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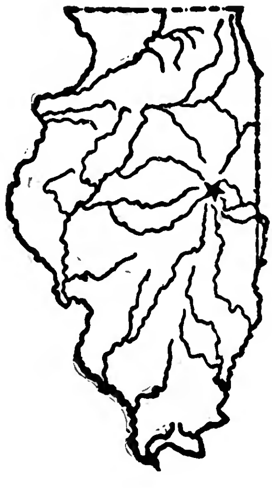
BULLETIN No. 125

THIRTY YEARS OF CROP ROTATIONS ON THE COMMON PRAIRIE SOIL OF ILLINOIS

By CYRIL G. HOPKINS, J. E. READHIMER AND WM. G. ECKHARDT



URBANA, ILLINOIS, MAY, 1908

SUMMARY OF BULLETIN NO. 125

1. Authentic records show that our oldest soil experiment fields were established at the University of Illinois in 1879. Page 327

2. Under one system of farming the yield of corn has decreased from 70 bushels to 27 bushels per acre within thirty years; while under another system the yield of corn has increased to 96 bushels per acre as an average. Page 324

3. The fertility of the soil can be maintained, or even increased, by a proper system of grain farming with legumes in rotation. Page 325

4. A good system of live stock farming, which may or may not be more profitable than grain farming, will also maintain the fertility of the soil. Page 326

5. Farm manure has given a net profit in the first three crops of $1.30 per ton, or of $7.80 an acre when six tons have been applied. Page 341

6. As an average of 18 tests, covering three years, with a rotation of corn, oats, and clover, the use of 75 pounds of phosphorus has produced increases in crop yields worth $12.39. Page 342

7. Larger crop yields have been secured (and phosphorus has been nearly twice as effective) in a three-year rotation of corn, oats, and clover, than in a two-year rotation of corn and oats. Page 346

8. While phosphorus is commonly the element that first limits the yields of crops on our common soils, nitrogen is lost from the soil so much more rapidly under poor systems of farming that nitrogen soon becomes the limiting element, after which phosphorus alone has no power to increase the crop yields. Page 353

9. This bulletin will be sent free of charge to anyone interested in Illinois agriculture, upon request to E. Davenport, Director Agricultural Experiment Station, Urbana, Illinois, and if so requested, the name of the applicant will be placed upon the permanent mailing list of the Experiment Station, so that all subsequent bulletins will be sent to him as they are issued.

THIRTY YEARS OF CROP ROTATIONS ON THE COMMON PRAIRIE SOIL OF ILLINOIS

BY CYRIL G. HOPKINS, CHIEF IN AGRONOMY AND CHEMISTRY,
J. E. READHIMER, SUPERINTENDENT OF SOIL EXPERIMENT FIELDS, AND
WM. G. ECKHARDT, ASSISTANT IN SOIL FERTILITY

Near the end of thirty years an average yield of 96 bushels of corn per acre on one field, and an average yield of 27 bushels of corn per acre on another field, must be accepted as the results of different systems of farming on land that was similar and uniform at the beginning. These results have been obtained in the heart of the corn belt and on typical Illinois prairie land, representing the most extensive and the most important type of soil in the state,—land whose present market value ranges from $150 to $200 per acre,—a value that may change rapidly in Illinois, as it has already changed in the older states.

The 96 bushels is the average yield per acre for the years 1905, 1906, and 1907, in one system of farming; and the 27 bushels is the average yield for the same years in another system of farming on land originally the same. Between these extremes other results have been obtained from several other systems of farming.

It is the purpose of this bulletin to report, especially to Illinois landowners and farmers, the valuable data that have been secured in these investigations. The results from these experiment fields are now beginning to influence the agricultural practice of the state, and they are destined to be of inestimable value to the commonwealth. Before discussing the details of the work, a comprehensive summary of the effects of the different systems of farming will be considered.

SYSTEMS OF FARMING

In Table 1 are given three-year averages of the yields of corn secured in recent years, including 1907, which is the 29th year of the oldest experiments and the 13th year of a newer and more extensive series of experiments with crop rotations and soil treatment with special reference to two markedly different systems of farming, of which one is termed grain farming and the other live stock farming. (Some preliminary cropping and other variations from the systems indicated are reported in the detailed discussion and tabular statements in the following pages.) The crops in the 30th year of the older experiments may be seen by visiting these fields during the season of 1908.

TABLE 1.—LATEST CORN YIELDS FROM THE UNIVERSITY OF ILLINOIS EXPERIMENT FIELD AT URBANA: TYPICAL CORN BELT PRAIRIE SOIL (Three-year averages: Bushels per acre)

Crop years.	Crop system.	13-year experiments.	29-year experiments.
1905,-6,-7	Corn every year..............	35 bu.	27 bu.
1903,-5,-7	Corn and oats..................	62 "	46 "
1901,-4,-7	Corn, oats, clover.............	66 "	58 "

Average of Three Corn Crops in Corn-Oats-Clover Rotation: 13-Year Experiments

Crop years.	Special treatment.	Grain farming (with legumes*).	Live stock farming (with manure†).
1905,-6,-7	None..............................	69 bu.	81 bu.
1905,-6,-7	Lime..............................	72 "	85 "
1905,-6,-7	Lime, phosphorus..............	90 "	93 "
1905,-6,-7	Lime, phosphorus, potassium...	94 "	96 "

*Legume catch crops and crop residues.
†Manure applied in proportion to previous crop yields.

As an average of the last three years where corn has been grown every year the yield has been 27 bushels in the 29-year experiments and 35 bushels in the 13-year experiments. The lesson of these experiments is that 12 years of cropping where corn follows corn every year reduces the yield from more than 70 bushels to 35 bushels per acre, after which the decrease is much less rapid, amounting to only 8 bushels reduction during the next 16 years. Undoubtedly the rapid reduction during the first 12 years of continuous corn growing is due in large part to the destruction of the more active decaying organic matter, resulting ultimately in insufficient liberation of plant food within the feeding range of the corn roots. In addition to this, the development of corn insects in soil on which their favorite crop is grown every year is sometimes an important factor in reducing the yield.

Where corn is followed by oats in a two-year rotation the average yield of the last three crops of corn is 46 bushels in the 29-

year experiments, whereas in the 13-year experiments the average yield for the same three years is 62 bushels of corn per acre. In this case the destruction of humus is less rapid, and the development of the corn insects is discouraged by changing to oats every other year, so that the decrease in yield is less marked during the early years, although the reduction continues persistently with passing years. During the first 11 years the yield decreased from more than 70 bushels to 62 bushels, and during the next 16 years a further reduction of 16 bushels has occurred.

With the three-year rotation corn is grown for one year, followed by oats with clover seeding the second year, and clover alone the third year. During the first 10 years under this system the yield of corn has decreased from more than 70 bushels to 66, and during the next 16 years the yield has further decreased to 58 bushels, the average reduction being only one-half bushel a year. In this system the most marked reduction in crop yields has not yet appeared, although it must be expected in the future because the clover crop is already beginning to fail on the oldest field even in seasons when clover succeeds well on newer land under the same crop rotation. When clover fails we substitute cowpeas for that year on that field, which thus provides a legume crop and preserves the three-year rotation. Further time is required to determine how much the cowpeas will help to lessen the rate of decrease in yield of corn and oats.

GRAIN FARMING

In the lower part of Table 1 (third column) are recorded the average yields of corn for the last three years in a system of grain farming, in a three-year rotation of corn, oats, and clover. This system when fully under way provides that the corn shall be husked and the stalks disked down in preparation for the seeding of oats and clover the second year. In harvesting the oats as much straw as possible is left in the stubble, which may be mowed later in the summer to prevent the seeding of the clover or weeds. In the spring of the third year the clover is mowed once or twice before the usual haying time and left lying on the land. The seed crop, if successful, is harvested with a hay buncher attached to the mower or in any other way to avoid raking, and afterward the threshed clover straw is returned to the land, all of this accumulated organic matter to be plowed under for the following corn crop, which begins the next rotation. In addition to this, catch crops of annual legumes, such as cowpeas, may be seeded in the corn at the time of the last cultivation and disked in the next spring with the corn stalks. If biennial or perennial legumes are used as catch crops, the corn ground may be plowed for oats.

The corn yields reported for this system in Table 1 were secured where the system was not fully under way, the legume catch crops being the only organic matter returned to the soil, aside from the residues necessarily left from the corn-oats-clover rotation. By using three different fields for this rotation, every crop may be grown every year, and the yields of corn reported are true three-year averages.

With no special soil treatment aside from the use of legume catch crops, the yield of corn for 1905, 1906, and 1907 averaged 69 bushels. Where the equivalent of ½ ton per acre of ground limestone was applied five years ago the corn has yielded 72 bushels per acre; and, with phosphorus added for six years at the rate per annum of 25 pounds per acre of the element phosphorus (in 200 pounds of steamed bone meal) the average yield of corn has been 90 bushels per acre for the last three years. The yearly addition of 42 pounds of potassium in 100 pounds of potassium sulfate has further increased the yield to 94 bushels.

The cost per ton delivered is about $2 for the limestone, $25 for the steamed bone meal, and $50 for the potassium sulfate.

LIVE STOCK FARMING

Under the heading "Live Stock Farming" in Table 1 are recorded the average yields of corn secured during the last three years where farm manure has been applied to the clover ground to be plowed under for corn. The plan of this system is to remove all crops from the land as usually harvested, including the corn and stover, oats and straw, and both first and second crops of clover. The amounts of manure applied to the different plots are determined by the crop yields secured during the previous rotation. While the system of cropping followed during the past 13 years on these plots, and on those just described under "grain farming," has been approximately equivalent to a three-year rotation of corn, oats, and clover, the applications of manure have been made only for the three years, 1905, 1906, and 1907. If the average yields are decreasing on plots that receive only the amounts of manure that can be produced in practice from the crops grown, then the applications of manure must also be reduced on such land; whereas if the crop yields are increasing where both manure and phosphorus are applied, then the applications of manure for such plots may be increased in direct proportion.

