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AGRICULTURAL EXPERIMENT STATION
KANSAS STATE COLLEGE OF AGRICULTURE
AND APPLIED SCIENCE
MANHATTAN, KANSAS

# TWENTY YEARS OF SOIL FERTILITY INVESTIGATIONS

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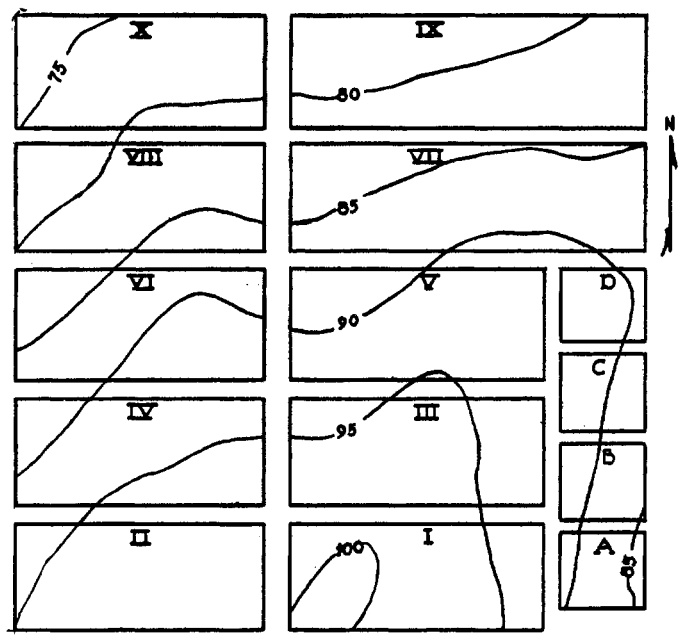


FIG. 1.—Plan of soil fertility project, showing series numbers and contour lines

# TWENTY YEARS OF SOIL FERTILITY INVESTIGATIONS[1]

R. I. THROCKMORTON AND F. L. DULEY

The farm land in much of Kansas is relatively new as compared with many other parts of the United States, and the soils are on the whole comparatively fertile. The fertility of these new soils, however, has already been greatly depleted because of improper cropping systems which have permitted severe erosion on many of the formerly fertile rolling prairies of the state.

This depletion of fertility has not been confined to the regions of greatest rainfall in eastern Kansas, but is gradually extending westward. Any methods that might be found to retard this depletion of the once fertile lands of the state should be of distinct value in the future. The experiments reported in this bulletin were originated with the idea of determining some of the more fundamental things governing the proper management of soils in the state.

## CLIMATIC CONDITIONS

The climatic conditions at Manhattan, Kan., like other points in this part of the United States, are subject to wide fluctuations. In order that some of the wide differences in crop yields from year to year may be understood, a summary of the monthly rainfall and temperature records is given in Tables I and II. It will be seen that except for 1915, when the total rainfall was 50.82 inches, there has not been a great variation in the annual rainfall, the lowest being 26.04 inches in 1914 and the highest 37.45 inches in 1927. The factor which has had the greatest effect on crops, particularly corn, has been the fluctuation in the July and August rainfall. This alone, however, will not satisfactorily explain the fluctuation in crop yields, which must also take into consideration the effects of excessively high temperatures. Table III shows the number of days when the maximum temperature reached 100° F. or more for the four months June to September. Only once did the temperature reach 100° in May. This was in 1913, making a total of 44 days during that year when these high temperatures were reached. Records of corn yields show that low yields have occurred most frequently in years when there have been a large number of days with very high temperatures. The average rainfall for the 20-year period covered by these experiments has been 31.84 inches. The 69-year average reported by the United States Weather Bureau for Manhattan is 31.1 inches.

1. Contribution No. 218 from the Department of Agronomy. The work on this project was originated in 1909-'10 by W. M. Jardine, then head of the Department of Agronomy, and L. E. Call, at that time professor of soils. From 1913 to 1925 the work was in charge of R. I. Throckmorton. F. L. Duley had direct charge of the work from 1925 to 1930.

TABLE I.—MONTHLY AND ANNUAL PRECIPITATION AT MANHATTAN, KANSAS

Precipitation in inches, 1911 to 1930 (*a*).

| Month | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | Av., 1911 to 1930 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan... | 0.61 | 0.30 | 0.75 | 0.10 | 2.60 | 1.47 | 0.30 | 0.65 | 0.26 | 0.12 | 1.08 | 0.35 | 0.01 | 0.54 | 0.15 | 1.15 | 0.33 | T | 1.95 | 0.85 | 0.68 |
| Feb... | 5.78 | 2.47 | 2.25 | 1.14 | 4.50 | .25 | .05 | .52 | 1.24 | .57 | .36 | 1.30 | .36 | 1.01 | .29 | 1.02 | 1.39 | 1.58 | .82 | .37 | 1.36 |
| Mar.. | .85 | 6.49 | .56 | 2.01 | 2.14 | 1.42 | .72 | .76 | 5.03 | .61 | .16 | 3.96 | 1.69 | 1.57 | 1.06 | 1.12 | 3.88 | 1.06 | .94 | .52 | 1.83 |
| Apr... | 1.89 | 1.40 | 2.96 | 1.19 | 2.04 | 2.17 | 4.59 | 4.60 | 3.40 | 4.17 | 2.95 | 5.13 | 2.67 | 1.15 | 4.13 | 1.73 | 5.48 | 1.77 | 5.49 | 6.72 | 3.28 |
| May.. | 2.18 | 1.93 | 7.18 | 2.33 | 9.45 | 6.40 | 5.04 | 5.17 | 3.15 | 1.75 | 3.32 | 3.70 | 3.07 | 2.60 | 1.48 | 1.55 | 1.67 | 2.21 | 3.35 | 5.23 | 3.64 |
| June.. | .10 | 3.53 | 1.55 | 4.58 | 6.69 | 7.43 | 4.80 | 1.56 | 4.66 | 2.24 | 6.25 | 3.52 | 6.64 | 3.02 | 6.57 | 1.74 | 7.59 | 4.99 | 7.96 | 6.39 | 4.59 |
| July.. | 2.13 | 3.23 | .17 | 2.40 | 12.01 | 1.92 | .68 | 1.98 | 1.45 | 4.83 | 4.21 | 6.08 | 8.31 | 3.75 | 3.18 | 2.02 | 3.42 | 7.38 | 3.05 | .57 | 3.64 |
| Aug... | 5.52 | 3.38 | .65 | 3.56 | 3.07 | .76 | 6.92 | 3.43 | 1.40 | 6.76 | 4.65 | .10 | 1.83 | 10.25 | 3.95 | 1.60 | 6.65 | 5.29 | 2.51 | 4.99 | 3.86 |
| Sept.. | 4.49 | 3.50 | 5.69 | 5.76 | 3.92 | 8.12 | 1.63 | 2.35 | 2.65 | 4.39 | 3.17 | 4.95 | 1.00 | 3.36 | 7.11 | 7.55 | 4.00 | 2.19 | 1.39 | 2.43 | 3.98 |
| Oct... | 1.55 | 3.37 | 2.61 | 1.58 | 2.71 | 2.65 | 1.06 | 4.87 | .68 | .90 | 1.38 | 2.14 | 2.76 | .65 | 2.42 | 4.40 | 2.31 | 1.33 | 5.07 | 2.86 | 2.37 |
| Nov.. | 1.05 | .05 | 1.92 | T | .93 | 3.42 | .10 | 1.55 | 2.62 | 2.20 | T | 5.86 | 1.08 | .29 | 1.16 | 1.65 | .09 | 5.79 | 1.10 | 3.14 | 1.70 |
| Dec... | 2.37 | .41 | 3.84 | 1.39 | .76 | 1.21 | .15 | 2.40 | .08 | 1.35 | .34 | .18 | .26 | 1.02 | .07 | 1.01 | .64 | .60 | T | .11 | .91 |
| Annl.. | 28.52 | 30.06 | 30.13 | 26.04 | 50.82 | 37.22 | 26.04 | 29.84 | 26.62 | 29.89 | 27.87 | 37.27 | 29.68 | 29.21 | 31.57 | 26.54 | 37.45 | 34.19 | 33.63 | 34.18 | 31.84 |

(*a*) Data from reports of the United States Weather Bureau.

TABLE II.—MEAN MONTHLY AND ANNUAL TEMPERATURES AT MANHATTAN, KANSAS

Degrees F., 1911 to 1930 (*a*).

| Month | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | Av., 1911 to 1930 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan... | 31.0 | 17.1 | 29.2 | 37.2 | 28.6 | 25.4 | 31.3 | 18.3 | 31.4 | 30.4 | 36.6 | 28.2 | 38.2 | 23.8 | 24.2 | 30.8 | 30.1 | 33.2 | 21.3 | 16.5 | 28.1 |
| Feb... | 34.4 | 28.1 | 26.1 | 28.1 | 38.1 | 30.5 | 31.0 | 34.4 | 34.0 | 34.5 | 40.2 | 33.4 | 30.8 | 35.2 | 38.9 | 40.3 | 38.0 | 36.8 | 23.9 | 47.2 | 34.2 |
| Mar.. | 45.8 | 30.5 | 39.2 | 43.9 | 35.0 | 46.7 | 44.3 | 50.8 | 44.2 | 45.4 | 51.6 | 44.8 | 41.7 | 37.0 | 48.6 | 41.2 | 44.0 | 48.2 | 47.6 | 43.6 | 43.7 |
| Apr... | 52.6 | 54.7 | 57.4 | 53.9 | 61.2 | 52.0 | 52.3 | 48.1 | 54.8 | 48.1 | 55.8 | 56.2 | 54.2 | 56.8 | 61.0 | 50.4 | 57.0 | 51.6 | 57.6 | 59.6 | 54.8 |
| May.. | 67.6 | 69.5 | 66.6 | 66.3 | 61.6 | 64.9 | 57.8 | 69.7 | 62.8 | 63.9 | 66.5 | 64.9 | 61.8 | 59.0 | 62.2 | 68.4 | 64.4 | 65.5 | 61.2 | 64.4 | 64.5 |
| June.. | 80.6 | 69.9 | 75.7 | 80.0 | 69.9 | 70.0 | 73.6 | 77.8 | 73.7 | 75.1 | 75.6 | 76.1 | 74.0 | 74.2 | 77.2 | 73.2 | 71.4 | 68.4 | 73.0 | 73.0 | 74.1 |
| July... | 80.1 | 81.2 | 83.6 | 82.0 | 75.4 | 80.5 | 80.6 | 77.8 | 81.4 | 77.2 | 79.6 | 76.2 | 78.2 | 76.4 | 79.0 | 80.4 | 76.4 | 77.8 | 79.5 | 83.6 | 79.2 |
| Aug... | 76.8 | 79.2 | 85.2 | 79.4 | 72.0 | 80.2 | 72.6 | 82.6 | 77.3 | 72.3 | 78.9 | 80.0 | 77.4 | 79.8 | 77.4 | 80.2 | 71.0 | 76.8 | 78.6 | 81.0 | 77.9 |
| Sept.. | 73.4 | 67.2 | 68.8 | 73.1 | 70.0 | 68.3 | 68.2 | 63.3 | 72.4 | 69.6 | 75.0 | 73.2 | 71.4 | 64.5 | 73.4 | 70.0 | 70.0 | 66.8 | 68.3 | 72.2 | 70.0 |
| Oct... | 54.3 | 58.2 | 55.2 | 61.1 | 60.6 | 57.8 | 50.1 | 61.0 | 55.1 | 60.8 | 60.8 | 60.3 | 53.6 | 62.6 | 47.0 | 58.3 | 60.8 | 59.2 | 58.2 | 55.6 | 57.5 |
| Nov.. | 38.2 | 46.4 | 50.9 | 50.4 | 48.9 | 45.3 | 48.6 | 44.2 | 40.0 | 40.0 | 42.8 | 46.2 | 45.0 | 45.9 | 42.7 | 40.0 | 43.4 | 43.4 | 37.7 | 46.7 | 44.3 |
| Dec... | 33.0 | 36.2 | 36.2 | 23.6 | 34.6 | 27.6 | 25.6 | 36.6 | 24.9 | 34.7 | 33.6 | 32.4 | 35.9 | 24.0 | 31.7 | 31.0 | 26.8 | 36.6 | 33.3 | 33.5 | 31.6 |
| Av.... | 55.6 | 53.2 | 56.2 | 56.6 | 54.7 | 54.1 | 53.0 | 55.4 | 54.3 | 54.3 | 58.1 | 56.0 | 55.2 | 53.3 | 55.3 | 55.4 | 54.4 | 55.4 | 53.4 | 56.4 | 55.0 |

(*a*) Data from reports of the United States Weather Bureau.

TABLE III.—NUMBER OF DAYS, JUNE TO SEPTEMBER, WHEN THE MAXIMUM TEMPERATURE WAS 100° F. OR ABOVE

| YEAR. | June. | July. | August. | September. | Total four months. |
|---|---|---|---|---|---|
| 1911 | 7 | 7 | 6 | 3 | 23 |
| 1912 | 0 | 3 | 4 | 4 | 11 |
| 1913 | 0 | 12 | 24 | 7 | (a) 43 |
| 1914 | 1 | 11 | 6 | 1 | 19 |
| 1915 | 0 | 0 | 0 | 0 | 0 |
| 1916 | 0 | 7 | 11 | 1 | 19 |
| 1917 | 1 | 8 | 1 | 0 | 10 |
| 1918 | 11 | 4 | 18 | 0 | 33 |
| 1919 | 1 | 13 | 6 | 2 | 22 |
| 1920 | 0 | 2 | 0 | 0 | 2 |
| 1921 | 0 | 0 | 4 | 0 | 4 |
| 1922 | 0 | 0 | 3 | 5 | 8 |
| 1923 | 0 | 0 | 1 | 0 | 1 |
| 1924 | 2 | 3 | 4 | 0 | 9 |
| 1925 | 0 | 4 | 1 | 3 | 8 |
| 1926 | 2 | 6 | 5 | 1 | 14 |
| 1927 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 1 | 0 | 0 | 1 |
| 1929 | 0 | 1 | 5 | 0 | 6 |
| 1930 | 0 | 18 | 9 | 0 | 27 |

(a) One day in May.

## ESTABLISHMENT OF EXPERIMENTS

These tests were established near Manhattan, Kan., on the agronomy farm, which was purchased by the state in 1909. The land is quite rolling, as may be seen from the contour map, figure 1. The plats, series I to X, were laid out in 1909, and some of the work started. On account of some of the soil treatments being incomplete the results for 1910 have not been included in this report. In 1914 series A, B, C, and D were added.

## PLAN OF EXPERIMENTS

The experiments were designed to study the effects of different cropping systems and soil treatments. After the work had been under way for some time, however, it was deemed advisable to make some changes in both the rotations and soil treatments.

The cropping systems used on the different series of plats have been as follows:

| Series | CROPPING SYSTEMS |
|---|---|
| I, II, III, IV | A 16-year rotation of alfalfa, 4 years; corn, corn, wheat for 12 years. The land is then put back to alfalfa. In 1922 one year of corn was changed to wheat, making the rotation: Alfalfa, 4 years; corn, wheat, wheat for 12 years. Plat 12 in each of these series has brome grass 4 years instead of alfalfa. |
| V, VI, VII | A 3-year rotation of corn, cowpeas, wheat. In 1928 soybeans were substituted for cowpeas. On plats 10 and 12 of the three series and on plats 13 and 15 of series VII, the rotation is: Corn, corn, wheat. |
| VIII | Wheat annually. |
| IX | Corn annually. |
| X | Alfalfa continuously. Since the beginning of the work it has been necessary to reseed this alfalfa twice, in 1923 and 1928. |
| A, B, C, D | A 16-year rotation of alfalfa, 4 years; kafir, corn, oats for 12 years. The land is then put back to alfalfa. |

## SOIL TREATMENTS

The fertilizer and other soil treatments used at the beginning of these tests were materially altered during the early years of the work. The changes in treatments are shown in Table IV. The large number of these changes makes it difficult to make definite comparisons, particularly on certain plats. The untreated check plats, however, have remained without change, and this affords a very definite basis for comparison of the different cropping systems.

