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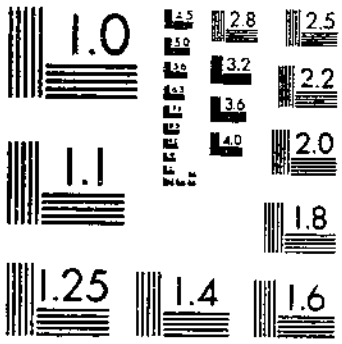

MICROCOPY RESOLUTION TEST CHART
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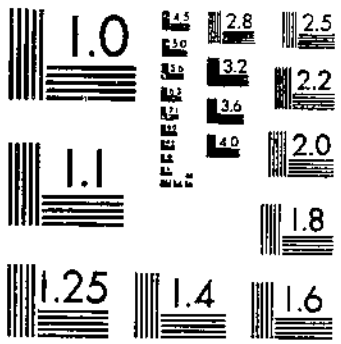

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NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL BULLETIN No. 144 October, 1929

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

IRRIGATED CROP ROTATIONS IN SOUTHERN MONTANA

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CONTENTS

INTRODUCTION

In 1912 a series of rotation experiments was begun at the Huntley Field Station,[2] located on the Huntley reclamation project, in the Yellowstone Valley of southern Montana. The station lies about 4 miles east of Huntley, at an altitude of 3,000 feet. The general agricultural conditions may be considered as fairly representative of those in a considerable area within the State as well as of those in areas in adjoining States having somewhat comparable conditions. The irrigated area in the Yellowstone Valley and in valleys tributary to the Yellowstone in southeastern Montana totals slightly more than 300,000 acres. In addition to the land in Montana watered by the Yellowstone River and its tributaries, there are probably more than 100,000 acres of irrigated land in northern Wyoming having somewhat similar soil and climatic conditions.

The Huntley reclamation project occupies about 32,000 acres of land in the Yellowstone Valley of Montana, somewhat east of the south-central part of the State. The project extends from Huntley east to Bull Mountain, a distance of about 25 miles. It varies in width from about one-half mile at Huntley to a maximum of about 4 miles near the central part, again narrowing gradually to a width of one-half mile at the lower end. Most of the project occupies a gentle slope, bounded on the south by low hills and sandstone bluffs and on the north by the Yellowstone River. Water for irrigation is diverted from the river at a point about 4 miles above Huntley.

[1] The Office of Western Irrigation Agriculture was established in 1904, with C. S. Scofield as Agriculturist in Charge, for the purpose of investigating and improving agricultural conditions on irrigated lands. This work at the various field stations was planned and inaugurated by Mr. Scofield with the assistance of F. D. Farrell. The supervision of the field work and the preparation of the detailed reports on which this bulletin is based were under the direction of the junior writer. He was assisted at various times by other members or former members of the scientific staff, who contributed toward procuring the data, as follows: E. G. Noble, J. W. Knorr, J. W. Boon, D. A. Savage, and LeRoy Powers.

[2] The station is maintained cooperatively by the Montana Agricultural Experiment Station, the Bureau of Reclamation of the Department of the Interior, and the Bureau of Plant Industry. Other cooperating branches of the United States Department of Agriculture are the the Bureaus of Animal Industry and Dairy Industry, as well as various offices of Plant Industry.

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The average elevation of the project is about 2,900 feet above sea level. The average annual precipitation as recorded at the Huntley station since 1910 is 14.58 inches, and the average frost-free period is 129 days. Slightly more than half of the rainfall occurs between April 1 and August 31, which is of material aid in supplementing irrigation water.

The soils of the Huntley project vary from sandy loam to heavy clay. The sandy soils occur over a comparatively small area and are found usually along the river. The larger part of the more productive soils are of a heavy clay-loam type and are included in the area in the upper end of the project and along the south side of the valley. On a bench which occupies less than 3,000 acres and which is about 50 feet above the floor of the valley east from the town of Ballantine, most of the soil is of a sandy-loam nature. In some places on this bench the surface soil contains gravel, and gravel underlies this entire area at comparatively shallow depths. The soils on most parts of this bench area are very productive and are worked more easily than the soils in the main part of the valley. On the lower end of the project is an area of 6,000 to 7,000 acres on which the soil is a heavy impervious clay containing an excessive amount of alkali salts, chiefly sodium sulphate. This land is difficult to reclaim, and much of it has not yet been brought into profitable production.

The surface soil of the valley is underlain by a stratum of sand and gravel at depths varying from 5 to 15 feet. This underlying gravel is broken by clay barriers, so that there is not a free movement of water through the subsoil. On most of the project it has been necessary to provide a rather complete underground drainage system. The native vegetation consists mainly of low-growing sage, greasewood, and grass.

The principal crops that have been grown on the project are alfalfa, sugar beets, oats, wheat, corn, and potatoes. An average of about 2,000 acres is devoted to summer pasture. The crops grown chiefly for sale are sugar beets, wheat, and oats, sugar beets being by far the most extensively grown. The forage produced is largely consumed by livestock permanently on the project or brought in from adjacent ranges to consume temporary surpluses for which there is no profitable cash market.