Where manure alone has been used in this rotation the corn has averaged 81 bushels per acre for the last three years; with lime added the average is 85 bushels; with lime and phosphorus the manured land has averaged 93 bushels of corn, and this was increased to 96 bushels by adding potassium.

While potassium has usually made some increase in crop yields on these fields it has not nearly paid its cost. The most profitable yields are the 90-bushel average in the grain farming or the 93-bushel average in the live stock system. The effect of limestone has not yet been sufficiently uniform to recommend its use on this soil, but marked profit has resulted from the addition of phosphorus, which is applied in sufficient amount actually to enrich the land and not as a stimulant.

HISTORY OF THE OLD EXPERIMENT FIELD

It appears that the oldest soil experiment field in the United States with an authentic record of its origin and with a present continuation of the experiments originally inaugurated is on the campus of the University of Illinois, or rather it is surrounded by the University campus. In the biennial report for 1879 and 1880, on page 232, and under date of March 10, 1880, is the following:

"The Farm Committee then submitted the following report:

To the Hon. Board of Trustees of the Illinois Industrial University:

"Your committee beg leave to submit the following recommendations from the Professor of Agriculture, in regard to experiments for the coming season:

"*Fifth*—The formal commencement of what is designed to be a long continued experiment to show the effect of rotation of crops, contrasted with continuous corn growing—with and without manuring, and also the effect of clover and grass in a rotation. A commencement was made last year, and we are fortunate in having a piece of land more than usually well adapted for such a test.

"The report was approved, and its recommendation concurred in."

Thus, these oldest rotation experiments, begun, according to the official records, by Professor George E. Morrow, in 1879, will complete a record of thirty years in 1908.

In Bulletin No. 13 of the Illinois Agricultural Experiment Station, published in 1901 and signed by Professor Morrow, the statement is made that from the beginning of these experiments plot No. 3 had "been in corn continuously," that plot No. 4 had been "in corn and oats alternately," and that plot No. 5 had "had this rotation: Corn, 2 years; oats, 1 year; meadow (clover, timothy, or both) 3 years." The records also state that these plots had received "no manure or commercial fertilizers of any kind."

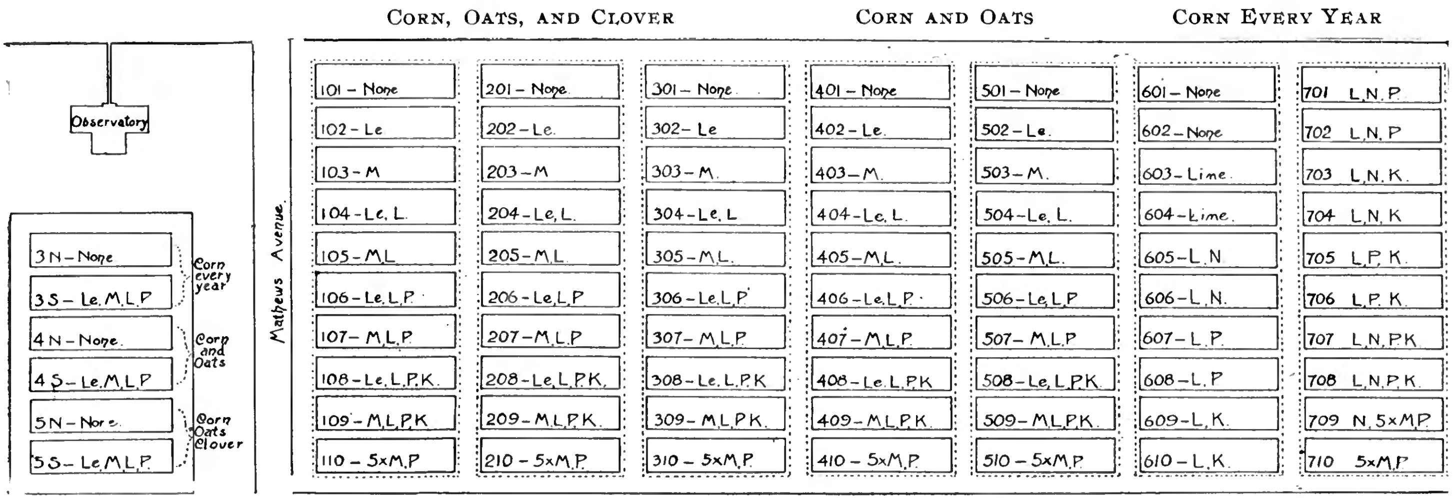


PLATE 1.—DIAGRAM (DRAWN TO SCALE) OF THE URBANA SOIL EXPERIMENT FIELDS, SHOWING THE OLD FIELD SOUTH OF THE OBSERVATORY, AND ALSO THE SEVEN SERIES OF TEN PLOTS EACH LYING EAST OF MATHEWS AVENUE.

The photographs shown on the opposite page were both taken from the same point. The lower view looking southwest shows the oldest plots on the right and series 100 on the left, with Mathews avenue between and farm buildings in the background. The upper view looking southeast shows plainly series 200 to 600, with series 700 and the University forestry in the background.

Note the plot labels (shown in full for series 400), also the oats harvesting in progress on series 500.

None means no soil treatment (except the regular crop system); *Le* means grain farming with legumes (including catch crops) and crop residues returned to the land; *M* means farm manure; *L* means limestone; *P* means phosphorus; *K* means potassium (kalium); and *N* means commercial nitrogen; *5x* means five times the standard applications.

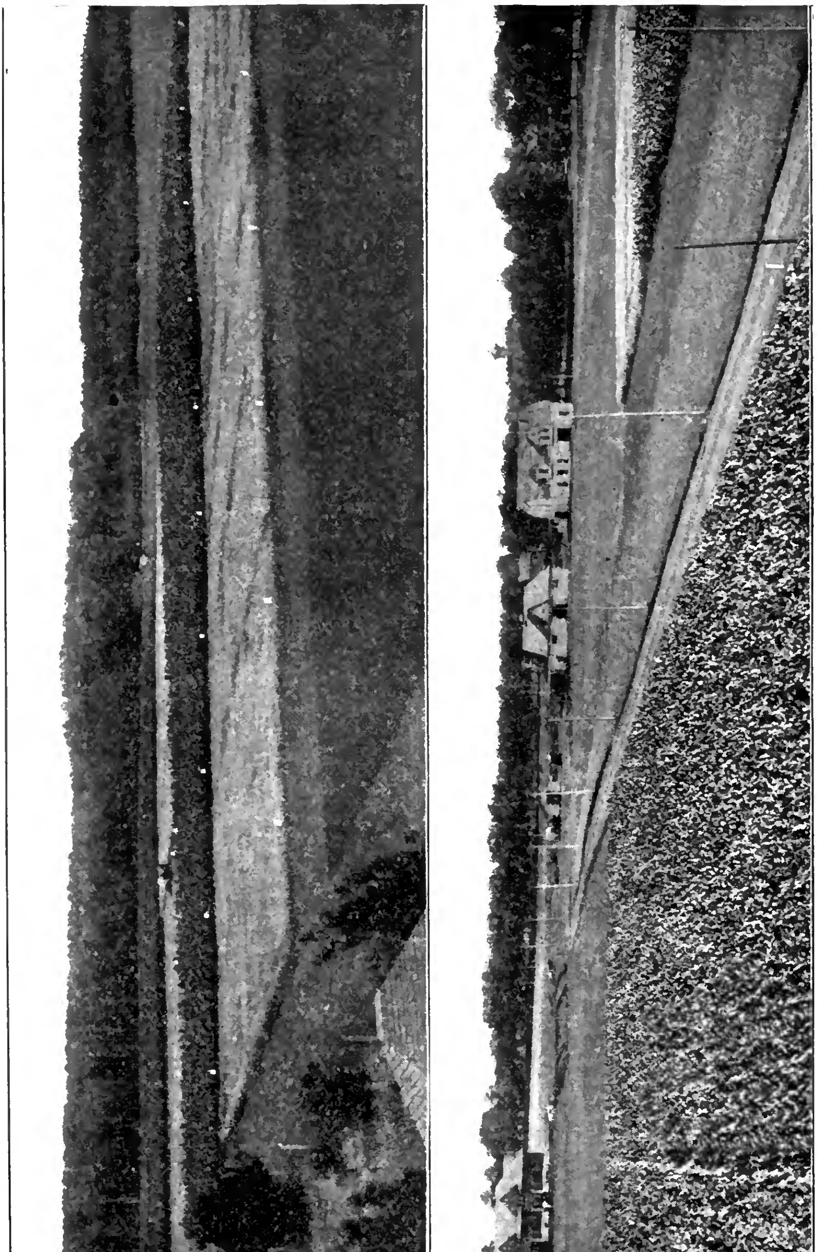


PLATE 2.—UNIVERSITY OF ILLINOIS SOIL EXPERIMENT FIELDS AT URBANA.

The Illinois Agricultural Experiment Station was established in 1888 and in the reports made by Professor Morrow and his assistants relating to these experiments and published in Experiment Station bulletins from 1888 to 1894 there is no record of crop yields previous to 1888. Whether it was considered sufficient during the first nine years to maintain the crop systems and wait for marked differences to develop before beginning to take exact crop yields, or whether the funds provided were inadequate to meet the expense of securing these complete records, is not stated. Certainly the most important thing is the record that the crop systems were maintained during those early years.