TABLE IV.—CHANGES IN SOIL TREATMENTS

| Plat. | Soil Treatments. | Application, pounds (or T.) per acre. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1910 to 1914. | | | 1915 to 1920. | | | 1921 to 1930. | | |
| | | Alfalfa. | Corn. | Wheat. | Alfalfa. | Corn. | Wheat. | Alfalfa. | Corn. | Wheat. |
| | **Sixteen-year Rotation—Series I, II, III, and IV** | | | | | | | | | |
| 1 | Superphosphate | 190 | 75 | 80 | 190 | 75 | 80 | 190 | 75 | 80 |
| | Cowpeas, green manure (1910 to 1920) | | Preceding | corn. | | Preceding | corn. | | | |
| 2 | Check, no treatment | | | | | | | | | |
| 3 | Potassium sulfate | 180 | 50 | 40 | | | | | | |
| | Rock phosphate | | | | | | | | 1,500 | |
| | Cowpeas, green manure | | Preceding | corn. | | Preceding | corn. | | Preceding | corn. |
| 4 | Superphosphate | 190 | 75 | 80 | 190 | 75 | 80 | 190 | 75 | 80 |
| | Potassium sulfate | 180 | 50 | 40 | 180 | 50 | 40 | 90 | 50 | 40 |
| | Cowpeas, green manure (1910 to 1920) | | Preceding | corn. | | Preceding | corn. | | | |
| 5 | Check, no treatment | | | | | | | | | |
| 6 | Sodium nitrate | 240 | 225 | F 50<br>S 110 | 240 | 110 | S 80 | 240 | 110 | F 40<br>S 40 |
| | Superphosphate | 190 | 75 | 80 | 190 | 75 | 80 | 190 | 75 | 80 |
| | Potassium sulfate | 180 | 50 | 40 | 180 | 50 | 40 | 90 | 50 | 40 |
| 7 | Manure (*a*) | 5 T. | 5 T. | | 5 T. | 5 T. | | 5 T. | 5 T. | |
| | Superphosphate | | | | | | | 190 | 75 | 80 |
| | Cowpeas, green manure (1910 to 1920) | | Preceding | corn. | | Preceding | corn. | | | |
| 8 | Check, no treatment | | | | | | | | | |
| 9 | Manure | 5 T. | 5 T. | | 5 T. | 5 T. | | 5 T. | 5 T. | |
| 10 | Manure | 5 T. | 5 T. | | 5 T. | 5 T. | | 5 T. | 5 T. | |
| | Lime (*b*) | | 800 | | | 800 | | | 2 T. | |
| 11 | Check, no treatment | | | | | | | | | |
| 12 | Manure | 5 T. | 5 T. | | 5 T. | 5 T. | | 5 T. | 5 T. | |
| | Cowpeas, green manure | | Preceding | corn. | | Preceding | corn. | | | |
| | Brome grass instead of alfalfa. | | | | | | | | | |

TABLE IV.—CHANGES IN SOIL TREATMENTS—*Continued*

| Plat. | Soil Treatments. | Application, pounds (or T.) per acre. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1910 to 1914. | | | 1915 to 1920. | | | 1921 to 1930. | | |
| | | Corn. | Legume. | Wheat. | Corn. | Legume. | Wheat. | Corn. | Legume. | Wheat. |
| | **Three-year Rotations—Series V, VI, and VII** | | | | | | | | | |
| 1 | Superphosphate | 75 | 90 | 80 | 75 | 90 | 80 | 75 | 90 | 80 |
| | Sodium nitrate | 100 | 110 | F 30<br>S 50 | ..... | ..... | ..... | ..... | ..... | ..... |
| 2 | Check, no treatment | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 3 | Superphosphate | 75 | 90 | 80 | 75 | 90 | 80 | 75 | 90 | 80 |
| | Potassium sulfate | 50 | 70 | 40 | 50 | 70 | 40 | 50 | 70 | 40 |
| 4 | Sodium nitrate | 110 | 100 | F 30<br>S 50 | ..... | ..... | ..... | ..... | ..... | ..... |
| | Potassium sulfate | 50 | 70 | 40 | 50 | 70 | 40 | 50 | 70 | 40 |
| 5 | Check, no treatment | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 6 | Sodium nitrate | 110 | 100 | F 30<br>S 50 | 110 | 100 | 80 | 110 | 100 | F 40<br>S 40 |
| | Superphosphate | 75 | 90 | 80 | 75 | 90 | 80 | 75 | 90 | 80 |
| | Potassium sulfate | 50 | 70 | 40 | 50 | 70 | 40 | 50 | 70 | 40 |
| 7 | Manure | 2½ T. | ..... | 2½ T. | 2½ T. | ..... | 2½ T. | 2½ T. | ..... | 2½ T. |
| 8 | Check, no treatment | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 9 | Manure | 5 T. | ..... | ..... | 5 T. | ..... | ..... | 5 T. | ..... | ..... |
| 10 | Corn 2 years, wheat | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 11 | Check, no treatment | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |

TABLE IV.—CHANGES IN SOIL TREATMENTS—*Continued*

| Plat. | Soil Treatments. | Application, pounds (or T.) per acre. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1910 to 1914. | | | 1915 to 1920. | | | 1921 to 1930. | | |
| | | Corn. | Legume. | Wheat. | Corn. | Legume. | Wheat. | Corn. | Legume. | Wheat. |
| | **Three-year Rotations—Series V, VI, and VII**—Concluded | | | | | | | | | |
| 12 | Corn 2 years, wheat | | | | | | | | | |
| | Cowpeas, green manure | Pre | ceding | corn (*g*). | Pre | ceding | corn. | Pre | ceding | corn. |
| 13 (*c*) | Corn 2 years, wheat | | | | | | | | | |
| | Cowpeas, green manure | Pre | ceding | corn. | Pre | ceding | corn. | Pre | ceding | corn. |
| | Rock phosphate (*d*) | 1,000 | | | 1,000 | | | 1,000 | | |
| 14 (*c*) | Check, no treatment | | | | | | | | | |
| 15 (*c*) | Corn 2 years, wheat | | | | | | | | | |
| | Cowpeas, green manure | Pre | ceding | corn. | Pre | ceding | corn. | Pre | ceding | corn. |
| | Rock phosphate (*d*) | 500 | | | 500 | | | 500 | | |

TABLE IV.—CHANGES IN SOIL TREATMENTS—*Continued*

| | | 1910 to 1914. | 1915 to 1920. | 1921 to 1930. |
|---|---|---|---|---|
| | **Wheat Continuously—Series VIII** | | | |
| 1 | Superphosphate | 80 | 80 | 80 |
| | Sodium nitrate | F 50<br>S 110 | ..... | ..... |
| 2 | Check, no treatment | ..... | ..... | ..... |
| 3 | Superphosphate | 80 | 80 | 80 |
| | Potassium sulfate | 40 | 40 | 40 |
| 4 | Sodium nitrate | F 50<br>S 110 | ..... | ..... |
| | Potassium sulfate | 40 | 40 | 40 |
| 5 | Check, no treatment | ..... | ..... | ..... |
| 6 | Sodium nitrate | F 50<br>S 110 | ..... | F 40<br>S 40 |
| | Superphosphate | 80 | S 80<br>80 | 80 |
| | Potassium sulfate | 40 | 40 | 40 |
| 7 | Superphosphate | 80 | 80 | 80 |
| | Potassium sulfate | 40 | 40 | 40 |
| | Cowpeas, green manure | Annually | Every 3d yr. | Every 3d yr. |
| 8 | Check, no treatment | ..... | ..... | ..... |
| 9 | Cowpeas, green manure | Annually | Every 3d yr. | Every 3d yr. |
| 10 | Manure, annually | 2½ T. | 2½ T. | 2½ T. |
| 11 | Check, no treatment | ..... | ..... | ..... |
| 12 | Rape, green manure | Annually | ..... | ..... |
| | Cowpeas, green manure | ..... | Every 3d yr. | Every 3d yr. |
| | Rock phosphate every 3d yr | ..... | 1,000 | 1,000 |
| | **Corn Continuously—Series IX** | | | |
| 1 | Superphosphate | 75 | 75 | 75 |
| | Sodium nitrate | 225 | ..... | ..... |
| 2 | Superphosphate | 75 | 75 | 75 |
| | Potassium sulfate | 50 | 50 | 50 |
| 3 | Check, no treatment | ..... | ..... | ..... |
| 4 | Sodium nitrate | 225 | ..... | ..... |
| | Potassium sulfate | 50 | 50 | 50 |
| 5 | Manure | 2½ T. | 2½ T. | 2½ T. |
| 6 | Check, no treatment | ..... | ..... | ..... |
| 7 | Sodium nitrate | 225 | 110 | 110 |
| | Superphosphate | 75 | 75 | 75 |
| | Potassium sulfate | 50 | 50 | 50 |
| 8 | Superphosphate | 75 | 75 | 75 |
| | Potassium sulfate | 50 | 50 | 50 |
| | Cowpeas, green manure | Seeded after | last cultivati | on annually |
| 9 | Check, no treatment | ..... | ..... | ..... |
| 10 | Cowpeas, green manure | Seeded after | last cultivati | on annually. |
| 11 | Rape, green manure | Annually | ..... | ..... |
| | Cowpeas, green manure | Seeded after | last cultivati | on annually. |
| | Rock phosphate (every third year) | ..... | 1,000 | 1,000 |
| 12 | Check, no treatment | ..... | ..... | ..... |
| 13 | (e) | ..... | ..... | ..... |
| | Manure | ..... | 2½ T. | 2½ T. |
| | Superphosphate | ..... | 160 | 160 |

TABLE IV.—CHANGES IN SOIL TREATMENTS—*Concluded*

| | | 1910 to 1914. | 1915 to 1920. | 1921 to 1930. |
|---|---|---|---|---|
| | **Alfalfa Continuously—Series X** | | | |
| 1 | Superphosphate<br>Sodium nitrate | 190<br>240 | 190 | 190 |
| 2 | Check, no treatment | | | |
| 3 | Superphosphate<br>Potassium sulfate | 190<br>180 | 190<br>180 | 190<br>90 |
| 4 | Potassium sulfate<br>Sodium nitrate | 180<br>240 | 180 | 90 |
| 5 | Check, no treatment | | | |
| 6 | Sodium nitrate<br>Superphosphate<br>Potassium sulfate | 240<br>190<br>180 | 240<br>190<br>180 | 240<br>190<br>90 |
| 7 | Manure annually<br>Rock phosphate annually | 2½ T.<br>380 | 2½ T.<br>380 | 2½ T.<br>380 |
| 8 | Check, no treatment | | | |
| 9 | Manure annually | 2½ T. | 2½ T. | 2½ T. |
| 10 | Manure annually | 5 T. | 5 T. | 5 T. |
| 11 | Check, no treatment | | | |
| 12 | Manure annually<br>Lime (*f*) | 2½ T.<br>1,000 | 2½ T.<br>1,000 | 2½ T.<br>(*f*) |

**Sixteen-year Rotation—Series A, B, C, and D**

| | Alfalfa, 4 years; kafir, corn, oats for 12 years.<br>SOIL TREATMENTS BEGINNING IN 1915. |
|---|---|
| 1 | Manure (fresh), 10 tons per acre. Manure is applied in winter before kafir except when kafir follows alfalfa sod. On that year no manure is applied. |
| 2 | Manure (fresh), 10 tons; rock phosphate, 1,000 pounds per acre. Rock phosphate is applied with manure and also when alfalfa is broken. It is applied on the alfalfa sod before plowing. |
| 3 | Check, no treatment. |
| 4 | Manure (weathered), 10 tons. This manure is weighed out and placed in a pile in the spring and is allowed to weather until the following winter when the residue is spread at the same time that manure is applied to plats 1 and 2. See page 26 for table showing changes taking place in manure during weathering. |

F—fall; S—spring.

(*a*) Manure applied in late fall or early winter on corn land and third-year alfalfa. When alfalfa is broken no manure is applied before corn.

(*b*) Lime applied as hydrated lime 800 pounds per acre on corn until 1924. Since then all series have had 2-ton applications of pulverized limestone.

(*c*) Plats 13 to 15 on Series VII only. Started in 1913.

(*d*) Rock phosphate plowed under with green manure.

(*e*) *Plat 13.*—Cowpeas, green manure, 1912 and 1913; manure, 2½ T., and rock phosphate, 380 lbs., 1914.

(*f*) Hydrated lime applied 1910 and every 4th year until 1922. In 1926, 6 tons of pulverized limestone were applied, and in 1928, 1 ton.

(*g*) On plats 12, 13, and 15 the green manure was cowpeas seeded after wheat and turned under in the fall before first corn crop.

## EXPERIMENTAL RESULTS

### CALCULATION OF YIELDS

Owing to the fact that the soil on these plats was somewhat variable it was deemed advisable, in order to make all plats directly comparable, to correct all yields on the basis of the average yield of the check plats. The basic yield was assumed to be gradual from one check plat to another, and in the case of the end plats was assumed to extend uniformly from the second check plat through the first check and on to the end plat. The calculations can be greatly simplified by plotting the yields of the check plats on graph paper and reading the value of the basic yield directly.

### SIXTEEN-YEAR ROTATION

Alfalfa, 4 years; corn, corn, wheat for 12 years, changed to corn, wheat, wheat in 1922.

**Alfalfa.** — The alfalfa occupies the land of each series for a period of four years and during the progress of this work has been on all series once, on Series II a second time, and is now on Series IV for the second time. Plat 12 of each series has been in brome grass at the same time the other plats were in alfalfa.

It may be seen from the results given in Table V that superphosphate has given an average increase of 528 pounds of hay per acre, while superphosphate and potassium sulfate have given an increase of 1,169 pounds per acre, or an increase over the superphosphate alone of 641 pounds. There is some doubt as to whether this increase should all be credited to the effect of potassium sulfate, since the superphosphate plat is the end plat in all cases and is next to the middle roadway.

TABLE V.—YIELDS OF ALFALFA PER ACRE IN 16-YEAR ROTATION

1911 to 1930.

| Plat. | SOIL TREATMENTS. | Corrected yields. | Increase due to treatment. |
|---|---|---|---|
| | | *Lbs.* | *Lbs.* |
| 2, 5, 8, 11 | Checks, no treatment | 4,793 | ..... |
| 1 | Superphosphate | 5,321 | 528 |
| 3 | Green manure, rock phosphate | 5,415 | 622 |
| 4 | Superphosphate, potassium sulfate | 5,962 | 1,169 |
| 6 | Superphosphate, potassium sulfate, sodium nitrate | 6,178 | 1,385 |
| 7 | Manure, superphosphate | 5,893 | 1,100 |
| 9 | Manure | 5,870 | 1,077 |
| 10 | Manure, lime | 6,197 | 1,404 |
| 12 | Manure, brome grass | (*a*) 1,139 | (*b*)—3,654 |

(*a*) Yield of brome grass hay.
(*b*) Brome grass compared with alfalfa.

Although there is a narrow border between the plat and the roadway there is some question whether the plat may not be slightly affected. It will be noted also that there is a still further increase of 216 pounds due to the sodium nitrate. Plat 6, which receives nitrogen, phosphorus, and potassium, produced a higher yield than any other plat except plat 10, receiving manure and lime which produced only 19 pounds more hay per acre. The increased yield from lime and manure was only 327 pounds more than from manure alone, thus indicating that lime is not necessary at present for the growing of alfalfa on this land.

The brome grass made a very low hay yield as compared with alfalfa. It made a dense sod, but was usually cut only once a year.

**Corn.**—When this work was started, corn was used two years in the rotation. In 1921 one year of corn was dropped and a second year of wheat inserted because when wheat followed corn it was not possible to prepare a satisfactory seedbed, and wheat yields were abnormally low. Table VI shows the results of soil treatments on the yield of corn and stover. The principal thing shown by the results on corn is that, on the average, the use of phosphates has resulted in a decrease in the average yield of grain.

TABLE VI.—YIELDS OF CORN IN 16-YEAR ROTATION

| Plat. | Soil Treatments. | Yield per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain (*a*). | Stover. | Grain. | Stover. |
| | **First Year of Corn—Average, 1911 to 1930** | | | | |
| | | *Bus.* | *Lbs.* | *Bus.* | *Lbs.* |
| 2, 5, 8, 11 | Checks, no treatment | 33.60 | 3,568 | ..... | ..... |
| 1 | Superphosphate | 29.90 | 3,350 | —3.70 | —218 |
| 3 | Green manure, rock phosphate, potassium sulfate | 32.61 | 3,810 | —.99 | 242 |
| 4 | Superphosphate, potassium sulfate | 33.54 | 3,870 | —.06 | 302 |
| 6 | Superphosphate, sodium nitrate | 35.27 | 3,892 | 1.67 | 324 |
| 7 | Manure, superphosphate | 36.19 | 3,858 | 2.59 | 290 |
| 9 | Manure | 36.52 | 3,885 | 2.92 | 317 |
| 10 | Manure, lime | 36.41 | 3,996 | 2.81 | 428 |
| 12 | Manure, brome grass | 34.89 | 3,789 | 1.29 | 221 |

TABLE VI.—YIELDS OF CORN IN 16-YEAR ROTATION—*Concluded*

| Plat. | Soil Treatments. | Yield per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain (*a*). | Stover. | Grain. | Stover. |
| **Second Year of Corn—Average, 1911 to 1920** | | | | | |
| | | *Bus.* | *Lbs.* | *Bus.* | *Lbs.* |
| 2, 5, 8, 11 | Check, no treatment | 24.80 | 3,414 | ..... | ..... |
| 1 | Superphosphate; cowpeas, green manure | 24.63 | 3,451 | —0.17 | 37 |
| 3 | Cowpeas, green manure | 25.17 | 3,574 | .37 | 160 |
| 4 | Superphosphate; potassium sulfate; cowpeas, green manure | 25.32 | 3,733 | .52 | 329 |
| 6 | Sodium nitrate, superphosphate, potassium sulfate | 24.95 | 3,594 | .15 | 180 |
| 7 | Manure; cowpeas, green manure | 26.96 | 3,727 | 2.16 | 313 |
| 9 | Manure | 27.06 | 3,757 | 2.26 | 343 |
| 10 | Manure; lime; cowpeas, green manure | 26.81 | 3,768 | 2.01 | 354 |
| 12 | Manure; cowpeas, green manure; brome grass instead of alfalfa | 24.94 | 3,704 | .14 | 290 |

(*a*) In 1913 and 1918 the grain yield was a complete failure. The stover was cut for silage and weighed green; therefore, weights of stover for these years are not included. The first-year corn was also a failure in 1914 and no grain yields were taken. The weights of dry stover were obtained and the yields included.

