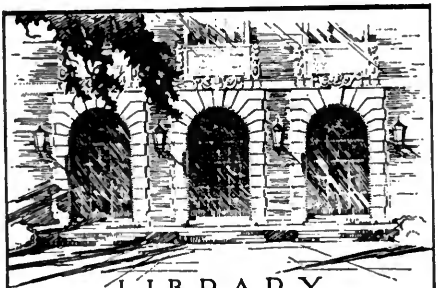

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LESSONS FROM THE MORROW PLOTS

By E. E. DeTurk, F. C. Bauer, and L. H. Smith

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FOREWORD

Whenever it develops that some one has been able to see across a half century to what facts are likely to be needed at that time, and patiently and painstakingly set about securing those facts, it should be noted. The history of the Morrow plots is the story of the results of such foresight.

The planning of these plots is all the more remarkable because it was done at a time when the Agricultural Experiment Stations of the country were young and the pressure was for investigations that would yield quick returns. Most intimately connected with the history of these plots are the names of Manley Miles, first professor of agriculture; George E. Morrow, professor of agriculture from 1876 to 1894; Eugene Davenport, dean *emeritus* of the College of Agriculture and for twenty-eight years director of the Agricultural Experiment Station; and Cyril George Hopkins, who for twenty-five years devoted himself untiringly to furthering the principle of a system of permanent soil fertility.

Begun fifty-two years ago, these investigations on the Morrow plots throw light on fundamental questions of soil fertility as vital today as any which farmers are asking. For instance: What will continuous cropping do for fertile prairie soils which used to be considered everlasting in fertility? What comparative results may be anticipated over a series of years from rotation systems supplemented with soil treatment and rotations without additional applications of plant food? Admitting the desirability of doing so, can I afford to leave my farm for posterity as productive as when I found it and took over its management?

It is my privilege to join with the farmers of Illinois in grateful acknowledgment to the men who had the vision to plan and to those who have had the persistence to carry thru these studies. Another period of fifty years may yield even more valuable information than is presented here.

H. W. Mumford

Director

LESSONS FROM THE MORROW PLOTS

By E. E. DeTurk, F. C. Bauer, and L. H. Smith[1]

To the hundreds of visitors who come each year to the College of Agriculture of the University of Illinois, the Morrow plots are a familiar sight. To other hundreds who have not seen them they have become familiar thru reputation. To anyone who will study these plots and their records they stand as a monument, marking the tragedy of soil exhaustion—a tragedy not so strikingly dramatic as are many of the great catastrophes of history but nevertheless as burdened with meaning. The impoverishment of the fertile soils of a country is obscured from the eyes of many, not only because of its imperceptible advance, seasons of plenty being interspersed with the lean years, but also because of the inherited belief that naturally rich soils are inexhaustible, a belief which oftentimes is not easily relinquished.

The Morrow plots tell also the story of Nature's eternal persistence in maintaining production where man has carried his share of the responsibility in providing suitable soil conditions. The records of these plots, covering thirty-nine years, like those of the oldest fertility plots in the world at the Rothamsted Experiment Station in England covering a period of eighty-four years, point to the possibility of maintaining crop production at an even higher level than that of the virgin soil.

EARLY HISTORY AND MANAGEMENT

The Morrow plots are located on the campus of the University of Illinois directly north of the New Agricultural Building. The soil on which these plots are located is classified by the Soil Survey of the Illinois Agricultural Experiment Station as Brown Silt Loam, and by the United States Soil Survey as Muscatine silt loam. It is naturally a productive soil and is representative of a vast area of prairie land in central and northern Illinois.

There has been some uncertainty regarding the exact date of the establishment of these plots, but statements found in various records of the Experiment Station may be taken as furnishing fairly conclusive evidence that these, the oldest experimental soil plots in America, have been in continuous operation since 1876. Thus the corn crop just harvested on Plot 3 (1927) is the fifty-second corn crop grown consecutively on this plot, while the rotations on the other two plots have been continued the same length of time, except for the modification in one as noted below.

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[1]E. E. DeTurk, Chief in Soil Technology, in charge of soil analysis of the Soil Survey; F. C. Bauer, Chief of Soil Experiment Fields; L. H. Smith, Chief in charge of the publications of the Soil Survey.

For the economic interpretation of the Morrow plots data, pages 131 to 136, including the selection of the cost data on which that discussion is based, the authors are indebted to Professors H. C. M. Case and R. H. Wilcox, of the Department of Farm Organization and Management.

The series as originally laid out consisted of 10 half-acre plots, each 5 rods by 16 rods. The growth of the University campus, however, necessitated subsequent reduction of the area. In 1895 the astronomical observatory was built on Plots 1 and 2, and in 1903 all the other plots except Nos. 3, 4, and 5 were discontinued and the land seeded down to lawn. During the following year, 1904, these remaining plots were cut down to 9 rods in length. At the same time division strips half a rod wide were established between the plots, and a cropped border one-fourth rod wide left around the plotted area. Furthermore, each of the three plots was divided into four quarters by half-rod division strips thru the center in both directions. Thus each of the three original half-acre plots now consists of four separate plots, each 2 rods wide north and south by 4 rods long east and west and containing one-twentieth of an acre.[1] At the time of the subdivision of the plots the land was tile-drained, a line of 4-inch tile being laid in the half-rod division strips between the north and south halves of each of the three original plots. Thus one line of tile lies adjacent to each of the twelve present plots, as indicated by the broken lines in Fig. 1.

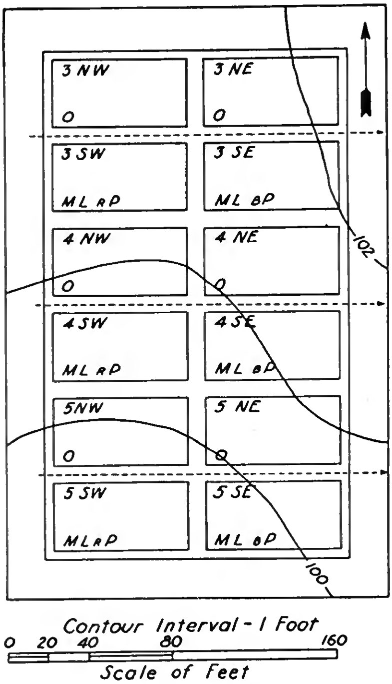

FIG. 1.—PLAN OF THE MORROW PLOTS

The Morrow plots are situated on Brown Silt Loam, a soil type which is representative of vast areas of corn-belt land. The surface of the plots is nearly level, and the area is drained by a tile line adjacent to each plot. Corn is grown every year on the four small plots numbered 3. The 4's carry a two-year rotation of corn and oats, while a three-year rotation of corn, oats, and clover occupies the plots at the south, numbered 5.

No record of crop yields from the various plots is available prior to 1888, the year in which the Experiment Station was established. In the earlier reports made by Professor George E. Morrow and his associates, no reason is stated as to why yields were not given.

The records do, however, state clearly the important fact that the

[1]The four plots thus formed from the original Plot 3 are numbered 3-NE, 3-NW, 3-SE, and 3-SW, and similar numbering is used for the plots formed from Plots 4 and 5.

cropping systems as originally planned were maintained during those early years and that no manures or fertilizers of any kind were applied.

Cropping Systems Practiced

Three different cropping systems are practiced on the plots of the Morrow series. Plot 3, to the north, has grown corn every year from the beginning of the experiment up to the present time. Plot 4, in the center, has grown corn and oats alternately during the same time, while Plot 5, to the south, has been cropped as follows: Up to and including 1899 a rotation was grown consisting of corn for two years, oats one year, meadow (clover, timothy, or both) three years. In 1900 this plot (Plot 5) was used for oats variety trials. Beginning in 1901 a three-year rotation of corn, oats, and red clover was adopted and has been continued uninterrupted to the present time, except that where clover failed cowpeas were substituted in 1906 and soybeans in 1912 and 1915.

Disposal of Crops Grown

On all NE and NW plots the grain, straw, stalks, and hay have been removed. No residues except stubble and roots have been returned either directly or in manure.

On Plots 3-SE and 3-SW, which are cropped continuously to corn, the stalks and grain have been harvested, and to each plot has been applied an amount of manure which could reasonably be expected to have been produced if the produce of the plot had been used as feed and bedding, as explained in the paragraph on manure applications (page 110). For some years legume cover crops were seeded in the corn at the last cultivation, but the failures were so frequent that the practice was discontinued.

On Plots 4-SE and 4-SW, on which a corn and oats rotation is followed, the grain, straw, and stalks of both crops are removed and manure returned to the respective plots according to the plan followed on Plots 3-SE and 3-SW. In addition, beginning in 1904, catch crops were seeded in the oats and plowed down the following spring for corn. Starting in 1912 this catch crop was a clover mixture, containing some sweet clover. In 1914, 15 pounds of sweet clover and 5 pounds of alsike an acre were seeded. The crop, however, was mainly alsike. In 1916 a mixture of sweet clover and red clover was seeded. Red clover predominated in the crop plowed under the following spring. Since 1916 sweet clover alone has been used, and satisfactory growth has been secured in practically all cases.

On Plots 5-SE and 5-SW, cropped to corn, oats, and clover in rotation, the stalks, straw, and grain as well as clover hay are removed and manure is returned as indicated above. There is no place in this rotation for a catch crop, since the red clover sod is plowed down for corn.

Application of Fertilizing Materials

Previous to the subdivision of the original plots in 1904 no manure or fertilizers of any kind were applied. Since that time the NE and NW plots have been continued without treatment, each pair being duplicates, identical except for natural soil variation. This has made it possible to continue the study of the effects of the different cropping systems without fertilizers.

On the SE and SW plots a plan of fertilization was adopted which included the return of farm manure and also the addition of limestone and phosphate. The details of these treatments follow.

Manure.—Beginning in 1904 manure has been applied to all SE and SW plots. Until 1909 the applications were made at the rate of 2 tons an acre a year; since then all applications have been in direct proportion to the crops removed from the respective plots; that is, in amounts equal in weight to the air-dry weight of the crops removed.

TABLE 1.—MANURE APPLIED TO MORROW PLOTS
(Tons per acre)

	Plot 3		Plot 4		Plot 5	
	SW	SE	SW	SE	SW	SE
Total, 1904 thru 1926	71.4	76.0	70.3	75.3	66.3	69.3
Average yearly amount	3.10	3.30	3.06	3.27	2.88	3.01

In all cases the manure is applied preceding the corn crop; hence manure is applied annually to Plots 3-SE and 3-SW, once in two years to Plots 4-SE and 4-SW, and once in three years to Plots 5-SE and 5-SW. The total amounts applied to these plots from 1904 thru 1926 are given in Table 1.