Since 1888 these crop systems for the three plots mentioned have been essentially maintained, with the modification on Plot No. 5 during the later years of adopting the more simple rotation of corn, oats, and clover, one year each. From the recorded statements and the existing knowledge it is safe to say that all crops have been removed, including the grain, hay, straw, and corn fodder, from 1879 to the present time.

Originally these plots were one-half acre each in size, being 5 rods wide (north and south) by 16 rods long (east and west), but in 1904, because of the enlargement of the University campus, it became necessary to reduce the length to 9 rods, in the central part of the original plots. At the same time one-half rod division strips were established between the plots, also a one-fourth rod cultivated or cropped protecting border around the plotted area, and each of the three plots was also divided in four quarters by half-rod division strips through the center in both directions. Thus from each of the original plots we have four plots of one-twentieth acre each. In each case the two plots on the north are continued as a duplicate test of the original system, without the use of manure or commercial fertilizers, while the two plots on the south are cropped the same, but they are now being improved by such applications of farm manure as can easily be made from the crops grown, by the use of legume catch crops, applications of ground limestone to correct possible soil acidity, and by the use of phosphorus, applied for each year in the rotation in 200 pounds of steamed bone meal or in 600 pounds of rock phosphate per acre.

The original plot numbers are retained, the untreated north part being known as 3N, 4N, and 5N; and the treated south part as 3S, 4S, and 5S, respectively; and to each of these may be added W or E to designate the west or east half. Thus plots 3NW and 3NE are the untreated duplicate plots on which the thirtieth crop of continuous corn is to be grown in 1908; and, while plots 3SW and 3SE are treated as above described, they, too, are still kept in corn every year. Corresponding to these are the divisions of the corn and oats plot (No. 4) and of the corn-oats-clover plot (No. 5), which are continually cropped by the respective rotations, the duplicate plots in the north half receiving no further treatment, while the south half is manured and fertilized.

In Table 2 are recorded the yields of these old plots for the last twenty years, from 1888 to 1907, including since 1904, for each rotation system, the average of the untreated duplicates and of the treated parts.

TABLE 2.—CROP YIELDS PER ACRE FROM THE OLDEST PERMANENT EXPERIMENT PLOTS: URBANA SOIL EXPERIMENT FIELD

Years.	Soil treatment applied.	Plot No. 3	Plot No. 4.		Plot No. 5.		
		Corn every year.	Two-year rotation.		Three-year rotation.		
		Corn bu.	Corn bu.	Oats bu.	Corn bu.	Oats bu.	Clover tons.
1879-87	None..................	....	.....	.....	......	......	....
1888	None.............	54.3	49.5			48.6	
1889	None................	43.2		37.4			4.04
1890	None......	48.7	54.3				1.51
1891	None...............	28.6	33.2				1.46
1892	None................	33.1		37.2	67.6		
1893	None................	21.7	29.6		34.1		
1894	None........... ...	34.8		57.2		65.1	
1895	None...............	42.2	41.6			22.2	
1896	None................	62.3		34.5			....
1897	None...............	40.1	47.0				....
1898	None................	18.1		.....			....
1899	None................	50.1	44.4		53.5		
1900	None................	48.0		41.5			
1901	None...............	23.7	33.7		34.3		
1902	None................	60.2		56.3		54.6	
1903	None................	26.0	35.9				1.11
1904	N. ½ None.........	21.5		17.5	55.3		
1904	S. ½ { Legume,*Manure,** Lime, Phosphorus** }	17.1		25.3	72.7		
1905	N. ½ None..........	24.8	50.0			42.3	
1905	S. ½ { Legume, Manure, Lime, Phosphorus }	31.4	44.9			50.6	
1906	N. ½ None	27.1		34.7			1.43†
1906	S. ½ { Legume, Manure, Lime, Phosphorus }	35.8		52.5			1.74†
1907	N. ½ None..........	29.0	47.8		80.5		
1907	S. ½ { Legume, Manure, Lime, Phosphorus }	48.7	87.6		93.6		

*Legume catch crops first grown in 1904 to benefit 1905 crops.
**Manure and phosphorus first applied to plot 5S for 1904 crop, but to plots 3S and 4S for 1905 crop. †Cowpea hay; the clover failed.

PLATE 3.—THE 29TH CROP OF CONTINUOUS CORN WITH NO MANURE OR FERTILIZERS: PLOT 3 (UNTREATED HALF), URBANA SOIL EXPERIMENT FIELD, 1907: YIELD 29.0 BUSHELS PER ACRE.

These old plots lie west of Mathews avenue and immediately south of the astronomical observatory, which is near the Agricultural Building. These plots, as well as the newer series of plots described more fully in the following pages, were all tile-drained in 1904, every plot having a 4-inch tile on one side, laid in the half-rod division strip.

Seasonal influences are so great that no very satisfactory comparison can be made between different years for the sake of determining the effect of the different systems upon the productive power of the soil, and the thorough under drainage provided for in 1904 must be expected to markedly increase the crop yields in subsequent seasons of excessive rainfall, such as 1907, for example, as compared with previous years. Thus, on the continuous corn plot the yield was 18.1 bushels in 1898 and 60.2 bushels four years later, in 1902, and the largest recorded corn yield in the corn-oats-clover

PLATE 4.—THE 29TH CROP IN CORN, OATS, AND CLOVER ROTATION: PLOT 5 (TREATED HALF), URBANA SOIL EXPERIMENT FIELD, 1907: YIELD 93.6 BUSHELS PER ACRE.

rotation was 80.5 bushels in the wet season of 1907, the land having been well tile-drained in 1904.

A fair comparison between different systems can usually be made in the same years, and the change in productive power under any system can best be ascertained by comparing the results from the older experiments with those from the newer experiments, as shown in Table 1, when the effect of sixteen years' cropping can be noted. It will be seen from the following tabular statements that every plot in the newer experiments produced more than 75 bushels of corn per acre in 1896 and that the average in 1897 was about 70 bushels. Upon these facts is based the assumption that all of the older plots originally produced 70 bushels or more per acre.

It is apparent that the legume catch crops (chiefly cowpeas) seeded in the corn decrease the yield for the first year at least, as shown in 1904 on plot 3 and, even in spite of the light manuring, on plot 4 in 1905.

The general effect of the system of soil improvement adopted for the south half of each of these old plots is already very marked, an increase of 40 bushels of corn per acre being secured in 1907 from the treatment on plot 4, where the most marked effect is to be expected because no clover or other legumes had been grown previous to 1904 in this rotation and the frequent change from corn to oats has helped to avoid the development of corn insects.

For the separate effect of each individual kind of treatment, as manure, lime, or phosphorus, reference must be made to the detailed statements in the tables of data from the newer experiments reported in the following pages.

THE NEWER SERIES OF SOIL EXPERIMENTS

On the opposite side of Mathews avenue and extending eastward to the University forestry plantation are seven series of additional experiment fields, laid out in 1895 and brought under definite systems of crop rotation and soil treatment since 1900.

During at least 16 years previous to 1895 this land was all in pasture continuously, and it may perhaps be fair to assume that the fertility of the soil was essentially maintained* during that period, so that 16 years of crops harvested and removed may represent the difference between the old and new fields.

On the new field, series 100 lies immediately east of Mathews avenue, with series 200 next east, and so on to series 700, which is near the forestry. Each series is divided into 10 plots numbered from north to south from 1 to 10. Thus, series 100 contains plots 101 to 110; series 200 contains plots 201 to 210, etc., etc. The individual plots are 2 by 8 rods, containing exactly one-tenth acre each, aside from the cultivated, or cropped, protecting border about one-fourth rod wide which completely surrounds every individual plot. A higher degree of accuracy is made possible by having an outside row of corn or strip of other crops surrounding each plot, thus giving half-rod† division strips between the tenth-acre plots, to prevent treatment applied to one plot from influencing the crop yields on adjoining plots.

Three series, 100, 200, and 300, are being cropped in the three-year rotation, corn, oats, and clover, in which every crop may be

*If the stock remain in the pasture day and night and receive a small amount of grain, the fertility will be maintained, and with heavier feeding of grain the fertility will be gradually increased; but if the stock remain in the pasture only during the day and receive no feed during the night, the fertility of the land will be gradually reduced, especially in phosphorus. Abundance of white clover in blue grass pastures will help to maintain the nitrogen.

†These strips are exactly 8¼ meet in the old field but only 7⅓ feet in the newer field.

represented every year. The next two series, 400 and 500, alternate in the two-year rotation of corn and oats. On the two remaining series, 600 and 700, corn is grown every year in what is termed a complete fertility test, containing duplicate plots treated with commercial nitrogen, phosphorus, and potassium, these elements being applied singly and also in every possible combination in uniform amount and form, and in addition a duplicate test is made to determine the effect of lime, and another for "extra heavy" treatment.

On the three series of plots in the three-year rotation, 100, 200, and 300, and on the two series of plots in the two-year rotation, 400 and 500, no commercial nitrogen is applied, but the investigation is designed to furnish information concerning the value of farm manure and legume crops and other crop residues in practical systems of live stock farming and of grain farming. These systems are each practiced without additional treatment, and also with the addition of lime, of lime and phosphorus, and of lime, phosphorus, and potassium. There is also in each of the five series one plot (No. 1) that receives no treatment (aside from the crop rotation) and another plot (No. 10) that receives "extra heavy" treatment by which it is hoped to remove the soil limit in crop production. In other words, the treatment of plot 10 is designed to show how large crops can be grown in Illinois with the rainfall and sunshine as the only limiting factors, all controllable factors being provided for, even at heavy expense.

Following is the general plan of soil treatment for the ten plots in each of the five series, 100 to 500.

