56.5
1906 Wheat, bu	3.8	5.4	17.9	11.3	15.0
1907 Clover, tons	.65	.81	1.92	2.56	2.23
1908 Corn, bu	35.2	35.6	43.9	42.9	50.6
1909 Wheat, bu	4.6	6.8	9.6	12.8	11.3
1910 Clover	removed	turned	turned	turned	turned
Value of seven crops	$45.65	$51.49	$80.74	$83.63	$91.04
Increase over Plot 2			$29.25	$32.14	$39.55
Plot No.	301	302	303	304	305
1902 Cowpeas	removed	turned	turned	turned	turned
1903 Wheat, bu	.4	.6	.7	8.0	11.0
1904 Corn, bu	30.5	35.5	49.1	49.4	44.7
1905 Cowpeas	removed	removed	removed	removed	removed
1906 Corn, bu	41.2	40.6	48.9	40.9	40.9
1907 Wheat, bu	4.3	6.1	13.0	13.6	15.6
1908 Cowpeas	removed	turned	turned	turned	turned
1909 Corn, bu	23.0	24.9	31.3	32.6	33.5
1910 Wheat, bu	3.1	8.7	13.7	14.4	14.6
Value of six crops	$38.61	$46.13	$64.44	$68.22	$70.53
Increase over Plot 2			$18.31	$22.09	$24 40
Average of three series	$37.14	$43.40	$65.14	$70.61	$78.06
Increase over Plot 2			$21.74	$27.21	$34.66
Cost of treatment			$11.25	$33.75	$56.25

possible, too, that half the quantity of limestone applied at the beginning would have given nearly or quite as good results, but the information available is not conclusive as to the initial amount of limestone to apply for the most profitable results. In any case the initial application should be considered as an investment to be added to the value of the land, while the cost of subsequent necessary applications should be calculated in the annual expense.

On this rolling hill land, the addition of $22.50 worth of steamed bone meal has increased the crop values by only $5.47 in nine years; and the further addition of $22.50 in potassium sulfate has produced only $7.45 increase in the value of the crops harvested, at the prices used for the increase in yields.

Whether a much larger use of organic manures will ultimately increase the nitrogen content of the soil to a point where phosphorus can be applied with profit on these hill lands, subject to rather serious surface washing, seems somewhat doubtful; and, considering the fact that such an increase in decaying organic matter will largely increase the liberation of potassium from the enormous supply contained in the soil, it seems even more doubtful if the addition of potassium will ever be advisable in permanent systems of general farming.

Both the pot cultures and the field experiments agree in showing that nitrogen is by far the most limiting element and that this can be secured from the air by legume crops where liberal use is made of ground limestone to correct the acidity of the soil; and of course the limestone also furnishes the element calcium, the supply of which in this soil is but little more than one-tenth as great as the supply of potassium, while the combined loss by leaching and cropping is nearly ten times greater with calcium than with potassium, as is more fully explained in the Appendix. As plant food, calcium is especially important for such crops as clover. (See Table A in the Appendix.)

RESULTS FROM FIELD EXPERIMENTS AT RALEIGH

The Raleigh experiment field, in Saline county, is located on the gently undulating timber land (yellow-gray silt loam), which is also the second most important upland soil type in Hardin county.

Six tons per acre of ground limestone were applied to certain plots on the Raleigh field in the fall of 1909; and as an average of the next two years (1910 and 1911) the limestone increased the yields per acre on one set of plots by 3.9 bushels of wheat, by .40 ton of hay (cowpeas or clover), by 14.1 bushels of oats, and by 13.4 bushels of corn; while on another set of plots the average increases produced by limestone were 4.8 bushels of wheat, 9.3 bushels of oats, and 12.0 bushels of corn. In this second series of experiments the legume crops (except the seed) are plowed under for soil improvement; but no seed was produced either on the cowpeas in 1910 or on the clover in 1911, and consequently the effect of the limestone on the legume crops was not determined in this system.

If we accept the average of the two series and compute the effect from these data for the four-year rotation, we find a return of $12.20 from an investment of $7.50 in limestone; and the limestone applied to the soil is sufficient to last for more than 10 years. These data strongly support those from the Vienna field in showing the positive value and need of limestone in the very beginning of improvement for these acid upland soils of southern Illinois.