Limestone.—In 1904 ground limestone was applied to the SE and SW plots at the rate of 1,704 pounds an acre, and in 1919 a further application at the rate of 5 tons an acre was made. The total limestone application made to each of the treated plots in the twenty-three years is thus 5.85 tons an acre. At the average price of $2 a ton, this would cost $11.70. The average annual acre cost would therefore be 51 cents.

Phosphate.—From 1904 thru 1918 steamed bone meal was applied yearly to the SE plots at the rate of 200 pounds an acre. During the same years rock phosphate was applied to the SW plots at three times the rate used for bone meal, or at the annual acre rate of 600 pounds. In 1919 the annual rate of bone meal was reduced to 50 pounds an acre, and the application of rock phosphate was reduced to the rate of 200 pounds an acre, so that the ratio of rock phosphate to bone meal now stands 4 to 1. At the same time enough additional rock phosphate was applied to bring the total application for the preceding fourteen years up to four times the total amount of bone meal which had been applied during the same period. In 1925 it was decided to discontinue the further application of phosphates for an indefinite period.

Prior to 1918 the phosphates were applied on Plots 3 and 4 once in two years, the year preceding that in which corn appeared on Plot 4; and on Plot 5 also the year preceding the corn crop, or once in three years. In 1918 it was decided to apply the phosphates to all three plots only once in six years, in the winter preceding the corn crop which appears simultaneously on all plots.

The total rock phosphate application made in twenty-three years to each of the SW plots has been 13,200 pounds an acre. This at $10 a ton, an average price for the past decade, would cost $66, or $2.87 an acre annually. The bone meal application, 3,300 pounds an acre for the twenty-three years, at $40 a ton, an average price, would cost the same on the acre basis as the rock phosphate. The profitableness of the treatments and of the different cropping systems is discussed on pages 131-136. For the purposes of this study the cost of the various fertilizing materials is reckoned uniformly for twenty-three years altho as a matter of fact certain of the applications have been in effect for only twenty-two crops.

EFFECTS OF ROTATION AND FERTILIZATION UPON CROP YIELDS

The most important lesson to be drawn from the Morrow plots is to be found in the crop yields obtained under the different systems of soil management. These yield records extend over a period of thirty-nine years. During the first sixteen years all yields were from untreated soil, no fertilization of any kind being practiced, as previously stated. Thruout the following twenty-three years the yields were from both fertilized and unfertilized crops.

Producing Power Wanes Under Continuous Corn Growing

The fact that continuous cropping to the same crop lowers the productive power of the soil is generally recognized. A positive proof of this fact and a measure of the amount of decrease is found in the yields on Plot 3-N, where corn has been grown continuously (Table 3). Without treatment this plot in the second period, 1904 thru 1926, yielded 14.6 bushels an acre a year less than in the first period, 1888 thru 1903; which is a falling off of more than one-third.

TABLE 2.—ANNUAL ACRE YIELDS OF CROPS FROM THE MORROW PLOTS

(Yields from steamed bone meal plots are combined with the yields from the raw rock phosphate plots. The separate yields are given in Table 8, pages 138-139.)

Year	Soil treatment applied[1]	Plot 3 Corn every year	Plot 4 Two-year rotation		Plot 5 Three-year rotation		
			Corn	Oats	Corn	Oats	Clover
		bu.	*bu.*	*bu.*	*bu.*	*bu.*	*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	70.2	....	....
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	0	21.5	....	17.5	55.3	....	....
	MLP	17.1	....	25.3	72.7	....	....
1905	0	24.8	50.0	....	....	42.3	....
	MLP	31.4	44.9	....	....	50.6	....
1906	0	27.1	....	34.7	....	....	1.42[2]
	MLP	35.8	....	52.4	....	....	1.74[2]
1907	0	29.0	47.8	....	80.5	....	....
	MLP	48.7	87.6	....	93.6	....	....
1908	0	13.4	....	32.9	....	40.0	....
	MLP	28.0	....	45.0	....	44.4	....
1909	0	26.6	33.0	....	....	....	.65 + .64[3]
	MLP	31.6	64.8	....	....	....	1.73 + 1.17[3]
1910	0	35.9	....	33.8	58.6	....	....
	MLP	54.6	....	59.4	83.3	....	....
1911	0	21.9	28.6	....	....	20.6	....
	MLP	31.5	46.3	....	....	38.0	....
1912	0	43.2	....	55.0	....	....	1.35[4]
	MLP	64.2	....	81.0	....	....	1.70[4]
1913	0	19.4	29.2	....	33.8	....	....
	MLP	32.0	25.0	....	47.8	....	....
1914	0	31.6	....	33.6	....	39.6	....
	MLP	39.4	....	58.2	....	60.4	....
1915	0	40.0	49.0	....	....	....	1.84[4]
	MLP	66.0	81.2	....	....	....	1.96[4]
1916	0	11.2	....	37.5	27.8	....	....
	MLP	10.8	....	64.7	40.6	....	....
1917	0	40.0	48.4	....	....	68.4	....
	MLP	78.0	81.4	....	....	86.9	....
1918	0	13.6	....	27.2	....	....	2.58
	MLP	32.6	....	59.3	....	....	4.04
1919	0	24.0	30.8	....	52.2	....	....
	MLP	43.4	66.2	....	70.8	....	....
1920	0	28.2	....	37.2	....	52.2	....
	MLP	54.4	....	51.6	....	69.7	....
1921	0	19.8	30.6	....	....	....	.26 + .53[3]
	MLP	42.2	68.4	....	....	....	1.33 + .85[3]
1922	0	24.6	....	39.3	49.2	....	....
	MLP	39.4	....	55.8	65.3	....	....
1923	0	15.0	17.2	....	....	53.4	....
	MLP	31.4	46.4	....	....	66.6	....
1924	0	28.0	....	36.0	....	....	1.83
	MLP	38.0	....	68.5	....	....	4.42[5]
1925	0	19.1	26.7	....	42.1	....	....
	MLP	45.4	39.5	....	58.7	....	....
1926	0	21.4	....	22.9	....	44.3	....
	MLP	35.4	....	76.3	....	85.0	....

[1]Treatment on south half of Plot 4 includes legume green manure beginning in 1904.
[2]Cowpea hay in 1906. [3]Clover seed harvested (bushels) in addition to hay.
[4]Soybean hay in 1912 and 1915. [5]Hay contaminated with sweet clover in 1924.

That the waning yields have come about steadily as a result of soil impairment rather than seasonal conditions is indicated by the decreasing yields in four successive nine-year periods. For the first nine years, 1888 thru 1896, the average annual yield was 41 bushels

TABLE 3.—SUMMARY OF YIELDS FROM MORROW PLOTS FROM 1888 TO 1926
(Average annual yields per acre; figures in italics indicate number of crops grown)

Years	Soil treatment applied[1]	Plot 3 Corn every year	Plot 4 Two-year rotation		Plot 5 Three-year rotation		
			Corn	Oats	Corn	Oats	Clover
		bu.	*bu.*	*bu.*	*bu.*	*bu.*	*tons*
		39	*20*	*18*	*12*	*12*	*9*
1888–1926	None..........	31.1	38.0	37.3	49.3	45.9	1.64
		16	*9*	*6*	*4*	*4*	*4*
1888–1903	None..........	39.7	41.0	44.0	48.0	47.6	2.03
		23	*11*	*12*	*8*	*8*	*7*
1904–1926	None..........	25.1	35.6	34.0	50.0	45.1	1.39[2]
	MLP..........	40.5	59.2	58.1	66.6	62.7	2.40[2]
Percentage increase for treatment..................		61.3	66.3	70.8	33.2	39.0	72.7

[1]Treatment on the south half of Plot 4 includes legume green manure beginning in 1904. [2]Cowpea and soybean hay included.

of corn. This was followed in the next three nine-year periods by average yields of 34.7, 27.6, and 24 bushels an acre. Further evidence that the decline in yield has been due to soil impairment rather than climatic conditions is shown by the large and increasing yields which have been maintained on other plots during the same years by crop rotation and fertilization.

Crop Rotation Checks Lowering Yields

In the corn and oats rotation the corn yields without soil treatment (Plot 4-N) have been reduced from 41 bushels an acre as an annual average for the first period, to 35.6 bushels in the last period, a reduction of only 5.4 bushels (Table 3). Thus the alternation with oats has checked, but not entirely stopped, the downward trend of the corn yields.

The comparison of the corn and oats rotation with continuous corn growing can be made more accurately by comparing the corn yields on the two plots during the years when both plots were in corn at the same time, thus eliminating any possible advantage to either plot that might be due to seasonal differences. We find that as an average of the twenty crops grown on the two plots in the same years, both without fertilizers, the continuous-corn plot yielded 30.8 bushels an acre, while in the corn and oats rotation the yield was 38.0 bushels, which is a gain of 7.2 bushels an acre a year.

The three-year rotation without soil treatment has been even more effective than the two-year rotation in maintaining crop yields. This is due, at least in part, to the fact that the third crop is clover. The corn yields in the first period, as will be noted from Table 3, averaged 48 bushels an acre in the three-year rotation, as compared with 41 bushels in the two-year rotation of corn and oats. In the second period the yield averaged 50.0 bushels in the three-year rotation and 35.6 bushels in the two-year rotation. Thus the benefit of the three-year rotation is cumulative, the advantage of 14.4 bushels an acre a year in the second period being double that for the first period.

Looking at the facts from a somewhat different angle, we see that on both the continuous-corn land and on that growing the two-year rotation, the average annual corn yields have fallen off 14.6 and 5.4 bushels an acre respectively in the second period as compared with the first. Where the clover is included the yield does not fall off but increases from an average of 48 bushels an acre to 50 bushels.

While the yields of oats on Plots 4 and 5 are not so striking as those of corn, they tell much the same story as the corn yields.

Fertilization Does Not Replace Rotation

The idea is held by many farmers that a sufficient use of fertilizers can solve the problem of maintaining yields, without rotating crops. The yields from the Morrow plots show clearly that this is not the case. Crop rotation is a fundamental part of soil management, as shown above, and fertilizers are used as a supplement in order to make good the deficiencies in the soil, whether such deficiencies are natural or have developed as a result of cropping.

Considering only the fertilized portion of the Morrow plots, decided increases in yield are to be observed as a result of crop rotation. Corn grown continuously on this fertilized land averaged only 40.5 bushels an acre annually; in the two-year rotation it rose to 59.2 bushels; while in the three-year rotation, which includes clover, the average yield reached 66.6 bushels. These higher yields have been obtained on the two rotation plots even tho all three plots received the full soil treatment, and in the case of Plot 5-S, which produced the highest yield, both cuttings of clover were removed in most cases, only the sod being plowed down for the following corn crop.