PLAN OF SOIL TREATMENT: SERIES 100 TO 500

Plot No.	Soil treatment.
1..........	None
2..........	Legume (catch crops and crop residues)
3..........	Manure
4..........	Legume, lime
5..........	Manure, lime
6..........	Legume, lime, phosphorus
7..........	Manure, lime, phosphorus
8..........	Legume, lime, phosphorus, potassium
9..........	Manure, lime, phosphorus, potassium
10..........	Legume, manure x 5, lime, phosphorus x 5

The lime was applied at the rate per acre of 250 pounds of air-slacked in 1902 and 600 pounds of limestone in 1903.

The phosphorus has been applied at the rate per annum of 25 pounds of the element in 200 pounds of steamed bone meal since 1902, the present practice being to apply 600 pounds of bone meal to the clover land to be plowed under for corn. Beginning with 1908 the west half of all plots receiving phosphorus will be treated with rock phosphate, while the use of bone meal will be continued on the east half. The potassium has been applied at the yearly rate of 42 pounds per acre in 100 pounds of potassium sulfate, usually in connection with the bone meal, the steamed bone being run through the grain box and the potassium salt through the fertilizer box of an ordinary fertilizer drill.

The six series, 100 to 600, were laid out in the spring of 1895 by Dean Eugene Davenport, who came to the University in January of that year. It was necessary to break the old pasture sod in the spring, and, as might be expected, the corn crop for that year was poor. Series 700 was broken later in 1895 and all plots were cropped in corn in 1896 and 1897, in order that any marked differences in the soil might be noted.

From 1897 to 1900, Professor P. G. Holden was in charge of the work reported in this bulletin. Series 100 to 300 were cropped somewhat irregularly, oats, cowpeas, and clover being the principal crops grown, with some catch crops one year on certain plots, as shown in the following tables, and series 400 to 700 were cropped in corn every year.

The definite crop rotations were begun in 1901 and the applications of lime, phosphorus, and potassium have been made as stated above and as shown in the tables. The growing of legume catch crops was begun in 1901 for the benefit of the succeeding crops, and a comparison of plots 2, 4, 6, and 8 with plots 3, 5, 7, and 9 will show what effect was produced by these catch crops during the three years, 1902, 1903, and 1904.

Beginning with 1905, manure has been applied as indicated in the tables, which will afford, when the results for 1908 and 1909 become available, a comparison between manure and legume catch crops for three years on each series. The standard applications of manure are the same weights of average fresh farm manure (containing about 25 percent of dry matter) as the weights of air-dry produce secured from the same plots during the previous rotation. This allows about one-third of the produce to be sold and also allows a loss of 20 percent of the manure possible to be produced from the remaining two-thirds. On plot 10 about five times as much manure and phosphorus are applied as on the other plots, but this "extra heavy" treatment was begun in 1906, only lime, phosphorus, and potassium having been applied in previous years.

TABLE 3.—CROP YIELDS PER ACRE FROM THREE-YEAR ROTATION; SERIES 100: URBANA SOIL EXPERIMENT FIELD

Land history: Pasture 1879 to 1894; corn 1895 to 1897; clover and grass 1898 to 1901; corn, oats, and clover rotation since 1901

Plot No.	101	102	103	104	105	106	107	108	109	110
1895 Corn, bu.	30.0	29.1	25.7	26.3	30.3	31.1	37.1	34.6	34.3	36.3
1896 Corn, bu.	87.9	89.5	89.8	94.8	96.9	99.5	94.6	92.7	103.9	102.2
1897 Corn, bu.	69.0	68.6	67.5	66.6	67.5	66.8	69.9	68.4	66.9	68.5
1898 (No record)	......	......	......	......	......	......	......	......	......	......
1899 Clover, tons	2.32	2.07	2.01	2.31	2.28	2.64	2.62	2.72	2.85	2.72
1900 Clover, tons	1.27	1.58	1.65	1.55	1.46	1.35	1.41	1.37	1.48	1.48
1901 (Blue grass etc.)	......	......	......	......	......	......	......	......	......	......
1902 { Partial soil treatment begun	None	Legume	None	Legume lime	Lime	Legume lime phosphorus	Lime phosphorus	Legume lime phosphorus potassium	Lime phosphorus potassium	Lime phosphorus potassium
1902 Corn, bu.	78.3	82.2	80.9	80.1	80.1	85.5	87.0	87.8	89.7	85.9
1903 Oats, bu.	47.5	mixed*	51.3	mixed*	66.3	mixed*	56.3	mixed*	49.2	50.9
1904 Clover,† tons	.43	failed	.22	failed	.28	failed	1.79	failed	2.79	2.50
1905 { Complete soil treatment begun	None	Legume	Manure	Legume lime	Manure lime	Legume lime phosphorus	Manure lime phosphorus	Legume lime phosphorus potassium	Manure lime phosphorus potassium	Lime phosphorus potassium
1905 Corn, bu.	76.9	73.3	82.8	71.8	79.6	82.3	82.1	83.9	87.0	81.3
1906 Oats, bu.	63.4	73.1	73.4	75.9	71.5	92.5	97.5	94.1	81.9	71.5
1907 Clover, tons	.91	.81	1.75	.83	1.60	1.80	2.20	2.08	2.19	2.26
Value of last three crops	$48.23	$48.79	$57.83	$49.09	$55.34	$62.73	$66.31	$65.37	$64.07	$59.89

Financial Statement for each Addition

Treatment by addition		Legume	Manure	Lime	Lime	Phosphorus	Phosphorus	Potassium	Potassium	
Gross gains 1905-7; 3 yrs.		$ .56	$ 9.60	$ .30	—$2.49	$13.64	$10.97	$ 2.64	—$ 2.24	
Cost for three years		1.00	1.80	1.50	1.50	7.50	7.50	7.50	7.50	
Net gains from 3 crops		—.44	7.80	—1.20	—3.99	6.14	3.47	— 4.86	—9.74	

*Clover seeded in the corn in 1902 smothered part of the oats and the young clover seeded in 1903, the corn ground having been disked for oats. †All plots were mowed and produce removed at clover harvest, after which this series was seeded to cowpeas, the crop being plowed under the next spring on all plots.

TABLE 4.—CROP YIELDS PER ACRE FROM THREE-YEAR ROTATION; SERIES 200: URBANA SOIL EXPERIMENT FIELD

Land history: Pasture 1879 to 1894; corn 1895 to 1897; oats 1898 to 1901; cowpeas 1902; corn, oats, and clover rotation since 1902

Plot No.	201	202	203	204	205	206	207	208	209	210
1895 Corn, bu.	26.3	30.6	29.7	14.6	12.3	16.3	17.1	11.4	13.7	19.1
1896 Corn, bu.	87.7	91.8	86.8	94.1	98.4	99.0	96.5	91.1	97.5	97.3
1897 Corn, bu.	65.9	69.7	72.0	73.2	72.9	75.2	72.6	71.3	70.2	69.8
1898 Oats (no record)	......	......	......	......	......	......	......	......	......	......
1899 Oats (no record)	......	......	......	Clover*	Soybeans*	Cowpeas*	Rape*	......	......	......
1900 Oats, bu.	51.9	57.2	54.1	45.3	46.9	75.9	55.0	45.9	43.1	45.3
1901 Oats, bu.	33.9	38.3	36.3	39.7	41.0	43.1	38.6	38.4	37.2	33.9
1902 Partial soil treatment begun†	None	Legume	None	Legume lime	Lime	Legume lime phosphorus	Lime phosphorus	Legume lime phosphorus potassium	Lime phosphorus potassium	Lime phosphorus potassium
1902 Cowpeas, tons	1.03	1.01	1.02	1.01	1.03	1.17	1.16	1.24	1.22	1.19
1903 Corn, bu.	72.8	75.8	70.0	71.4	73.0	83.6	81.8	87.4	86.9	82.1
1904 Oats, bu.	45.6	52.2	46.6	48.4	45.6	60.3	50.3	60.0	46.9	42.5
1905 Clover, tons	.84	.81	.77	.87	.81	1.83	1.83	2.00	2.00	2.14
1906 Complete soil treatment begun	None	Legume	Manure	Legume lime	Manure lime	Legume lime phosphorus	Manure lime phosphorus	Legume lime phosphorus potassium	Manure lime phosphorus potassium	Legume Manure x 5 lime phosphorus x 5
1906 Corn, bu.	57.0	56.5	70.4	57.6	73.6	84.2	87.4	85.8	86.6	71.0
1907 Oats, bu.	27.2	32.8	35.3	35.6	37.8	45.3	44.4	46.3	43.8	50.0
Value of last three crops	$31.79	$32.84	$38.09	$34.28	$40.07	$51.78	$52.67	$53.61	$53.26	$50.20

Financial Statement for each Addition

Treatment by addition		Legume	Manure	Lime	Lime	Phosphorus	Phosphorus	Potassium	Potassium	
Gross gains 1905-7; 3 yrs.		$ 1.05	$ 6.72‡	$ 1.44	$ 1.98	$17.50	$12.60	$ 1.83	$ .59	
Cost for three years		1.00	1.20‡	1.50	1.50	7.50	7.50	7.50	7.50	
Net gain for 3 crops		.05	5.52‡	— .06	.48	10.00	5.10	—5.67	—6.91	

*Seeded after oat harvest, as catch crops, and probably plowed under the next spring.
†The legume catch crops were first seeded in 1903.
‡For only two crops.