The work at Raleigh has been carried on for only two years, and the organic manures thus far produced and returned to the soil are too meager to produce results from which trustworthy conclusions can be drawn concerning either the nitrogen secured or the phosphorus and potassium liberated; but that the addition of fine-ground raw rock phosphate in connec-

TABLE 6.—FERTILITY IN THE SOILS OF HARDIN 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	Limestone required
	Upland Timber Soils								
135	Yellow silt loam	9670	1390	1930	71340	19780	7650		8910
134	Yellow-gray silt loam	13600	1500	1820	64320	15000	8060		2780
864	Yellow fine sandy loam	12920	1640	1960	67640	17560	7840		5000
	Swamp and Bottom-land Soils								
1323	Red-brown clay loam	35120	3960	3180	86200	25240	9720	3220	
1331	Deep gray silt loam	10480	960	880	55280	11640	11400		2280
1361.1	Mixed fine sandy loam	28460	2580	1220	56860	8960	9860	2000	
1380	River sand	18960	760	1840	33640	10640	20080	30760	
	Terrace Soils								
1516	Gray clay	43920	4160	2080	77200	28200	23240		40
1530	Gray silt loam on tight clay	21400	2080	1800	88720	34480	13160		2800

TABLE 7.—FERTILITY IN THE SOILS OF HARDIN 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	Limestone required
	Upland Timber Soils								
135	Yellow silt loam	8060	1310	2700	109070	30670	19580		10060
134	Yellow-gray silt loam	10020	1620	2610	94530	25830	12330		13950
864	Yellow fine sandy loam	8400	1500	3240	107400	29580	13320		10080
	Swamp and Bottom-land Soils								
1323	Red-brown clay loam	35910	4080	4440	130800	36210	14610	4560	
1331	Deep gray silt loam	12300	1380	1440	86340	21600	17760		2520
1361.1	Mixed fine sandy loam	41550	3990	2370	78180	13590	17100	3000	
1380	River sand	24480	660	1740	47160	13080	24960	32880	
	Terrace Soils								
1516	Gray clay	33480	3000	2460	106200	43560	36180		60
1530	Gray silt loam on tight clay	31200	3420	2880	132660	51120	19980		1500

tion with organic manures (farm manure, green manures or crop residues) will prove profitable on these undulating or gently rolling upland soils is very certain from the results already secured from other experiment fields. (See Soil Reports Nos. 1 and 2, and Circulars 116, 149, and 157.) On the other hand, the first step in the upbuilding of these soils is the liberal use of limestone in connection with clover or other legume crops grown in rotation with corn and other grains; and when the legume crops or farm manures are available to plow under in significant amount then is the time to begin the application of phosphate, to be turned under in intimate contact with the decaying organic matter. Where used in this way on very similar land at the Ohio Agricultural Experiment Station, as an average of duplicate tests on three different series of plots during a period of fifteen years, every dollar invested in raw phosphate paid back $7.42, counting $7.50 per ton for the phosphate, 35 cents a bushel for corn, 70 cents for wheat, and $6.00 a ton for clover hay; while in a corresponding experiment every dollar invested in acid phosphate (at $15 per ton) paid back $3.69. (See Illinois Circulars 116, 127 and 130 for more details of these valuable Ohio experiments.)

No field experiments have been conducted on the less extensive soil types, but their composition is shown in Tables 2, 6 and 7, and their general characteristics and needs are discussed for each individual type in the following pages.

THE SUBSURFACE AND SUBSOIL

In Tables 6 and 7 are recorded the amounts of plant food per acre in the subsurface (6⅔ to 20 inches) and subsoil (20 to 40 inches), but it should be remembered that these supplies are of little value unless the top soil is kept rich, except that they serve as a source of renewal, even by very slight surface washing, for any element which they contain in great abundance, as is the case with potassium; and where much surface soil is removed by erosion, as on the rolling hill land, even the supply of phosphorus is renewed from the substrata in amounts which may equal or exceed the requirements of the crops that are grown where nitrogen is so commonly the limiting element.

Among the most important information contained in Tables 6 and 7 is that the upland soils are even more strongly acid in the subsurface and subsoil than in the surface stratum, thus emphasizing the importance of putting plenty of limestone in the surface soil to neutralize the acid moisture which rises from the lower strata by capillary action during the periods of partial drouth, which are also critical periods in the life of such plants as clover.

In the case of the less rolling upland (yellow-gray silt loam) where surface washing is not marked, the basic elements have been leached out and replaced with acid to such a depth that the subsoil is even more strongly acid than the subsurface, altho this is not the case with the yellow silt loam; and where very marked recent erosion has occurred, almost unleached subsoil containing limestone is sometimes exposed.

INDIVIDUAL SOIL TYPES

(a) UPLAND TIMBER SOILS

Yellow Silt Loam (135)

This is by far the most common type in the county, occupying 70.5 percent of the area, or 120 square miles. The soil was formed from material derived from glacial or alluvial formations, carried by the winds and deposited at all altitudes. The average depth of this loess or wind-blown material is not far from ten feet. The residue from the decay of the rocks has been so completely buried that it forms ordinarily no part of the soil. This residual material may be seen in some cuts as a reddish clay, frequently mixed with angular cherty or flinty pebbles. The topography of this type varies from rolling to very hilly and includes some land that should not be cultivated at all or that may be farmed only with the greatest care to avoid loss by erosion. Much of this type has been abandoned agriculturally already, and some of it should never have been cleared of its protecting forests. It frequently occurs that the northern slopes are abrupt, while those toward the south are more gradual and may be cultivated fairly well.