Clover Demonstrates Value in Maintaining Yields

The importance of clovers in a crop rotation for the maintenance of a satisfactory level of production can scarcely be overstated. Their value is demonstrated in the two-year rotation on Plot 4-S, where sweet clover is used as a green-manure crop (see page 109), as well as on Plots 5-S and 5-N, where red clover is used as one of the full season crops in the three-year rotation.

Since 1916 only biennial white sweet clover (*Melilotus alba*) has been used on Plot 4-S. It is seeded with the oats in the spring and in the following spring the entire clover crop is plowed down for corn. A satisfactory growth is practically always obtained, the amount of clover plowed down usually being equal to about 1¼ tons of dry matter, disregarding the roots, which are nearly if not quite equal in weight to the tops at that time of year.

During the eleven years from 1904 thru 1914, which was before the adoption of sweet clover as a green manure on this plot,[1] five crops of corn were grown averaging 53.7 bushels an acre. In the next twelve years six more crops of corn were grown on that plot with exactly the same treatment except for the addition of the sweet-clover green-manure crop, and the average yield was 63.8 bushels, or a gain amounting to 10.1 bushels an acre a year for the years in which the corn followed sweet clover. The larger yields during the second period were due largely to the presence of sweet clover in the rotation, and not to an accidental series of more favorable corn seasons. This is apparent from the fact that the corn yields on the untreated plot of the same rotation (Plot 4-N) averaged 37.7 bushels for the earlier period and 33.8 bushels for the next twelve years—a falling off of 3.9 bushels during the same years in which the sweet-clover plot gained 10.1 bushels.

The producing capacity of this treated land, Plot 4-S, during twelve years of sweet-clover green manuring, has attained a capacity (63.8 bushels of corn) almost equal to that of the similar land in Plot 5-S, which, during its twenty-two years of a three-year red-clover rotation, has averaged 66.6 bushels.

Rotation Without Fertilization Insufficient

Even good rotations cannot maintain crop production at a high level, except in unusual cases, without the addition of supplementary materials, either limestone or fertilizing materials or both. In the first place rotations which are most effective in maintaining the productivity of the soil include legumes. Legumes are more or less sensitive to acid soils, and this necessitates the use of limestone in a great many cases before the rotation can be established.

In planning the modifications made on the Morrow plots in 1404, the possible necessity of fertilization as a farm practice was recognized, and consequently a treatment was adopted for half of the plots that included limestone, manure, and phosphate, as described on pages 110-111. Unfortunately there was not sufficient land to permit each of

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[1]As previously noted (page 109) no sweet clover was used during this period except in 1912 and 1914, when it was grown in a mixture with alsike clover.

the three fertilizers to be applied separately. Only the composite effect of the entire treatment, therefore, and not the effect of the materials used separately, can be studied on these plots.

The results of this experiment can leave no doubt of the efficacy of this treatment on the soil type here concerned. It is a comparatively easy matter to increase the yields on exhausted or run-down soil by means of adequate soil treatment. But here we have a soil which is naturally productive, and we find that this system of fertilization not only brings up the yields where the soil has been depleted by continuous cropping, but has produced an equally large increase in a rotation which maintained the untreated corn yields at an average of 50 bushels. The average crop increases for the twenty-three years from 1904 thru 1926 range from 33.2 percent for the corn on Plot 5-S, to 72.7 percent for the clover on the same plot (Table 3). In some years the yields of all crops were more than doubled by the soil treatment.

Trend of Production as Influenced by Rotation and Soil Treatment

In summing up this discussion of the productive capacity of the soil as affected by the different systems of management, it may be well to observe the general direction in which production is going.

In the following discussion the yields are given in money values instead of bushels or tons. This is done, not in order to place a financial interpretation upon the results, but to convert the results into a common denominator so that all are comparable. The prices used are: corn, 75 cents a bushel; oats, 45 cents; soybeans (grown where clover failed in two cases), $1.50 a bushel; hay, $15 a ton, and clover seed, $15 a bushel.

In the accompanying curves (Figs. 2 to 6) the values of the crops from the various plots each year are shown by the zigzag lines. These values vary widely from year to year because of seasonal conditions. The straight lines drawn thru the zigzag lines show the trend, or general direction, taken by the annual yields.[1]

The results from the three different cropping systems on the treated land are compared in Fig. 2. Not only are the financial returns greater in the two-crop system than in continuous corn, and still greater in the three-year rotation, but these differences have been maintained consistently thruout the period. It is significant that in all three cropping systems where the land is treated the trends are upward.

[1]The location of this trend line is determined by the method of least squares, using the following formulas: (1) Sum $y =$ sum x (m) + sum (n); (2) sum $xy =$ sum x^2 (m) + sum x (n); in which $y =$ observed yields, $x =$ successive points on abscissa, $m =$ slope of line, $n =$ point of origin of straight line.

When the cropping systems on the untreated plots are compared, a different situation is observed (Fig. 3). At the time when the records were started (1888) the continuous-corn land was producing the highest financial returns ($31.81). Since at the beginning of the experiment the soil of all the plots was presumably about alike in productive power, it would appear that this early advantage in financial returns from the continuous growing of corn was due to the fact that corn was the high-

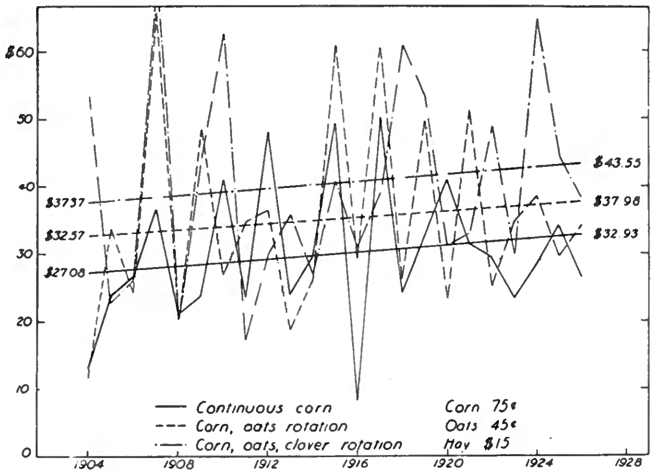

FIG. 2.—ANNUAL CROP VALUES AND TRENDS IN PRODUCING POWER OF THE TREATED LAND OF THE MORROW PLOTS

The use of manure, limestone, and phosphate has kept the trend of production upward for twenty-three years in all three cropping systems, as indicated by the three straight lines in the center of the graph.

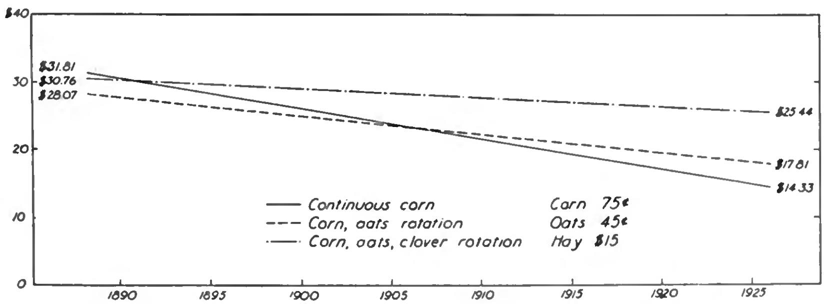

FIG. 3.—TREND IN PRODUCING POWER OF THE UNTREATED LAND OF THE MORROW PLOTS

Without soil treatment, production declines regardless of the cropping system followed. The decline is much more rapid under continuous corn than where rotation of crops is practiced.

est priced crop of the group. The introduction of oats, a crop of low value, in the other two rotations cut down the financial returns so long as the plots all remained equal in productivity. The continuous-corn plot still enjoys the advantage of growing the crop of highest money value every year, but in spite of this advantage it has dropped to the lowest position in financial returns because of the more rapid decline in yielding power under this system of farming. At the close of the period (1926) the average annual crop values are $3.48 lower than for the two-year rotation. The three-year rotation, which stood higher than the two-year at the beginning of the experiment, has increased its lead.

These curves (Fig. 3) furnish one answer to the question, What are the objections to a two- or three-year rotation without fertilization? Without fertilization these rotations *check but do not prevent* declining production. In thirty-nine years the annual value of the crop from the plot growing corn continuously has declined from $31.81 an acre to $14.33, or $17.48. In the same time production in the two-year rotation has declined from $28.07 to $17.81, or $10.26, while in the three-year rotation there has been a reduction from $30.76 to $25.44, amounting to $5.32. If these trends continue, the land must eventually become unprofitable.

Figs. 4, 5, and 6, illustrating the effect of the manure, limestone, phosphate treatment in the three rotations, all tell the same story. In all three cropping systems the treatment used, as compared with no treatment, has maintained production at a significantly higher level and has converted a *downward* trend in production into an *upward* trend.

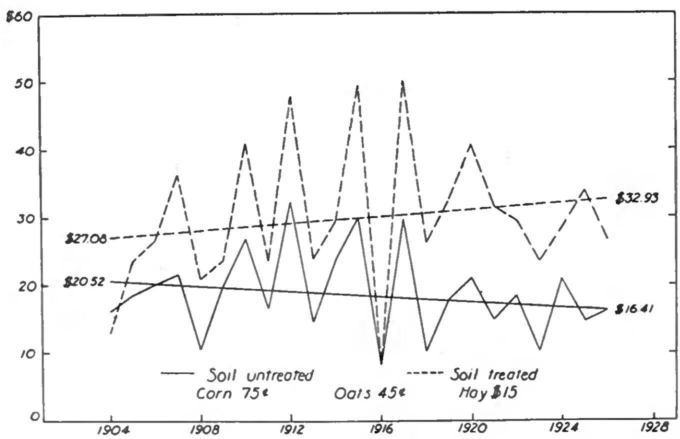

FIG. 4.—ANNUAL CROP VALUES AND TRENDS FROM LAND CONTINUOUSLY IN CORN, MORROW PLOTS

On continuous-corn land, manure, limestone, and phosphate convert a downward trend in production into an upward trend.