TABLE 5.—CROP YIELDS PER ACRE FROM THREE-YEAR ROTATION; SERIES 300: URBANA SOIL EXPERIMENT FIELD

Land history: Pasture 1879 to 1894: corn 1895 to 1897; cowpeas 1898; oats 1899; cowpeas 1900; corn, oats and clover rotation since 1900

Plot No.	301	302	303	304	305	306	307	308	309	310
1895 Corn, bu.	30.0	32.9	26.9	32.9	38.6	32.9	31.4	31.4	35.7	33.7
1896 Corn, bu.	89.6	88.2	85.1	92.0	99.4	97.0	95.2	100.1	99.9	98.4
1897 Corn, bu.	64.7	69.9	67.6	73.2	78.3	75.6	77.3	75.4	71.4	72.6
1898 Cowpeas, (no record)	......	......	......	......	......	......	......	......	......	......
1899 Oats, (no record)	......	......	......	......	......	......	......	......	......	......
1900 Cowpeas, (no record)	......	......	......	......	......	......	......	......	......	......
1901 Corn, bu.	43.6	44.4	47.8	54.7	54.4	54.0	53.5	56.0	56.6	55.6
1902 { Partial soil treatment begun*	None	Legume	None	Legume lime	Lime	Legume lime phosphorus	Lime phosphorus	Legume lime phosphorus potassium	Lime phosphorus potassium	Lime phosphorus potassium
1902 Oats, bu.	53.4	54.3	53.4	58.4	62 8	62.8	63.1	67.8	66.8	66 2
1903 Clover,† tons	2.38	2.50	2.63	2.44	2.63	2.94	2.88	3.44	3.63	3.69
1904 Corn, bu.	75.0	74.2	75.1	83.7	89.2	94.9	97.5	95.0	94.8	91.5
1905 Oats, bu.	49.1	50.0	55.6	64.4	70.0	74.4	72.8	74.7	75.0	75.6
1906 Clover, tons	.81	.76	.85	.96	1.16	1.71	1.62	1.75	1.92	1.99
1907 { Complete soil treatment begun	None	Legume	Manure	Legume lime	Manure lime	Legume lime phosphorus	Manure lime phosphorus	Legume lime phosphorus potassium	Manure lime phosphorus potassium	Legume manure x 5 lime phosphorus x 5
1907 Corn, bu.	80.5	75.8	88.4	87.4	101.1	104.6	110.1	111.6	113.1	118.0
Value of last three crops	$45.31	$43.59	$49 94	$52.45	$59.85	$ 65.47	$ 66.46	$ 68.24	$ 69 86	$ 72.14

Financial Statement for each Addition

Treatment by addition		Legume	Manure	Lime	Lime	Phosphorus	Phosphorus	Potassium	Potassium	
Gross gains 1905-7; 3 yrs.		—$1.72	$ 2.77‡	$ 8.86	$ 9.91	$13.02	$ 6.61	$ 2.77	$ 3.40	
Cost for three years		1.00	.60‡	1.50	1.50	7.50	7.50	7.50	7.50	
Net gain for 3 crops		—2.72	2.17‡	7.36	8 41	5.52	—.89	—4.73	—4.10	

*The legume catch crops were first seeded in 1901 at the last cultivation of the corn. †This clover crop lodged so badly that it could not be harvested satisfactorily or accurately, and consequently the entire crop was plowed under on all plots, small measured areas having been harvested carefully by hand to ascertain the yield on every plot. ‡For only one crop.

PLATE 5.—CORN AFTER CLOVER WITH NO SPECIAL SOIL TREATMENT: PLOT 301, URBANA SOIL EXPERIMENT FIELD, 1907: YIELD 80.5 BUSHELS PER ACRE.

The complete grain system is first put under way for the 1908 corn crop, the equivalent of the clover grown in 1907 having been returned to the legume plots (102, 104, 106, and 108) to be plowed under for corn. The corn stalks will be disked down when seeding to oats and clover in the spring, and the effect of this on a subsequent crop of corn on series 300 cannot be seen till 1913. Thus, while much valuable information has already been secured from these fields, as shown in this bulletin and in Circular 96 (published in 1905), it should be kept in mind that the full effect of these systems of soil improvement will not be seen for several years.

THREE-YEAR ROTATION

In Tables 3, 4, and 5 are reported in detail the crop yields from series 100, 200, and 300, for the 13 years from 1895 to 1907.

PLATE 6.—CORN AFTER CLOVER WITH LEGUME-LIME-PHOSPHORUS TREATMENT (GRAIN FARMING): PLOT 306, URBANA SOIL EXPERIMENT FIELD, 1907: YIELD 104.6 BUSHELS PER ACRE.

With few exceptions all yields of grain and hay are recorded in the tables, and a financial statement is also given at the bottom of each table showing the effect of each addition in the soil treatment during the last three years, on each series of plots, counting corn at 35 cents a bushel, oats at 25 cents, and hay at $6 a ton.

It will be seen that but little effect has been produced by sowing legume catch crops in the corn in the three-year rotation, where corn is followed by oats and clover. From 1902 to 1905-6-7, the legume catch crops produced but little benefit on other crops, as shown by comparing plots 2, 4, 6, and 8 with plots 3, 5, 7, and 9, except on the oat crop in 1904 and 1905.

The effect of the farm manure on each of the three crops is shown only in Table 3 (series 100), the manure on series 200 and 300 having benefited only two crops and one crop, respectively. Six tons of manure per acre on series 100 have produced increases in the three crops amounting to $9.60 per acre, or to $1.60 per ton of manure applied, leaving a profit of $1.30 a ton for the manure of the farm if it can be hauled and spread for 30 cents a ton. Of still greater interest will be the effect on the next three crops of the second application of manure (made for the 1908 corn crop on series 100), including any possible residual effect carried over from the previous application.

Aside from the legume and manure, there is a duplicate test for each addition, and the effect is determined independent of the check plot (No. 1). Thus the effect of lime is determined by comparing plots 4 and 5, not with plot 1, but with plots 2 and 3; and the effect of phosphorus is determined by comparing plots 6 and 7 with plots 4 and 5, respectively.

On five plots out of six lime has shown some increase, and on three plots it has paid more than 50 cents per acre per annum, which is more than sufficient to pay for the applications actually made to these plots, but the results vary so greatly with the different crops and seasons that safe conclusions cannot be drawn until further data are secured. The apparently marked effects on plots 304 and 305 are evidently due in part at least to original soil differences,* indicated in the early records for those plots, as compared with 302 and 303.

Aside from farm manure the only well established benefit is derived from the application of phosphorus, which has produced a marked increase on every plot and in five cases out of six has much

*The large amount of data accumulated and reported in the preceding and following pages concerning these plots previous to the beginning of soil treatment has suggested, of course, that even small natural soil differences could be detected in the early yields secured under similar conditions of cropping, so that corrections might be made for such natural variations when considering subsequent yields as affected by soil treatment. A careful study of all the results shows, however, that it is very unsafe to try to make any such corrections. That plot A has produced larger yields than plot B for two or three years does not prove that it will continue to do so. In fact, under normal conditions, this relation may be reversed. The larger crops from plot A remove more plant food, and the later crops may be smaller in consequence; whereas, if smaller crops are removed from plot B in the early years, the yields may be larger than on plot A in subsequent years.

Several illustrations of this have actually occurred in these experiments. Thus for the three years, 1895 to 1897, plot 406 produced, as an average, 5 bushels more corn per acre than plot 506, but as an average of the next three years plot 506 produced 2.9 bushels more corn per acre than plot 406. Likewise, a decision based upon the first three years would hold the natural productiveness of plot 407 to be 3.8 bushels higher than plot 507, but the records of the next three years would reverse the decision because for those years plot 407 was not 3.8 bushels better but 3.1 bushels poorer than plot 507, as an average. The average yield for the entire six years differs by less than half a bushel for these two plots. (See also the last page of this bulletin.)

Because of these facts it seems unsafe to try to make any corrections or to use "corrected" results. The data actually secured are correctly reported and if there is reason to believe that any results are untrustworthy they may be discarded.

more than paid for its cost even in 200 pounds per annum of steamed bone meal, in which more phosphorus is applied than is removed from the soil in the crops grown. This, of course, gives promise of some residual effect in subsequent years, more especially for clover, because the land is growing richer year by year in phosphorus and because clover should not be limited in yield by lack of nitrogen, while corn or oats may be, no matter how much phosphorus is supplied.

The very marked effect of phosphorus upon the yield of clover during the last three years, averaging more than 75 percent increase, is especially significant, and constitutes probably the most valuable information furnished from these particular experiment fields.

The addition of potassium has produced some increase on most plots, but never sufficient to pay for even one-half its cost. The effect of potassium indicates the need of more decaying organic matter, which has power to liberate sufficient potassium from the immense total supply in the soil. (Soil samples 59 to 421, whose analyses are reported on page 270 of Bulletin 123 were collected in 1901 from series 100 to 700, respectively, and samples 467 to 472 from plot 3 of the old experiment field.)

TWO-YEAR ROTATION

In Tables 6 and 7 are given data from the two-year rotation of corn and oats on series 400 and 500.

It will be seen that corn was grown for six years on series 400 and 500 before the two-year rotation was begun. The subsequent substitution of oats for corn in alternate years lessens the liability to insect injury and somewhat reduces the draft upon the soil, so that larger corn yields are likely to be secured for a few years than were produced near the close of the six years of continuous corn, even with no increase in the annually available fertility.

The legume catch crops, as cowpeas seeded in the corn at the last cultivation or clover seeded with the oats, have produced but little effect, and this effect has been a decrease as often as an increase in the regular crops. Plot 1 is apparently slightly better land than plots 2 and 3, as indicated by the crop yields secured previous to the beginning of soil treatment; but a comparison of plots 2, 4, 6, and 8 with plots 3, 5, 7, and 9, from 1902 to 1904-5 shows only a small average benefit on the oats. On the other hand, the legume treatment produced noticeably larger yields of corn in 1907 than were obtained from the plots to which light applications of farm manure had been applied.