Plat 6, which receives nitrogen in addition to phosphate and potassium sulfate, has given a small increase. The plat receiving manure has produced an average increase over the no-treatment plat of less than 3 bushels per acre. Corn following brome grass has been nearly as good as corn in rotation with alfalfa. On the average, none of the soil treatments used in these tests has shown any very striking results with corn.

**Wheat.**— During the early years of this work the wheat was somewhat at a disadvantage because it was always seeded after corn. In 1922 one year of corn was dropped from the rotation and another year of wheat added. This gave one wheat crop following corn and the second crop following wheat. The average yields of grain and straw are shown in Table VII.

It may be seen from these results that soil treatments have been much more effective on wheat than on corn. The average yields of wheat from the untreated plats for the second year of wheat in the rotation have been 3.94 bushels higher than those of the wheat following corn when the years 1922 to 1930 are averaged. The increases due to soil treatments also have been higher in most cases. These differences are brought out by a comparison of the various sections of Table VII. In the second-year wheat, plat 6, which receives the application of a complete fertilizer, is decidedly the highest-yielding plat. The average increase for the two wheat crops

TABLE VII.—AVERAGE CORRECTED YIELDS OF WHEAT AND STRAW FOLLOWING CORN IN 16-YEAR ROTATION (1911 TO 1930), FOLLOWING WHEAT IN 16-YEAR ROTATION (1922 TO 1930), AND FOLLOWING CORN IN 16-YEAR ROTATION (1922 TO 1930).

| Plat. | Soil Treatments (a). | Corrected yields per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain. | Straw. | Grain. | Straw. |
| **Following Corn in Sixteen-year Rotation—1911 to 1930** | | | | | |
| | | *Bus.* | *Lbs.* | *Bus.* | *Lbs.* |
| 2, 5, 8, 11 | Checks, no treatment | 18.00 | 2,144 | ..... | ..... |
| 1 | Superphosphate | 18.87 | 2,105 | 0.87 | —39 |
| 3 | Green manure, rock phosphate | 20.55 | 2,388 | 2.55 | 244 |
| 4 | Superphosphate, potassium sulfate | 20.99 | 2,266 | 2.99 | 122 |
| 6 | Sodium nitrate, superphosphate, potassium sulfate | 22.59 | 2,518 | 4.59 | 374 |
| 7 | Manure, superphosphate | 22.42 | 2,579 | 4.42 | 435 |
| 9 | Manure | 22.35 | 2,679 | 4.35 | 535 |
| 10 | Manure, lime | 22.77 | 2,769 | 4.77 | 625 |
| 12 | Manure, brome grass | 22.52 | 2,517 | 4.52 | 373 |
| **Following Wheat in Sixteen-year Rotation—1922 to 1930 (b)** | | | | | |
| 2, 5, 8, 11 | Checks, no treatment | 24.10 | 2,658 | ..... | ..... |
| 1 | Superphosphate | 26.49 | 2,636 | 2.39 | —22 |
| 3 | Green manure, rock phosphate | 28.05 | 3,111 | 3.95 | 453 |
| 4 | Superphosphate, potassium sulfate | 29.04 | 2,942 | 4.94 | 284 |
| 6 | Sodium nitrate, superphosphate, potassium sulfate | 32.57 | 3,532 | 8.47 | 874 |
| 7 | Manure, superphosphate | 30.52 | 3,537 | 6.42 | 879 |
| 9 | Manure | 27.69 | 3,079 | 3.59 | 421 |
| 10 | Manure, lime | 30.61 | 3,647 | 6.51 | 989 |
| 12 | Manure, brome grass | 27.89 | 2,795 | 3.79 | 137 |
| **Following Corn in Sixteen-year Rotation—1922 to 1930** | | | | | |
| 2, 5, 8, 11 | Checks, no treatment | 20.16 | 2,149 | ..... | ..... |
| 1 | Superphosphate | 20.67 | 2,143 | 0.51 | —6 |
| 3 | Green manure, rock phosphate | 24.53 | 2,684 | 4.37 | 535 |
| 4 | Superphosphate, potassium sulfate | 23.88 | 2,430 | 3 72 | 281 |
| 6 | Sodium nitrate, superphosphate, potassium sulfate | 25.73 | 2,749 | 5.57 | 645 |
| 7 | Manure, superphosphate | 26.28 | 2,949 | 6.12 | 800 |
| 9 | Manure | 24.40 | 2,689 | 4.24 | 540 |
| 10 | Manure, lime | 26.31 | 2,800 | 6.15 | 651 |
| 12 | Manure, brome grass | 22.45 | 1,966 | 2.29 | —183 |

(a) See Table IV for changes in treatments and rate of application of fertilizers.
(b) Rotation changed in 1922 from two years of corn and one year of wheat to one year of corn and two years of wheat for 12 years following alfalfa in the 16-year rotation.

is also higher for this treatment. In the first year after corn, however, the yields of the plat receiving manure and superphosphate and the plat receiving manure and lime are slightly higher for the period 1922 to 1930.

### THREE-YEAR ROTATION

On Series V, VI, and VII a three-year rotation of corn, cowpeas, and wheat has been followed. In 1928 soybeans were substituted for cowpeas. On plats 10 and 12 the rotation is corn, corn, wheat. This rotation was inserted to determine the effect of substituting corn for the legume in the rotation. On Series VII there are three additional plats that were added to study the effect of raw rock phosphate.

**Corn.**—The average results with corn are shown in Table VIII. These tests show that manure has given higher increases in yields of corn than the fertilizer. Plat 6 that received a complete fertilizer is the only fertilized plat that did not show a decrease in yield. Rock phosphate gave some increase on the second-year corn. The effect of leaving out the legume has been to reduce the yield of corn by 5.08 bushels per acre. Dividing the application of manure and placing one half of it on the wheat and one half on the corn had practically no influence on the yield compared with making the full application on the corn. Rock phosphate has given some increase, but not enough to pay for the cost of treatment.

TABLE VIII.—AVERAGE CORRECTED YIELDS OF CORN, 1911 TO 1930, THREE-YEAR ROTATION

| Plat. | Soil Treatments. | Corrected yields per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain. | Stover. | Grain. | Stover. |
| 2, 5, 8, 11 | Checks, no treatment | *Bus.* 30.69 | *Lbs.* 3,253 | *Bus.* ..... | *Lbs.* ..... |
| 1 | Superphosphate | 27.16 | 3,015 | —3.53 | —238 |
| 3 | Superphosphate, potassium sulfate | 29.58 | 3,168 | —1.11 | —85 |
| 4 | Potassium sulfate | 30.26 | 3,229 | —.43 | —24 |
| 6 | Superphosphate, potassium sulfate, sodium nitrate | 33.37 | 3,626 | 2.68 | 373 |
| 7 | Manure, 2½ T., on corn and wheat | 34.78 | 3,495 | 4.09 | 242 |
| 9 | Manure, 5 T., on corn | 34.82 | 3,554 | 4.13 | 301 |
| 10 | Corn, corn, wheat | 25.61 | 3,019 | —5.08 | —234 |
| 12 | Corn, corn, wheat, cowpeas as green manure | 30.95 | 3,292 | .26 | 39 |
| 13 | Same as 12, plus rock phosphate 1,000 lbs | 33.52 | 3,377 | —1.33 | 105 |
| 15 | Same as 12, plus rock phosphate 500 lbs | 32.85 | 3,507 | —2.00 | 235 |
| 14 | Check for plats 13 and 15 (*a*) | 34.85 | 3,272 | ..... | ..... |

TABLE VIII.—AVERAGE CORRECTED YIELDS OF CORN, 1911 TO 1930, THREE-YEAR ROTATION—*Concluded*

| Plat. | Soil Treatments. | Corrected yield per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain. | Stover. | Grain. | Stover. |
| | **Corrected Yields of Corn, Second Year, in Corn, Corn, Wheat Rotation (b)** | | | | |
| | | *Bus.* | *Lbs.* | *Bus.* | *Lbs.* |
| 10 (c) | Corn, corn, wheat | 25.30 | 2,797 | ..... | ..... |
| 12 (c) | Corn, corn, wheat, cowpeas as green manure | 26.38 | 3,138 | 1.08 | 341 |
| 13 | Same as 12, plus rock phosphate 1,000 lbs | 29.43 | 3,902 | 8.35 | 1,158 |
| 15 | Same as 12, plus rock phosphate 500 lbs | 27.18 | 3,598 | 6.10 | 854 |
| 10 (d) | Corn, corn, wheat | 21.08 | 2,744 | ..... | ..... |
| 12 (d) | Corn, corn, wheat, cowpeas as green manure | 26.42 | 3,160 | 5.34 | 416 |

(a) Corn, cowpeas, wheat rotation. Plats 13 to 15 are on Series VII only. They have had but six crops of corn, one of which (1918) was a complete failure. The increase for plats 13 and 15 is obtained by comparison with plat 14.
(b) When the other plats of the series are in a legume these plats are in corn.
(c) Average for all years.
(d) Average for years when plats 10, 12, 13, and 15 on Series VII were in corn second year. Increase for plats 13 and 15 obtained by comparison with plat 10 on years when Series VII was in corn.

Green manure, which consisted of cowpeas seeded after wheat and grown during the summer from about July 15 to October 1, has increased the yield of the following corn crop 5.34 bushels per acre. The second crop of corn has been increased 1.08 bushels and the yield of wheat 0.85 of a bushel, as shown in Table IX. These increases would about pay the cost of seed and seeding, but the increase is too small to justify a wide interest in this practice.

**Wheat.**—The yields of wheat as shown by Table IX have been increased slightly by all soil treatments. The greatest increase was on plat 6, which received a complete fertilizer. The manured plats also gave a reasonably good increase. Whether the manure was all applied to the corn or divided on corn and wheat made little difference in yield. The heavy application of rock phosphate gave a fair increase, but the lighter application gave a negligible increase on the grain and a decrease in yield of straw.

The rotation of corn, corn, wheat, plat 10, gave 3.23 bushels per acre less wheat than where the rotation was corn, cowpeas, wheat.

Soybeans have in some cases seemed to retard the growth of wheat, because the crop removes moisture and plant nutrients from the soil until late in the growing season. The crop is removed only about three weeks before wheat seeding time. The development of nitrates has been shown to be very slow after wheat is seeded on disked soybean stubble.

**Cowpeas and Soybeans.**—This soil has produced cowpeas and soybeans quite satisfactorily without any special soil treatment. The use of phosphate alone, as shown in Table X, has been of no value, and even indicates a slight loss in yield. The manure treat-

TABLE IX.—AVERAGE YIELD OF WHEAT IN THREE-YEAR ROTATION, 1911 TO 1930

| Plat. | Soil Treatments. | Corrected yields per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain. | Straw. | Grain. | Straw. |
| | | *Bus.* | *Lbs.* | *Bus.* | *Lbs.* |
| 2, 5, 8, 11 | Checks, no treatment | 17.33 | 1,798 | ..... | ..... |
| 1 | Superphosphate | 18.43 | 2,032 | 1.10 | 234 |
| 3 | Superphosphate, potassium sulfate | 20.03 | 1,981 | 2.70 | 183 |
| 4 | Potassium sulfate | 17.66 | 1,809 | .33 | 11 |
| 6 | Superphosphate, potassium sulfate, sodium nitrate | 24.52 | 2,538 | 7.19 | 740 |
| 7 | Manure, 2½ T., on corn and wheat | 21.50 | 2,257 | 4.17 | 459 |
| 9 | Manure, 5 T., on corn | 21.90 | 2,231 | 4.57 | 453 |
| 10 | Corn, corn, wheat | 14.10 | 1,392 | —3.23 | —406 |
| 12 | Corn, corn, wheat, cowpeas as green manure | 14.95 | 1,682 | —2.38 | —116 |
| 13 | Same as 12, except rock phosphate, 1,000 lbs | (*a*) 19.68 | (*a*) 2,308 | (*b*) 3.70 | (*b*) 346 |
| 15 | Same as 12, except rock phosphate, 500 lbs | 16.54 | 1,656 | .56 | —306 |
| 14 | Check for plats 13 and 15 | 16.35 | 1,968 | ..... | ..... |
| 12 | Same six years as plats 13 and 15 | 15.98 | 1,962 | ..... | ..... |

(*a*) Plats 13 to 15 in wheat 1914, 1917, 1920, 1923, 1926, and 1929.
(*b*) Increase from rock phosphate obtained by comparing with yield of plat 12 on the same years.

ments have shown some increase on these crops, but only about one fourth of a ton per acre. The largest increase has resulted from the complete fertilizer treatment. There seems to be no satisfactory explanation for this, since the plants were usually well inoculated and presumably should have been able to get sufficient nitrogen for their growth.

TABLE X.—AVERAGE YIELD OF COWPEAS AND SOYBEANS IN THREE-YEAR ROTATION 1911 to 1930 (*a*).

| Plat. | Soil Treatments. | Yield of hay per acre. | Increase due to treatment. |
|---|---|---|---|
| | | *Lbs.* | *Lbs.* |
| 2, 5, 8, 11 | Check, no treatment | 3,869 | ..... |
| 1 | Superphosphate | 3,678 | —191 |
| 3 | Superphosphate, potassium sulfate | 3,938 | 69 |
| 4 | Potassium sulfate | 4,028 | 159 |
| 6 | Superphosphate, potassium sulfate, sodium nitrate | 4,635 | 766 |
| 7 | Manure, 2½ T. on corn and wheat | 4,387 | 518 |
| 9 | Manure, 5 T. on corn | 4,338 | 469 |

(*a*) Cowpeas, 1911 to 1927; soybeans, 1928 to 1930.

### WHEAT CONTINUOUSLY-SERIES VIII

This land was in wheat for about six years immediately before these experiments were begun and continuously during the 20 years of the experiments. This may in part account for the fact that the yield has held up throughout these tests to approximately where it was during the first few years of the experiments. (Tables XI and XXI.)

TABLE XI.—AVERAGE YIELD OF WHEAT GROWN CONTINUOUSLY ON THE SAME LAND 1911 to 1930.

| Plat. | Soil Treatments (a), | Yield per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain. | Straw. | Grain. | Straw. |
| 2, 5, 8, 11 | Checks, no treatment | *Bus.* 15.31 | *Lbs.* 1,860 | ..... | ..... |
| 1 | Superphosphate | 16.34 | 1,929 | 1.03 | 69 |
| 3 | Superphosphate, potassium sulfate | 18.45 | 1,991 | 3.14 | 131 |
| 4 | Potassium sulfate | 15.68 | 1,799 | .37 | —61 |
| 6 | Superphosphate, potassium sulfate, sodium nitrate | 20.85 | 2,467 | 5.54 | 607 |
| 7 | Superphosphate, potassium sulfate, green manure every 3d year | 20.05 | 2,290 | 4.74 | 430 |
| 9 | Green manure every 3d year | 14.18 | 1,837 | —1.13 | —23 |
| 10 | Manure | 21.89 | 2,673 | 6.58 | 813 |
| 12 | Rock phosphate, green manure every 3d year, | 18.79 | 2,323 | 3.48 | 463 |

(a) See Table IV for changes in treatments.

The results from fertilizer and manure have been no more striking than on the rotated land. The plat receiving manure, 2 1/2 tons annually, gave the greatest increase in yield, but was closely followed by plat 6, which had complete fertilizer. The green manure grown between wheat crops every third year on plat 7 did not result in so high yields as were produced on plat 6 where nitrogen was supplied in the form of sodium nitrate.

### CORN CONTINUOUSLY— SERIES IX

The corn grown continuously on the same land has given decidedly lower yields than the corn grown in rotation. A part of this difference, however, is undoubtedly due to the fact that this series is farther down the slope and erosion has been more severe. This has put the continuous corn at a decided disadvantage.