The soil of the Huntley Field Station, which is located on the south side of the valley, is of the heavy clay-loam type, typical of the better soils on the larger part of the project. Slight variations in the soil occur over most areas, and this is true to some extent in field K, in which most of the rotation experiments are conducted. The soil there is particularly heavy in the lower part of the field in Series V. This variation in the soil resulted in the early years of the experiment in differences in plant growth within plots and series. These differences have become less apparent in recent years.

In field L–IV the soil is also heavy, but it is rather more uniform than that in field K.

The general plan and objectives in the rotations reported herein are similar to those described in a former publication relating to the rotation investigations conducted on the Scotts Bluff (Nebr.) Field Station [3] and also incorporated as a part of the investigational work being conducted at the Belle Fourche (S. Dak.) Field Station.

[3] SCOFIELD, C. S., and HOLDEN, J. A. IRRIGATED CROP ROTATIONS IN WESTERN NEBRASKA. U. S. Dept. Agr. Tech. Bul. 2, 26 p., illus. 1927.

OBJECTIVES OF THE ROTATIONS

It was desired in these experiments to ascertain what rotations and cropping methods were best suited to the irrigated area representative of south-central Montana and other similar areas of the Great Plains. This information was sought through (1) comparing the yields from continuously cropped plots, using the seven most important crops with those in a rotation of two or more years; (2) noting the effect of alfalfa in a rotation as compared with a rotation where no leguminous crop is grown; and (3) observing the effect of barnyard manure in comparison with a similar rotation receiving none.

In addition to the above, which were the chief aims of the rotations, information was obtained as to (1) the value of rye as a green-manure crop when used in a rotation with oats and potatoes; (2) the effect on subsequent crop yields where alfalfa and corn are pastured, as compared with a rotation where these crops are harvested by the ordinary method and removed; and (3) the effect on yields on a plot continuously cropped to wheat where the straw is returned to the land, as compared with a plot where the straw is removed.

The original series of 29 rotations located in field K were started in 1912. In 1916, 10 additional rotations were added in field L–IV for the purpose of furnishing additional information not given by the original series. Field K was broken up from native sod in 1909. In 1910 approximately the west three-fourths of the field was cropped to sugar beets and the remainder of the field to corn. In 1911 the entire field was cropped to oats. Field L–IV was broken up from native sod in the fall of 1914 and was cropped uniformly to oats in 1915. The field before being broken up was covered with a light growth of buffalo grass and bluejoint grass.

In the first series of rotations started in 1912 the following crops and crop sequences were included: Crops grown continuously on the same land each year: (1) Oats, (2) sugar beets, (3) wheat, (4) potatoes, (5) wheat, (6) corn, (8) alfalfa, and (9) flax.

The following are the 2-year rotations, which include those that receive no special treatment as well as those having a treatment of barnyard manure at the rate of 12 tons to the acre as indicated: (16) Oats, corn; (18) wheat, sugar beets; (20) potatoes, beets; (21) potatoes (manured) followed by beets; (22) oats, sugar beets; (23) oats followed by sugar beets (manured); (24) oats, potatoes; (25) oats followed by potatoes (manured); (26) potatoes, corn; and (28) wheat, oats.

The following are the 3-year rotations, which include one rotation (31) receiving an application of 12 tons of barnyard manure following oats during the period: (30) Potatoes, oats, beets; (31) potatoes, oats, followed by beets (manured); and (32) corn, oats, beets.

Three 4-year rotations were included, in which two years of alfalfa appear, as follows: (40) Potatoes, sugar beets, alfalfa, alfalfa; (42) oats, sugar beets, alfalfa, alfalfa; and (44) potatoes, oats, alfalfa, alfalfa.

The following 6-year rotations were included, in which alfalfa appears three successive years in each, and manure as indicated was used in rotation 61: (60) Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa; and (61) potatoes, oats followed by sugar beets (manured), alfalfa, alfalfa, alfalfa.

In connection with the foregoing crop sequences, information was sought along the lines of determining the merits of wheat continuously (3 and 5) as compared with wheat continuously cropped where the straw was returned to the land each year (7). The 2-year rotation with oats and potatoes with no special treatment (24) was compared with oats followed by winter rye and potatoes. In the two 6-year rotations (60 and 61) potatoes, oats, sugar beets, and three years of alfalfa appear and are harvested in the customary manner. A 6-year rotation, No. 67, includes three years of alfalfa, followed by corn, flax, and beets. In this rotation the third-year alfalfa and the corn are pastured by hogs.

In 1916, 10 rotations were added to the above list for the purpose of obtaining further information on crop sequences. It will be observed that several continuously cropped plots, identical with those adopted in 1912, are included in this new list. This seemed desirable because there were soil differences between field K, originally selected, and field L–IV, where these new rotations were established. The 10 rotations added in 1916 were as follows:

Continuously cropped: (1–a) Oats, (2–a) sugar beets, (4–a) potatoes, (6–a) corn, (8–a) alfalfa.

Two 3-year rotations were added, as follows: (34) Potatoes, sugar beets, oats; (35) potatoes (manured), sugar beets, oats. Rotation 34 is to be compared with 35, with which it is identical except that 35 has an application of 12 tons of stable manure every three years preceding the potato crop. Rotations 30 and 31 may also be compared with 34 and 35, with which they are identical as far as crops are concerned, but are different in that the crop sequences are not the same. Potatoes, oats, and sugar beets is the order in which the crops appear in rotations 30 and 31, whereas in the case of 34 and 35 the sequence is potatoes, beets, and oats.