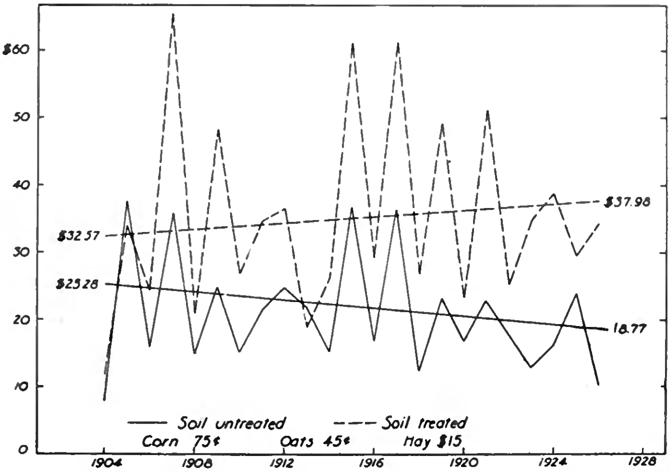

FIG. 5.—ANNUAL CROP VALUES AND TRENDS IN THE CORN, OATS ROTATION OF THE MORROW PLOTS

Yields from the treated land in this rotation have exceeded those from the untreated land every year but two for nearly a quarter of a century. The two adverse years, 1905 and 1913, indicate how misleading a single year's results may be as a test of a soil practice.

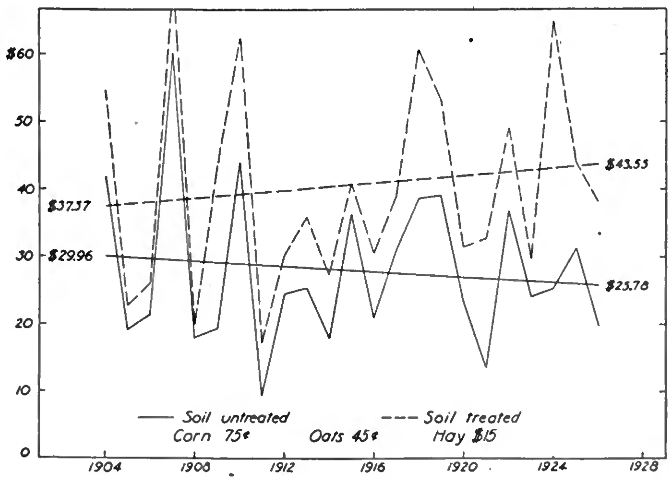

FIG. 6.—ANNUAL CROP VALUES AND TRENDS IN THE CORN, OATS, CLOVER ROTATION OF THE MORROW PLOTS

Even in this, the best of the three cropping systems, the fertilization scheme used has reversed the direction of the production trend, carrying it consistently upward.

The gap in the production trend lines between the treated and the untreated land is about the same in all three cropping systems for the beginning of the period of soil treatment (1904). The widening of this gap by soil treatment has been greatest in the two-year rotation, where it amounts to $19.21 at the end of the period, and is narrowest on the continuous-corn plot, namely, $16.52. Thus while the treatment used has not produced widely different results in the three cropping systems, the effect of soil treatment as compared to no soil treatment has been very marked in each of them.

Soil Treatment and Crop Rotation Hasten Maturity of Crops

The maturity of corn, one of the indexes of its quality, is indicated largely by the moisture content at husking time. The record of the moisture content of corn from the Morrow plots given in Table 4 would indicate that the rotations as well as the soil treatment tend to hasten the maturing of corn.

The effect of the soil treatment and of the cropping systems in advancing the development of the crop is shown in the accompanying pictures. These photographs were taken on July 26, 1925. On that date no tassels had appeared on the untreated portion of Plot 3 (Fig. 7) and only an occasional tassel was to be seen on the treated portion. The size of the corn, however, was noticeably increased where soil

FIG. 7.—THE CORN CROP ON THE CONTINUOUS-CORN PLOT AS IT APPEARED JULY 26, 1925

The crop is further along on the treated plot than where no soil treatment has been applied. On August 4 the treated plot was fully tasseled, while the untreated plot was only partially tasseled out. The occasional large stalk in the foreground of the untreated plot is explained by the fact that the front hill in each row is a border hill, not a part of the plot proper. Since these border hills have less competition with surrounding plants, the growth is much larger than that in the plot itself.

FIG. 8.—CORN IN THE TWO-YEAR ROTATION JULY 26, 1925

The stage of development of this corn, as with that on the continuous-corn land, is advanced by the use of manure, limestone, and phosphate. On the treated plots the tasseling was well started at this time, while very few tassels were in evidence on the untreated land.

treatment has been followed. The greatest advance in growth and in earliness of tasseling is to be observed on the treated portion of the rotation plots (Figs. 8 and 9). It is evident both from the pictures and from the results given in Table 4 that the soil treatment has had a more pronounced effect in advancing the crop toward maturity than have the rotations.

FIG. 9.—CORN IN THE THREE-YEAR ROTATION JULY 26, 1925

The effect of soil treatment in advancing maturity is evidenced here as in the other cropping systems shown in Figs. 7 and 8. The favorable effect of the three-year rotation may also be noticed by comparing the untreated land of this plot with that of Plot 3, Fig. 7.

TABLE 4.—EFFECT OF SOIL TREATMENT AND OF CROP ROTATION ON MOISTURE CONTENT OF CORN, MORROW PLOTS, AVERAGE 1909-1926

Rotation	Percentage of water-free shelled corn from ear corn at husking time	Field weight of ear corn to make 1 bushel of No. 1 shelled corn[1]
	percent	*lbs.*
Continuous corn		
No treatment	57.8	86.3
MLP	60.1	83.4
Corn, oats		
No treatment	58.8	85.2
MLP	61.4	81.4
Corn, oats, clover		
No treatment	59.2	84.5
MLP	61.1	82.0

[1]Based upon 12 percent moisture.

EFFECTS OF ROTATION AND FERTILIZATION ON THE SOIL

The cropping system practiced on a soil and the fertilization used may affect not only the crops grown, but also the physical condition, the biological activities, and the chemical character of the soil itself. The following investigations were undertaken in order to study certain chemical and biological aspects of the soil of the various plots. For this purpose, soil samples were used which had been collected in 1913 and 1923, together with a less complete set taken in 1904. The samples were taken from three strata in each plot, an upper or surface stratum extending to a depth of 6⅔ inches, a middle stratum extending from 6⅔ to 20 inches, and a lower stratum, extending from 20 to 40 inches. The upper stratum corresponds approximately to 2 million pounds an acre of dry soil. The middle and lower strata represent, respectively, two and three times this amount, and the results of analyses are computed to pounds per acre on this basis. Most of the feeding roots of our common crop plants are distributed within the upper 20 inches of soil, altho some roots of all these plants extend to a depth of 40 inches or more. Thus while the upper stratum, with which the manure and fertilizing materials are incorporated, constitutes the most important feeding zone and the second stratum is one of secondary importance, it must be considered that the entire 40 inches may possibly be drawn upon by crops to some extent. Since, however, differences brought about by cropping or fertilization that are great enough to be discernible by chemical methods, are found mainly in the upper stratum, and only to a very slight extent in the second, the data presented and the discussion will be confined to these two strata, even tho the chemical investigations have been made on the lower stratum as well.

Decline in Nitrogen and Organic Matter Prevented by Soil Treatment

The soil on which the Morrow plots are located is fairly well supplied with nitrogen and organic matter. The untreated soil to a depth of 6⅔ inches contains approximately 45,000 pounds of organic carbon[1] to the acre. The organic matter continues to a considerable depth. The second stratum, 6⅔ to 20 inches, which is twice as thick as the upper one, contains nearly 80,000 pounds of organic carbon to the acre, a slightly lower concentration than is found in the surface soil. Nitrogen is associated with the organic matter, most soil nitrogen being in the organic form.

Since both nitrogen and organic matter are fairly high in this soil, it is not necessary that they be actually increased in order to maintain a high level of production; it is necessary, however, to keep the quantities of these important soil constituents at somewhere near their original level.

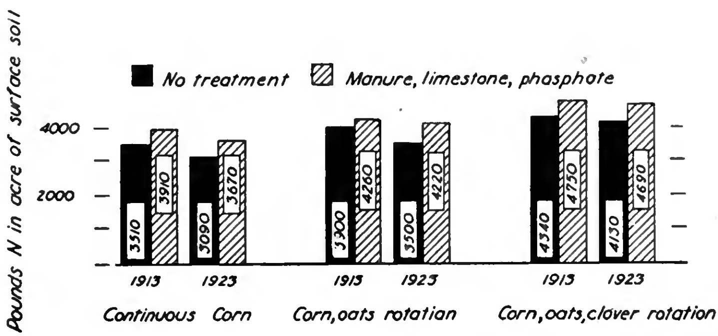

FIG. 10.—TOTAL NITROGEN IN SURFACE SOIL OF THE MORROW PLOTS, 1913 AND 1923

The use of limestone, manure, and phosphate has in all cases maintained the quantity of total nitrogen in this stratum (0 to 6⅔ inches) at a slightly higher level than where no treatment has been applied. In this respect the rotations show some advantage over continuous cropping to corn. It will be noted also that the treated plots all contained more nitrogen in 1923 than the untreated plots contained at the beginning of the ten-year period.

The results of analyses for nitrogen presented in Figs. 10 and 11 show that during the ten years from 1913 to 1923 there was no great change in the total amount of this element to a depth of 20 inches. The decreases in the untreated soil averaged approximately 90 pounds an acre a year for the entire 20-inch stratum. While this amount is but little more than could be accounted for by unavoidable errors in collecting two different sets of samples at different times, it is clear that it is not wholly due to such errors, since in both the surface and subsurface of every untreated plot the variation is consistently a decrease, even tho slight. It would appear then that there has been a

[1]Organic carbon constitutes approximately 58 percent of the organic matter and is used as a measure of the organic matter in the soil.

definite reduction in the amount of nitrogen in the soil of the untreated plots. In the treated plots the applications of manure, limestone, and phosphate have prevented this decrease in the total nitrogen content of the soil. All these plots at the present time contain not

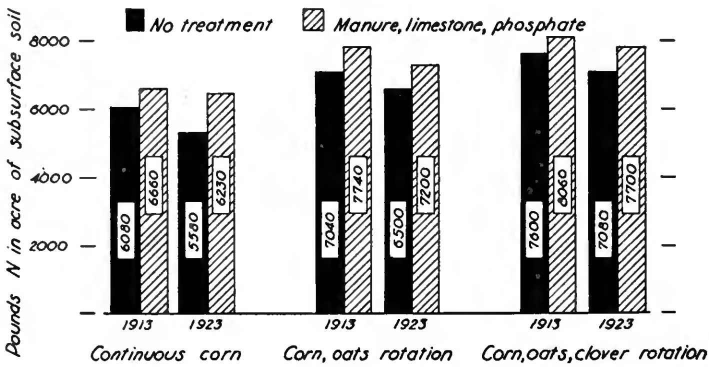

FIG. 11.—TOTAL NITROGEN IN SUBSURFACE SOIL OF THE MORROW PLOTS, 1913 AND 1923

The greater quantities of total nitrogen in the second stratum (6⅔ to 20 inches) of the treated plots as compared with the untreated plots indicate that these treatments have been effective below the 6⅔-inch level.

only more nitrogen than the corresponding untreated plots, but more than those untreated plots contained at the beginning of the ten-year period. These differences again are not large, but their consistency lends weight to their significance.