Owing to the lack of uniformity between the different plats the results from the various treatments as shown in Table XII are not so consistent in some cases as might be expected. Plat 1 is on land that is decidedly more fertile than plats 2 and 3. Plat 3 has been

TABLE XII.—AVERAGE YIELDS OF CORN GROWN ON THE SAME LAND CONTINUOUSLY 1911 to 1930 (*a*).

| Plat. | Soil Treatments. | Yield per acre. | | Increase due to treatment. | |
|---|---|---|---|---|---|
| | | Grain. | Stover. | Grain. | Stover. |
| 3, 6, 9, 12 | Checks, no treatment | *Bus.* 19.42 | *Lbs.* 2,240 | *Bus.* ..... | *Lbs.* ..... |
| 1 | Superphosphate | 28.08 | 3,217 | 8.66 | 977 |
| 2 | Superphosphate, potassium sulfate | 21.61 | 2,832 | 2.19 | 592 |
| 4 | Potassium sulfate | 22.53 | 2,638 | 3.11 | 398 |
| 5 | Manure | 26.54 | 2,819 | 7.12 | 579 |
| 7 | Superphosphate, potassium sulfate, sodium nitrate | 25.96 | 2,771 | 6.54 | 531 |
| 8 | Superphosphate, potassium sulfate, green manure | 23.02 | 2,614 | 3.60 | 374 |
| 10 | Cowpeas, green manure, every year | 22.47 | 2,547 | 3.05 | 307 |
| 11 | Green manure, rock phosphate | 21.83 | 2,668 | 2.41 | 428 |
| 13 | Superphosphate, barnyard manure | 23.50 | 2,737 | 4.08 | 497 |

(*a*) Complete failure of grain in 1913 and 1918, but these years are included in the averages.

very severely eroded. This difference in fertility undoubtedly accounts for the greater increase indicated for superphosphate on this series as compared with the results in the rotations. Plats 4 to 13 are more uniform and erosion has been less severe than on plats 2 to 4. Plats 5, 7, and 13 usually stand out well as compared with the other plats. Cowpeas seeded at last cultivation and used as green manure gave a fair increase. Rock phosphate failed to increase the yield when added to the green manure treatment. Superphosphate and manure gave a smaller yield than manure alone.

### ALFALFA CONTINUOUSLY—SERIES X

The average yields on this series have been far below the yields in the 16-year rotation. This difference cannot, however, all be attributed to the advantage of rotation, since the yields at the beginning of the test showed that the land where this series is located was decidedly poorer than that of the 16-year rotation. This point will be discussed more in detail in a later paragraph.

The frequent seeding of alfalfa in the 16-year rotation reduces the yield, since the production during the year following seeding is usually low. The continuous alfalfa had to be reseeded twice since the beginning of the tests, in 1923 and again in 1928.

The effect of soil treatments as shown in Table XIII is quite marked in several cases. Superphosphate alone gave an average increase of 691 pounds per acre. When potassium sulfate was added to this a further increase of 201 pounds was obtained, but when po-

TABLE XIII.—AVERAGE YIELDS OF ALFALFA GROWN CONTINUOUSLY ON THE SAME LAND

1911 to 1930.

| Plat. | Soil Treatments. | Yield per acre. | Increase due to treatment. |
|---|---|---|---|
| | | *Lbs.* | *Lbs.* |
| 2, 5, 8, 11 | Checks, no treatment | 2,683 | ..... |
| 1 | Superphosphate | 3,374 | 691 |
| 3 | Superphosphate, potassium sulfate | 3,575 | 892 |
| 4 | Potassium sulfate | 2,637 | —46 |
| 6 | Superphosphate, potassium sulfate, sodium nitrate | 3,779 | 1,096 |
| 7 | Manure, 2½ T., rock phosphate | 4,933 | 2,250 |
| 9 | Manure, 2½ T. | 4,494 | 1,811 |
| 10 | Manure, 5 T. | 5,641 | 2,958 |
| 12 | Manure, 2½ T., lime | 4,793 | 2,110 |

tassium sulfate was used alone the yield was slightly less than the untreated yield. The complete fertilizer on plat 6 increased the yield slightly over one half ton per acre, and maintained a good stand throughout most of the period. The addition of nitrogen increased the yield somewhat over plat 3, which received superphosphate and potassium sulfate. Manure and rock phosphate and manure and lime have been about equally effective. Manure alone when used at 2 1/2 tons per acre gave an increase of 1,811 pounds, while 5 tons per acre gave 2,958 pounds increase, which was more than any other treatment.

The yields on this series have been reduced in recent years because of the exhaustion of moisture in the deep subsoil. During periods of dry weather when the surface soil moisture is low very little growth is made. At such periods growth is suspended until rains come, when it is resumed.

**Sixteen-year Rotation—Series A, B, C, and D**

Alfalfa, 4 years; kafir, corn, oats for 12 years.

A second 16-year rotation was started in 1913, or three years after the work was begun on Series I to X. The yields reported begin with the crop of 1914 and therefore cover a period of 17 years. The first yields of alfalfa, however, are reported for 1915. The main object in this rotation was for comparison with the 16-year rotation on Series I to IV, which included alfalfa 4 years, corn, wheat, wheat. The soil treatments were for determining the effect of rock phosphate when used to reinforce manure, and the effect of allowing manure to weather before applying.

TABLE XIV.—AVERAGE YIELDS PER ACRE ON SERIES A, B, C, AND D

1914 to 1930

| Plat. | Soil Treatment. | Alfalfa (a). | | Kafir. | | Corn. | | Oats. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Yield per acre. | Increase due to treatment. | Yield per acre, grain. | Increase due to treatment. | Yield per acre, grain. | Increase due to treatment. | Yield per acre, grain. | Increase due to treatment. |
| | | *Lbs.* | *Lbs.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* |
| 1 | Manure | 6,410 | 264 | 41.01 | 0.22 | 37.88 | —1.09 | 42.42 | 6.14 |
| 2 | Manure, rock phosphate | 7,224 | 1,078 | 45.44 | 4.65 | 42.68 | 3.71 | 44.33 | 8.05 |
| 3 | Check, no treatment | 6,146 | ..... | 40.79 | ..... | 38.97 | ..... | 36.28 | ..... |
| 4 | Manure (weathered) | 6,664 | 518 | 41.14 | .35 | 38.09 | —.88 | 40.41 | 4.13 |
| | **Straw and Stover.** | | | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* |
| 1 | Manure | ..... | ..... | 7,588 | 540 | 3,796 | 287 | 1,987 | 271 |
| 2 | Manure, rock phosphate | ..... | ..... | 7,760 | 712 | 3,959 | 450 | 2,150 | 434 |
| 3 | Check, no treatment | ..... | ..... | 7,048 | ..... | 3,509 | ..... | 1,716 | ..... |
| 4 | Manure (weathered) | ..... | ..... | 6,988 | —60 | 3,654 | 145 | 1,892 | 176 |

(a) Yields of alfalfa are for 1915 to 1930.

The results given in Table XIV show that this land has produced higher yields of crops on the untreated land than were produced on untreated land in the 16-year rotation, Series I to IV. The increases in yield due to soil treatments have not been very striking. Alfalfa yields were increased an average of only 264 pounds per acre by the use of fresh manure and 1,078 pounds by manure and rock phosphate. The yields of kafir and corn were very slightly affected by the use of manure. Rock phosphate gave some increase but not enough to be considered profitable. The manure had more effect on oats than on corn and kafir, but the effect of the rock phosphate was less. The weathered manure gave higher yields of all crops except oats than did the fresh manure. However, the fresh manure produced higher yields of straw and stover.

### COMPOSITION OF MANURE USED

The average composition of manure used on these plats is given in Table XV. It will be seen that the amount of plant food added in the manure used on plat 4, even though it had been leached, was almost as high as that used on plats 1 and 2. This is due in part at least to the fact that the manure placed outside for leaching in the spring was, on the average, a little higher in plant food than that applied during the winter.

TABLE XV.—AVERAGE COMPOSITION OF MANURE USED

| | Total dry matter per ton. | Pounds per ton. | | |
|---|---|---|---|---|
| | | Nitrogen. | Phosphorus. | Potassium. |
| | *Lbs.* | | | |
| Fresh manure applied in fall or winter.... | 814 | 13.18 | 4.23 | 17.04 |
| Fresh manure used for leaching..... | 817 | 15.47 | 4.48 | 18.72 |
| Same manure as above after weathering (*a*) | 596 | 11.57 | 3.76 | 12.47 |
| Percentage of loss during weathering..... | 27.05 | 25.21 | 15.07 | 33.38 |

(*a*) This represents the amount of plant food left after one ton of manure had been weathered for approximately seven months.

### SULFUR TREATMENTS FOR ALFALFA

In the spring of 1919 a few additional plats were started to determine the effect of sulfur applications on the growth of alfalfa and on the soil. Six one-tenth-acre plats were laid out on an established field of alfalfa north of Series IX. There were two untreated plats, while the annual sulfur applications ranged from 50 to 200 pounds per acre in 50-pound steps, The sulfur was applied broadcast on the surface about the time growth started in the spring. These plats were continued for seven years until 1925. At this time the stand became uneven and the work was discontinued. Table XVI shows the corrected yields for the different treatments.

TABLE XVI.—EFFECT OF SULFUR ON YIELDS OF ALFALFA HAY

| Plat. | Soil Treatments. | Corrected yields of hay—pounds per acre. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1919. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. | Average 1919 to 1925. | Increase due to treatment. |
| 2, 5 | Check, no treatment | 8,480 | 5,727 | 3,460 | 4,650 | 3,598 | 2,342 | 1,285 | 4,220 | ..... |
| 1 | Sulfur, 50 pounds | 8,270 | 4,435 | 3,750 | 3,410 | 2,825 | 2,332 | 1,221 | 3,749 | —471 |
| 3 | Sulfur, 100 pounds | 7,930 | 4,592 | 3,190 | 3,555 | 3,347 | 2,117 | 1,137 | 3,695 | —525 |
| 4 | Sulfur, 150 pounds | 9,660 | 4,658 | 3,210 | 3,652 | 3,978 | 1,667 | 1,028 | 3,979 | —241 |
| 6 | Sulfur, 200 pounds | 10,660 | 5,627 | 3,130 | 4,390 | 4,293 | 2,422 | 1,165 | 4,527 | 307 |

It may be seen from these results that decreases in yields resulted from all the sulfur treatments except plat 6, which had 200 pounds per acre. The increase on this plat is thought to have been due primarily to unevenness in the soil. The land was considerably more fertile near the southwest corner of the plat. It would seem from these results that this land is not in need of sulfur treatment for alfalfa production. Where treated with sulfur the alfalfa plants usually showed a more yellowish leaf color and sometimes many of the leaves died.

The sulfur treatments increased the acidity of this soil. Table XVII shows the pH values for each plat for the surface 6 inches and also for the 6- to 12-inch depth.

TABLE XVII.—EFFECT OF SULFUR ON pH VALUES OF THE SOIL

Samples taken in October, 1924

| Plat. | SOIL TREATMENTS. | Depth. | pH value (a). |
|---|---|---|---|
| | | *Ins.* | |
| 1 | Sulfur, 50 pounds | 0–6 | 5.5 |
| | Sulfur, 50 pounds | 6–12 | 5.6 |
| 2 | Check, no treatment | 0–6 | 6.2 |
| | Check, no treatment | 6–12 | 6.5 |
| 3 | Sulfur, 100 pounds | 0–6 | 5.0 |
| | Sulfur, 100 pounds | 6–12 | 3.8 |
| 4 | Sulfur, 150 pounds | 0–6 | 5.1 |
| | Sulfur, 150 pounds | 6–12 | 5.9 |
| 5 | Check, no treatment | 0–6 | 5.9 |
| | Check, no treatment | 6–12 | 5.7 |
| 6 | Sulfur, 200 pounds | 0–6 | 4.7 |
| | Sulfur, 200 pounds | 6–12 | 5.1 |

(a) Determinations made with hydrogen electrode.

## TREND OF CROP YIELDS

The real value of a given cropping system can be determined only by average results over a period of years. The yields of the untreated soils having different cropping systems have been averaged by four-year periods to show relative yields at the beginning of these experiments and toward the end of the 20-year period. It must be remembered that in Kansas seasonal variations are wide and, therefore, a series of good years may give yields far above what might reasonably be expected on the average for the cropping system in use. A series of poor crop years may likewise cause a marked depression from the average. For these reasons it is evident that a 20-year period is hardly long enough to give a satisfactory summary by four-year periods. Some important results, however, are indicated by such averages to date.

## ALFALFA

The yields of alfalfa at the beginning of these tests were low, due to unfavorable years during 1911 and 1913. The second four-year period was more favorable. During the last three periods the yields have been somewhat lower than during the second period.

TABLE XVIII.—ANNUAL YIELDS PER ACRE FROM UNTREATED PLATS AND AVERAGES BY FOUR-YEAR PERIODS OF CONTINUOUS AND ROTATED ALFALFA

| YEAR. | Alfalfa continuously. | | Sixteen-year rotation. | | Percentage increase due to rotation. |
|---|---|---|---|---|---|
| | Annual yield. | Average yield by four-year periods. | Annual yield. | Average yield by four-year periods. | |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | |
| 1911 | 2,463 | | 5,195 | | |
| 1912 | 920 | 1,904 | 4,388 | 3,304 | 73.5 |
| 1913 | 1,901 | | 3,633 | | |
| 1914 | 2,330 | | ..... | | |
| 1915 | 5,570 | | 7,882 | | |
| 1916 | 5,307 | 4,581 | 9,656 | 6,375 | 39.2 |
| 1917 | 5,116 | | 7,274 | | |
| 1918 | 2,330 | | 688 | | |
| 1919 | 5,588 | | 5,690 | | |
| 1920 | 2,952 | 3,143 | 5,217 | 5,183 | 64.9 |
| 1921 | 2,940 | | 4,280 | | |
| 1922 | 1,090 | | 5,545 | | |
| 1923 | 519 | | 6,662 | | |
| 1924 | 2,844 | 1,535 | 5,635 | 4,322 | 181.6 |
| 1925 | 902 | | 3,367 | | |
| 1926 | 1,876 | | 1,624 | | |
| 1927 | 4,020 | | 7,155 | | |
| 1928 | 235 | 2,251 | 5,238 | 4,780 | 112.4 |
| 1929 | 2,828 | | 3,487 | | |
| 1930 | 1,919 | | 3,238 | | |
| Average | 2,683 | ..... | 4,793 | ..... | ..... |

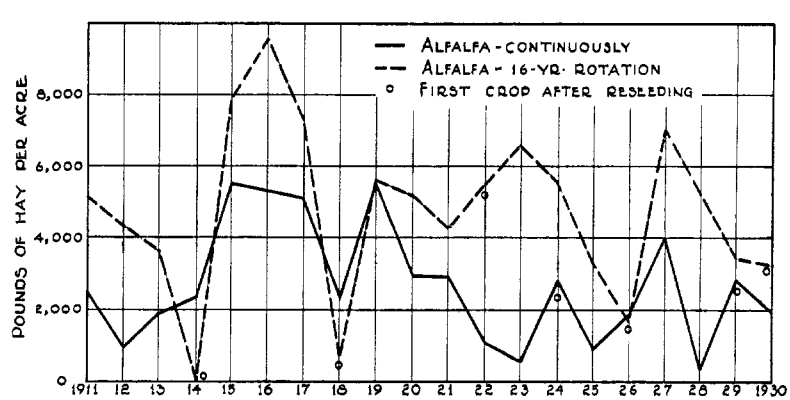


FIG. 2.—Graphs showing annual yields of continuous and rotated alfalfa.

It will be seen from Table XVIII that the yields of alfalfa in the 16-year rotation, except the first year after seeding, were decidedly higher than the continuous alfalfa even during the first years of the experiments. (Fig. 2.) This indicates that the land in the 16-year rotation was much better than the land in Series X when these tests were begun. In fact, it was with the idea of determining the possibility of growing alfalfa continuously on relatively thin land, even with good treatments, that Series X was started. The average increase from the 16-year rotation cannot, therefore, be attributed entirely to the cropping system. In fact, if the three years 1911 to 1913 are averaged, which was the time when these two series could be considered comparable (that is, it was immediately after the two series had been seeded to alfalfa for the first time, and up to 1913 both could be considered continuous alfalfa), the alfalfa on Series II gave an increase of 150 percent over the untreated yield on Series X. This is a greater percentage difference and a greater difference in weight than was obtained during the last four-year period, 1927 to 1930.