One 4-year rotation was added as follows: (46) Sugar beets, oats, alfalfa (two years).

Two 6-year rotations were also added, as follows: (64) Alfalfa, alfalfa, alfalfa, potatoes, beets, oats; (69) alfalfa seeded in oat stubble in fall, alfalfa, alfalfa pastured with hogs, corn harvested by hogs, corn harvested by hogs, oats. Rotation 64 may be compared with No. 60, from which it varies only in the sequence of the crops. Rotation 69 is supplementary and is included for the purpose of determining the value of a rotation where livestock is available and the opportunity is taken of harvesting the third-year alfalfa and the two crops of corn.

These rotations were so arranged that each crop involved in each rotation is grown every year. To carry out this plan it was necessary to have as many plots devoted to the rotation as there are years in the cycle of rotation. By following this method it is possible each year to compare the yields from the same crops grown in the different rotations.

LIST OF THE ROTATIONS

The following is a list of the rotations, arranged in numerical order for convenience of reference.

CROPS GROWN CONTINUOUSLY ON THE SAME PLOTS

1. Oats.
1–a. Oats.
2. Sugar beets.
2–a. Sugar beets.
3. Wheat.
4. Potatoes.
4–a. Potatoes.
5. Wheat.
6. Corn.
6–a. Corn.
7. Wheat (straw returned).
8. Alfalfa.
8–a. Alfalfa.
9. Flax.

TWO-YEAR ROTATIONS

16. Oats, corn.
18. Wheat, sugar beets.
20. Potatoes, sugar beets.
21. Potatoes (manured), sugar beets.
22. Oats, sugar beets.
23. Oats, sugar beets (manured).
24. Oats, potatoes.
25. Oats, potatoes (manured).
26. Potatoes, corn.
27. Oats (followed by rye plowed under), potatoes.
28. Wheat, oats.

THREE-YEAR ROTATIONS

30. Potatoes, oats, sugar beets.
31. Potatoes, oats, sugar beets (manured).
32. Corn, oats, sugar beets.
34. Potatoes, sugar beets, oats.
35. Potatoes (manured), sugar beets, oats.

FOUR-YEAR ROTATIONS

40. Potatoes, sugar beets, alfalfa (two years).
42. Oats, sugar beets, alfalfa (two years).
44. Potatoes, oats, alfalfa (two years).
46. Sugar beets, oats, alfalfa (two years).

SIX-YEAR ROTATIONS

60. Potatoes, oats, beets, alfalfa (three years).
61. Potatoes, oats, sugar beets (manured), alfalfa (three years).
64. Potatoes, sugar beets, oats, alfalfa (three years).
67. Corn (harvested with hogs), flax, sugar beets, alfalfa (three years, pastured with hogs the third year).
69. Corn (harvested with hogs, two years), oats, alfalfa (three years, pastured with hogs the third year).

The location of these various rotations with reference to one another is shown in Figures 1 and 2.

CULTURAL PRACTICES AND CROP VARIETIES

The cultural operations used in conducting these investigations were considered to be in keeping with the more modern practices in vogue and the most desirable to bring about the best results. In order that the yields of the same crop appearing in the different rotations might be as nearly comparable as possible, the same cultural practices, planting date, and harvesting methods were followed as closely as was permissible under the existing conditions at the time the various operations were scheduled to be performed. The same varieties of crops were always planted each season, although as more improved strains or varieties were introduced in certain instances they were substituted for those formerly grown.

Plots to be planted to cultivated crops are plowed to a depth of about 8 inches the previous fall and left in the rough during the winter; the only exception to this is in rotation 27, where rye is seeded in oat stubble in the fall and plowed under the following spring. Where oats, wheat, flax, or alfalfa follow a cultivated crop the land is not plowed but is double disked in the spring before planting. Where grain follows an uncultivated crop the land is fall plowed.

In the event that alfalfa is to be followed by another crop, the alfalfa is crowned to a depth of about 4 inches, and about a week or 10 days later it is harrowed with a spike-tooth harrow and later

plowed to a depth of about 8 inches, in order to kill as many of the roots as possible. All plots planted to grain are double disked in the fall immediately after the crop is removed, even if later they are to be plowed. This practice is followed to put the land into better condition for plowing and also to destroy weeds and germinate shattered grain which otherwise would be a source of annoyance the