As a rule lime has produced some increase, but as an average it amounts to but little more than cost.

TABLE 6.—CROP YIELDS PER ACRE FROM TWO-YEAR ROTATION; SERIES 400: URBANA SOIL EXPERIMENT FIELD
Land history: Pasture 1879 to 1894; corn 1895 to 1900; corn and oats rotation since 1901

Plot No	401	402	403	404	405	406	407	408	409	410
1895 Corn, bu.	31.4	31.4	27.1	30.0	32.9	37.1	35.7	25.7	21.4	22.3
1896 Corn, bu.	88.2	85.3	87.6	89.8	96.5	99 8	99.1	94.1	100.4	98.1
1897 Corn, bu.	69.2	67.0	68.8	71.7	72.0	75.7	74.3	69.2	72.3	76.6
1898 Corn, bu.	55.1	53.5	55.9	55.2	56.9	58.1	52.7	37.2	50.6	65.6
1899 Corn, bu.	63.0	58.7	61.9	64.0	61.9	64.3	69.4	62.0	65.1	65.6
1900 Corn, bu.	59.7	57.0	55.0	63.9	55.7	58.0	58.7	52.4	54.1	56.9
1901 Corn, bu.	38.9	34.6	33.1	35.2	36.0	35.1	29.9	32.9	34.7	37.5
1902 Partial soil treatment begun*	None	Legume	None	Legume lime	Lime	Legume lime phosphorus	Lime phosphorus	Legume lime phosphorus potassium	Lime phosphorus potassium	Lime phosphorus potassium
1902 Oats, bu.	52.8	57.5	59.6	61.2	62.1	67 1	62.5	62.1	66.5	66.2
1903 Corn, bu.	47.0	42.9	50.2	45.1	48.0	......**	......**	......**	48.9	46.0
1904 Oats, bu.	35.0	38.4	34.1	39.6	36.8	53.7	42.8	44.6	36.5	39.1
1905 Complete soil treatment begun	None	Legume	Manure	Legume lime	Manure lime	Legume lime phosphorus	Manure lime phosphorus	Legume lime phosphorus potassium	Manure lime phosphorus potassium	Lime phosphorus potassium
1905 Corn, bu.	69.4	62.9	69.4	64.1	72.0	68.0	71.4	58.0	74.1	67.0
1906 Oats, bu.	59.7	54.4	57.5	58.7	63.1	74.1	63.1	62.8	58.4	58.7
1907 Corn, bu.	68.4	69.9	69.4	75.9	66.6	84.6	68.6	84.1	71.4	95.6††
Value of last two crops	$38.85‡	$38.07	$38.67	$41.24	$39.09	$48.14	$39.79	$45.14	$39.59	$48.14

Financial Statement for each Addition

Treatment by addition		Legume	Manure	Lime	Lime	Phosphorus	Phosphorus	Potassium	Potassium	
Gross gains 1906-7; 2 yrs		—$ .78	—$ .18	$3.17	$ .42	$ 6.90	$ .70	—$3.00	—$ .20	
Cost for two years		2.00	1.20	1.00	1.00	5.00	5.00	5.00	5.00	
Net gains from 2 years		—2.78	—1.38	2.17	— .58	1.90	—4.30	—8.00	—5.20	

*Legume catch crops were first seeded in the corn in 1901.
**Yield lost by error. ††Extra heavy manure and phosphorus beginning in 1907.
‡The end plot, No. 401, receives some surface wash and consequently may yield above normal.

TABLE 7.—CROP YIELDS PER ACRE FROM TWO-YEAR ROTATION; SERIES 500: URBANA SOIL EXPERIMENT FIELD
Land history: Pasture 1879 to 1894; corn 1895 to 1900; corn and oats rotation since 1901

Plot No.	501	502	503	504	505	506	507	508	509	510
1895 Corn, bu.	37.7	31.4	29.4	27.4	29.1	28.6	24.3	23.4	24.0	22.9
1896 Corn, bu.	88.6	88.1	86.2	85.9	96.0	94.3	98.9	92.6	95.9	96.9
1897 Corn, bu.	69.6	69.7	68.3	67.4	72.4	74.7	74.4	70.2	73.5	69.7
1898 Corn, bu.	59.5	57.0	54.4	51.7	57.1	64.7	58.1	40.4	40.7	43.6
1899 Corn, bu.	64.9	62.0	61.9	61.3	64.0	67.0	71.1	70.4	70.0	68.7
1900 Corn, bu.	58.7	54.1	51.4	51.4	51.4	57 3	60.9	61.1	63.1	53.9
1901 Oats, bu.	48.5	46.0	44.8	45.9	50.4	53.6	58.3	53.0	52.0	48.8
1902 { Partial soil treatment begun	None	Legume	None	Legume lime	Lime	Legume lime phosphorus	Lime phosphorus	Legume lime phosphorus potassium	Lime phosphorus potassium	Lime phosphorus potassium
1902 Corn, bu.	57.6	58.4	55.3	54.6	57.2	61.6	66.2	68.4	70.0	65.3
1903 Oats, bu.	42.5	43.2	43.2	46.9	52.1	63.4	73.1	68.8	67.1	62.8
1904 Corn, bu.	59.0	52 6	46.2	46.0	48.9	71 6	63.2	63.6	63.0	57.1
1905 Oats, bu.	52.5	55.6	51.6	52.8	58.1	64.4	63.8	61.2	56.6	42.2
1906 { Complete soil treatment begun	None	Legume	Manure	Legume lime	Manure lime	Legume lime phosphorus	Manure lime phosphorus	Legume lime phosphorus potassium	Manure lime phosphorus potassium	Legume manure x 5 lime phosphorus x 5
1906 Corn, bu.	58.3	51.9	54.3	48.9	57.8	63.3	61.8	58.3	49.6	64.9
1907 Oats, bu.	28.4	29.4	29.7	29.1	33.8	38.8	41.3	39.1	36.6	44.4
Value of last two crops	$27.51*	$25.52	$26.43	$24.39	$28.68	$31.86	$31.96	$30.18	$26.51	$33.82

Financial Statement for each Addition

Treatment by addition		Legume	Manure	Lime	Lime	Phosphorus	Phosphorus	Potassium	Potassium	
Gross gains 1906-7; 2 yrs.		—$1.99	—$1.08	—$1.13	$2.25	$ 7.47	$ 3.28	—$1.68	—$5.45	
Cost for two years		2.00	1.20	1.00	1.00	5.00	5.00	5.00	5.00	
Net gain from two years		—3.99	—2.28	—2.13	1.25	2.47	—1.72	—6.68	—10.45	

*The end plot, No. 501, receives some surface wash and consequently may yield above normal.

Phosphorus has nearly always produced an appreciable increase on both corn and oats, and as an average of twenty-two tests, covering the six years, the value of the increase is greater than the cost of the phosphorus in steamed bone meal, and the amount of phosphorus applied (25 pounds per acre for each year) is nearly twice as much as removed in the crops, so that the soil is being enriched quite rapidly in phosphorus.

It must be understood, however, that phosphorus alone cannot make the soil highly productive, because the nitrogen limit is but little higher than the limit due to phosphorus, and the yields cannot be very high unless ample provision is made for both elements. The three-year rotation makes better provision for nitrogen, and in consquence the crop yields are not only larger but the phosphorus also becomes more effective.

Thus, as an average of the last three years, plot 4 (without phosphorus) has produced 63 bushels of corn per acre, in the two-year rotation, and 72 bushels in the three-year rotation, while plot 6 (with phosphorus) has averaged 72 bushels per acre in the two-year rotation, and 90 bushels in the three-year rotation. In other words, phosphorus has made an average increase of 18 bushels per acre in the three-year rotation, but only 9 bushels in the two-year rotation. Smaller but nearly proportionate differences have been made as an average of all tests with corn and oats during the last three years, larger yields having been secured in the three-year rotation and the difference between that and the two-year rotation being still greater where phosphorus is applied to both.

As an average of all tests during the past three years the value of the crops on plots 6 and 7 has been about one dollar an acre a year greater for the three-year rotation than for the two-year rotation, counting corn at 35 cents a bushel, oats at 25 cents, and clover hay at $6 a ton. At higher prices the difference in favor of the three-year rotation would be still greater. Furthermore some clover seed has been secured in the three-year rotation, but we have begun to try to save clover seed only recently and have as yet too little data on that crop to justify further discussion of it.

Potassium has actually reduced the yield as an average of all tests in the two-year rotation during the entire period of six years, the average decrease amounting to 2 bushels of corn and 4 bushels of oats per acre, aside from the total loss of the cost of the potassium applied.

CONTINUOUS CORN IN COMPLETE FERTILITY EXPERIMENTS

In Tables 8 and 9 are reported the corn yields from series 600 and 700, where experiments are in progress which include the use of commercial nitrogen, phosphorus, and potassium, singly and in all combinations. In all tests there are duplicate plots with the same kind of treatment. Besides this two plots remain untreated (601 and 602), two are treated with lime only (603 and 604), and two plots are now being given "extra heavy" treatment, including farm manure.

Corn is grown every year in these complete fertility experiments, a part of the investigation being to ascertain how much of the rapid decrease in yield resulting from continuous corn growing is due to insect injuries and how much is due to other causes, such as depletion of decaying organic matter and lack of available plant food. In other words, the experiments on series 600 and 700 are designed, not to demonstrate any good system of farming, but rather to secure definite information concerning insect injuries, plant food requirements, and possible injurious effects of too much corn-growing on the same land, as contrasted with a good crop rotation such as is practiced on series 100, 200, and 300.

Plots 601 and 602 serve as duplicate check plots on which corn is grown every year with good preparation of the land and with good cultivation of the crop, but the entire crop is harvested and removed, and no manure or fertilizer is returned. (See Table 8).