In the part of the county in the vicinity of Elizabethtown and Cave-in-Rock the rolling topography is due in part to the many sink-holes formed by the solution of the underlying limestone. These depressions vary in size from about 30 feet to several hundred feet in diameter and perhaps from 10 to 40 feet deep. They drain naturally into underground channels, but in many cases these drainage outlets have been stopped and sinkhole ponds result. About three miles northwest of Cave-in-Rock this obstructed drainage has resulted in the formation of a lake that covers an area of 100 acres or more, varying in extent with the time of year and the amount of rainfall. (The soil area shown as 1361.1 shows the limit of the lake when at its greatest size.)

The surface soil of the common hill land, 0 to 6⅔ inches, is a light brown to yellow silt loam varying with the amount of organic matter, which in turn is dependent to a large extent upon the amount of erosion. Usually the latter color prevails. The organic matter content is very low in this type, much too low for a fertile soil, about 1.1 per cent, as an average, in the surface soil, or only 11 tons per acre. From its yellow color this type is commonly called a clay soil; but it contains from 25 to 30 percent of fine sand, and much the larger part of the remaining 70 to 75 percent is silt, thus rendering it porous and mealy and easily worked; whereas true clay is plastic or gummy and very difficult to work. The surface soil is usually distinguished from the subsurface by a difference in color due to the still lower organic content of the subsurface soil.

The subsurface stratum is somewhat variable in thickness, depending upon the amount of erosion that has taken place, the average being about 8 or 9 inches. In some spots it is practically absent, while in others it is from 10 to 12 inches in thickness. It is a light yellow silt loam, mealy, porous, and pulverulent, the physical composition being a little finer than in the surface. The average organic matter content is .4 percent, or only 8 tons per acre for 4 million pounds of soil (6⅔ to 20 inches).

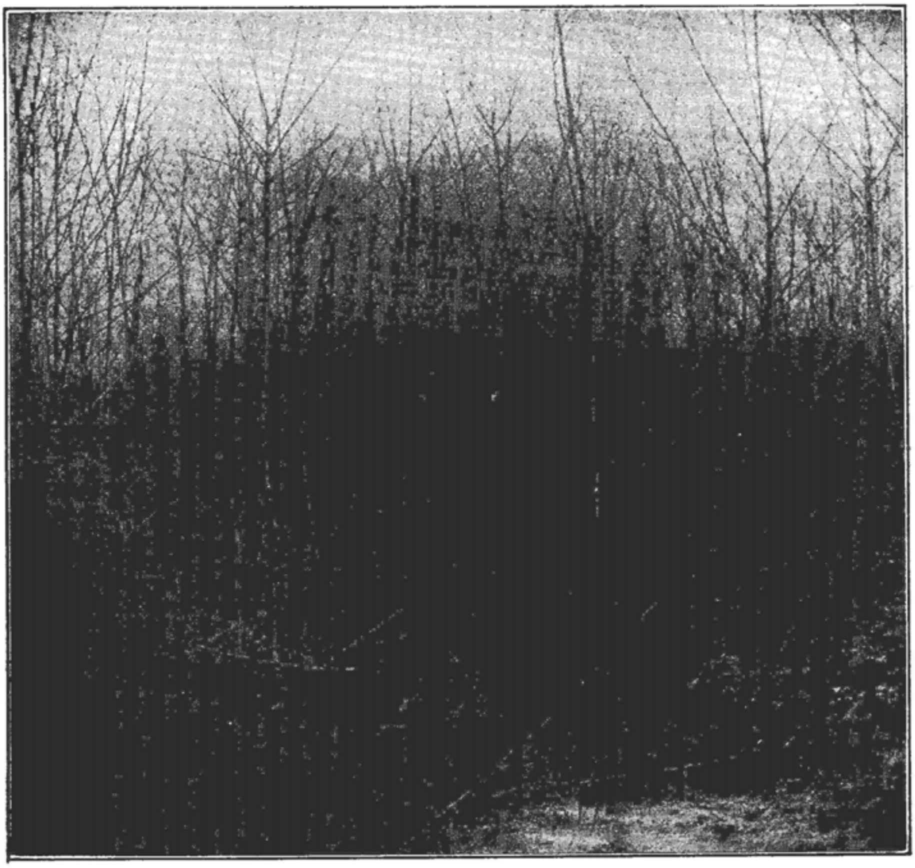

PLATE 3. YOUNG GROVE OF BLACK LOCUST TREES ON ROLLING HILL LAND IN JOHNSON COUNTY, ILLINOIS. (GROWN BY J. C. B. HEATON.)

The subsoil, extending from the subsurface stratum to a depth of 40 inches, is a yellow silt or slightly clayey silt. Gray blotches of unoxidized material often occur in the deeper subsoil. This stratum is more compact and not quite so porous as those above it, yet sufficiently pervious to allow water to pass thru it.

The variations of this type are produced chiefly by erosion. It represents varying degrees of fertility. In some places very little washing has occurred, in others the surface has been largely removed, while in others the subsoil may be exposed as unproductive yellow "clay points."