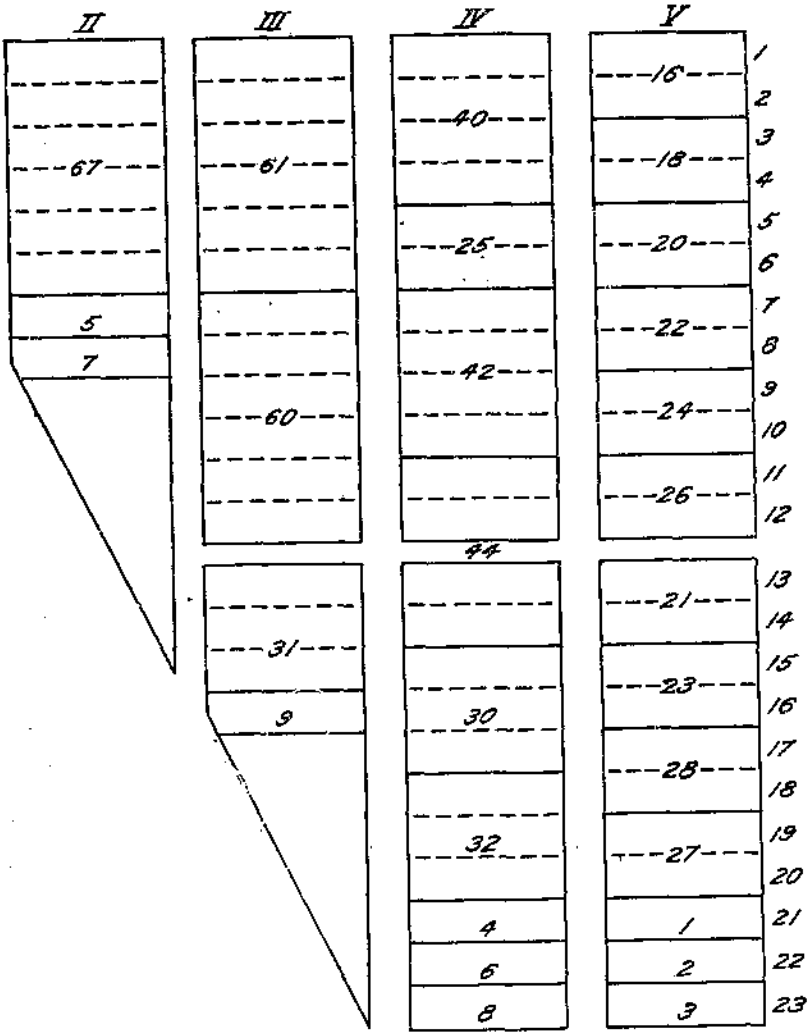

FIGURE 1.—Location of the irrigated rotations in field K, Huntley Field Station, started in 1912

following season. All alfalfa plots where the crop has been seeded for two or more years are renovated by harrowing with a spike-tooth harrow about the time the green shoots appear in the spring. In the fall well-rotted barnyard manure is applied at the rate of 12 tons per acre to all plots to be so treated, and the manure is plowed under immediately following the application. As soon as the oat crop is harvested, winter rye, used as a green-manure crop in rotation 27, is

seeded in the oat stubble in the fall and plowed under the following spring immediately preceding the planting of the potatoes. After

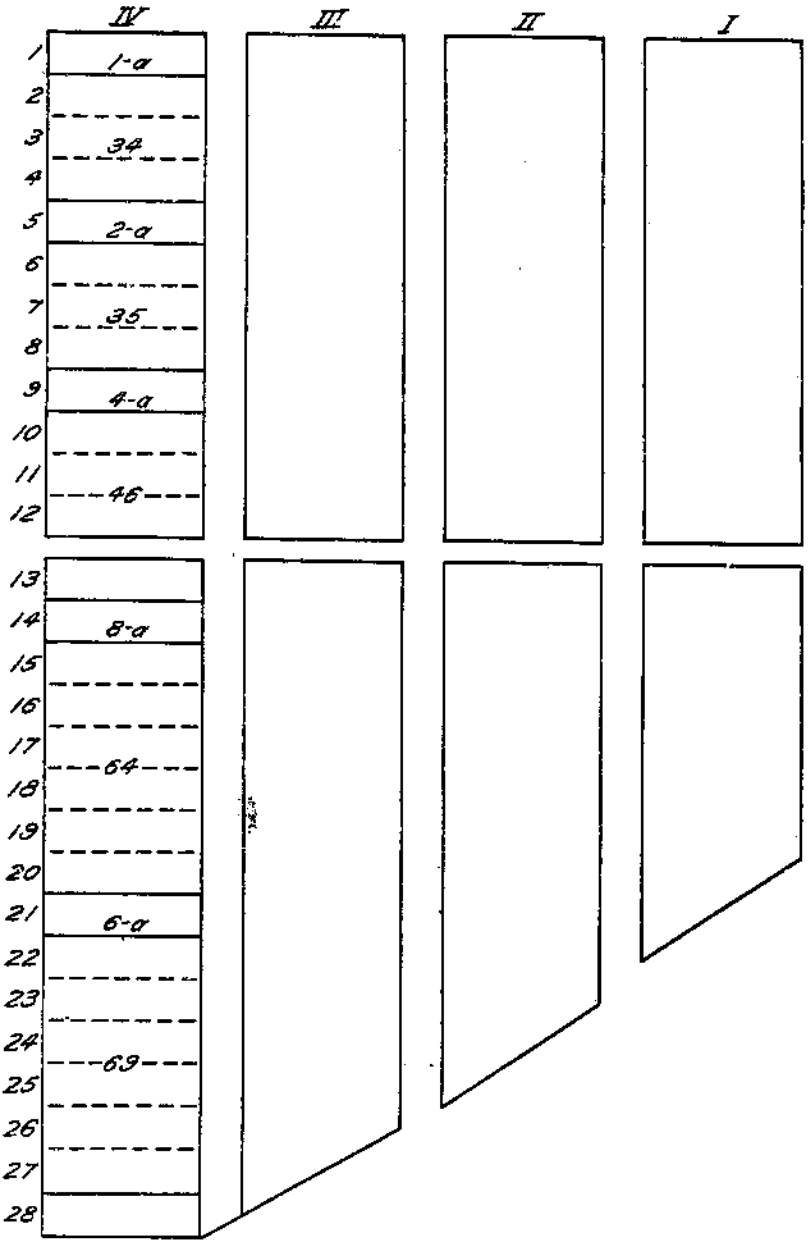

FIGURE 2.—Location of the irrigated rotations in field L, Huntley Field Station, started in 1916