On plots 603 and 604 a duplicate test is made to determine the effect of applying lime, and on the other six plots in the 600 series are duplicate tests with each of the three elements, nitrogen, phosphorus, and potassium, the effect of each element being determined by comparing the results obtained with the yields of plots 603 and 604.

On the 700 series (Table 9) a duplicate test is made of every possible pair of elements and of all three elements together (plots 707 and 708), and "extra heavy" treatment is applied to the last two plots (709 and 710).

It will be seen that no treatment was applied to any of the plots previous to 1901. From 1901 to 1905 nitrogen was applied at the rate of 100 pounds per acre a year. That is less than the nitrogen contained in a 70-bushel crop of corn. It soon became apparent, however, that that amount was not sufficient to meet the nitrogen requirements of the crops actually grown and that the crop yields on certain nitrogen plots were decreasing because of insufficient nitrogen, consequently, beginning with 1906, the annual application was increased to 250 pounds per acre of the element nitrogen. This provides sufficient nitrogen for a hundred-bushel crop of corn and allows for a loss in drainage water of 40 percent of the nitrogen applied, a loss which is no greater than commonly occurs where commercial nitrogen is used.

TABLE 8.—CROP YIELDS PER ACRE FROM CONTINUOUS CORN; SERIES 600: URBANA SOIL EXPERIMENT FIELD
Land history: Pasture 1879 to 1894; corn 1895 and every year since

Plot No.	601	602	603	604	605	606	607	608	609	610
1895 Corn, bu.	28.6	28.6	30.6	28.6	32.0	34.3	30.0	27.1	27.1	30.0
1896 Corn, bu.	80 8	86.5	81.8	83.5	94.6	93.2	94.0	91.6	92 4	96.5
1897 Corn, bu.	66.2	64.3	67.0	71.4	72.4	73.9	71.1	66.1	69.3	72.4
1898 Corn, bu.	52.7	50.7	52.7	47.2	55.9	59.2	48.9	42.6	53.9	63.5
1899 Corn, bu.	61.0	56.3	60.0	64.9	64.7	66.3	61.9	58.4	59.1	63.6
1900 Corn, bu.	56.9	53.7	57.4	60.4	60.3	60.4	56.6	50.7	54.0	58.7
1901 { Partial soil treatment begun	None	None	Lime	Lime	Lime nitrogen	Lime nitrogen	Lime phosphorus	Lime phosphorus	Lime potassium	Lime potassium
1901 Corn, bu.	29.6	26.9	31.9	33.2	30.9	33.9	33.6	32.0	32.7	35.6
1902 Corn, bu.	51.8	51.2	52.6	54.3	55.9	54.8	62.0	63.3	54.7	55.5
1903 Corn, bu.	41.9	42.2	41.9	43.5	46.6	47.6	44.9	52.2	42.9	45.8
1904 Corn, bu.	44.6	36.0	45.2	49.1	49.4	52.9	56.9	45.8	39.1	50.4
1905 Corn, bu.	43.4	38.3	41.6	45.3	48.0	48.6	40.9	37.4	42.8	47.1
1906 { Complete soil treatment begun	None	None	Lime	Lime	Lime nitrogen	Lime nitrogen	Lime phosphorus	Lime phosphorus	Lime potassium	Lime potassium
1906 Corn, bu.	37.0	30.8	33.8	42.4	52.1	54.6	47.1	44.9	34.3	38.8
1907 Corn, bu.	40.6	34.6	37.1	37.1	52.0	54 1	35.3	32.0	32.3	37.9

Average increase in yield for each addition; corn, bushels

Treatment by addition			Lime	Lime	Nitrogen	Nitrogen	Phosphorus	Phosphorus	Potassium	Potassium
Av. increase 1901-2			3.2	4.7	1.2	2.1	5.6	5.4	1.5	3.3
Av. increase 1903-4			4.5	7.2	4.5	6.7	7.4	5.4	—2.6	4.6
Av. increase 1905-6			3.2	9.3	12.4	13.9	6.3	3.5	.9	5.2
Increase for 1907			2.5	2.5	14.9	17.0	—1.8	—5.1	—4.8	.8

TABLE 9—CROP YIELDS PER ACRE FROM CONTINUOUS CORN; SERIES 700: URBANA SOIL EXPERIMENT FIELD
Land history: Pasture 1879 to 1895; corn 1896 and every year since

Plot No.	701	702	703	704	705	706	707	708	709	710
1896 Corn, bu.	82.9	83.5	81.8	84.3	89.4	86.1	82.5	77.5	76.2	82.4
1897 Corn, bu.	70.5	74.4	74.9	79.6	77.8	79.1	78.7	76.3	82.7	75.5
1898 Corn, bu.	60.8	61.3	48.0	30.5	30.1	55.8	76.6	68.6	64.7	67.5
1899 Corn, bu.	62.4	62.9	60.4	60.7	60.4	59.1	63.1	62.0	62.7	62.6
1900 Corn, bu.	60.0	54·9	62.1	62.9	63.9	60.3	58.1	57.6	56.3	55.1
1901 Partial soil treatment begun	Lime nitrogen phosphorus	Lime nitrogen phosphorus	Lime nitrogen potassium	Lime nitrogen potassium	Lime phosphorus potassium	Lime phosphorus potassium	Lime nitrogen phosphorus potassium	Lime nitrogen phosphorus potassium	Nitrogen phosphorus potassium	Nitrogen phosphorus potassium
1901 Corn, bu.	35.5	38.8	43 4	42.8	42.9	40.9	41.5	36.2	36.2	38.5
1902 Corn, bu.	62.3	67.3	61.5	59.3	63.4	69.5	69.7	69.2	66.7	70.5
1903 Corn, bu.	54.1	55.8	54.0	54.4	47.4	50.4	56.6	54.5	50.6	51.3
1904 Corn, bu.	73.7	78 4	72.4	72.1	59.5	70.5	82.4	79.4	78.6	82.1
1905 Corn, bu	60.4	58.8	63.9	63.1	49.3	52.4	58.5	57.5	60.6	63.6
1906 Complete soil treatment begun	Lime nitrogen phosphorus	Lime nitrogen phosphorus	Lime nitrogen potassium	Lime nitrogen potassium	Lime phosphorus potassium	Lime phosphorus potassium	Lime nitrogen phosphorus potassium	Lime nitrogen phosphorus potassium	Manure x 5 nitrogen phosphorus x 5	Manure x 5 phosphorus x 5
1906 Corn, bu.	73.4	73.9	71.5	72.3	54.1	59.0	78.3	77.0	92.9	79.8
1907 Corn, bu.	63.5	64.3	68.9	66.9	35.0	42.0	65.3	62.5	71.8	65.0

Average increase in yield for each addition; corn, bushels

	Nitrogen*	Phosphorus†	**	**	**	**	Potassium	Potassium	Treatment	Treatment
Av. increase 1901-2	3.3	7.1					4.6	1.7	12.4	15.5
Av. increase 1903-4	16.5	16.4					4.0	1.4	25.5	27.6
Av. increase 1905-6	25.4	15.8					1.8	.6	42.2	37.2
Increase for 1907	31.9	10.8					1.4	—1.4	37.2	30.4

*Average increase for plots 701 and 702 above plot 608. †Average increase for plots 701 and 702 above the average of plots 605 and 606. **Plots 703, 704, 705, and 706 occupy in part a slight depression which has received some surface wash and thus they are not strictly comparable with the other plots.

In 1901 the nitrogen was applied in sodium nitrate, but since that year dried blood has been used as the nitrogen fertilizer. It is well to keep in mind that while nitrogen can be secured with profit from the inexhaustible supply of the air by means of clover and other legume crops, it costs at least 15 cents a pound in commercial form. The 250 pounds of nitrogen now being applied each year to all nitrogen plots on series 600 and 700 costs at least $37.50 per acre a year.

It should be understood that the growing of clover produces several effects on the land and upon subsequent yields of other crops, only one of whch is due to the nitrogen secured from the air. In fact the chief effect of clover in increasing the yield of a subsequent crop of corn is not due to the nitrogen secured from the air, but rather to the liberation of phosphorus by the decay of the clover residues in the soil. The physical improvement of the soil and subsoil are also important factors in some cases.

PLATE 7.—CORN EVERY YEAR WITH NO MANURE OR FERTILIZERS: PLOT 602, URBANA SOIL EXPERIMENT FIELD, 1907: YIELD 34.6 BUSHELS PER ACRE.

But to determine the need and the effect of nitrogen itself we must apply nitrogen in some form and dried blood is the most satisfactory form to use. Sodium nitrate and ammonium sulfate are also common concentrated nitrogen fertilizers but they are soluble salts which may produce marked indirect effects, not infrequently of greater consequence than the effect due to the nitrogen itself.

Phosphorus has been applied in steamed bone meal at the rate of 25 pounds of the element per acre per annum, the requirement of a hundred-bushel crop of corn being 23 pounds, and the annual loss in drainage water being about 1 pound per acre. The annual cost of the bone meal is $2.50 per acre.

Potassium is applied at the rate of 42 pounds per acre a year in 100 pounds of potassium sulfate, also at a cost of $2.50. A hundred-bushel crop of corn contains 19 pounds of potassium in the grain and 52 pounds in the stalks. The application made is not

Plate 8.—Corn Every Year with "Extra Heavy" Soil Treatment: Plot 709, Urbana Soil Experiment Field, 1907: Yield 71.8 Bushels Per Acre.

sufficient for the entire crop, but the natural supply of potassium in the soil is so exceedingly large that it is both unnecessary and unprofitable to return the potassium removed from the land in any ordinary systems of farming.