That these small but consistent differences are significant is indicated by computing the odds by means of a statistical method.[1] The odds that the decrease of 90 pounds of nitrogen annually is significant are 5,000 to 1. The increases in the treated soil are significant by odds of over 3,000 to 1, while the increases in the treated soil as compared to the untreated soil at the beginning of the ten-year interval are backed by odds of 76 to 1.

The organic-matter content of the soil of the plots has been affected in much the same way as the nitrogen content (Figs. 12 and 13).

It will be noted that the organic carbon and nitrogen tend to be higher in the soil of the plots where the two- and three-year rotations are grown than where corn has been grown continuously. Since no soil samples were taken when these plots were established, there is no way of determining with certainty whether this is a result of the

[1]Student's Method. H. H. Love, in Jour. Amer. Soc. of Agron. **16**, 68. 1924.

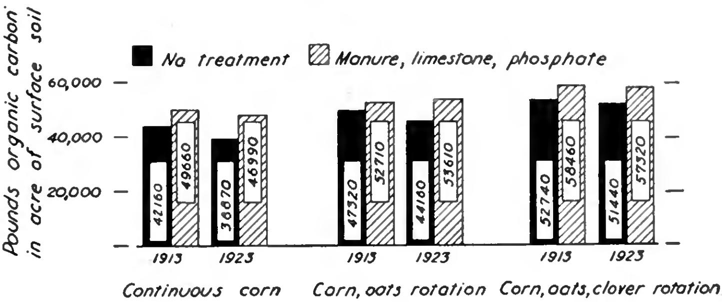

FIG. 12.—ORGANIC CARBON IN SURFACE SOIL OF THE MORROW PLOTS, 1913 AND 1923

Total nitrogen and organic carbon are associated in a fairly constant ratio in the organic matter of the soil. Consequently the variations here shown in organic carbon parallel those for total nitrogen shown in Fig. 10. The treated plots are seen to be somewhat better supplied than the untreated plots with this element, and the rotations show some advantage over continuous corn.

crop rotations or whether the soil was naturally richer in these elements toward the south end of the field in the beginning.

While the foregoing data do not prove conclusively that the cropping systems have greatly affected the *amount* of organic matter in the soil at the present time, the results presented in the following section do afford evidence of the effect of both cropping systems and soil treatment upon the *quality* of the organic matter. That is to say, these cropping systems and soil treatments have periodically added to the comparatively inactive organic matter already in the soil varying quantities of active organic matter which, because of its susceptibility to decomposition, has an enhanced value in maintaining conditions favorable to high production.

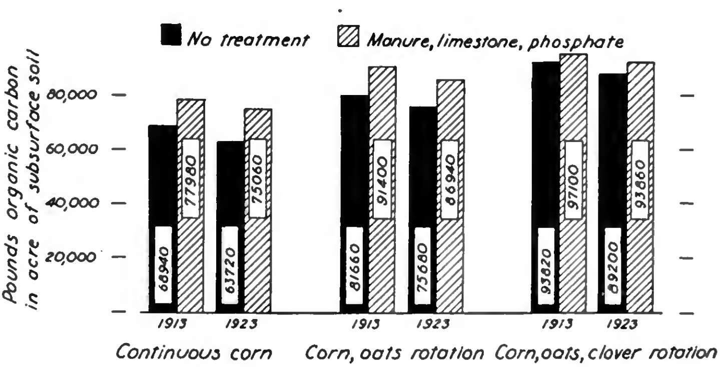

FIG. 13.—ORGANIC CARBON IN SUBSURFACE SOIL OF THE MORROW PLOTS, 1913 AND 1923

As in the case of nitrogen, the influence of the soil treatments and crop rotations on the organic matter reaches below the 6⅔-inch level.

Biological Activity Increased by Better Practices

Organic matter in the soil is of greatest value when it is undergoing decay. This process is brought about by bacteria and other microscopic organisms. The rate at which it proceeds depends largely upon the age, condition, and origin of the organic matter, and also upon the existence in the soil of conditions favorable to the growth of the organisms which cause decay. Much of the organic matter in the soil consists of old plant residues which have accumulated thru the centuries because of their resistance to decay, and 20 tons of such old inactive organic matter may be of less benefit to a crop than 2 tons of clover or cowpeas freshly plowed under.

The biological activity in a soil, which is a reflection of the quality of the organic matter, may be effectively measured by determining the rate at which nitrogen in the soil is converted by soil bacteria into the nitrate form and thus made available for use by crops. This has been done in the laboratory[1] with soil taken from the Morrow

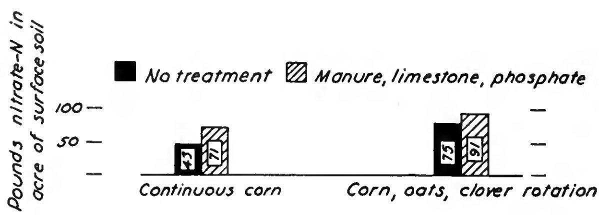

FIG. 14.—NITROGEN CONVERTED INTO NITRATE IN FOUR WEEKS, IN SAMPLES OF SOIL TAKEN FROM THE MORROW PLOTS IN 1923

Even the comparatively resistant nitrogen of the soil is made available more rapidly under conditions brought about by good management than where rotations and soil treatment are ignored. The nitrogen converted to nitrate in the soil of the three-year rotation under treatment would be sufficient to produce more than twice the crop possible in the case of the untreated, continuous-corn plot. As a matter of fact, the yields from these plots have been in very nearly that ratio.

plots in 1923, after forty-seven years of cropping, and in the case of the treated plots, after nineteen years of fertilization.

The amounts of nitrogen converted into nitrate in four weeks from the soil organic matter alone are shown in Fig. 14. When it is considered that approximately 1½ pounds of nitrate nitrogen are required to grow a bushel of corn, the significance of these results is at once apparent. The 91 pounds of nitrogen converted to nitrate in the soil growing the three-year rotation under treatment would produce more than twice the crop possible in the case of the untreated continuous-corn plot, where but 43 pounds an acre was thus liberated. Indeed, the amounts of nitrogen liberated from the soil of the differ-

[1]The authors are indebted to Professor O. H. Sears for the nitrification determinations.

ent plots stand in very nearly the same ratio as the actual average crop yields from those plots during the last twenty-three years.

The results of a similar study are given in Fig. 15, the only difference being that ammonium sulfate was added in equal amounts to all the soil samples at the beginning of the four-week period. This material furnishes an abundant supply of nitrogen which is capable of being converted into the nitrate form more readily than soil nitrogen. The results here are even more striking. Both rotation and fertilization are shown to keep the soil in much more favorable condition for the growth of these beneficial bacteria than is the case where these practices are not followed.

Thus while the better practices in soil management have not caused the *accumulation* of a large excess of organic matter which

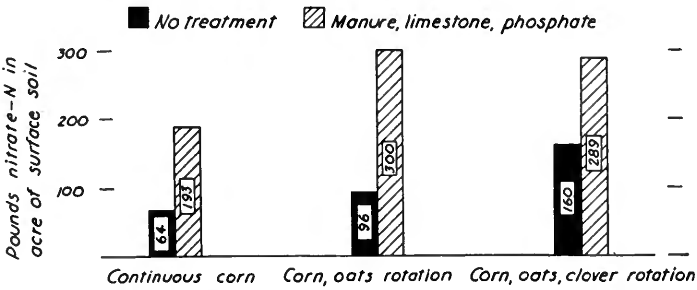

FIG. 15.—NITRATE NITROGEN FORMED IN FOUR WEEKS IN SAMPLES OF SOIL TAKEN FROM THE MORROW PLOTS IN 1923 AND TREATED WITH AMMONIUM SULFATE

The relative ability of different soils to convert unavailable nitrogen into available form (nitrate) is readily measured in the laboratory by determining the rate of nitrate formation from equal amounts of ammonium sulfate. As is shown in this graph, the amount of nitrate nitrogen thus formed is very greatly enhanced in the soil carrying good rotations and in that which has received the manure, limestone, phosphate treatment.

may be demonstrated by soil analysis, they nevertheless have added significantly greater amounts of active organic materials than the poorer practices. The growth of plant parts, such as stubble, roots, and clover sod, is greater, and the manure applied to the treated plots has amounted to about 3 tons an acre yearly. This excess organic matter, produced thruout the entire period, has been largely decomposed year by year for the benefit of the crops grown and therefore does not appear in the final analysis of the soil.

The benefit from the increased amount of active organic matter consists not solely in the increased liberation of nitrogen; it makes possible also the liberation from soil minerals of other elements used by crops, such as phosphorus, calcium, and potassium.

Phosphorus Depletion Offset by Phosphates and Manure

Soil phosphorus is removed by cropping. The corn on the untreated continuous-corn plot has removed phosphorus at the rate of approximately 6 pounds an acre a year, or a total of 60 pounds an acre during the ten years from 1913 to 1923 if we use as a basis for our figures the actual crop yields and the average composition of corn. This is the smallest amount of phosphorus removed from any of the plots. Figured on the same basis, the largest amount removed from any one plot has been from the treated plot carrying the three-year rotation (Plot 5-S). The corn, oats, and clover harvested from this plot have taken from the soil about 136 pounds of phosphorus an acre during the ten-year period. Most of this has probably been taken

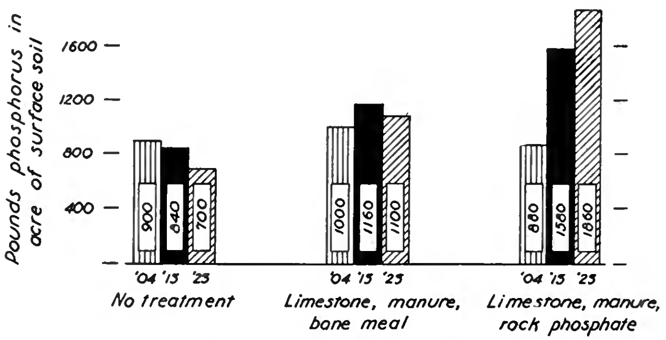

FIG. 16.—TOTAL PHOSPHORUS IN SURFACE SOIL OF THE MORROW PLOTS IN CONTINUOUS CORN: 1904, 1913, 1923

The gradual reduction of soil phosphorus by cropping is easily offset by the application of phosphate fertilizers. It is interesting to note that the phosphorus content of the soil has just about been maintained by the bone-meal applications, while the larger amounts of rock phosphate used have practically doubled the phosphorus reserve in the surface soil.

from the upper 6⅔ inches of soil, but some has been obtained from the second stratum and perhaps from still deeper layers. Since duplicate chemical determinations of phosphorus on the same soil sample will vary on the average from 50 to 75 pounds in the surface soil of one acre, this reduction in phosphorus content in the Morrow plots due to crop removals obviously could not be determined with certainty by chemical analyses of the soil made at the beginning and end of a ten-year period.