plowing, the seed bed is thoroughly prepared by disking, harrowing, and leveling. As early in the spring as the land can be prepared, wheat is seeded at the rate of 5 pecks to the acre. Sugar beets and

spring-seeded alfalfa are planted the last of April or early in May; corn, potatoes, oats, and flax as soon as danger of frost is over, usually about the middle of May. Rape, used as a supplementary pasture crop for hogs in rotation 69, is seeded in the corn plots the latter part of July.

Irrigation practices adopted and followed were those consistent with methods in vogue locally and adjusted to meet the varying climatic conditions occurring throughout the period. Row crops were furrow irrigated, whereas the grain crops—alfalfa and flax—were irrigated by flooding.

The difficulties met from time to time in connection with maintaining uniformity throughout the planting and cultural operations during the period covered in data herein reported have had at times a tendency to affect the comparative results. Owing to weather conditions it has not been possible always to perform the cultural operations at the time and in the manner outlined. Insects, disease, and storm damage have been factors; and the injury has not always been uniform on all the rotations during any one season. There have also been certain accidental injuries which have not been uniformly distributed throughout all the rotations. In most instances these could not be allowed for because the effect on the yield could not be definitely measured. When recognition could be taken of these factors, and it is believed they have had a material tendency to distort the yearly comparative results, they are described in the text.

BASIC-YIELD DATA

In presenting the results of these rotation experiments it appears to be desirable to follow the same general plan of presentation as that adopted in connection with the Scotts Bluff rotations reported in a former publication [4] by giving in detail the basic facts as to the crop yields obtained. These facts may be summarized and compared in a number of different ways. Some of these comparisons and summaries accompany and follow the tables of yields.

The details as to crop yields are given in a series of tables, one table for each crop. The yields per acre are given for each year and for each rotation. Mean yields are given both for all plots of the same crop for each year and for each rotation for the period of 15 years covered by the experiments. In addition, the mean yields for the last 6 years of the experiments are reported for the purpose of ascertaining the trend of the yields for that period as compared with the total period.

The acre yields of oats in bushels in 13 rotations for the entire period are given in Table 1. Rotations 1–a, 34, 35, 46, 64, and 69 are rotations started in 1916 and consequently are for the 11-year period from 1916 to 1926, inclusive. Yields from rotations 1 and 28 in 1916 are not given, as both these plots in that season were so badly infested with wild oats that the crop was cut and burned, and the same condition obtained in rotation 28 in 1919, which explains why yields do not appear for the years given in these rotations.

[4] SCOFIELD, C. S., and HOLDEN, J. A. Op. cit.

TABLE 1.—*Acre yields of oats (bushels) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1926	Mean, 1921–1926
1	37.2	37.8	45.7	43.1	----	40.8	45.5	21.0	31.5	27.1	56.2	41.9	47.5	36.3	19.2	37.9	38.0
1–a	----	----	----	----	60.3	76.8	82.0	57.5	59.5	40.7	78.7	43.2	51.2	42.5	34.0	56.0	48.4
16	49.8	85.3	78.5	75.5	67.8	55.8	81.4	50.0	43.2	66.4	73.7	79.0	72.5	55.0	43.8	65.2	65.1
22	63.4	96.7	109.5	79.2	94.5	81.5	96.8	63.7	70.0	91.1	88.7	90.5	80.0	76.0	51.9	82.0	78.7
23	45.5	84.3	93.7	96.2	82.3	70.5	79.6	48.1	58.8	66.4	105.0	87.9	97.5	81.3	64.8	77.5	83.8
24	66.9	106.0	102.7	81.5	72.1	68.5	93.4	41.9	54.2	74.1	78.7	84.9	95.0	65.0	44.0	75.5	73.6
25	57.5	126.8	115.0	78.8	87.3	84.8	92.5	54.4	53.0	76.1	97.5	101.6	117.5	90.0	60.4	86.2	90.5
27	39.5	70.5	82.6	83.7	45.5	46.1	76.1	23.1	36.0	59.1	80.0	70.2	78.7	58.8	31.6	58.8	63.1
28	33.5	42.5	62.5	50.5	----	34.6	49.5	----	45.5	48.4	72.5	59.5	53.7	46.3	17.9	47.4	49.7
30	41.0	85.9	87.0	103.7	40.9	45.9	80.1	26.9	40.8	58.8	81.8	75.3	87.5	74.1	35.6	64.8	68.8
31	43.8	77.6	94.5	102.9	77.3	50.0	86.5	30.6	43.6	60.5	92.5	75.4	113.7	83.8	32.1	71.0	76.3
32	49.2	59.1	75.2	85.5	61.5	60.5	63.8	26.9	42.8	48.6	75.0	59.2	65.0	52.5	31.3	56.4	55.3
34	----	----	----	----	50.3	116.9	113.0	68.7	96.0	75.8	92.5	89.0	72.5	72.5	62.5	83.2	77.5
35	----	----	----	----	50.6	102.3	110.8	83.1	90.5	73.1	92.5	89.0	86.2	76.3	62.5	84.1	79.9
42	60.3	103.1	83.7	73.3	61.4	89.4	103.2	57.5	97.8	73.0	105.0	94.5	96.2	102.5	75.0	87.1	91.1
44	44.0	81.0	105.2	78.7	83.5	61.6	93.0	54.4	58.5	75.0	100.0	101.3	113.7	90.3	66.3	80.9	92.1
46	----	----	----	----	50.0	106.8	103.0	60.0	86.3	85.9	101.2	94.6	101.2	101.3	103.4	90.4	97.9
60	47.2	86.6	108.4	81.8	101.6	66.8	127.0	71.2	73.8	80.1	96.2	94.2	120.0	126.3	80.8	92.1	98.6
61	50.0	116.2	102.9	75.8	104.8	110.6	118.9	64.4	70.1	80.8	98.7	96.5	113.7	117.5	95.8	94.5	100.5
64	----	----	----	----	58.1	95.0	100.3	76.2	79.8	79.4	93.7	96.6	95.0	105.0	96.9	89.3	94.4
69	----	----	----	----	57.8	99.6	100.2	73.7	96.5	85.5	98.7	85.0	105.0	101.3	95.8	90.8	95.1
Annual mean	48.7	84.2	89.8	79.3	71.1	75.0	90.7	52.7	63.7	67.9	88.5	81.4	88.7	78.8	57.4	74.5	77.1
Maximum	66.9	126.8	115.0	103.7	104.8	116.9	127.0	83.1	99.5	91.1	105.0	101.6	120.0	126.3	103.4	----	----
Range	33.4	89.0	69.3	60.6	59.3	82.3	81.5	61.2	68.0	64.0	48.8	59.7	72.5	90.0	85.5	----	----