On plots 709 and 710, beginning in 1906, the application of phosphorus was increased to five times the standard amount, and the application of manure was begun, using about five times as much manure as could easily be made from the crops grown, or 20 tons per acre each year. The addition of commercial potassium was discontinued on both plots and commercial nitrogen was also discontinued on 710, but is still used on plot 709, at the rate of 250 pounds per acre each year since 1906.

The plots on series 600 and 700 are not quite so uniform in character and in natural productive power as on series 100 to 500, but since being tile-drained in 1904 the natural differences are reduced. It may be seen that in 1896, for example, plots 703 to 706 were among the best yielding plots, while in the season of 1898 those four plots produced markedly smaller yields than the other plots in the series. This is explained in the foot note to Table 9.

One other natural condition should be understood: A slight ridge crosses series 600 and 700, the crest passing through plots 606 and 607 and through 708. The lowest plots in the 600 series are the end plots, 601 and 610, while in the 700 series the lowest parts are plot 710 and the depression that covers part of plots 703, 704, 705, and 706. Because of the continuous cropping with a cultivated crop these two series are continuously exposed to surface washing, and there is some tendency for surface wash to be deposited on 601, 610, and 710 and to a less extent on the four plots affected by the depression mentioned. There is also a slight tendency for the dried blood applied to plots 605 and 606 to be carried north to plot 604 and south to 607.

Because of these facts the most trustworthy data are secured from plots 602, 603, 605, 606, 608, and 609 and from plots 701, 702, 707, 708, and 709, and this is recognized in making the summary given in the lower part of Tables 8 and 9.

EFFECT OF LIME.—The effect of lime on the yield of corn is chiefly due to the fact that calcium carbonate (limestone) encourages nitrification and the consequent liberation of the nitrogen and to a less extent of the phosphorus contained in the natural humus of the soil. This is best seen by comparing plots 603 and 602. The summary shows an increase from lime of 3.2 bushels in 1901-2, rising to 4.5 bushels in 1903-4, and falling to 2.5 bushels in 1907. Plot 604 shows larger effects, but the possible washing of dried blood from the adjoining plot may account for this difference.

Plot 709 compared with the average of 707 and 708 shows an average increase of 2 bushels per acre from lime from 1901 to 1905.

From all of the investigations thus far conducted on the common brown silt loam prairie soils of the Illinois corn belt, it is evident that the time is near for most of this soil, and already here for some of it, when ground limestone must be applied to give the most profitable results in crop yields. These soils were not rich in lime in the beginning, and lime is constantly being lost from the soil, both in crops removed and in the drainage waters, which percolate through the soils and when collected in surface wells are always recognized as "hard" waters because of the lime contained in them.

EFFECT OF NITROGEN AND PHOSPHORUS.—The effect of nitrogen is determined* by comparing plots 605 and 606 with plot 603. These results are summarized in the lower part of Table 8. They show but very little effect from nitrogen in 1901-2, the average increase being about 1½ bushels. This was raised to about 5½ bushels in 1903-4 to 13 bushels in 1905-6 and to 16 bushels in 1907. It is noteworthy, however, that this increasing difference is not due to an actual increase in yield on the nitrogen plots, but rather to a decrease in the yield of the plots not receiving nitrogen, so far as we can judge.

By comparing plots 608 and 603 we have the most trustworthy data as to the effect of phosphorus with no addition of nitrogen or potassium. This shows an average increase of 5.4 bushels during the four years, 1901 to 1904, chiefly produced during the second and third years. The gain was 3.5 bushels for 1905-6; while the effect in 1907 was a loss of 5.1 bushels. The somewhat higher yields on plot 607 may be due to dried blood washed over from 606.

In comparison with nitrogen, it will be seen that at the beginning of soil treatment in 1901 phosphorus was clearly the limiting element and produced a greater effect than nitrogen during the first four years, after which the effect of phosphorus soon decreased until it produced smaller yields than the untreated plots, while the effect of nitrogen has been nearly to maintain the actual crop yields, with increasing differences above the untreated land.

The lesson taught by these experiments is that on our ordinary corn belt prairie soils phosphorus is the most deficient element of plant food, because of which nitrogen applied alone produces little or no increase in crops; but in continuous corn growing the supply of nitrogen is so rapidly depleted by removal in crops and in drainage waters that within a few years nitrogen itself becomes the most

*Plot 605 is probably the more trustworthy of the two nitrogen plots because of possible wash from 607 to a part of 606.

deficient element, after which phosphorus alone has no power to increase the crop yields.

Thus on plots 605 and 606, more than 60 bushels were grown in 1900, and, although nitrogen has been applied every year since, that yield has not been equaled; whereas on plots 607 and 608 phosphorus actually increased the yields for two or three years.* After that time the yields have been nearly maintained on the nitrogen plots but have steadily decreased on the phosphorus plots, nitrogen having become the limiting element.

If, now, we first restore the nitrogen so as to remove the nitrogen limit to crop yields, then phosphorus should again have power to increase the yield above that produced by nitrogen on plots 605 and 606, which averaged 53 bushels for 1906 and 1907. This has been done on plots 701 and 702, where both nitrogen and phosphorus have been applied and where the average yield for 1906 and 1907 has been 69 bushels per acre. This is 16 bushels higher than on the nitrogen plots (605 and 606) and 30 bushels higher than on the phosphorus plot (608).

This is shown in greater detail in the summary in the lower part of Table 9. The effect of nitrogen and phosphorus above that of phosphorus alone was 3.3 bushels in 1901-2, 16.5 bushels in 1903-4, 25.4 bushels in 1905-6, and 31.9 bushels in 1907; whereas, the effect of phosphorus applied in addition to nitrogen was 7.1 bushels the first two years, about 16 bushels the next four years, but only 10.8 bushels in 1907. Here again the apparent gain for nitrogen is not due to increasing yields on plots 701 and 702, which as a matter of fact were about the same in 1904-5 as they were in 1906-7, but the difference is due rather to the actual decrease on the phosphorus plot (608) where nitrogen has become the limiting element.

It is very apparent that nitrogen alone cannot increase the yield of corn on this soil, and that the increase from phosphorus alone is very temporary, but that both nitrogen and phosphorus together have power to produce a decided increase. This is in harmony with the marked benefit of phosphorus on clover, which has power to secure nitrogen from the air when the soil nitrogen becomes deficient, as shown in the three-year rotation (Tables 3, 4, and 5).

EFFECT OF POTASSIUM.—The effect of potassium can be ascertained by comparing plot 609 with plot 603, also by comparing 707 and 708 with the average of 701 and 702. Under the most favorable conditions, with both nitrogen and phosphorus present, the addition of potassium produced an average increase of 3 bushels in

*The year 1901 must be overlooked because of the drouth.

1901-2, but this has steadily grown less and amounted to nothing in 1907.

FURTHER OBSERVATIONS.—Tables 8 and 9 afford other interesting comparisons and valuable information. For example, plot 602 produced 86.5 bushels and plot 709 produced 76.2 bushels of corn per acre in 1896, but in 1906 (ten years later) plot 602 (untreated) produced only 30.8 bushels, while plot 709 (treated) produced 92.9 bushels per acre. In other words, the yield of plot 709 was increased by 16 bushels while the yield of plot 602 decreased by 55 bushels per acre in eleven years.

With liberal supplies of available plant food large crops have been grown with corn every year in spite of insect injuries, which have been very noticeable on the continuous corn plots, especially the injuries from the corn root worm which cause the corn to fall or to be blown over easily on all continuous corn plots, while the corn on the rotated plots stands up well.

An interesting and suggestive relationship appears between the comparable plots in the 600 and 700 series. Plots 2, 7, 8, and 9 in the two series lie end-to-end and for reasons previously explained they are considered trustworthy and comparable plots.

Corn was grown on the 600 series in 1895 while the 700 series was not cropped. Besides the small crop of 1895, the yields in 1896 were greater on the 600 than on the 700 series, so that by the end of 1896 the four plots mentioned had produced as an average 39.4 bushels more corn per acre on the 600 series than on the 700 series.

But during the next four years, from 1897 to 1900, previous to the beginning of soil treatment, the 700 series yielded more every year, the average difference amounting to 35.9 bushels per acre during the four years. In other words, the average difference of 39.4 bushels in favor of series 600 at the end of 1896 had been reduced to only 3.5 bushels at the close of 1900, every one of the four plots having produced more corn every year on the 700 than on the 600 series, the excess amounting to 3 bushels even in 1900, thus indicating that the remaining difference of 3.5 bushels would have been wiped out in perhaps two more years.

The point suggested by these data is, that there is a relationship between the plant food to be made available and the crops possible to be produced. The land that was not cropped in 1895 grew enough larger crops from 1897 to 1900 so that the five crops on series 700 practically equaled the six crops on the 600 series. In other words, the plant food removed in the 1895 crop apparently reduced proportionately the productive power of the soil for subsequent crops.

The production of these comparatively large crops in the early years is principally due to the rapid liberation of plant food from the decay of fresh organic matter accumulated in the roots and other residues of clover and grasses and animal droppings during the previous years of pasturing; but the lesson that is so well brought out in this comparison between the 600 and 700 series during the first few years is a true prophesy of a more important lesson which applies to the future years, to-wit:

Certain essential elements of plant food (nitrogen and phosphorus) are present in limited quantities in the common Illinois corn belt soil, and every crop removed with no adequate return reduces to that extent the power of that soil to produce future crops.

NOTE.—For further information concerning farm manure, effect of crop rotations, sources of plant food materials, methods of application, comparative value of natural rock phosphate, etc., Illinois readers are referred to Circular 108, "Illinois Soils in Relation to Systems of Permanent Agriculture," and Circular 116, "Phosphorus and Humus in Relation to Illinois Soils."