Since the yields at the beginning of these tests indicated that the land in the 16-year rotation is more productive than the land where the continuous alfalfa is grown, it would be expected that this would remain higher throughout the experiments. This is exactly what happened, and the two curves have tended to get only a little wider apart. (Fig. 3.) If the curves are drawn for the three-year

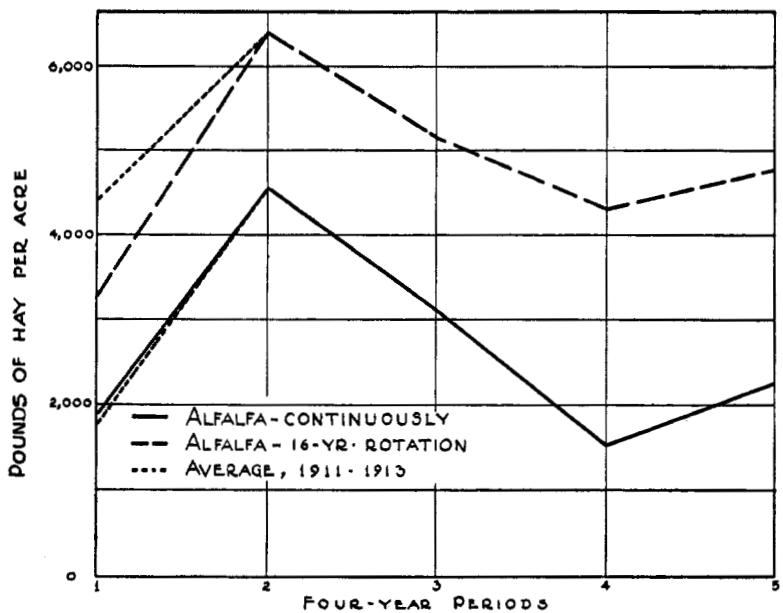


FIG. 3.—Graphs showing yields of continuous and rotated alfalfa. Averages by four-year periods. (Dotted lines represent first three years only.)

average 1911 to 1913 at the beginning, the curves are as wide at the start as during the last four-year period.

The stand has become difficult to maintain in good condition on the continuous alfalfa, however, and reseeding must be done often or grass and weeds choke out the alfalfa. This difficulty is due to the increase in the amount of weeds and grass rather than to an actual decrease in the number of alfalfa plants. The weeds have increased on the continuous alfalfa because the smaller growth of alfalfa plants offers less competition.

The production of alfalfa in the 16-year rotation is also more difficult than formerly, but this seems to be due largely to the exhaustion of deep subsoil moisture.[2] The lack of deep subsoil moisture is also a tremendous factor in reducing the yield of the continuous alfalfa. When alfalfa is grown on this land for four years the soil moisture is reduced to a low point to a depth of about 20 feet. This moisture is not regained during the 12 years the land is grown to corn and wheat. Consequently, when alfalfa is reseeded on this land it is retarded in its growth because the roots cannot obtain moisture from the deep subsoil.

If the yields for the manured or fertilized land are considered it may be seen from Table XIX and figures 2 and 3 that the alfalfa in the 16-year rotation has shown a greater tendency to maintain a higher trend of yields than has the continuous alfalfa. In other words, good soil treatment seems to have been slightly more effective in maintaining high yields on the rotated than on the continuous alfalfa. This is undoubtedly due in part to the fact that weeds and grass were controlled more effectively on the rotated land.

The yields of alfalfa on the fertilized land in the 16-year rotation were higher than the manured land on the average and in four of the five four-year periods. In the continuous alfalfa the yields from the fertilized plats were consistently lower than from the manured plats. This may be due in part to the fact that the manure application was heavier on the continuous alfalfa, and also because the manured plat is farther down the slope and probably gets considerably more subsoil moisture. In recent years the alfalfa getting complete fertilizer, plat 6 on Series X, has shown very strikingly the effect of a shortage of subsoil moisture. During dry weather in midsummer the plants make no growth and the leaves wither. This plat is on the highest ground of any treated plat in the series.

### CORN

During the first four years of these experiments the yields of corn were very low. In 1913 the crop was a complete failure and in 1914 there was a complete failure in the 16-year rotation and only very light yields on the other series. The average yields in the different cropping systems as shown by Table XX and figure 4 were

2. Duley, F. L. Effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron. 21:224-231. 1929.

TABLE XIX.—COMPARISON OF YIELDS OF ALFALFA ON MANURED LAND AND LAND RECEIVING COMPLETE CHEMICAL FERTILIZERS

| YEAR. | Yields—pounds per acre. | | | |
|---|---|---|---|---|
| | Manure (a). | | Complete fertilizer (a). | |
| | Annual. | Four-year average. | Annual. | Four-year average. |
| **Sixteen-year Rotation, 1911 to 1930** | | | | |
| 1911 | 4,770 | 3,412 | 6,095 | 4,318 |
| 1912 | 4,806 | | 6,560 | |
| 1913 | 4,073 | | 4,613 | |
| 1914 | 0 | | 0 | |
| 1915 | 10,237 | 7,802 | 9,997 | 8,110 |
| 1916 | 12,293 | | 11,885 | |
| 1917 | 7,919 | | 9,224 | |
| 1918 | 760 | | 1,335 | |
| 1919 | 7,990 | 6,787 | 7,525 | 6,948 |
| 1920 | 7,362 | | 6,622 | |
| 1921 | 5,580 | | 5,560 | |
| 1922 | 6,215 | | 8,085 | |
| 1923 | 7,644 | 5,162 | 7,559 | 4,977 |
| 1924 | 6,170 | | 6,240 | |
| 1925 | 4,645 | | 3,774 | |
| 1926 | 2,188 | | 2,334 | |
| 1927 | 8,330 | 6,189 | 8,885 | 6,539 |
| 1928 | 7,333 | | 7,123 | |
| 1929 | 4,247 | | 4,789 | |
| 1930 | 4,846 | | 5,358 | |
| **Alfalfa Continuously, 1911 to 1930** | | | | |
| 1911 | 3,659 | 3,166 | 3,739 | 2,767 |
| 1912 | 1,620 | | 1,360 | |
| 1913 | 3,041 | | 2,873 | |
| 1914 | 4,342 | | 3,097 | |
| 1915 | 11,110 | 7,732 | 7,970 | 6,240 |
| 1916 | 9,027 | | 8,122 | |
| 1917 | 7,391 | | 6,316 | |
| 1918 | 3,400 | | 2,550 | |
| 1919 | 8,373 | 4,704 | 8,368 | 4,139 |
| 1920 | 4,187 | | 3,777 | |
| 1921 | 4,370 | | 2,730 | |
| 1922 | 1,886 | | 1,679 | |
| 1923 | 1,606 | 2,902 | 1,509 | 2,415 |
| 1924 | 4,449 | | 3,389 | |
| 1925 | 1,897 | | 1,481 | |
| 1926 | 3,657 | | 3,280 | |
| 1927 | 6,760 | 3,965 | 4,962 | 3,337 |
| 1928 | 1,057 | | 660 | |
| 1929 | 5,200 | | 4,328 | |
| 1930 | 2,843 | | 3,399 | |
| Average | 4,494 | ..... | 3,779 | ..... |

(a) See Table IV for treatments of plats 9 and 6.

TABLE XX.—ANNUAL YIELDS OF CORN ON UNTREATED LAND AND AVERAGES BY FOUR-YEAR PERIODS

1911 to 1930.

| YEAR. | Sixteen-year rotation. | | Three-year rotation. | | Corn two years, wheat. | | | | Corn continuously. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yield per acre. | Four-year average. | Yield per acre. | Four-year average. | Yield per acre first year. | Yield per acre second year. | Average, two years. | Four-year average. | Yield per acre. | Four-year average. |
| | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* |
| 1911 | 17.51 | | 19.51 | | 20.97 | 24.31 | 22.64 | | 13.60 | |
| 1912 | 27.35 | 11.22 | 27.53 | 14.54 | 28.93 | 31.90 | 30.42 | 15.32 | 24.10 | 11.05 |
| 1913 | .00 | | .00 | | .00 | .00 | .00 | | .00 | |
| 1914 | .00 | | 11.10 | | 11.30 | 5.14 | 8.22 | | 6.50 | |
| 1915 | 63.90 | | 66.20 | | 63.40 | 61.10 | 62.25 | | 53.70 | |
| 1916 | 40.80 | 37.40 | 42.25 | 35.31 | 36.78 | 33.89 | 35.34 | 30.87 | 23.00 | 23.58 |
| 1917 | 44.91 | | 32.80 | | 22.70 | 29.10 | 25.90 | | 17.60 | |
| 1918 | .00 | | .00 | | .00 | .00 | .00 | | .00 | |
| 1919 | 15.60 | | 20.10 | | 16.50 | 2.36 | 9.43 | | 6.43 | |
| 1920 | 40.21 | 35.04 | 31.82 | 33.30 | 39.02 | 26.50 | 32.76 | 29.54 | 29.67 | 23.53 |
| 1921 | 40.00 | | 33.10 | | 31.80 | 38.50 | 35.15 | | 34.90 | |
| 1922 | 44.35 | | 48.17 | | 42.60 | 39.00 | 40.80 | | 23.12 | |
| 1923 | 49.40 | | 50.90 | | 29.88 | 50.22 | 40.05 | | 26.46 | |
| 1924 | 49.05 | 33.47 | 35.16 | 28.85 | 22.87 | 29.90 | 26.39 | 22.46 | 14.56 | 17.95 |
| 1925 | 35.05 | | 19.14 | | 9.46 | 23.21 | 16.34 | | 26.54 | |
| 1926 | 7.38 | | 10.19 | | 7.45 | 6.59 | 7.04 | | 4.25 | |
| 1927 | 72.59 | | 68.71 | | 60.64 | 53.41 | 57.03 | | 45.18 | |
| 1928 | 63.78 | 50.86 | 57.82 | 41.44 | 51.28 | 28.01 | 39.65 | 29.13 | 24.20 | 20.98 |
| 1929 | 60.73 | | 33.31 | | 16.16 | 19.90 | 18.03 | | 13.78 | |
| 1930 | 6.32 | | 5.90 | | .48 | 3.11 | 1.80 | | .76 | |
| Average | 33.60 | ..... | 30.69 | ..... | 25.61 | 25.30 | 25.45 | ..... | 19.43 | ..... |

approximately the same for this first four-year period. During the second, third, and fourth periods the spread between the continuous corn and the 16-year rotation was wider with the three-year rotations intermediate. It should be noted, however; that the differences were almost constant during these 12 years. This indicates that the soil in the 16-year rotation was more productive at the beginning of these experiments than was the land used for the growing of corn continuously. During the last four-year period there was a decided spread in the yields, and the corn in the 16-year rotation averaged nearly 30 bushels per acre more than the continuous corn. It should be noted, however, that this difference was due to a greater yield of corn in the 16-year rotation rather than to a decrease in the yields of continuous corn.

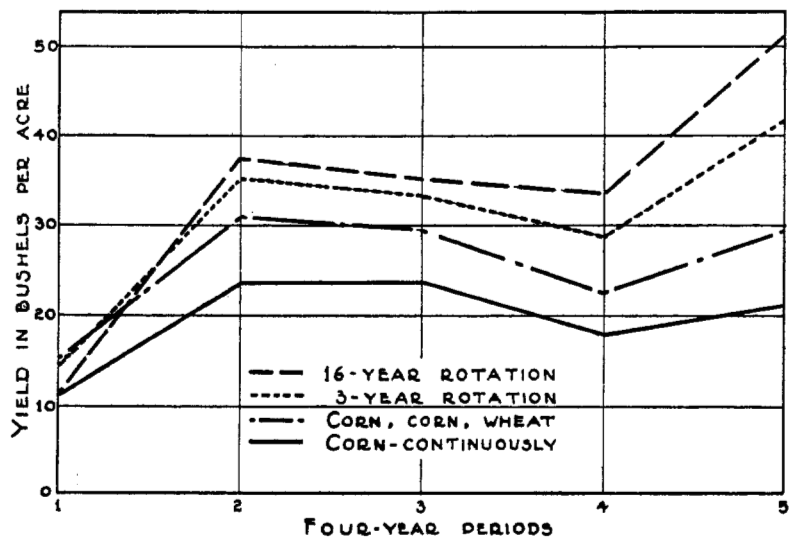


FIG. 4.—Graphs showing effect of cropping system on yields of corn. Averages by four-year periods.

One of the striking things about these results is the fact that the yield of corn grown continuously has not appreciably declined. The reason for this, however, may be largely in the fact that the years 1927,1928, and 1929 were quite favorable for corn production. It has also been found that the greatest spread between rotated and continuous corn occurs in the years that are favorable for corn. At such times the yields on the rotated land are very high. Since the years 1927 to 1929 were very favorable for corn, this may account for much of the wide difference between the continuous corn and the 16-year rotation during the last four-year period.

TABLE XXI.—ANNUAL YIELDS OF WHEAT ON UNTREATED LAND AND AVERAGES BY FOUR-YEAR PERIODS

1911 to 1930.

| YEAR. | Sixteen-year rotation. | | Sixteen-year rotation (second-year wheat). | | Three-year rotation. | | Corn two years, wheat. | | Wheat continuously. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yield per acre. | Four-year average. | Yield per acre. | Four-year average. | Yield per acre. | Four-year average. | Yield per acre. | Four-year average. | Yield per acre. | Four-year average. |
| | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* | *Bus.* |
| 1911 | 18.00 | | ..... | ..... | 15.83 | | 12.66 | | 25.84 | |
| 1912 | 10.97 | 18.25 | ..... | ..... | 9.04 | 16.16 | 7.59 | 13.76 | 5.73 | 18.18 |
| 1913 | 11.43 | | ..... | ..... | 9.95 | | 5.17 | | 17.64 | |
| 1914 | 32.60 | | ..... | ..... | 29.80 | | 29.60 | | 23.50 | |
| 1915 | 19.52 | | ..... | ..... | 15.27 | | 12.41 | | 12.75 | |
| 1916 | 18.47 | 14.77 | ..... | ..... | 16.73 | 15.16 | 16.31 | 12.78 | 6.86 | 9.48 |
| 1917 | 10.10 | | ..... | ..... | 13.63 | | 9.96 | | 11.85 | |
| 1918 | 11.00 | | ..... | ..... | 15.02 | | 12.44 | | 6.45 | |
| 1919 | 20.29 | | ..... | ..... | 19.55 | | 24.91 | | 19.17 | |
| 1920 | 10.99 | 17.70 | ..... | ..... | 11.82 | 19.86 | 15.04 | 17.90 | 11.27 | 17.62 |
| 1921 | 15.32 | | ..... | ..... | 21.37 | | 11.36 | | 9.64 | |
| 1922 | 24.20 | | 34.40 | ..... | 26.70 | | 20.30 | | 30.40 | |
| 1923 | 23.71 | | 19.46 | | 25.57 | | 18.35 | | 21.41 | |
| 1924 | 11.62 | 14.90 | 16.06 | 19.24 | 14.61 | 16.25 | 9.81 | 10.46 | 12.19 | 14.40 |
| 1925 | 16.10 | | 21.10 | | 19.14 | | 9.46 | | 14.32 | |
| 1926 | 8.15 | | 20.33 | | 5.69 | | 4.23 | | 9.67 | |
| 1927 | 30.33 | | 19.97 | | 19.44 | | 17.42 | | 14.81 | |
| 1928 | 28.75 | 24.43 | 42.18 | 26.39 | 29.70 | 19.23 | 19.22 | 15.60 | 23.71 | 16.90 |
| 1929 | 11.47 | | 20.77 | | 12.76 | | 9.43 | | 13.20 | |
| 1930 | 27.15 | | 22.64 | | 15.00 | | 16.34 | | 15.88 | |
| Average | 18.00 | ..... | 24.10 | ..... | 17.33 | ..... | 14.10 | ..... | 15.31 | ..... |

### WHEAT

The trend of wheat yields with the different cropping systems is illustrated in figure 5. It will be seen from this, and also from Table XXI, that during the first three four-year periods the differences in yield from the different cropping systems were not great. The low yield of the continuous wheat during the period 1915 to 1918 was the greatest deviation from what seems to have been a normal trend. This was due largely to winterkilling in 1916 and 1918 when the yield dropped to less than 7 bushels of wheat per acre. During the last two periods the wheat in the corn, corn, wheat rotation has dropped below the continuous wheat. The three-year rotation, corn, cowpeas, wheat, gave higher yields than the 16-year rotation during the second, third, and fourth periods, but dropped decidedly below during the fifth period. The yields in the 16-year rotation made a very marked increase over the other cropping systems during the last four-year period. This was due to the much higher yields during the years 1927 and 1930. The yield of the second-year wheat in the 16-year rotation was higher than for any other cropping system during the last two four-year periods. The yields of this second-year wheat have been higher than the first year after corn in six out of nine years.