The highest yield harvested during the entire period covering all plots was 127 bushels per acre in rotation 60 in 1918; and the lowest yield was from rotation 28, in 1926, from which only 17.9 bushels were harvested.

The annual mean ranged from 48.7 bushels obtained in 1912 to 90.7 harvested in 1918, with a 15-year annual mean of 74.5 bushels per acre. The lowest mean yield, obtained both for the 15-year period and for the last 6 years, was from rotation 1 continuously cropped; and the highest mean yield was from rotation 61 both for the 15-year and the 6-year period, a 6-year rotation in which alfalfa appears three times and 12 tons of stable manure is applied once during the cycle. With the exception of rotation 35, there is a consistent increase in mean yields for the last 6 years over those obtained from the rotations in effect for the full 15 years where alfalfa appears or manure is applied as compared with those continuously cropped and the untreated rotations.

The yields of sugar beets are given in Table 2. The mean annual yield has ranged from a maximum of 19.06 tons in 1923 to a minimum of 7.63 tons harvested in 1920. The season of 1920 was extremely unfavorable, mainly because of adverse climatic conditions occurring in the spring and also in part because of insect injury, which reduced the stand somewhat on all plots. The percentage of stand resulting from rotations 18 and 22 was so poor that measurable yields were not obtained. Rotation 2–a was reseeded, but so late that the yield was very much lower than otherwise would have been the case. In several other plots in the season of 1920 varying degrees of a stand occurred, but not sufficiently poor to justify reseeding; and this condition tended to distort the comparative results from the plot yields recorded for that year. The very low yield of 2.77 tons per acre in 1925 from rotation 2–a was largely due

to the black-rot disease, which either kills the plants entirely or materially lowers their vigor. Beets grown in several other plots were also injured from this cause, but to a much less extent. The same disorder was prevalent in 1926 to even a greater extent and is reflected in the apparent inconsistency in the yields recorded. This is particularly noticeable in yields from rotations 18 and 40.