On all treated plots phosphorus has been added, not only in bone meal and phosphate rock, but also in manure, which has been the means of returning to the soil more than half of the phosphorus removed by the crops harvested and fed. Fig. 16 gives the phosphorus content of the surface soil of the continuous-corn plots as found by analysis, showing separately the untreated plot and the plots treated with bone meal and with rock phosphate. The results of an earlier analysis in 1904, just before the treatments were started, are inserted for comparison.

The plots on which rock phosphate has been applied show a much greater increase in phosphorus content than those on which bone meal has been applied. It will be remembered that rock phosphate, which contains approximately the same percentage of phosphorus as bone meal, has been applied in four times as great amounts as the bone. The results in the rotation plots, which are not presented here, are very similar to those given for the plot growing corn continuously.

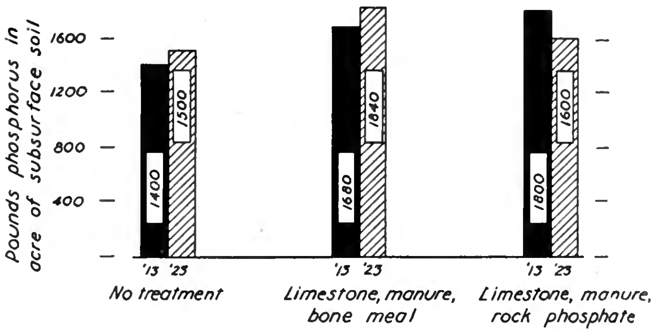

FIG. 17.—TOTAL PHOSPHORUS IN SUBSURFACE SOIL OF THE MORROW PLOTS IN CONTINUOUS CORN: 1913, 1923

The influence of phosphate applications to the soil is largely limited to the surface stratum.

It should be noted also that the treatments used have had no observable effect upon the phosphorus content of the soil below the surface (Fig. 17).

While cropping makes relatively slight inroads upon the total amount of phosphorus in the soil, it draws heavily upon that portion which readily becomes soluble, as in the case of nitrogen. This is an important fact reflected in the trend of crop yields. The removal year after year of the more available fraction of the soil phosphorus leaves a residue from which it becomes increasingly difficult for succeeding crops to extract the amount required for their growth. This difficulty may be overcome in part by renewing the supply of active organic matter in the soil, so that biological activity will be maintained and will aid in the liberation of this element, as discussed earlier (pages 126 and 127). Two additional methods of remedying the situation are possible, both of which are used on the Morrow plots. One is to apply relatively available phosphates, such as bone meal or acid phosphate, from time to time in amounts commensurate with crop removals. The other is to use a comparatively insoluble phosphate, rock phosphate for example, in much larger quantities, under the assumption that the small percentage of it becoming available each year will fulfill crop requirements.

Calcium, Magnesium, and Sulfur

No pronounced differences are to be found in the total amounts of calcium, magnesium, or sulfur in the various plots due to either cropping or fertilization, with the exception of a gain in calcium in the surface soil of the treated plots, where calcium has been added in both the limestone and the phosphates applied.

What has been said of phosphorus is equally true of these other minerals, namely, that as continuous cropping, with the accompanying gradual soil exhaustion, proceeds, it is that portion which can readily become available which suffers the most complete removal by crops. An interesting side light on this situation is shown in the "come-back" which soils undergoing gradual exhaustion sometimes exhibit in the year following a bad season. For example, in 1916, a poor corn year, Plot 3-N yielded 11.2 bushels of corn (Table 2), followed in the next year by a yield of 40 bushels. It is conceivable that the high yield in 1917 was due, not wholly to the more favorable weather conditions, but also in part to the light drain upon the available nutrient elements by the small crop of 1916, which permitted some accumulation.

Soil Acidity Neutralized by Limestone

Chemical tests show that the surface soil of all of the untreated plots is distinctly acid, while on the treated plots the acidity has been almost completely neutralized by the moderate amount of limestone used. The untreated soil has not yet become so acid as to prevent the growth of red clover, satisfactory stands being maintained both on Plot 5-N and 5-S, but it has become too acid to grow sweet clover. This was shown by an accidental seeding of sweet clover in the oats on Plots 5-N and 5-S in 1923 in addition to the red clover. In the following year sweet clover grew abundantly on the limed plot, almost crowding out the red clover and producing a yield of 4.42 tons of hay, while on the untreated plot there was a good growth of red clover, yielding 1.83 tons an acre of hay, but no sweet clover. The handicap of even a moderately acid soil is evident from an observation of Plots 4-S and 4-N in the years when these plots are in oats. An abundant growth of sweet clover is to be seen on the former, which has been limed, while on the latter, which is still acid, only a light covering of grasses and small weeds will be seen.

ECONOMIC LESSONS FROM THE PLOTS

The foregoing analysis has been concerned only with the questions of soil maintenance and crop yields. A question of equal importance is: What is the relative profitableness of the different cropping and fertilization practices used on the Morrow plots? The farmer is particularly concerned with this question, and while the answer may be determined to a considerable extent by factors which can be measured in plot experiments, it must be remembered that the results

TABLE 5.—COST OF PRODUCING THE CROPS GROWN ON THE MORROW PLOTS, 1904-1926

(Based on production costs secured in cost-accounting investigations carried on by the Department of Farm Organization and Management of the University of Illinois, in Champaign and Piatt counties)

	Plot 3	Plot 4		Plot 5		
	Corn	Corn	Oats	Corn	Oats	Clover
Yearly cost per acre without soil treatment						
Average yield per acre	25.1 bu.	35.6 bu.	34.0 bu.	50.0 bu.	45.1 bu.	1.39 tons
Costs that are the same regardless of the crop						
Interest and taxes on land[1]	$11.83	$11.83	$11.83	$11.83	$11.83	$11.83
General tillage machinery and hitches	.72	.72	.72	.72	.72	.72
Costs that vary with different crops and with varying yields						
Man labor						
(a) harvesting and threshing	.84	1.26	.17	1.73	.22	1.33
(b) other	2.23	2.23	1.37	2.23	1.37	.66
Horse labor						
(a) harvesting and threshing	1.22	1.83	1.26	2.45	1.34	1.26
(b) other	4.68	4.68	1.40	4.68	1.40	1.21
Seed	.39	.39	.84	.39	.84	2.64
Twine	....	....	.30	....	.33	....
Fuel	....	....	.10	....	.11	....
Threshing	....	....	.88	....	1.17	....
General farm expense	2.80	3.12	1.80	3.36	2.24	1.95
Crop machinery	.45	.50	.54	.54	.61	.68
Total cost of each crop per acre	$25.16	$26.56	$21.21	$27.93	$22.18	$22.28
Annual cost of producing an acre of rotation	$25.16	$23.89		$24.13		
Cost with soil treatment						
Increase in yield	15.4 bu.	23.6 bu.	24.1 bu.	16.6 bu.	17.6 bu.	1.01 tons
Cost of limestone, phosphate, and manure[2]	$ 5.78	$ 5.75		$ 5.59		
Cost of harvesting increased crop	1.39	1.83		1.94		
Production costs without soil treatment	25.16	23.89		24.13		
Total annual cost of producing an acre of rotation	$32.33	$31.47		$31.66		

[1]Land valued at $200 an acre; interest at 5 percent.
[2]Manure at 75 cents a ton; limestone and phosphate as on pages 110 and 111. Cost of applying is not included.

TABLE 6.—ANNUAL NET RETURN PER ACRE OF ROTATION WITH AND WITHOUT SOIL TREATMENT, MORROW PLOTS, 1904-1926

(Corn valued at 75 cents a bushel, oats at 45 cents a bushel, and clover hay at $15 a ton. These approximate the average prices for the last ten years)

	Plot 3		Plot 4		Plot 5	
	Without soil treatment	With soil treatment	Without soil treatment	With soil treatment	Without soil treatment	With soil treatment
Average corn yield.........	25.1 bu.	40.5 bu.	35.6 bu.	59.2 bu.	50.0 bu.	66.6 bu.
Average oats yield..........	....	....	34.0 bu.	58.1 bu.	45.1 bu.	62.7 bu.
Average clover yield........	....	....	....	....	1.39 T	2.40 T
Annual crop value per acre of rotation..................	$18.83	$30.38	$21.00	$35.28	$26.22	$38.06
Annual cost per acre of rotation....................	25.16	32.33	23.89	31.47	24.13	31.66
Annual net return per acre of rotation..................	$−6.33	$−1.95	$−2.89	$ 3.81	$ 2.09	$ 6.40
Annual net increase due to soil treatment............	$4.38		$6.70		$4.31	

which any individual farmer will achieve will depend in large part upon his own business ability and thrift.

A satisfactory method for determining the relative profitableness or unprofitableness of the different cropping systems used on the Morrow plots with or without soil treatment is to deduct from the value of all the crops produced the total cost of growing them. In Table 6 are shown the results of such a computation for each of the plots from 1904 thru 1926, the cost data[1] being taken from the cost analysis given in Table 5. Table 7 contains the results for the earlier years, 1888 thru 1903, when no soil treatment was given.

An inspection of Table 6 shows that the continuous growing of corn without soil treatment has resulted in a loss, as a long-time proposition. Computed for the earlier years alone, 1888 thru 1903 (Table 7), the results show that if the same cost and price conditions had prevailed, a profit would have been realized from the continuous growing of corn during that period, owing to the high initial productiveness of the soil. The corn and oats rotation without soil treatment was maintained without loss during the early period. The average annual net profit, however, amounted to only 69 cents an acre, and this cropping system gradually became unprofitable because of declining yields. During the last twenty-three years a net annual loss of $2.89 an acre has resulted.