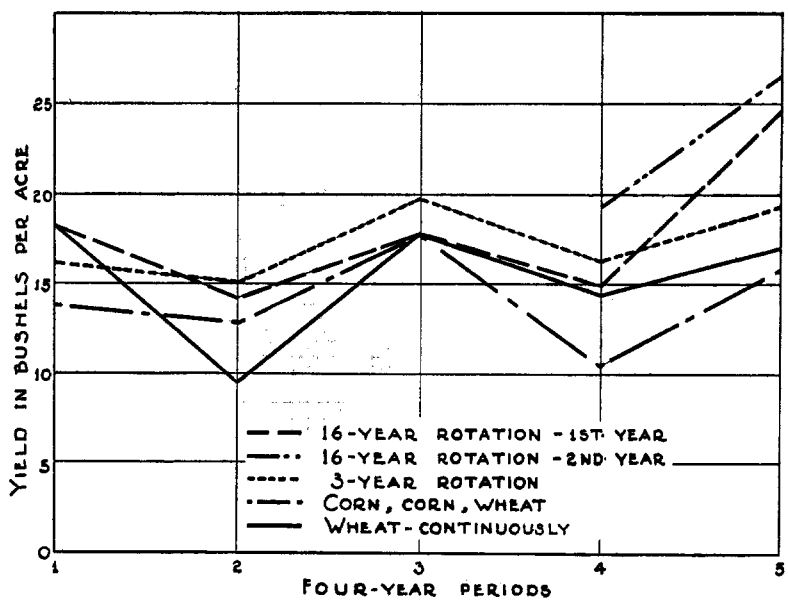


FIG. 5.—Graphs showing effect of cropping system on yields of wheat. Averages by four-year periods.

### COWPEAS

The trend of yields of cowpeas has been greatly affected by seasonal conditions, but Table XXII will show a tendency toward a reduction in yield during the later years of the tests. There has not been what could be considered a high yield since 1923. The average for the last eight years, however, has been only slightly below that of the first period. It is doubtful if these results are definite enough to indicate any marked change in the ability of this land to produce cowpeas. Beginning in 1928 soybeans have been used instead of cowpeas in this rotation.

TABLE XXII.—ANNUAL YIELDS OF COWPEAS IN THREE-YEAR ROTATION UNTREATED LAND AND AVERAGES BY FOUR-YEAR PERIODS

| YEAR. | Yield per acre. | Four-year average. |
|---|---|---|
| | *Lbs.* | *Lbs.* |
| 1911 | 4,185 | |
| 1912 | 2,550 | 3,396 |
| 1913 | 730 | |
| 1914 | 6,120 | |
| 1915 | 7,005 | |
| 1916 | 4,700 | 5,580 |
| 1917 | 6,420 | |
| 1918 | 4,193 | |
| 1919 | 4,052 | |
| 1920 | 3,460 | 4,103 |
| 1921 | 4,820 | |
| 1922 | 5,078 | |
| 1923 | 5,780 | |
| 1924 | 2,732 | 2,961 |
| 1925 | 2,989 | |
| 1926 | 341 | |
| 1927 | 3,326 | |
| 1928 (*a*) | 4,094 | 3,058 |
| 1929 | 2,893 | |
| 1930 | 1,920 | |

(*a*) Soybeans were substituted for cowpeas in this rotation in 1928 and thereafter.

## EFFECT OF FERTILIZER TREATMENTS

The effect of individual fertilizer treatments is shown in Table XXIII. It will be seen that the largest and most consistent increases were obtained from the land receiving a complete fertilizer treatment, or sodium nitrate, superphosphate, and potassium sulfate. The increase from phosphate has been quite consistent except on corn and cowpeas. The effect of potassium sulfate used alone has not been very marked on this soil. Lime has given slight increases on corn and wheat, but it is not essential even for the production of alfalfa on this land, since the soil is already well supplied with available calcium. Manure has given increases in crop yields on all crops and in each cropping system. It is more consistent than any of the fertilizer treatments except the complete fertilizer, which has given results very similar to those of the manure.

TABLE XXIII.—INCREASES IN CROP YIELDS THAT CAN BE ATTRIBUTED TO DIFFERENT FERTILIZERS AND TO MANURE

1911 to 1930.

| CROP. | Different commercial fertilizers. | | | | | Manure—rate of application. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Super-phosphate. | Potassium sulfate. | Super-phosphate, potassium sulfate. | Super-phosphate, potassium sulfate, sodium nitrate. | Lime. | 5 T. on corn and third-year alfalfa. | 2½ T. on corn and wheat. | 5 T. on corn. | 2½ T. annually. | 5 T. annually. |
| **Sixteen-year Rotation** | | | | | | | | | | |
| Alfalfa (lbs.) | 528 | ..... | 1,169 | 1,385 | 327 | 1,077 | ..... | ..... | ..... | ..... |
| Corn (bus.) | —3.70 | ..... | —.06 | 1.67 | —.11 | 2.92 | ..... | ..... | ..... | ..... |
| Wheat after corn (bus.) | .87 | ..... | 2.99 | 4.59 | .42 | 4.35 | ..... | ..... | ..... | ..... |
| Wheat after wheat (bus.) | 2.39 | ..... | 4.94 | 8.47 | 2.92 | 3.59 | ..... | ..... | ..... | ..... |
| **Three-year Rotation** | | | | | | | | | | |
| Corn (bus.) | —3.53 | —0.43 | —1.11 | 2.68 | ..... | ..... | 4.09 | 4.13 | ..... | ..... |
| Cowpeas or soybeans (lbs.) | —191 | 159 | 69 | 766 | ..... | ..... | 518 | 469 | ..... | ..... |
| Wheat (bus.) | 1.10 | .33 | 2.70 | 7.19 | ..... | ..... | 4.17 | 4.57 | ..... | ..... |
| **Continuous Crops** | | | | | | | | | | |
| Alfalfa (lbs.) | 691 | —46 | 892 | 1,096 | 299 | ..... | ..... | ..... | 1,811 | 2,958 |
| Corn (bus.) | (a)8.66 | 3.11 | 2.19 | 6.54 | ..... | ..... | ..... | ..... | 7.12 | ..... |
| Wheat (bus.) | 1.03 | .37 | 3.14 | 5.54 | ..... | ..... | ..... | ..... | 6.58 | ..... |

(a) Increase here probably due to more fertile plat.

Lime has given very small increases in yields in the 16-year rotation and in the continuous alfalfa.

Wheat yields have been increased more by fertilizer than have corn yields. Alfalfa has been increased considerably in yield by superphosphate and to a slight extent by sodium nitrate. The use of superphosphate and potassium sulfate combined has given reasonably good increases on alfalfa, whether in rotation or continuous culture.

Sodium nitrate has given some increase on all crops when used in connection with superphosphate and potassium sulfate. The increase has been 216 pounds per acre on rotated and 204 pounds on continuous alfalfa. The increase on cowpeas and soybeans in the three-year rotation has averaged 697 pounds of hay for this treatment. It is of interest to note that in these tests there has been a larger increase from sodium nitrate when used in combination with other fertilizers than from superphosphate alone in all cases except on alfalfa or corn grown continuously.

TABLE XXIV.—MANURE COMPARED TO COMPLETE FERTILIZER BY PERCENTAGE OF INCREASE IN YIELD OF CROPS

| CROP. | Percentage of increase. | |
|---|---|---|
| | Manure. | Complete fertilizer. |
| **Sixteen-year Rotation** | | |
| Alfalfa | 22.47 | 28.90 |
| Corn | 8.69 | 4.97 |
| Wheat, first year | 24.16 | 25.50 |
| Wheat, second year | 14.90 | 35.15 |
| **Three-year Rotation** | | |
| Corn | 13.33 | 8.73 |
| Cowpeas | 13.39 | 19.80 |
| Wheat | 24.06 | 41.48 |
| **Continuous Crops** | | |
| Alfalfa | (a) 67.50 | 40.85 |
| Corn | 36.66 | 33.68 |
| Wheat | 42.98 | 36.19 |

(a) An annual application of 2½ tons.

The relative returns from the fertilized and the manured land given in Table XXIV show that in the rotations the yields of crops except corn were maintained somewhat better with fertilizer than with manure. In the continuously cropped plats the manure has

TABLE XXV.—NUTRIENTS ADDED ANNUALLY IN MANURE OR FERTILIZER

Pounds per acre.

| | Sixteen-year rotation. | | Three-year rotation. | | Continuous crops. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Wheat. | | Corn. | | Alfalfa. | |
| | Manure, plat 9. | Fertilizer, plat 6. | Manure, plat 9. | Fertilizer, plat 6. | Manure, plat 10. | Fertilizer, plat 6. | Manure, plat 5. | Fertilizer, plat 7. | Manure, 2½ T., plat 9. | Fertilizer, plat 6. |
| Nitrogen | 16.47 | 19.1 | 21.96 | 14.5 | 32.95 | 12.0 | 32.95 | 16.5 | 32.95 | 36.0 |
| Phosphorus | 5.29 | 7.3 | 7.05 | 5.5 | 10.57 | 5.5 | 10.57 | 5.2 | 10.57 | 13.7 |
| Potassium | 21.30 | 22.5 | 28.36 | 21.9 | 42.60 | 16.4 | 42.60 | 20.5 | 42.60 | 36.9 |

given the higher returns, and this is most marked in the case of alfalfa. In the case of continuous corn and wheat the amount of fertility elements was decidedly higher in the manure added than in the fertilizer. (Table XXV.) This may account, in part at least, for the greater increase from manure on these plats.

## PLANT AND GRAIN CHARACTERISTICS AND QUALITY OF WHEAT

During the course of this work measurements have been made to determine the effect of various rotations and fertilizer treatments on the characteristics of the wheat plant and grain that are not shown by yield results.[3] These included the height of plants, length of heads, test weight of grain, weight of 1,000 grains, percentage of yellowberry, protein content of grain, and baking quality of flour.

### HEIGHT OF PLANTS

The height of wheat plants varied widely with the different rotations and to a lesser extent with the fertilizer treatments. Table XXVI gives a summary of the average height of plants in each cropping system and from all treatments. The second-year wheat in the 16-year rotation produced the tallest wheat, and the wheat in the three-year rotation of corn, corn, wheat was the shortest. The three-year rotation of corn, cowpeas, wheat has not produced so tall wheat as the land in continuous wheat.

Superphosphate used alone has had little effect on the height in the different tests, but where sodium nitrate, manure, or green manure has been applied with superphosphate there has been some increase in height due to superphosphate. Potassium sulfate also seems to have had a slight effect, although this is hardly noticeable in the field. The lime in the 16-year rotation also increased the height slightly over land similarly manured but unlimed.

### LENGTH OF HEADS

The head length was determined by measuring at random 100 heads scattered through the plat while the wheat was standing. The length of wheat heads has not been materially affected by the cropping system or soil treatment, as Table XXVI will show. It often happens that the untreated plats having a thin stand of wheat will produce longer heads than the treated plats, even though the yield of the untreated plats may be decidedly less. There seems to be no correlation between the length of wheat heads and the yield, since differences in stand which are usually in favor of the treated plats may easily overbalance the variation in head length. It is doubtful if the differences in length of heads due to soil treatments are enough to be significant.

3. Throckmorton, R. I. Controlling the quality of wheat through rotation and proper crop sequence. Jour. Amer. Soc. Agron. 18:623-629. 1926.

TABLE XXVI.—HEIGHT OF WHEAT PLANTS AND LENGTH OF WHEAT HEADS IN EACH CROPPING SYSTEM FOR EACH SOIL TREATMENT USED

| SOIL TREATMENTS. | Sixteen-year rotation. | | Three-year rotation. | | Wheat continuously. | Average. | Variations from nearest check (*a*). |
|---|---|---|---|---|---|---|---|
| | Wheat after corn. | Wheat after wheat. | Corn, peas, wheat. | Corn two years, wheat. | | | |
| **Height of Plants (Inches)** | | | | | | | |
| Superphosphate | 32.9 | 33.7 | 31.9 | ..... | 32.4 | 32.7 | 0.0 |
| Check | 32.0 | 34.9 | 31.7 | ..... | 32.0 | 32.7 | ..... |
| Rock phosphate, green manure | 33.1 | 36.2 | ..... | ..... | 32.9 | 33.8 | 1.2 |
| Superphosphate, potassium sulfate | 32.7 | 35.0 | 30.6 | ..... | 32.2 | 32.6 | 1.4 |
| Check | 31.3 | 34.8 | 29.2 | ..... | 29.4 | 31.2 | ..... |
| Sodium nitrate, superphosphate, potassium sulfate | 34.0 | 37.0 | 31.1 | ..... | 31.6 | 33.4 | 2.2 |
| Superphosphate, manure | 33.8 | 36.6 | ..... | ..... | ..... | 35.2 | 2.2 |
| Check | 31.8 | 34.1 | 27.3 | ..... | 29.2 | 30.6 | ..... |
| Manure | 33.2 | 35.5 | 31.0 | ..... | 33.1 | 33.2 | 2.6 |
| Manure, lime | 34.7 | 36.8 | ..... | ..... | ..... | 35.8 | 3.0 |
| Check | 31.4 | 34.2 | 29.0 | 26.8 | 29.6 | (*b*) 31.1 | ..... |
| Manure, brome grass | 32.8 | 34.7 | ..... | ..... | ..... | 33.8 | 1.0 |
| Potassium sulfate | ..... | ..... | 29.5 | ..... | 30.2 | 29.9 | .6 |
| Green manure | ..... | ..... | ..... | ..... | 29.3 | 29.3 | .1 |
| Corn, corn, wheat, green manure | ..... | ..... | ..... | 28.8 | ..... | 28.8 | ..... |
| Superphosphate, potassium sulfate, green manure | ..... | ..... | ..... | ..... | 30.6 | 30.6 | 1.4 |
| Average of checks | 31.6 | 34.5 | 29.3 | 26.8 | 30.1 | ..... | ..... |
| Average of treatments | 33.4 | 35.7 | 30.8 | 28.8 | 31.5 | ..... | ..... |

TABLE XXVI.—HEIGHT OF WHEAT PLANTS AND LENGTH OF WHEAT HEADS IN EACH CROPPING SYSTEM FOR EACH SOIL TREATMENT USED—*Concluded*

| SOIL TREATMENTS. | Sixteen-year rotation. | | Three-year rotation. | | Wheat continuously. | Average. | Variations from nearest check (*a*). |
|---|---|---|---|---|---|---|---|
| | Wheat after corn. | Wheat after wheat. | Corn, peas, wheat. | Corn two years, wheat. | | | |
| **Length of Wheat Heads (Inches)** | | | | | | | |
| Superphosphate | 2.31 | 2.34 | 2.25 | ..... | 2.25 | 2.29 | —0.04 |
| Check | 2.30 | 2.43 | 2.24 | ..... | 2.33 | 2.33 | ..... |
| Rock phosphate, green manure | 2.32 | 2.39 | ..... | ..... | 2.17 | 2.29 | —.06 |
| Superphosphate, potassium sulfate | 2.25 | 2.37 | 2.22 | ..... | 2.23 | 2.27 | —.03 |
| Check | 2.32 | 2.39 | 2.17 | ..... | 2.33 | 2.30 | ..... |
| Sodium nitrate, superphosphate, potassium sulfate | 2.39 | 2.51 | 2.23 | ..... | 2.35 | 2.37 | .07 |
| Superphosphate, manure | 2.31 | 2.35 | ..... | ..... | ..... | 2.33 | ..... |
| Check | 2.24 | 2.42 | 2.16 | 2.09 | 2.36 | 2.30 | ..... |
| Manure | 2.37 | 2.36 | 2.28 | ..... | 2.31 | 2.33 | .03 |
| Manure, lime | 2.31 | 2.38 | ..... | ..... | ..... | 2.35 | —.02 |
| Check | 2.32 | 2.41 | 2.17 | ..... | 2.30 | 2.30 | ..... |
| Manure, brome grass | 2.25 | 2.26 | ..... | ..... | ..... | 2.26 | —.11 |
| Potassium sulfate | ..... | ..... | 2.27 | ..... | 2.36 | 2.32 | .07 |
| Green manure | ..... | ..... | ..... | ..... | 2.37 | 2.37 | .01 |
| Corn, corn, wheat, green manure | ..... | ..... | ..... | 2.24 | ..... | 2.24 | .15 |
| Superphosphate, potassium sulfate, green manure | ..... | ..... | ..... | ..... | 2.38 | 2.38 | .02 |
| Average of checks | 2.30 | 2.41 | 2.19 | 2.09 | 2.33 | ..... | ..... |
| Average of treatments | 2.31 | 2.37 | 2.25 | 2.24 | 2.30 | ..... | ..... |

(*a*) Plat 10, 3-year rotation, corn, corn, wheat, not in average.
(*b*) Comparison on equal numbers of cases.

### TEST WEIGHT

The test weight per bushel has not varied greatly between the different cropping systems nor between the different fertilizer treatments. Table XXVII will show that the wheat following corn in the 16-year rotation and that from the continuous wheat series gave the lowest test weight on the untreated land. In general, phosphates seemed to have a tendency to give a slightly higher test weight, whereas nitrogen fertilizers and green manure have a tendency to decrease the test weight. The greatest increase in the test weight was obtained in the 16-year rotation where brome grass was used instead of alfalfa. This again indicates that a good supply of available nitrogen tends to decrease the test weight, since the brome grass land is usually very low in nitrates.