Of most importance in the management of this type is preventing much loss by washing. This process has gone on to such an extent that a large percentage of the type has been agriculturally abandoned, and so far not only has nothing been done to reclaim the abandoned land, but very little has been done to prevent further loss on land now under cultivation. Erosion occurs as sheet-washing and gullying. Ordinarily we do not think of sheet-washing as doing very much damage, but it is really the form that does the greatest amount of injury. Gullying results in the absolute ruin of small areas, but sheet washing reduces the productive capacity of large areas to such a point that not only profitable crops cannot be grown, but even the

PLATE 4. GROVE OF LOCUST TREES ABOUT TWENTY-FIVE YEARS OLD ON ROLLING HILL LAND IN JOHNSON COUNTY, ILLINOIS. (GROWN BY J. C. B. HEATON.)

growth of crops large enough to pay for the raising becomes impossible. Every means should be taken to prevent this loss.

Steep gullied slopes probably never can be reclaimed with profit for cropping purposes at the present average prices for labor and farm produce. They were originally forested and these forests should never have been entirely removed. It was the only thing that made these lands valuable in the first place, and to make them of any future value they should be reforested. This has been done in a few cases with excellent success. The accompanying illustrations show such results. The black locust can be used most successfully for this purpose as it is largely independent of the supply of nitrogenous organic matter in the soil. Where not in forest the steep land should be kept in pasture as much as possible, and if plowed should be cropped for only one or two years and then reseeded to pasture. Live stock is indispensable to farming on this type of soil.

Sheet washing on the moderate slopes may be prevented to a great extent by the following methods:

(1) By increasing the organic matter content, thus rendering the soil more porous, and binding the soil particles together. This can be done by adding farm manure, plowing under stubble, straw, cornstalks, and legume crops, such as clover and cowpeas.

(2) By deep plowing to increase the absorption of water and diminish the run-off. Ten inches of loose soil will readily absorb 2 inches of rainfall without run-off. Plowing should be done seven to ten inches deep.

(3) By contour plowing. Plowing in this state is often done up and down the hill, producing dead furrows that furnish excellent beginnings for gullies. Even the little depressions between furrows will aid washing. On land subject to serious washing, plowing should always be done across the slope on the contour, so that water will stand in the furrow without running in either direction. Every furrow will act as an obstruction to the movement of water down the slope, thus diminishing the velocity of the water, facilitating absorption, and diminishing the amount of run-off and the power of the water to do washing.

(4) By the use of cover crops to hold the soil during the winter and spring. Rye is a fairly good cover crop to sow in the corn during the late summer or early fall. Wheat, especially when seeded late, is a poor crop to grow on rolling land because it does not usually make sufficient growth to

TABLE 8.—CROP YIELDS PER ACRE FROM RECLAIMED ABANDONED HILL LAND: VIENNA EXPERIMENT FIELD

Year	Field 1	Field 2	Field 3	Field 4
1906	Corn 20.4 bu.	Cowpeas turned		
1907	Cowpeas turned	Wheat 9.6 bu.	Clover 1.00 ton	Corn 24.4 bu.
1908	Wheat 7.9 bu.	Clover .77 ton	Corn 33.5 bu.	Cowpeas turned
1909	Clover .60 ton*	Corn 37.8 bu.	Cowpeas turned	Wheat 8.8 bu.
1910	Corn 38.6 bu.	Cowpeas turned	Wheat 15.6 bu.	Clover 1.53 tons
1911		Wheat 17.6 bu.		Corn 32.8 bu.

Average Yields of Crops Grown

	Corn	Wheat	Clover
1906–1908	25.1 bu.	8.8 bu.	.89 ton
1909–1911	36.4 bu.	14.0 bu.	1.07 tons

*The yield of clover for 1909 is estimated, the weights not having been taken because of a misunderstanding.

afford a good protection to the soil during winter. Of course both rye and wheat invite the development of chinch bugs. A mixture of winter vetch, and clover, with a few cowpeas, seeded at the time of the last cultivation of the corn, gives results in favorable seasons.

Experiments in methods of preventing soil erosion are being carried on in Johnson county near Vienna on abandoned land purchased in 1906 by the University of Illinois. In addition to the methods above described, two tons per acre of ground limestone are applied every four years. The results show that this land may be reclaimed and made to produce fair crops, as is shown in Table 8.

These results show that fairly good crops may be grown upon this abandoned land if proper care is taken to reduce washing, and if use is made of ground limestone and a good crop rotation. The results also indicate that the crop yields tend to increase under this system. (See also Tables 3, 4 and 5.)

Alfalfa may well be one of the crops grown in this type of soil. Note the suggested rotation and directions under *Yellow-Gray Silt Loam* and *Yellow Fine Sandy Loam.*

Yellow-Gray Silt Loam (134)

This type occurs only in limited, somewhat isolated areas over the county, usually surrounded by yellow silt loam (135). The type covers 10.5 square miles, or 6.17 percent of the area of the county. It comprises the less rolling areas of the upland and furnishes some good agricultural land. The topography varies from slightly undulating to rolling. All of this land may be cultivated but in some places where it grades toward the yellow silt loam care must be taken to prevent washing. Its origin is the same as the yellow silt loam (135).