[1]The figures on cost of production used in the tables and discussion are based on data secured in farm-accounting investigations which have been carried on by the Department of Farm Organization and Management of the University of Illinois in Champaign and Piatt counties, since it would be impossible to obtain the actual cost of production from crops grown under experimental conditions on plots of such limited size. As no manager's salary has been included in the production costs, the net profits, where they occur, may be considered as the manager's or owner's wage.

TABLE 7.—ANNUAL NET RETURN PER ACRE OF ROTATION WITHOUT SOIL TREATMENT, MORROW PLOTS, 1888-1903[1]

	Plot 3	Plot 4		Plot 5		
	Corn	Corn	Oats	Corn	Oats	Clover
Yield per acre	39.7 bu.	41.0 bu.	44.0 bu.	48.0 bu.	47.6 bu.	2.03 T
Annual cost of each crop per acre	$26.41	$27.11	$22.05	$27.83	$22.35	$23.29
Annual crop value per acre of rotation	$29.77	$25.29		$29.29		
Annual cost per acre of the rotation	26.41	24.58		24.52		
Annual net return per acre of rotation	$ 3.36	$ .69		$ 4.77		

[1]Cost data taken from Table 6 and corrected for differences in yield.

The greatest net profits have been realized from the two- and three-year rotations in which manure, limestone, and phosphate have been used. The annual net acre profit in these two systems from 1904 thru 1926 has averaged $3.81 and $6.40 respectively (Table 6). The plot growing corn continuously even with the soil treatment shows a loss of $1.95. Any variation in prices of farm products would of course change these results, and might even convert small net profits into losses, or vice versa. Changes in economic conditions affecting production cost, such as the varying costs of supplying fertilizers, would likewise exert their effect upon the absolute profit or loss.

One factor in particular merits attention in this discussion of the relative profitableness of different rotation and fertilization practices, because of the marked influence which it exerts upon the total cost of producing crops. This is the distribution of labor thruout the year. Fig. 18 illustrates the labor distribution on a typical farm in Champaign county which is devoted to the growing of corn, oats, and clover. It will be observed that the inclusion in the rotation of either oats or clover, or both, results in a demand for labor at times when the labor is not being used to its full capacity on the corn crop. Consequently a given acreage in a two- or three-year rotation, such as that used on the Morrow plots, could be handled with fewer men and work horses than if it were all planted to corn; also, more hours of work could be secured per man and per horse, and at a lower cost per hour. These statements should not be construed to mean that the two rotations used on these plots are ideal or that they are to be recommended in any particular case. Other rotations could be devised which might fit the conditions on any given farm better than these. The point is that diversification of crops grown in rotation does bring about a more economical distribution of farm labor than continuous cropping to the same crop.

Variations in the productive power of land are certain to be reflected in land values. In computing the cost of production to be deducted from the total crop value, as has been done in Tables 6 and 7, there has been included a charge of 5 percent interest on the value of the land, which is placed at $200. If, however, we base the value of the land on what it will produce, we have a vivid picture of what declining productiveness means. If all costs except the land charge are

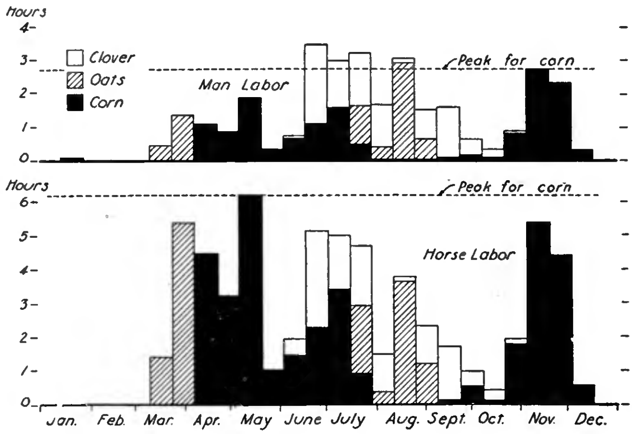

FIG. 18.—DISTRIBUTION OF LABOR THRU THE YEAR BY TWO-WEEK PERIODS ON TYPICAL CORN-BELT FARMS

The height of the bars represents the number of man hours or horse hours an acre required by the various crops. Diversification of crops grown in rotation brings about a more economical distribution of farm labor than continuous cropping to the same crop. The labor necessary in producing oats and clover, for instance, comes at a different time than the peak of the labor requirement for corn, and fills in the gaps when work would otherwise be slack.

deducted from the value of the crops, the remainder is the income to the land. By dividing this figure by .05, we obtain the land value upon which these crops would yield 5 percent interest. Thus in Fig. 20 are given the land values as determined by the soil management practices used on the Morrow plots. While they are slightly high, no manager's wage having been deducted, they do give an accurate expression of the relative land values of these plots based upon their productiveness.

One hesitates to extend these results obtained upon the Morrow plots to a state-wide basis. In the case of any given crop, such as corn, for example, the crop is grown on many soil types. The natural productiveness of these types varies greatly and the response of crops to fertilization or to other practices varies in no less degree. Furthermore, individuals differ so greatly in ability and efficiency that like treatments and rotations on two similar farms might produce very different financial returns under the management of different operators. However, some generalizations which apply to the state at large can safely be made.

The three-year rotation with soil treatment has produced more than 30 bushels of corn an acre a year in excess of the yield in the two-year rotation of corn and oats on untreated land (Table 3). The two-year rotation without soil treatment is very commonly practiced in the corn belt. It would not of course be fair to assume that this

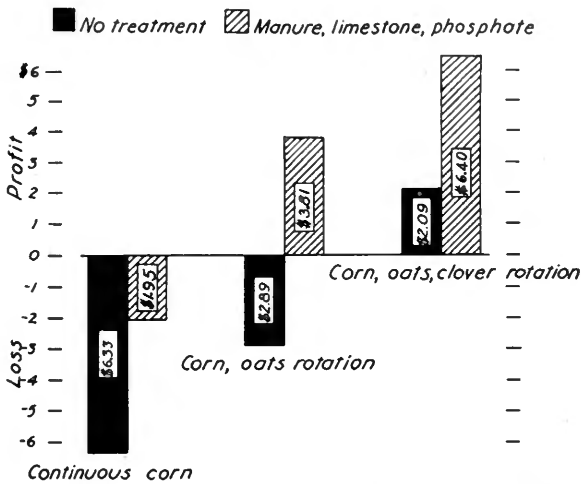

FIG. 19.—ANNUAL PROFIT AND LOSS FROM DIFFERENT METHODS OF FARMING PRACTICED ON THE MORROW PLOTS

Continuous corn production on the same land, even with a good fertilization program, cannot be made profitable over a long period of years. Alternation with oats effects a marked betterment in the situation, which is still further improved by the introduction of red clover. Similar improvement could be equally well accomplished by the use of other crops than oats and red clover. (Graph based on crop records for twenty-three years, 1904 to 1926. Land valued at $200 an acre, with interest rate of 5 percent.)

30-bushel increase might be obtained on the entire 8 million acres of corn grown in Illinois annually, an assumption that would appear to double the state's corn production. It can be said, however, that improved practices in rotation and fertilization would significantly raise the acre yield, possibly enough to offset the reduced corn acreage brought about by the introduction of other crops into the rotation.

Thus while the total amount of corn produced in the state would not, in all probability, be increased should the practice of a three-year rotation with clover and fertilizers be generally introduced, the present production or somewhat less than that would be secured on a greatly reduced acreage and at less cost, while at the same time a large area would be released for the growing of clovers and other crops. Also, without greatly affecting the total production of agricultural crops, the quality of the products would be improved, particularly as feed for animals, because of the increase in protein pro-

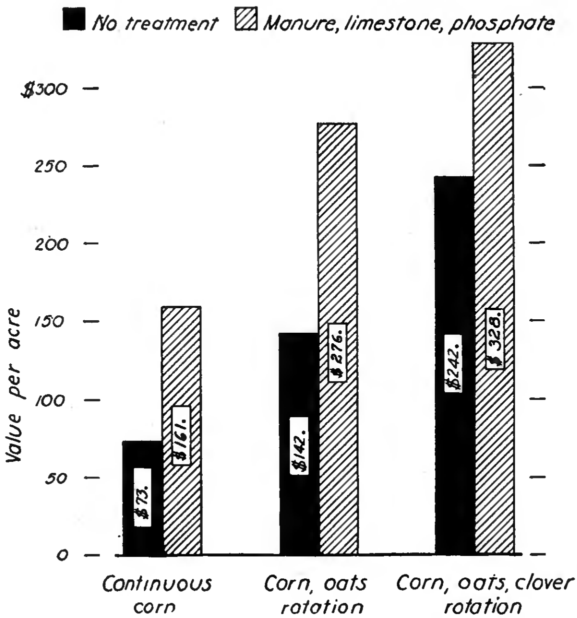

FIG. 20.—HOW LAND VALUES ARE AFFECTED BY SOIL TREATMENT AND CROP ROTATION

This graph, based on twenty-three years of crop records from the Morrow plots, shows how relatively low land values which result from soil exhaustion under poor management are replaced by mounting values as the capacity of the soil to produce good yields is increased thru good rotations and soil treatment.

duction. Protein feeds are required in balanced animal rations, and if not produced on the farm in the form of clover or other legumes, they have to be purchased, usually in the form of costly nitrogenous concentrates. Thus the economy of production would be improved, and the result would be a general improvement in the economic status of the farmer. These changes, moreover, might reasonably be expected to result in an upward trend in land values.

SUMMARY

The Morrow plots have been in operation for fifty-two years and are known as the oldest experimental soil plots in the United States. On one of the plots corn has been grown continuously; on a second plot a rotation of corn and oats has been practiced for the entire period; and on the third a rotation of corn, oats, and clover has been grown for the last twenty-four years. Results from these three cropping systems without fertilizers are presented from the twelfth year of the operation of these plots thru 1926, or for thirty-nine years, and results for the last twenty-three years are given for the same cropping systems with applications of manure, limestone, and phosphate.

Crop rotation has noticeably improved the yields over continuous corn growing. The three-year rotation has been more effective than the two-year rotation in maintaining yields over the entire period. The two-year rotation, however, has been gaining on the three-year rotation in recent years because of the influence of sweet clover.

Clover has been of much benefit in the cropping system, both red clover grown as a hay crop and sweet clover used as a green manure.

On the untreated land crop yields have steadily declined, not only where corn has been grown continuously, but also in the rotations. The decline is most pronounced, however, under continuous cropping to corn.