### WEIGHT OF ONE THOUSAND GRAINS

Table XXVII will show that on untreated land the weight of 1,000 grains in the three-year rotation was 10.1 percent higher than from the continuous wheat. The green-manure treatments and the application of sodium nitrate lowered the weight in comparison with the checks. The brome-grass land in the 16-year rotation gave the greatest increase in weight over the checks and was higher than where alfalfa was used in the rotation. From these results it seems that increasing the supply of available nitrogen had a tendency to reduce the weight of the grains, or at least to reduce the weight in comparison with the phosphate treatments. The latter seemed to have a distinct tendency to increase the weight of the grains.

### YELLOWBERRY IN WHEAT

The amount of yellowberry, or grains showing some soft starch in hard wheat, has been determined. The average for the nine-year period 1922 to 1930 is given in Table XXVIII. This period was used because of changes in the treatments in 1921. The untreated plats in the three-year rotation gave the highest percentage of yellowberry and the wheat following corn in the 16-year rotation produced the smallest percentage. Most of the soil treatments increased the percentage of yellowberry. Potassium sulfate gave a decrease.

### PROTEIN CONTENT OF WHEAT

The protein content of wheat has been found to vary widely from year to year. This seems to be due to a number of factors, including climatic conditions, amount of nitrates in the soil, and yield of wheat per acre. The results reported in Table XXVIII give an average for only six years, 1922 to 1924 and 1928 to 1930. These years were used because they are the ones during which protein determinations from all plats of the different series were obtained. The determinations previous to 1922 have been omitted because

TABLE XXVII.—TEST WEIGHT PER BUSHEL AND WEIGHT OF 1,000 GRAINS OF WHEAT IN EACH CROPPING SYSTEM FOR EACH SOIL TREATMENT USED

| SOIL TREATMENTS. | Sixteen-year rotation. | | Three-year rotation. | | Wheat continuously. | Average. | Variations from nearest check. |
|---|---|---|---|---|---|---|---|
| | After corn. | After wheat. | Corn, peas, wheat. | Corn, corn, wheat. | | | |
| **Test Weight—Pounds Per Bushel** | | | | | | | |
| Superphosphate | 56.9 | 57.8 | 59.1 | ..... | 57.4 | 57.8 | 0.5 |
| Check | 56.4 | 57.4 | 58.5 | ..... | 56.7 | 57.3 | ..... |
| Rock phosphate, green manure | 56.3 | 57.6 | ..... | ..... | ..... | 56.8 | .0 |
| Superphosphate, potassium sulfate | 56.9 | 58.7 | 59.2 | ..... | 57.6 | 58.1 | 1.3 |
| Check | 56.0 | 57.1 | 57.8 | ..... | 56.2 | 56.8 | ..... |
| Sodium nitrate, superphosphate, potassium sulfate | 56.4 | 57.9 | 58.9 | ..... | 56.4 | 57.4 | .6 |
| Superphosphate, manure | 56.9 | 57.8 | ..... | ..... | ..... | 57.4 | 1.1 |
| Check | 56.1 | 56.4 | 57.2 | 57.7 | 55.7 | 56.4 | ..... |
| Manure | 56.9 | 57.7 | 58.2 | ..... | 56.7 | 57.4 | 1.0 |
| Manure, lime | 57.0 | 57.9 | ..... | ..... | ..... | 57.5 | .7 |
| Check | 56.3 | 57.3 | 57.2 | ..... | 56.4 | 56.8 | ..... |
| Manure, brome grass | 58.2 | 59.0 | ..... | ..... | ..... | 58.6 | 1.8 |
| Potassium sulfate | ..... | ..... | 58.3 | ..... | 56.6 | 57.5 | .5 |
| Green manure | ..... | ..... | ..... | ..... | 55.0 | 55.0 | —.7 |
| Corn, corn, wheat, green manure | ..... | ..... | ..... | 57.2 | ..... | 57.2 | —.5 |
| Superphosphate, potassium sulfate, green manure | ..... | ..... | ..... | ..... | 56.1 | 56.1 | .4 |
| Average of checks | 56.2 | 57.1 | 57.7 | 57.7 | 56.3 | ..... | ..... |
| Average of treatments | 56.9 | 58.1 | 58.7 | 57.2 | 56.5 | ..... | ..... |

TABLE XXVII.—TEST WEIGHT PER BUSHEL AND WEIGHT OF 1,000 GRAINS OF WHEAT IN EACH CROPPING SYSTEM FOR EACH SOIL TREATMENT USED—*Concluded*

| SOIL TREATMENTS. | Sixteen-year rotation. | | Three-year rotation. | | Wheat continuously. | Average. | Variations from nearest check. |
|---|---|---|---|---|---|---|---|
| | After corn. | After wheat. | Corn, peas, wheat. | Corn, corn, wheat. | | | |
| **Weight in Grams of 1,000 Grains of Wheat** | | | | | | | |
| Superphosphate | 22.50 | 23.13 | 25.67 | ..... | 23.16 | 23.62 | 1.06 |
| Check | 21.62 | 22.76 | 24.17 | ..... | 21.70 | 22.56 | ..... |
| Rock phosphate, green manure | 21.67 | 23.71 | ..... | ..... | 22.97 | 22.78 | .74 |
| Superphosphate, potassium sulfate | 22.78 | 24.92 | 25.12 | ..... | 23.68 | 24.13 | 1.62 |
| Check | 21.55 | 23.47 | 23.82 | ..... | 21.21 | 22.51 | ..... |
| Sodium nitrate, superphosphate, potassium sulfate | 22.01 | 24.42 | 24.96 | ..... | 22.05 | 23.36 | .85 |
| Superphosphate, manure | 22.39 | 23.48 | ..... | ..... | ..... | 22.94 | 1.16 |
| Check | 21.29 | 22.26 | 22.83 | ..... | 21.29 | 21.92 | ..... |
| Manure | 22.75 | 23.35 | 24.16 | ..... | 23.89 | 23.54 | 1.62 |
| Manure, lime | 22.62 | 23.46 | ..... | ..... | ..... | 23.04 | .58 |
| Check | 22.08 | 22.84 | 23.66 | 23.53 | 21.56 | 22.54 | ..... |
| Manure, brome grass | 24.35 | 24.77 | ..... | ..... | ..... | 24.56 | 2.10 |
| Potassium sulfate | ..... | ..... | 24.00 | ..... | 22.39 | 23.20 | .68 |
| Green manure | ..... | ..... | ..... | ..... | 20.89 | 20.89 | .40 |
| Corn, corn, wheat, green manure | ..... | ..... | ..... | 23.41 | ..... | 23.41 | —.12 |
| Superphosphate, potassium sulfate, green manure | ..... | ..... | ..... | ..... | 22.40 | 22.40 | 1.11 |
| Average of checks | 21.64 | 22.83 | 23.62 | 23.53 | 21.44 | ..... | ..... |
| Average of treatments | 22.63 | 23.91 | 24.78 | 23.41 | 22.68 | ..... | ..... |

TABLE XXVIII.—PERCENTAGE OF YELLOWBERRY AND PERCENTAGE OF PROTEIN IN WHEAT GROWN UNDER DIFFERENT CROPPING SYSTEMS AND SOIL TREATMENTS

| SOIL TREATMENTS. | Sixteen-year rotation. | | Three-year rotation. | | Wheat continuously. | Average. | Variations from nearest check. |
|---|---|---|---|---|---|---|---|
| | Wheat after corn. | Wheat after wheat. | Corn, peas, wheat. | Corn, corn, wheat. | | | |
| **Percentage of Yellowberry—1922 to 1930** | | | | | | | |
| Superphosphate | 27.3 | 36.0 | 41.1 | ..... | 45.2 | 37.4 | 8.1 |
| Check | 17.8 | 30.9 | 31.2 | ..... | 37.2 | 29.3 | ..... |
| Rock phosphate, green manure | 27.7 | 34.5 | ..... | ..... | 41.5 | 34.6 | 6.8 |
| Superphosphate, potassium sulfate | 28.0 | 38.8 | 38.4 | ..... | 46.0 | 37.8 | 10.6 |
| Check | 18.7 | 27.5 | 37.4 | ..... | 25.3 | 27.2 | ..... |
| Sodium nitrate, superphosphate, potassium sulfate | 19.3 | 30.2 | 34.7 | ..... | 28.1 | 28.1 | .9 |
| Superphosphate, manure | 22.6 | 34.9 | ..... | ..... | ..... | 28.8 | 5.6 |
| Check | 18.5 | 27.9 | 29.5 | ..... | 22.9 | 24.7 | ..... |
| Manure | 21.6 | 30.1 | 32.2 | ..... | 30.6 | 28.6 | 3.9 |
| Manure, lime | 21.9 | 32.4 | ..... | ..... | ..... | 27.2 | 3.9 |
| Check | 18.6 | 27.9 | 31.6 | 29.5 | 24.0 | 25.5 | ..... |
| Manure, brome grass | 37.6 | 46.5 | ..... | ..... | ..... | 42.1 | 18.8 |
| Potassium sulfate | ..... | ..... | 28.0 | ..... | 25.2 | 26.6 | —4.8 |
| Green manure | ..... | ..... | ..... | ..... | 22.5 | 22.5 | —.4 |
| Corn, corn, wheat, green manure | ..... | ..... | ..... | 32.5 | ..... | 32.5 | 3.0 |
| Superphosphate, potassium sulfate, green manure | ..... | ..... | ..... | ..... | 32.2 | 32.2 | 9.3 |
| Average of checks | 18.4 | 28.6 | 32.4 | 29.5 | 27.4 | ..... | ..... |
| Average of treatments | 25.8 | 35.4 | 34.4 | 32.5 | 33.9 | ..... | ..... |

TABLE XXVIII.—PERCENTAGE OF YELLOWBERRY AND PERCENTAGE OF PROTEIN IN WHEAT GROWN UNDER DIFFERENT CROPPING SYSTEMS AND SOIL TREATMENTS—*Concluded*

| Soil Treatments. | Sixteen-year rotation. | | Three-year rotation. | | Wheat continuously. | Average. | Variations from nearest check. |
|---|---|---|---|---|---|---|---|
| | Wheat after corn. | Wheat after wheat. | Corn, peas, wheat. | Corn, corn, wheat. | | | |
| **Percentage of Protein—1922-'24 and 1928-'30** | | | | | | | |
| Superphosphate | 12.2 | 12.7 | 10.7 | ..... | 10.3 | 11.5 | —0.8 |
| Check | 13.6 | 13.1 | 11.3 | ..... | 11.1 | 12.3 | ..... |
| Rock phosphate, green manure | 12.6 | 12.7 | ..... | ..... | 10.5 | 11.9 | —.7 |
| Superphosphate, potassium sulfate | 12.3 | 12.5 | 10.9 | ..... | 10.3 | 11.5 | —1.4 |
| Check | 13.8 | 13.4 | 11.7 | ..... | 12.7 | 12.9 | ..... |
| Sodium nitrate, superphosphate, potassium sulfate | 13.6 | 13.6 | 11.5 | ..... | 12.0 | 12.7 | —.2 |
| Superphosphate, manure | 12.8 | 12.9 | ..... | ..... | ..... | 12.9 | —1.4 |
| Check | 14.0 | 14.5 | 12.4 | ..... | 13.0 | 13.5 | ..... |
| Manure | 13.8 | 13.9 | 11.8 | ..... | 11.4 | 12.7 | —.8 |
| Manure, lime | 13.5 | 13.9 | ..... | ..... | ..... | 13.7 | —.2 |
| Check | 13.7 | 14.1 | 12.0 | 11.9 | 12.0 | 13.0 | ..... |
| Manure, brome grass | 11.7 | 10.9 | ..... | ..... | ..... | 11.3 | —2.6 |
| Potassium sulfate | ..... | ..... | 11.9 | ..... | 12.4 | 12.2 | .0 |
| Green manure | ..... | ..... | ..... | ..... | 13.2 | 13.2 | .2 |
| Corn, corn, wheat, green manure | ..... | ..... | ..... | 11.9 | ..... | 11.9 | .0 |
| Superphosphate, potassium sulfate, green manure | ..... | ..... | ..... | ..... | 11.4 | 11.4 | —1.6 |
| Average of checks | 13.8 | 13.8 | 11.9 | 11.9 | 12.2 | ..... | ..... |
| Average of treatments | 12.8 | 12.9 | 11.4 | 11.9 | 11.4 | ..... | ..... |

several plat treatments were changed at that time. Thus the averages given represent the effect of the soil treatments now in operation. During the years 1925 to 1927 only the check plats were sampled for protein determinations.

The highest average protein content is found in the 16-year rotation. It should be remembered that these plats also made the highest yields. This combination of high yields and high protein content is undoubtedly due largely to the effect of the alfalfa in keeping up the nitrate content of the soil. Under many conditions factors which increase the yield of wheat tend to decrease the protein content. This is well shown by the effect of the soil treatments, most of which increased the yield, but only one, the green manure in the continuous wheat, increased the protein content, and in this series the average yield has been lower than on the check plats. Phosphate has decreased the protein content in all the cropping systems. Where it stimulates a greater yield there is more starchy material produced in the grain, and consequently a lower percentage of protein. Land treated with barnyard manure has produced wheat with a lower protein content than the untreated land. Liming has had little effect on the protein content of wheat in these tests. Sodium nitrate applied with superphosphate and potassium sulfate gave an increase in both yield and percentage of protein over land receiving only superphosphate and potassium sulfate.

Probably the most significant effect on the protein content of wheat was produced by the substitution of brome grass for alfalfa in the 16-year rotation. In this case the protein was decreased 2.6 percent as compared with land in alfalfa. Although the nitrate content of the brome grass plats is usually low and would seem to account for the low protein content, the yield of wheat has been slightly higher on the average than on the alfalfa land.

### BAKING QUALITY OF WHEAT

For a time tests were carried on in coöperation with the Department of Milling Industry to determine the baking quality of wheats produced under these different treatments, as well as determinations of the protein content of the flour. The results of several years' tests on this phase of the work showed that the grain from all these plats was of exceptionally high baking quality and there was practically no difference in the bread produced from plats in different rotations or having different fertilizer treatments. The work on the baking qualities of the wheat was therefore discontinued in 1927. In Table XXIX will be found baking data for the years 1926 and 1927, showing the more or less constant results obtained.

TABLE XXIX.—EFFECT OF ROTATIONS AND SOIL TREATMENTS ON BAKING QUALITIES OF WHEAT FLOUR

Average for 1926 and 1927 (a).

| | Soil Treatments. | Average absorption percentage. | Average loaf volume, c.c. |
|---|---|---|---|
| | **Sixteen-year Rotation** | | |
| First-year wheat.... | Checks, no treatment | 68 | 2,018 |
| | Manure | 68 | 2,042 |
| | Manure, lime | 68 | 2,050 |
| | Manure, brome grass | 67 | 2,100 |
| Second-year wheat.. | Checks, no treatment | 70 | 2,030 |
| | Manure | 73 | 2,055 |
| | Manure, lime | 73 | 2,022 |
| | Manure, brome grass | 73 | 1,955 |
| | **Three-year Rotation** | | |
| | Checks, no treatment | 72 | 2,005 |
| | 2 years corn, 1 year wheat | 73 | 2,035 |
| | 2 years corn, 1 year green manure | 73 | 2,050 |
| | **Wheat Continuously** | | |
| | Checks, no treatment | 73 | 2,069 |
| | Rock phosphate, cowpeas as green manure | 73 | 2,020 |

(a) Data obtained in coöperation with the Department of Milling Industry.

## THE ECONOMIC FACTOR IN CROP ROTATION VERSUS CONTINUOUS CROPPING

The results obtained in these experiments afford material for some consideration of the economic value of crop rotation, as well as the effect of rotation on the maintenance of soil productivity, control of weeds, plant disease, and insect pests. Rotations have been widely recommended as almost the key to successful agriculture. It is believed that many people advocating rotations have not recognized fully their limitations nor have they given enough attention to the variation in rotations themselves, and in many cases the economic returns for crop rotations, as compared with continuous cropping, have not been carefully studied. Mention has seldom been made of the possibility that some rotations may be less effective in maintaining fertility and decidedly less remunerative than certain types of continuous cropping, at least for a considerable period of years. Furthermore, the mere fact that crops are rotated is no assurance that the soil fertility is being maintained. Continuous cropping to cultivated crops like corn or cotton may permit soils to deteriorate because of erosion rather than by any detrimental effect of the crop itself.

The Ohio Agricultural Experiment Station has shown that the use of their five-year rotation of corn, oats, wheat, clover, and timothy for a period of 30 years has resulted in an average loss of 22

percent of the original supply of soil nitrogen regardless of fertilizer treatment.[4]

The Texas Agricultural Experiment Station has shown that with prices prevailing in 1928 the annual value of continuous cotton had been greater than from a rotation of cotton, corn, cowpeas, and oats.[5]

It must be remembered, however, that the relative monetary return from rotation and continuous cropping will depend primarily upon the price of the various crops. If a crop having a high acre value is grown continuously it may produce a higher acre return than if lower-priced crops are substituted a part of the time. (Table XXX.)