TABLE 2.—*Acre yields of sugar beets (tons) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1926	Mean, 1921–1926
2	6.38	9.25	8.17	9.98	11.19	8.47	8.92	5.75	5.89	8.40	11.05	14.35	9.71	7.89	6.61	8.80	9.67
2-a					13.08	11.94	14.59	12.92	1.75	10.57	7.84	13.99	6.38	2.77	4.98	9.21	7.75
18	11.96	9.46	9.56	5.94	8.24	9.11	7.15	6.47		3.65	9.44	13.38	8.68	8.61	3.33	8.28	8.01
20	12.28	12.57	15.09	8.33	15.02	9.58	14.59	8.58	6.71	12.49	13.04	19.93	16.61	9.75	9.63	12.27	13.56
21	12.57	13.33	14.40	12.79	17.93	12.07	13.69	12.48	8.17	14.66	16.35	25.73	19.91	16.03	15.88	15.07	18.08
22	11.66	15.22	10.38	6.80	11.14	11.32	10.20	9.28		6.90	11.19	12.09	9.93	4.39	5.57	9.72	8.34
23	14.37	13.36	12.60	10.69	11.98	12.46	11.38	11.90	10.09	10.79	15.64	13.71	16.42	16.05	16.14	13.17	14.79
30	7.34	11.39	6.57	4.84	6.73	6.66	8.44	7.72	6.09	5.48	11.35	12.42	9.54	7.96	7.45	8.00	9.03
31	8.34	15.32	12.80	9.13	10.02	9.62	10.65	7.70	9.98	8.51	15.27	23.06	15.03	13.27	16.08	12.32	15.20
32	8.15	11.26	6.82	6.34	5.86	7.11	9.55	9.33	8.11	5.79	13.80	19.07	11.04	10.19	9.33	9.56	11.80
34					10.63	10.52	13.54	15.86	7.52	10.91	12.16	18.90	11.82	9.44	5.04	11.48	11.38
35					13.15	10.26	13.54	13.33	7.27	14.77	14.97	24.59	18.35	13.35	12.78	14.19	16.47
40	9.62	13.34	13.91	15.45	10.38	8.41	16.19	6.40	5.75	12.67	12.47	20.16	16.93	13.23	4.70	11.97	13.36
42	9.49	14.38	9.30	7.65	11.39	5.92	13.15	7.56	8.14	9.17	10.18	18.45	14.56	12.21	6.09	10.51	11.78
46					12.76	9.57	9.40	9.41	5.72	14.49	13.66	17.40	9.34	10.89	5.72	10.76	11.91
60	9.69	11.63	9.28	12.90	7.40	8.27	14.23	12.02	10.13	9.49	15.05	20.41	15.01	16.03	16.09	12.51	15.35
61	12.17	15.76	13.57	8.73	15.56	13.00	14.67	13.66	10.11	14.44	18.54	26.15	17.73	16.25	14.28	14.97	17.90
64					12.34	10.31	12.23	10.38	7.38	14.19	14.96	22.81	16.31	13.77	10.23	13.13	15.30
67	10.26	16.80	13.78	14.62	13.50	11.91	16.53	12.00	10.83	13.58	17.69	25.42	16.13	18.12	15.04	15.13	17.76
Annual mean	10.31	13.08	11.16	9.58	11.53	9.82	12.23	10.15	7.63	10.79	13.40	19.06	13.54	11.59	9.77	11.57	13.02
Maximum	14.37	16.80	15.09	15.45	17.93	13.00	16.53	15.86	10.83	14.77	18.54	26.15	19.91	18.12	16.14	-----	-----
Range	7.99	7.55	8.52	10.61	12.07	7.08	9.38	10.11	9.08	9.29	10.70	14.06	13.55	15.35	12.81	-----	-----

The lowest mean yields of less than 10 tons per acre quite consistently occur in either the rotations continuously cropped or from those untreated, a condition which appears in both the 15-year period and the last 6-year mean. The conspicuous exception to this is the yield from the 2-year rotation 20, where potatoes is the companion crop. The yields from beets following potatoes indicate that potatoes up to the present time even in a 2-year untreated rotation have had a beneficial effect on the soil as far as the yield on sugar beets is concerned. Where manure was applied or alfalfa was incorporated, the past six years show an increase in yield over the 15-year mean, indicating the cumulative desirable effect of such rotations.

The highest yield for the 6-year period is from 2-year rotation No. 21, which consisted of potatoes, manured, followed by sugar beets. Closely second to the yield from this rotation are the yields from the two 6-year rotations, Nos. 61 and 67, for the same period.

Yields of potatoes are given in Table 3. These include yields from 13 rotations for the full 15-year period and from 4 rotations for the 11-year period from 1916 to 1926, inclusive. The maximum yield of 519.3 bushels per acre occurred in 1918 in rotation 25, and the minimum of 5.5 bushels in rotation 27 in 1914. The mean annual yield for the entire period from all rotations was 228.7 bushels. The lowest mean annual yield occurred in 1920. In that year unfavorable weather conditions early in the season resulted in failure to obtain satisfactory stands from the first planting, and it was necessary to replant.