The surface soil, 0 to 6⅔ inches, is a yellow to yellowish gray silt loam, porous, mealy, and pulverulent. Its good physical condition is due to the considerable percentage of fine sand that it contains. The organic matter content is low, the average being 1.35 percent—but slightly higher than the yellow silt loam.

The subsurface stratum, varying from about 8 to 12 inches in thickness, is a yellow to grayish yellow silt loam distinguished from the surface soil by its lighter color. Its physical composition is very much like the surface except that there is less organic matter, only .56 percent.

The subsoil from the subsurface to a depth of 40 inches is a compact yellow or grayish yellow silt or clayey silt, plastic when wet. Concretions of iron are found in the subsurface and subsoil in the more nearly level areas.

While the type is one of the best in the county, the supply of organic matter should be increased to keep the soil in good physical condition and thus prevent washing.

At least 2 tons per acre of ground limestone should be applied, and 4 or 5 tons would be even more profitable for the initial application, after which about 2 tons every four or five years will be sufficient to keep the soil sweet. Legume crops should be grown in a good rotation, such, for example, as corn, cowpeas, wheat, and clover, on four fields, with alfalfa on a fifth field. After five years the alfalfa field may be broken up and used for the four-year rotation, one of the four fields being seeded to alfalfa for another five-year period. (See also Yellow Fine Sandy Loam, page 18.)

The organic matter and nitrogen should be increased either by using all crops except the wheat for feed and bedding, saving and retaining the manure produced, or by selling only grain or seed and some alfalfa hay and plowing under all other crops and residues.

About 1,000 pounds per acre of very finely ground rock phosphate should be plowed under with the organic matter every four or five years, and the initial application may well be at least 1 ton per acre. Temporarily some use may well be made of steamed bone meal, as by drilling about 200 pounds per acre when seeding wheat on land where no adequate provision has been made for the decaying organic matter required to liberate phosphorus from the raw phosphate used in the more profitable permanent systems of soil improvement.

In composition this type of soil resembles that of the gray silt loam prairie (330) described in Soil Report No. 1, and the reader's attention is called to Tables 3, 6 and 7 in that report, showing the composition of the prairie soil and the results obtained from field experiments conducted in that soil at DuBois and Fairfield. The Raleigh experiment field, referred to in the preceding pages, is located in the yellow-gray silt loam, and, tho recently established, is already beginning to show valuable results from proper methods of soil improvement.

Yellow Fine Sandy Loam (864)

Only a small area of this type is found in the county, amounting to 294 acres. It occurs on the point extending southward in a bend of the Ohio river, thus furnishing a place of deposit for the material picked up by the wind sweeping over the bottom land when exposed at times of low water.

The area is small and very rolling so that very little is under cultivation. In some counties along the Mississippi river this type occurs in very extensive areas. Where cultivated it should be protected from excessive surface washing, and liberal use should be made of ground limestone and organic matter. The soil is especially adapted to the growing of alfalfa when well inoculated and sweetened with about 5 tons per acre of limestone; but, in order to give the alfalfa a good start, a moderate application of farm manure or 500 to 1000 pounds per acre of acid phosphate (or still better, both manure and acid phosphate) should be plowed under. After the alfalfa is well started it roots very deeply and becomes almost independent of the top soil, except with respect to limestone.

Stony Loam (198)

This type occurs on the slopes of hills and ridges where erosion has removed most of the loess and residual material, to a large extent leaving a mixture of these and stones to constitute the soil. The stones vary from a few inches to several feet in diameter. It comprises 17.05 square miles, or 10 percent of the entire area. It is of little agricultural value, its only use, aside from growing of forests, being for pasture.

Rock Outcrop (199)

This can hardly be considered a type of soil but may have some value as a source of limestone for use on acid soils.

The outcrop occurs frequently as perpendicular ledges, and the horizontal width is often somewhat exaggerated in order to show the boundary lines on the soil map.

(b) SWAMP AND BOTTOM-LAND SOILS

Red-Brown Clay Loam (1323)

This type comprises the greater amount of the bottom land along the Ohio river, the total area being 3.16 square miles or 1.86 percent of the area of the county. Two large areas occur, one in the southwest and the other in the southeast. A few small areas occur at the mouths of some of the small creeks that flow into the Ohio. This type is formed by deposit from the flood waters of the Ohio river and has been found in all of the counties surveyed that border on that river.

The topography varies from almost flat to gently undulating, the undulations being due to the narrow but elevated ridges and depressions formed by currents during overflow. The drainage is not always good, there being many low, wet places in which the crop may be badly damaged.