With the relatively high prices received for farm crops during a part of the period of these tests, as shown in Table XXX, the annual value of the crops produced on untreated land in the 16-year rotation and also in the three-year rotation of corn, cowpeas, wheat, has been higher than any of the crops grown continuously. The rotation of corn, corn, and wheat, however, has been less valuable than either continuous alfalfa or continuous wheat. In addition, this corn, corn, wheat rotation would undoubtedly be more exhaustive of fertility than continuous wheat or alfalfa, because of losses through erosion.

If a lower price for crops is considered, as shown in the last two columns of Table XXX, and alfalfa hay is calculated at $10 a ton, corn at 50 cents a bushel, and wheat at 60 cents, the situation is greatly altered. With these prices, the continuous alfalfa gives a higher acre value than the three-year rotation of corn, corn, wheat, and approximately the same as the three-year rotation including cowpeas.

If the results from the manured land are considered (Table XXX) the monetary return is even more in favor of some of the continuous crops. With the relatively high prices for crops the continuous alfalfa is more valuable than any of the rotations. Even the 16-year rotation which includes alfalfa one fourth of the time, could not overcome the loss sustained by the introduction into the rotation of corn and wheat, which have lower acre values than alfalfa. Furthermore, continuous wheat produced a higher acre value than the three-year rotation and higher than the 16-year rotation, which included brome grass instead of alfalfa. Under these conditions continuous corn produced the lowest acre value of any of the cropping systems.

The situation is again changed, however, if lower prices for crops are considered. In this case the continuous alfalfa is decidedly more valuable than any of the other cropping systems, and continuous wheat and continuous corn are slightly more valuable than the 16-year rotation, which includes brome grass instead of alfalfa.

4. Morris, V. H. The comparative effects of additions of nitrogen, phosphorus, and potassium on the nitrogen economy of a Wooster silt loam soil. Soil Science 18:87-97. 1924.

5. Reynolds, E. B. Experiments with fertilizers on rotated and nonrotated crops. Tex. Agr. Expt. Sta. Bul. 390:1-39. 1928.

TABLE XXX.—AVERAGE ANNUAL VALUE PER ACRE OF CROPS UNDER DIFFERENT CROPPING SYSTEMS ON UNTREATED LAND AND ON MANURED LAND

| CROPPING SYSTEM. | Average yield. | Relatively high prices. | | Relatively low prices. | |
|---|---|---|---|---|---|
| | | Price per unit. | Value. | Price per unit. | Value. |
| **Average Annual Value on Untreated Land** | | | | | |
| SIXTEEN-YEAR ROTATION. | | | | | |
| Alfalfa (lbs.) | 4,793 | $12.00 T. | $28.76 | $10.00 | $23.97 |
| Corn (bus.) | 33.6 | .60 | 20.16 | .50 | 16.80 |
| Wheat (bus.) | 18.0 | 1.00 | 18.00 | .60 | 10.80 |
| Wheat, 2d year. (bus.) | 24.1 | 1.00 | 24.10 | .60 | 14.46 |
| Average annual value | ..... | ..... | $22.76 | ..... | $16.51 |
| THREE-YEAR ROTATION. | | | | | |
| Corn (bus.) | 30.69 | $0.60 | $18.41 | $0.50 | $15.35 |
| Cowpeas (lbs.) | 3,869 | 10.00 T. | 19.35 | 8.00 | 15.48 |
| Wheat (bus.) | 17.33 | 1.00 | 17.33 | .60 | 10.39 |
| Average annual value | ..... | ..... | $18.36 | ..... | $13.74 |
| THREE-YEAR ROTATION. | | | | | |
| Corn (bus.) | 25.61 | $0.60 | $15.37 | $0.50 | $12.81 |
| Corn, 2d year (bus.) | 25.30 | .60 | 15.18 | .50 | 12.65 |
| Wheat (bus.) | 14.10 | 1.00 | 14.10 | .60 | 8.46 |
| Average annual value | ..... | ..... | $14.88 | ..... | $11.31 |
| CONTINUOUS CROPS. | | | | | |
| Alfalfa (lbs.) | 2,683 | $12.00 T. | $16.10 | $10.00 | $13.42 |
| Corn (bus.) | 19.42 | .60 | 11.65 | .50 | 9.71 |
| Wheat (bus.) | 15.31 | 1.00 | 15.31 | .60 | 9.19 |
| **Average Annual Value on Manured Land** | | | | | |
| SIXTEEN-YEAR ROTATION. | | | | | |
| Alfalfa (lbs.) | 5,870 | $12.00 T. | $35.22 | $10.00 | $29.35 |
| Corn (bus.) | 36.52 | .60 | 21.91 | .50 | 18.26 |
| Wheat (bus.) | 22.35 | 1.00 | 22.35 | .60 | 13.41 |
| Wheat, 2d year (bus.) | 27.67 | 1.00 | 27.67 | .60 | 16.60 |
| Average annual value | ..... | ..... | $26.79 | ..... | $19.40 |
| SIXTEEN-YEAR ROTATION. | | | | | |
| Brome grass (lbs.) | 1,139 | $10.00 | $5.70 | $8.00 | $4.56 |
| Corn (bus.) | 34.89 | .60 | 20.93 | .50 | 17.45 |
| Wheat (bus.) | 22.52 | 1.00 | 22.52 | .30 | 13.51 |
| Wheat, 2d year (bus.) | 27.89 | 1.00 | 27.89 | .30 | 16.73 |
| Average annual value | ..... | ..... | $19.26 | ..... | $13.06 |
| THREE-YEAR ROTATION. | | | | | |
| Corn (bus.) | 34.78 | $0.60 | $20.87 | $0.50 | $17.39 |
| Cowpeas (lbs.) | 4,387 | 10.00 | 21.94 | 8.00 | 17.55 |
| Wheat (bus.) | 21.50 | 1.00 | 21.50 | .60 | 12.90 |
| Average annual value | ..... | ..... | $21.44 | ..... | $15.95 |
| CONTINUOUS CROPS. | | | | | |
| Alfalfa (lbs.) | 4,494 | $12.00 T. | $26.96 | $10.00 | $22.47 |
| Corn (bus.) | 26.54 | .60 | 15.92 | .50 | 13.27 |
| Wheat (bus.) | 21.89 | 1.00 | 21.89 | .60 | 13.13 |

Any shift in crop prices will cause a change in the relative value of the different cropping systems, but the fact will remain that relatively high-priced crops may oftentimes produce higher acre values even when grown continuously, at least for a considerable time, than could be produced by rotations including crops having lower acre values.

Furthermore, it is not necessarily a fact that continuous cropping is more exhaustive of fertility or the cause of lower yields than rotation of crops. As an example in these experiments, the continuous alfalfa would certainly not be considered more exhaustive of soil fertility than the three-year rotation containing all annual cultivated crops. Likewise, continuous wheat is doubtless less exhaustive of fertility than the three-year rotation which does not have a legume, and possibly not more exhaustive than the regular three-year rotation with cowpeas, if the yield of wheat as shown in figure 5 is to be used as a criterion. Continuous grass sod would undoubtedly also be less exhaustive of fertility than any of the rotations.

Rotation of crops should not be loosely recommended without stating specifically what the rotation should be, or having in mind the wide differences existing between different possible rotations. It should be noted that in these experiments the difference in the monetary return between different rotations may be greater than between certain rotations and continuous cropping. Rotations are not all of equal value and must be selected with definite knowledge of the conditions where they are to be used. The matter of choosing the most valuable rotation is just as important as attempting to avoid continuous cropping.

In this discussion the cost of production of each crop has not been included, since this would simply introduce another variable factor, but it is a point that must be considered in the planning of any practical rotation. The only point being emphasized here is that certain crops may be grown more or less continuously, particularly with good soil treatments, without greatly reducing the yields and possibly with as much profit as some rotations. In these tests, wherever crops of low-acre value have been introduced, the tendency is to reduce the total value of the crops produced during a period of years.

In connection with the comparisons of the value of rotated and nonrotated crops here presented, there are certain differences in soil and soil treatments that should be kept in mind in making comparisons. The soil on the continuous alfalfa land is less fertile than the land used in the 16-year rotation, and probably less fertile than most of the land used for the three-year rotations, due to the greater amount of erosion that had taken place here before these experiments were started.

The continuous wheat and continuous corn are also located on land that has been eroded more than the land in the 16-year rotation and more than Series V and VII in the three-year rotation.

This tends to put the results on the continuously cropped land at a disadvantage in comparison with the rotations.

On the other hand the manure has been applied on the continuously cropped land at 2 1/2 tons per acre annually, while it has been applied at a somewhat lower rate on the rotated land. This gives the continuous crops some advantage on the manured land except for the differences in fertility. While these variations in soil and manurial treatments are unfortunate and may tend to alter somewhat the value of these results, it is believed the principles involved are well illustrated by the material presented in Table XXX.

### EFFECTS OF ROTATIONS ON CONTROL OF WEEDS, PLANT DISEASES, AND INSECTS

The statement is often made that rotation of crops is an effective method of weed control. In these experiments the plats in continuous wheat and continuous corn have had fewer weeds than any other land in the field. The land having the most weeds is in the three-year rotation in which cowpeas or soybeans are included. This is caused largely by the weed growth that develops in the wheat stubble which lies without plowing from wheat cutting time until late fall. During this time certain weeds, particularly crab grass *(Digitaria sanguinalis)*, fox tail *(Setaria viridis)*, and "shoo-fly" *(Hibiscus trionum),* have developed in spite of rather frequent mowings of the stubble. The continuous alfalfa has had more weeds than the rotated alfalfa, largely because of the less vigorous growth of the alfalfa plants.

The effect of rotation in controlling plant diseases is also usually considered of much importance. There has been observed but little difference in the disease on the rotated and nonrotated land except in the case of "take-all" in wheat. This has, during several seasons, been more serious on the continuous wheat, but it is not consistently bad on this land. In the 16-year rotation including alfalfa, very little "take-all" has been found, but the plats have not been entirely free from it.

The value of rotation in the control of insects is often emphasized. Studies made on these plats during the last six years by Mr. H. R. Bryson, assistant entomologist, led him to make the following statement:

> Crop rotations are not always to be recommended for the control of injurious insects, unless the crops, as well as their sequence in the rotation, are specified. Wireworm injury was found to be more severe in corn following wheat and oats than on land which had been cropped to corn continuously for a period of 20 years. On the other hand, corn root worm damage was found to be very slight on corn grown in rotation as compared with the amount present on corn grown on land cropped to corn continuously.

### SUMMARY

1. In this bulletin are summarized the results obtained on the soil-fertility project at the Kansas Agricultural Experiment Station at Manhattan, during the 20-year period 1911 to 1930.

2. The work consists of comparisons of several different cropping systems, including numerous fertilizer and other soil treatments,

3. There is difficulty in summarizing the results, due to the fact that some of the treatments were changed quite radically in 1914 and also in 1921. For this reason it has been necessary to make many of the comparisons on the basis of the untreated land, or for the period 1922 to 1930.

4. In the 16-year rotation the yield of alfalfa has been materially increased by some treatments. Manure, superphosphate, lime, potassium sulfate, and complete fertilizer gave increases ranging from 528 pounds per acre for superphosphate to 1,404 pounds for a combination of manure and lime.

5. Corn yields were not increased in this rotation by applications of superphosphate, but small increases were obtained from manure.

6. The yield of wheat was increased by most of the fertilizer and manure treatments.

7. Wheat following brome grass gave slightly higher average yields than after alfalfa. Corn gave slightly increased yields after alfalfa, but the differences were not great.

8. In the three-year rotation corn yields were increased by manure and complete fertilizers, but the other treatments were ineffective. Wheat gave increases from the use of superphosphate. Cowpea yields were increased by potassium sulfate, complete fertilizers, and manure, but not by superphosphate alone.

9. Continuous wheat yields were increased by all fertilizers and manure, but the green manure plat gave a yield slightly below the check. The highest yield was from manure 2 1/2 tons annually.

10. Continuous corn has shown some increase from each treated unit. However, the rock phosphate used with green manure did not increase the yield over that of green manure alone.

11. Continuous alfalfa has given the largest increase from a 5-ton application of manure. Superphosphate and rock phosphate gave some increase, but lime and manure gave only about 300 pounds more hay than manure alone.

12. In the 16-year rotation of alfalfa, kafir, corn, oats, fresh manure and weathered manure gave about the same results, neither producing a marked return. Rock phosphate gave a fair increase in addition to the effect of manure.

13. The yields of alfalfa in the 16-year rotation have been much higher than the alfalfa grown continuously on Series X. A part of this increase seems to be due to the fact that the land on Series X was less productive at the beginning as is shown by the yields for the early years of the experiment and before there had been any effect from the rotation. The stand apparently is becoming more difficult to maintain on Series X and frequent reseeding is necessary. The production of alfalfa in the 16-year rotation is also more difficult, largely because of the exhaustion of deep subsoil moisture.

14. The corn yields in all cropping systems were low and about equal during the first four-year period. During the next three four-

year periods, the yields were highest in the 16-year rotation followed by the three-year rotations and then by continuous cropping. The relative yields, however, remained about the same for the 12 years. During the last four-year period the yields have been in the same order, but with a greater spread in favor of the rotations. The rotations have been found to have their greatest advantage in the most favorable crop years.

15. Wheat yields in the different cropping systems have been less consistent than corn yields. The second-year wheat in the 16-year rotation has given the greatest yields since 1922, when it was started. The continuous wheat has held up remarkably well and has given higher yields during the last two four-year periods than the three-year rotation including two years of corn and one year of wheat.

16. Cowpeas and soybeans have given fair yields, but their effect on the wheat immediately following has not been favorable. The corn yields in this rotation, however, have been only 2.91 bushels per acre less than in the 16-year rotation.

17. The rotation of corn, corn, wheat, has been unsatisfactory for both corn and wheat. The yield of wheat has been less than wheat grown continuously, and the corn yield less than in the three-year rotation including a legume, but it has been higher than corn grown continuously.

18. Phosphates have been of value on alfalfa and wheat, but little return has been obtained on other crops. Potassium sulfate has given only slight increases except in the 16-year rotation where it was used in addition to superphosphate. The increase is likely due largely to the location of the plat.

19. Complete fertilizer has increased the yield of all crops.

20. Manure has increased the yield of all crops.

21. In the rotations where the amount of nitrogen, phosphorus, and potassium sulfate added was about the same in fertilizer and the manure, the fertilizer gave greater crop increases than manure. With the crops grown continuously, the manure gave slightly greater increases on corn and wheat, but the amount of nutrient elements was much greater than was applied in the fertilizer. With continuous alfalfa the elements supplied were about equal and the manure gave the greatest increase.

22. Sulfur treatments have not increased the yields of alfalfa in these experiments. This material did increase the acidity of the soil.

23. The height of wheat plants has varied considerably with the different rotations and has been increased by fertilizer and manure.

24. The length of wheat heads has not been greatly affected by the cropping system or soil treatment.

25. The test weight of wheat has not varied greatly with different cropping systems or soil treatments. Phosphates seemed to increase slightly the weight per bushel and nitrogen fertilizer or green manure had a tendency to decrease it. The greatest increase in

test weight was in the 16-year rotation on the brome-grass plat where the supply of nitrates was lower than on the other plats.

26. The plumpness of wheat, as indicated by the weight of 1,000 grains, varied considerably under different conditions. The brome-grass land produced wheat with the highest weight of individual grains.

27. The percentage of yellowberry in wheat was usually increased by soil treatment.

28. The highest protein content of wheat, as well as the highest yield, has been obtained on the land in the 16-year rotation. Phosphate decreased the protein content in all cropping systems. Manure also gave a decrease, and liming had little effect on the protein percentage. Sodium nitrate applied with phosphate and potassium sulfate slightly increased the percentage of protein. Brome-grass land gave the lowest amount of protein, the average being 2.6 percent less than wheat rotated with alfalfa.

29. With high prices for crops the 16-year rotation and the three-year rotation including a legume gave higher annual values of crops than did any of the crops grown continuously. The three-year rotation of corn, corn, wheat, gave a lower annual value of crops than did continuous alfalfa or wheat. With a lower price scale for products the continuous alfalfa was more valuable than the three-year rotation of corn, corn, wheat, and approximately the same as the three-year rotation including cowpeas.

30. On manured land continuous alfalfa gave a higher acre value than any of the rotations. When lower prices are considered, continuous corn and continuous wheat were slightly more valuable than the 16-year rotation which includes brome grass instead of alfalfa.

31. There seem to be certain conditions where continuous cropping, or at least continuous cropping for a considerable period of years, may be more remunerative and in some cases less exhaustive of soil fertility than certain types of rotations. To obtain the greatest value from the use of a rotation the crop and crop sequence must be carefully considered. High-priced crops grown continuously, at least for a considerable period, may be more valuable than a crop rotation which introduces some crops having a much lower acre value.

□