The manure, limestone, phosphate treatment in all three cropping systems has converted a downward trend in yield into an upward trend. The beneficial effect of the treatment has been even more pronounced in the good rotations than on the plot growing corn continuously.

Thruout the season the crops growing on the treated soil are usually at a more advanced stage of development than those growing on the untreated soil. In corn this shows up at husking time in drier, sounder ears than those found on the untreated land.

Cropping the land without treatment has used up phosphorus, nitrogen, and other elements, and has resulted in the destruction of organic matter by decay. While these decreases in total amount have been too small to be of great significance, the decrease in *active* organic matter and the removal of *available* plant-food elements has been a matter of much importance, being largely responsible for the decline in yielding power.

By increasing the proportion of active organic matter that can be readily attacked by microorganisms, the crop rotations and soil treatments used have had a marked effect in improving soil conditions for bacterial activity, as measured by the nitrate-production test.

The practices in rotation and soil treatment which have been the most effective in increasing the crop-producing capacity of the soil have also been the most profitable financially. These better practices not only have increased the yields but they have made possible a greater economy in production, an important factor in increasing farm profits.

The state-wide application of the better practices used on the Morrow plots, with modifications necessary to suit local conditions, would result in larger acre yields of all crops grown and in reduced production costs. Moreover the produce from the land would be better balanced in feeding value because of its higher protein content. These changes might reasonably be expected to result in an upward trend in land values and a general improvement in the economic status of the farmer.

TABLE 8.—ANNUAL ACRE YIELDS FROM MORROW PLOTS SHOWING SEPARATELY THE YIELDS FROM PLOTS TREATED WITH STEAMED BONE MEAL (bP) AND FROM THOSE TREATED WITH RAW ROCK PHOSPHATE (rP)

Year	Soil treatment applied[1]	Plot 3 Corn every year	Plot 4 Two-year rotation		Plot 5 Three-year rotation		
			Corn	Oats	Corn	Oats	Clover
		bu.	*bu.*	*bu.*	*bu.*	*bu.*	*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	70.2	....	....
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	0	21.1	....	17.5	51.4	....	....
	MLrP	16.1	....	22.5	76.4	....	....
	0	22.5	....	17.5	67.1	....	....
	MLbP	19.3	....	28.1	81.4	....	....
1905	0	22.5	48.0	....	....	35.6	....
	MLrP	26.8	40.0	....	....	45.0	....
	0	27.0	52.0	....	....	49.0	....
	MLbP	36.0	49.8	....	....	56.2	....
1906	0	25.3	....	30.6	....	....	1.36[2]
	MLrP	32.5	....	44.3	....	....	1.88[2]
	0	28.9	....	38.7	....	....	1.49[2]
	MLbP	39.1	....	60.6	....	....	1.60[2]
1907	0	28.5	43.9	....	77.4	....	....
	MLrP	40.8	81.4	....	91.4	....	....
	0	29.4	51.7	....	83.6	....	....
	MLbP	56.5	93.8	....	95.8	....	....
1908	0	10.9	....	31.9	....	38.8	....
	MLrP	24.8	....	46.9	....	43.8	....
	0	15.9	....	33.8	....	41.3	....
	MLbP	31.1	....	43.1	....	45.0	....
1909	0	26.4	31.6	....	....	....	.40 + .52[3]
	MLrP	30.4	60.4	....	....	....	1.72 + 1.17[3]
	0	26.8	34.4	....	....	....	.90 + .75[3]
	MLbP	32.8	69.2	....	....	....	1.75 + 1.17[3]
1910	0	32.6	....	31.3	52.3	....	....
	MLrP	48.9	....	51.9	78.3	....	....
	0	39.1	....	36.3	64.9	....	....
	MLbP	60.3	....	66.9	88.3	....	....
1911	0	20.7	26.6	....	....	16.0	....
	MLrP	29.0	44.4	....	....	37.8	....
	0	23.0	30.6	....	....	25.1	....
	MLbP	34.0	48.2	....	....	38.2	....
1912	0	40.0	....	52.8	....	....	1.20[4]
	MLrP	64.4	....	81.2	....	....	1.85[4]
	0	46.4	....	57.1	....	....	1.50[4]
	MLbP	64.0	....	80.9	....	....	1.55[4]

[1]Treatment on the south half of Plot 4 includes legume green manure beginning in 1904.
[2]Cowpea hay in 1906. [3]Clover seed harvested (bushels) in addition to hay.
[4]Soybean hay in 1912.

TABLE 8.—*Concluded*

Year	Soil treatment applied[1]	Plot 3 Corn every year	Plot 4 Two-year rotation		Plot 5 Three-year rotation		
			Corn	Oats	Corn	Oats	Clover
		bu.	*bu.*	*bu.*	*bu.*	*bu.*	*tons*
1913	0	17.6	26.8	....	29.6	....	....
	MLrP	32.4	22.0	....	45.2	....	....
	0	21.2	31.6	....	38.0	....	....
	MLbP	31.6	28.0	....	50.4	....	....
1914	0	28.8	....	32.9	....	33.9	....
	MLrP	37.2	....	56.9	....	58.9	....
	0	34.4	....	34.2	....	45.3	....
	MLbP	41.6	....	59.6	....	62.0	....
1915	0	37.6	48.0	....	....	....	1.75[2]
	MLrP	62.8	80.8	....	....	....	1.99[2]
	0	42.4	50.0	....	....	....	1.94[2]
	MLbP	69.2	81.6	....	....	....	1.94[3]
1916	0	10.8	....	33.8	26.8	....	....
	MLrP	9.6	....	62.5	37.6	....	....
	0	11.6	....	41.2	28.8	....	....
	MLbP	12.0	....	66.9	43.6	....	....
1917	0	40.8	44.4	....	....	59.4	....
	MLrP	60.4	77.6	....	....	82.5	....
	0	39.2	52.4	....	....	77.5	....
	MLbP	73.6	85.2	....	....	91.2	....
1918	0	13.2	....	25.6	....	....	2.37
	MLrP	29.6	....	53.1	....	....	4.05
	0	14.0	....	28.8	....	....	2.79
	MLbP	35.6	....	65.6	....	....	4.04
1919	0	21.6	30.0	....	51.6	....	....
	MLrP	41.2	65.6	....	69.2	....	....
	0	26.4	31.6	....	52.8	....	....
	MLbP	45.6	66.8	....	72.4	....	....
1920	0	26.8	....	36.2	....	47.5	....
	MLrP	52.0	....	48.1	....	73.8	....
	0	29.6	....	38.1	....	56.9	....
	MLbP	56.8	....	55.0	....	65.6	....
1921	0	16.0	26.8	....	....	....	.17 + .30[3]
	MLrP	38.4	68.0	....	....	....	1.47 + .80[3]
	0	23.6	34.4	....	....	....	.35 + .77[2]
	MLbP	46.0	68.8	....	....	....	1.18 + .90[3]
1922	0	21.3	....	37.5	45.1	....	....
	MLrP	38.5	....	56.3	67.3	....	....
	0	27.8	....	41.3	53.2	....	....
	MLbP	39.2	....	55.0	73.2	....	....
1923	0	13.2	16.4	....	....	50.0	....
	MLrP	32.0	50.4	....	....	67.5	....
	0	16.8	18.0	....	....	56.9	....
	MLbP	30.8	42.4	....	....	65.6	....
1924	0	27.2	....	34.4	....	....	1.67
	MLrP	40.4	....	68.1	....	....	4.29[4]
	0	28.8	....	37.5	....	....	1.98
	MLbP	35.6	....	68.8	....	....	4.54[4]
1925	0	15.4	25.6	....	40.2	....	....
	MLrP	41.7	39.4	....	57.4	....	....
	0	22.9	27.8	....	43.9	....	....
	MLbP	49.1	39.6	....	59.9	....	....
1926	0	20.4	....	23.8	....	40.6	....
	MLrP	33.2	....	76.3	....	83.1	....
	0	22.4	....	21.9	....	48.1	....
	MLbP	37.6	....	76.3	....	86.9	....

[1]Treatment on the south half of Plot 4 includes legume green manure beginning in 1904.
[2]Soybean hay in 1915. [3]Clover seed harvested (bushels) in addition to hay.
[4]Hay contaminated with sweet clover in 1924.

Note on Origin of Morrow Plots

As is often the case with things of great age, the exact date of the origin of the Morrow plots is somewhat veiled by uncertainty. A search thru the official University records of these early years has revealed the following statements which bear upon the subject:

In the minutes of a meeting of the Board of Trustees of the Illinois Industrial University held December 14, 1875 (page 153), occurs the following recommendation by Manley Miles, then professor of agriculture, referring to the need for rotation experiments:

"The larger portion of the farm should be cultivated with a variety of crops in rotation to illustrate as far as practicable the advantages of high tillage and thorough manuring. The advantages of a systematic alternation of crops should also be determined."

In the minutes for March 10, 1880, quoted in Bulletin 125 of the Agricultural Experiment Station (page 327), appear the following paragraphs:

"The Farm Committee then submitted the following report:

"To the Honorable Board of Trustees of the Illinois Industrial University:

"'Your committee beg leave to submit the following recommendations from the professor of agriculture [George E. Morrow] for the coming season: . . . . 'Fifth—the formal commencement of what is designed to be a long continued experiment to show the effect of the 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.'"

This record would appear to fix the date of the *official* commencement of these experiments as 1879. In the published bulletins of the Experiment Station, however, several references are made to these same plots,[1] all of which point to 1876 as the year in which the rotation experiments were actually started. These references are as follows:

In Bulletin 8 (February, 1890, page 266) T. F. Hunt, assistant agriculturist, states: "Ten half-acre plots, 5 x 16 rods, have been cropped during the past 14 years as follows . . . . ."

In Bulletin 13 (February, 1891, page 431) the same writer states: "Ten half-acre plots, 5 x 16 rods, have been cropped during the past 14 years as follows . . . . ." Evidently this statement was copied from Bulletin 8 without correcting the number of years as necessary in a publication of a year later.

In Bulletin 31 (March, 1894, page 357) Professor George E. Morrow makes the following statement: "For eighteen years tests have been made of the yield of corn on half-acre plots."

In Bulletin 31 (page 358), Bulletin 37 (page 20), and in Bulletin 42 (page 177) the column headings of the tables state, concerning Plots 1, 2, and 3, "In corn annually since 1876," and concerning Plots 4 to 10, "In rotation since 1876."

It seems proper to conclude, therefore, that the Morrow plots have been in operation for fifty-two years, including the present season, 1927.

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[1]The Morrow plot experiments are referred to as "Experiment 23" in all the early records.