The surface soil, 0 to 6⅔ inches, is a yellow to reddish brown clay loam, plastic, but granular under proper conditions. Like all clays and clay loams, it will become hard and intractable if worked when wet, due to puddling or the breaking down of the granules. This will be restored by the moistening and drying produced by showers or by freezing and thawing.

The amount of organic matter varies from 2¼ to 3½ percent, with an average of about 2¾ percent. The physical composition varies somewhat, the heavier phase being near the bluff and on the lower ground, and the lighter or more sandy near the river.

The subsurface, 6⅔ to 20 inches, is not distinctly separated from either the surface or subsoil. The color gradually becomes lighter with depth, due to the smaller amount of organic matter, which is 1.5 percent in this stratum.

The subsoil, 20 to 40 inches, is a yellowish brown clay loam, tough and plastic, yet pervious to water. It varies slightly with the topography, the lower areas having a heavier subsoil.

This soil is more difficult to manage than a lighter soil, owing to the danger of puddling if worked when too wet and to its cloddy character when dry. This type cracks rather badly owing to the property of shrinkage which clay possesses to such a degree. Corn is the chief crop, but where protected from overflow other crops can be grown. The soil is rich in mineral plant food, but legumes should be grown in the rotation where the land does not overflow.

Deep Gray Silt Loam (1331)

This type is found in some of the wider bottoms of the small streams, mostly near their mouths. It is formed from material washed from the hills. It seems to be an older deposit than the mixed sandy loam (1361.1) and is occasionally a little higher bottom land. Since its deposition the iron has been deoxidized, and as a result the color has been changed from a yellow or brownish to a gray or light drab. The topography is flat to gently undulating. The extent of this type in the county is 768 acres, constituting only .65 percent of the total area of the county.

The surface, 0 to 6⅔ inches, is a gray silt loam varying to a yellowish gray silt loam or fine sandy loam. Iron concretions are usually found upon the surface and mixed with the surface and subsurface strata. All of this type contains considerable fine sand, giving it an almost ideal physical composition. It is very low in oragnic matter, having only about 1 percent.

The subsurface, 6⅔ to 20 inches, is a gray silt loam, friable, pulverulent, but compact and not very pervious, especially upon the higher and apparently older areas.

The subsoil is mostly a gray silt, but varies from this to a gray silty clay, compact, tough and almost impervious, resembling the subsoil of the gray silt loam on tight clay on the more elevated parts of the bottom land

The type is drained poorly as a rule, and better drainage with the addition of organic matter are the first requirements for improvement, altho it will be necessary to add limestone to get the organic matter by the growing of legumes, because of the acidity of the soil and subsoil. Where protected from overflow phosphorus should also be applied in systems of permanent improvement.

Mixed Fine Sandy Loam (1361.1)

This type is found along the small stream of the county as bottom land, varying in width from a few rods to a half mile, altho in these wider places the soil may grade toward the deep gray silt loam. The material forming this type has been rather recently washed from the surrounding hills, the finer particles being carried into the Ohio river, while the coarser are deposited in these bottoms.

The topography is flat to gently undulating, the undulations being due to the old system channels and those produced during floods. Natural drainage is usually good. In some places the type is underlain by gravel.

The total area of the type is 8074 acres or 7.4 percent of the entire area of the county.

The surface, subsurface and subsoil are practically the same, the chief difference being in the amount of organic matter in some places, altho this does not vary as much as might be supposed. The amount varies from 1 to 1½ percent in the surface soil. This is one of the best types in the county, producing fair crops of corn, wheat and cowpeas.

As a rule this soil is not acid, more or less of the material being almost unweathered, having been recently washed out of deep gullies.

Because of the porous character of the soil and subsoil, and the consequent deep-feeding range afforded to plant roots, and also because of the liability to overflow, it is very doubtful if any purchased materials should be applied to this kind of land; but legumes should be grown in rotation where conditions permit.

River Sand (1380)

This type covers about 130 acres along the Ohio river in the southward extension southwest of Rosiclare and is a deposit formed by water and reworked to some extent by wind. The sand is largely derived from a sand bar beside this area on the north side of the river, this sand bar being exposed during low water.

There is very little difference between the different strata of sand except that occasional layers of silt or clay from 2 to 4 inches thick are found in the subsoil. These have been deposited during overflow from the Ohio river.

The sand is exceedingly poor in organic matter and nitrogen, altho the ratio between the organic carbon and nitrogen indicates that the small amount of organic matter present is in moderately fresh condition, as might be expected from the formation and age of this river sand. Where it is cultivated, legume crops should be grown in the rotation if practicable. Considering its composition and very porous character, no applications can be advised except nitrogenous organic matter, best secured as a rule by legume crops.

(c) Terrace Soils

Gray Clay (1516)

This type comprises about 196 acres, mostly in the northeast part of the county. There are two small areas in the southwestern part along small streams. This with the type described below (gray silt loam on tight clay) represents an old fill, or terrace deposit, caused by the silting up of the Ohio and its tributaries and later cutting down thru them by stream erosion to the level of the present bottom land. The topography is flat, with the exception of a few small draws that have been made by streams.

The surface, 0 to 6⅔ inches, is a gray to dark drab clay, with iron stains, very plastic, and possessing the property of shrinkage to a marked degree. This stratum contains about 3 percent of organic matter.

The subsurface and subsoil are composed of a gray, sticky, plastic clay with blotches of yellow.

The soil is very difficult to work; it is easily puddled when too wet, and when dry is very cloddy. It granulates under proper conditions of moisture. Its chief value is for permanent pasture or hay, but even for these purposes it is not a good soil; and because of the physical difficulties it is doubtful if any method of enrichment would be profitable; but if so it would be with limestone, organic matter and possibly phosphorus.

Gray Silt Loam on Tight Clay (1530)

This type is like the gray clay (1516) in that it is part of an old clay terrace, but in this case a deposit of silt from 7 to 12 inches deep was made upon the tight clay layer. It occurs in the northeastern part of the county along Harris creek and Saline river and along three small creeks in the vicinity of Elizabethtown.

The total area is 755 acres. It is very flat and poorly drained. While it is a distinct terrace yet part of it overflows during extremely high water. Tile would be of little use because of the almost impervious subsoil.

The surface soil, 0 to 6⅔ inches, is a gray silt loam having about 2 percent of organic matter, sometimes with a yellow tinge due to iron. It varies from a loose pulverulent silt loam to a somewhat sticky clayey silt loam.

The subsurface stratum is sometimes represented by a layer of gray silt loam extending to a depth of 12 inches, but often the clay subsoil begins at a depth of 7 inches and continues without any material change to a depth of 40 inches. The subsoil is a gray or yellowish clay, tough, plastic and nearly impervious.

The type has a very low value for agricultural purposes. It produces but little corn or wheat, and grass makes but poor growth. Much of it is still covered with timber, and probably this is the best crop that can be grown upon it. If put under cultivation and protected from overflow, it should be treated with ground limestone, and legume crops should be grown in the rotation; and with long continued cropping phosphorus would need to be supplied, altho in its virgin condition it is fairly rich in that element, as shown in Table 2.

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 of Illinois Soils," which contains a colored general survey soil map of the entire state.

Other publications of general interest are:

Bulletin No. 76, "Alfalfa on Illinois Soils"
Bulletin No. 94, "Nitrogen Bacteria and Legumes"
Bulletin No. 99, "Soil Treatment for the Lower Illinois Glaciation"
Bulletin No. 115, "Soil Improvement for the Worn Hill Lands of Illinois"
Bulletin No. 125, "Thirty Years of Crop Rotation on the Common Prairie Lands of Illinois"
Circular No. 110, "Ground Limestone for Acid Soils"
Circular No. 127, "Shall we use Natural Rock Phosphate or Manufactured Acid Phosphate for the Permanent Improvement of Illinois Soils?"
Circular No. 129, "The Use of Commercial Fertilizers"
Circular No. 149, "Some Results of Scientific Soil Treatment" and "Methods and Results of Ten Years' Soil Investigation in Illinois"

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 149.

SOIL SURVEY METHODS

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

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

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

Each surveyor is provided with a base map of the proper scale, which is carried with him in the field; and the soil-type boundaries, additional streams, and necessary corrections are placed with 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 being carried in the field for this purpose.

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

SOIL CHARACTERISTICS

The unit in the soil survey is the soil type, and each type possesses more or less definite characteristics. The line of separation between adjoining types is usually distinct, but sometimes one type will grade 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) native vegetation, as forest or prairie grasses; (4) the structure, or the depth and character of the surface, subsurface, and subsoil; (5) the physical or mechanical composition of the different strata composing the soil, as the percentages of gravel, sand, silt, clay, and organic matter which they contain; (6) the texture, or porosity, granulation, friability, plasticity, etc.; (7) the color of the strata; (8) the natural drainage; (9) agricultural value, based upon its natural productiveness; (10) the ultimate chemical composition and reaction.

The common soil constituents are indicated in the following outline:

CONSTITUENTS OF SOILS

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

*25 millimeters equal 1 inch.

Further discussion of these constituents is given in Circular 82.

GROUPS OF SOIL TYPES

The following gives the different general groups of soils:

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

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

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

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

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

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

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

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

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

Sands—Soils with more than 75 percent of sand.

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

Gravels—Soils with more than 50 percent of gravel.

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

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

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

SUPPLY AND LIBERATION OF PLANT FOOD

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

The chemical analysis of the soil gives the invoice of fertility actually present in the soil strata sampled and analyzed, but the rate of liberation is governed by many factors, some of which may be controlled by the farmer, while others are largely beyond his control. Chief among the important controllable factors which influence the liberation of plant food are limestone and decaying organic matter, which may be added to the soil by direct application of ground limestone and farm manure. Organic matter may also be supplied by green-manure crops and crop residues, such as clover, cowpeas, straw, and cornstalks. The rate of decay of organic matter depends largely upon its age and origin, and it may be hastened by tillage. The chemical analysis shows correctly the total organic carbon, which represents, as a rule, but little more than half the organic matter; so that 20,000 pounds of organic carbon in the plowed soil of an acre correspond to nearly 20 tons of organic matter. But this organic matter consists largely of the old organic residues that have accumulated during the past centuries because they were resistant to decay, and 2 tons of clover or cowpeas plowed under may have greater power to liberate plant food than the 20 tons of old inactive organic matter. The recent history of the individual farm or field must be depended upon for information concerning recent additions of active organic matter, whether in applications of farm manure, in legume crops, or in grass-root sods of old pastures.

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

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

As already explained, fresh organic matter decomposes much more rapidly than the old humus, which represents the organic residues most resistant to decay and which consequently have 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 which thus furnish or liberate organic matter and inorganic food for bacteria, which, under such favorable conditions appear to have power to attack and decompose the old humus. It is probably for this reason that peat, a very inactive and inefficient fertilizer when used by itself, becomes much more effective when incorporated with fresh farm manure; so that, when used together, two tons of the mixture may be worth as much as two tons of manure, but if applied separately, the peat has little value. Bacterial action is also promoted by the presence of limestone.

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

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

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

CROP REQUIREMENTS

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

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

Produce: Kind	Produce: Amount	Nitrogen, pounds	Phosphorus, pounds	Potassium, pounds	Magnesium, pounds	Calcium, pounds
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*	42	51	16	4
Total in four crops		510*	77	322	68	168

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

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

On the Fairfield experiment field in Wayne county, on the common prairie land of southern Illinois, yields have been obtained in favorable seasons as high as 90 bushels per acre of corn, and 3½ tons of air-dry clover hay.

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

METHODS OF LIBERATING PLANT FOOD

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

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

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

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

PERMANENT SOIL IMPROVEMENT

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

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

(2) Adopt a good rotation of crops, including a liberal use of legumes, and increase the organic matter of the soil either by plowing under the legume crops and other crop residues (straw and corn stalks) or by using for feed and bedding practically all of 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 (with some winter legume, such as red clover, alsike, sweet clover, or alfalfa, or a mixture, seeded on part of the field at the last cultivation).

Second year, oats or barley or wheat (fall or spring) on one part and cowpeas or soybeans where the winter catch crop is plowed down late in the spring.

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

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

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

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

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

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

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

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

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

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

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

On soils which are subject to surface washings, 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) tend 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 shoud be grown during a period of ten or twelve years, the land being kept in pasture most of the time; and where the soil is acid a liberal use of limestone, as top dressings if necessary, and occasional reseeding with clovers will benefit both the pasture and indirectly the grain crops.

ADVANTAGE OF CROP ROTATION AND PERMANENT SYSTEMS

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

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

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

THE POTASSIUM PROBLEM

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

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

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

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

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

From all of these facts it will be seen that the potassium problem is not one of addition but of liberation; and the Rothamsted records show that for many years other soluble salts have practically the same power as potassium to increase crop yields in the absence of sufficient decaying organic matter. Whether this action relates to supplying or liberating potassium for its own sake, or to the power of the soluble salt to increase the availability of phosphorus or other elements, it 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 costing $5.10, increased the yield of corn by 9.3 bushels per acre; while 600 pounds of kainit, containing only 60 pounds of potassium and costing $4.00, gave an increase of 10.7 bushels. Thus, at 40 cents a bushel for corn, the kainit has paid for itself; but these results, like those at Rothamsted, were secured where no adequate provision had been made for decaying organic matter.

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

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

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

If, however, the entire produce of the land is sold from the farm, as in hay farming, or when both grain and straw are sold, of course the draft on potassium will then be so great that in time it must be renewed by some sort of application. As a rule, such farmers ought to secure manure from town, since they furnish the bulk of the material out of the 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* of Illinois well-waters drawn chiefly from glacial sands, gravels, or till, 3 million pounds of water (about the average annual drainage per acre for Illinois) contained 11 pounds of potassium, 130 of magnesium, and 330 of calcium. These figures are very significant, and it may be stated that if the plowed soil is well supplied with the carbonates of magnesium and calcium, then a very considerable proportion of these amounts will be leached from that stratum. Thus the loss of calcium from the plowed soil of an acre at Rothamsted, England, where the soil contains plenty of limestone, has averaged more than 300 pounds a year as determined by analyzing the soil in 1865 and again in 1905. And practically the same amount of calcium was found by analyzing the Rothamsted drainage waters.

Common limestone, which is calcium carbonate ($CaCO_3$), contains, when pure, 40 percent of calcium, so that 800 pounds of limestone are equivalent to 320 pounds of calcium. Where 10 tons per acre of ground limestone were applied at Edgewood, Illinois, the average annual loss during the next ten years amounted to 790 pounds per acre. The definite data from careful investigations seems 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.

*Reported by Doctor Bartow and associates, of the Illinois State Water Survey.

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