TABLE 3.—*Acre yields of potatoes (bushels) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1926	Mean, 1921–1926
4	233.6	193.8	118.3	232.0	175.3	88.7	232.0	204.1	78.6	132.6	138.0	171.3	124.7	96.0	88.7	153.8	125.2
4-a	.....	.....	.....	.....	137.7	213.2	443.3	193.3	122.0	272.6	166.0	200.0	179.3	166.2	92.0	198.7	179.3
20	273.6	199.8	178.7	350.0	227.7	241.3	390.3	282.3	108.6	251.3	112.7	191.3	148.7	200.7	143.3	226.0	174.7
21	270.4	226.1	176.0	386.5	293.6	276.7	310.5	246.6	124.0	226.0	126.0	179.7	230.7	200.3	274.8	241.7	217.7
24	262.8	316.1	171.4	273.4	236.2	229.5	315.2	240.6	106.6	180.7	169.7	131.7	166.0	150.7	131.3	206.8	158.3
25	413.2	362.0	201.3	373.9	324.0	292.4	519.3	389.0	226.6	239.3	275.3	303.5	271.3	340.7	367.3	322.6	289.6
26	260.8	158.2	204.5	251.0	278.8	239.0	303.6	221.6	116.0	178.0	136.0	148.7	129.8	136.7	93.3	190.8	137.1
27	98.4	30.0	5.5	199.4	45.3	70.4	159.6	170.0	58.6	105.3	71.3	124.3	65.3	74.7	174.0	97.2	102.5
30	205.2	188.2	156.3	227.6	224.5	175.0	260.4	167.3	123.3	220.6	159.0	174.3	163.3	113.3	183.3	184.5	169.0
31	199.2	159.7	140.4	273.5	212.0	90.7	324.5	148.0	114.6	189.3	128.7	212.0	102.0	92.7	237.3	177.7	167.0
34	.....	.....	.....	.....	254.4	272.9	425.3	258.0	197.3	226.6	236.7	235.3	281.3	205.8	216.7	263.6	248.7
35	.....	.....	.....	.....	203.7	265.9	448.0	232.3	222.6	258.6	283.3	342.0	376.0	358.8	324.0	301.4	323.8
40	210.4	259.2	156.1	349.6	246.7	224.5	445.3	246.0	182.6	268.6	272.3	243.9	270.3	330.3	333.3	268.5	289.4
44	237.6	112.8	195.3	169.8	166.0	181.7	373.3	203.1	111.0	212.6	204.7	144.7	150.0	236.7	309.3	202.3	210.7
60	228.4	285.3	203.3	306.8	292.0	238.3	345.3	379.7	169.3	358.0	212.0	203.3	244.0	310.7	324.7	288.8	285.4
61	273.6	276.8	184.0	420.6	401.7	295.7	473.7	354.7	90.6	341.2	279.3	321.0	326.7	312.7	324.0	311.8	317.5
64	.....	.....	.....	.....	167.9	311.6	445.0	301.0	196.6	310.6	282.0	212.0	231.3	369.0	394.0	292.8	299.9
Annual mean	244.1	212.7	167.8	301.8	228.7	218.2	367.6	249.3	136.5	232.5	191.4	211.7	209.2	227.3	232.4	228.7	217.4
Maximum	413.2	362.0	203.3	420.6	401.7	311.6	519.3	389.0	226.6	358.0	283.3	342.0	376.0	369.6	394.0	.....	.....
Range	314.8	326.0	287.8	230.2	356.4	241.2	359.7	241.0	168.0	252.7	212.0	217.7	310.7	294.9	305.3	.....	.....

Relatively low yields have occurred in most years in rotation 27, in which potatoes follow oats with rye seeded in the fall in the oats stubble and plowed under as green manure immediately preceding the planting of potatoes. This has proved to be an undesirable practice, mainly due to the difficulty in obtaining a proper seed bed from spring plowing because of the heavy nature of the soil. This usually requires irrigation for germination of the seed pieces, which results in puddling of the soil and a consequent poor stand and delayed growth.

The yields of wheat as this crop appears in the various rotations are given in Table 4. In 3 years out of the 15 (1912, 1916, and 1919), yields from certain rotations were not recorded. At the time the rotations were started, in 1912, winter wheat was scheduled for rotations 5 and 7 and consequently was not seeded until the fall of 1912 and harvested in the spring of 1913, and the first crops harvested in these rotations were credited to that year. In 1914 all wheat plots were seeded to spring wheat in the interest of uniformity in results.

TABLE 4.—*Acre yields of wheat (bushels) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1926	Mean, 1921–1926
3	20.9	28.2	30.5	39.6	.....	16.6	17.3	.....	27.8	14.7	30.6	17.7	10.7	24.7	11.0	21.7	18.3
5	.....	58.3	35.6	36.3	21.7	29.5	25.4	.....	30.6	18.6	26.9	12.4	20.6	32.7	13.9	27.9	20.7
7	.....	61.9	32.9	37.6	24.8	29.1	24.3	.....	26.6	19.0	23.3	11.3	12.7	19.3	16.4	26.1	17.0
18	31.6	36.1	40.7	47.0	32.7	35.7	35.4	27.3	17.8	33.6	26.0	30.8	34.0	34.7	38.1	33.8	33.9
28	23.5	17.4	22.9	19.2	.....	21.4	16.1	.....	28.8	18.9	28.6	24.0	16.7	16.6	15.7	20.7	20.0
Annual mean	25.3	40.4	32.5	34.1	26.4	26.5	23.9	27.3	26.3	21.0	27.0	20.4	16.8	25.5	19.1	26.3	22.0
Maximum	31.6	61.9	40.7	47.0	32.7	35.7	35.4	.....	30.6	33.6	30.0	30.8	34.0	34.7	38.1	.....	.....
Range	10.7	44.5	17.8	27.8	11.0	19.1	19.3	.....	12.8	18.9	7.3	25.5	23.3	18.7	26.5	.....	.....

The winter of 1912 and the following spring were exceptionally favorable, and notably high yields of winter wheat, harvested in 1913, resulted. A further factor in favorably influencing the yields was the fallowing of these two plots during the summer of 1912. No yields were recorded for rotations 3 and 28 for 1916, which was due to a severe infestation of wild oats, resulting in its proving to be desirable to destroy the entire crop before maturity of the seed in order to eradicate the wild oats. The same condition resulted in 1919, when only one rotation (No. 18) was harvested.

The outstanding feature in connection with this table is the relatively poor yield resulting from rotation 7, in which the straw is returned, and more particularly the past six years. This plot has produced the lowest yields for the 6-year period of any in the series and 9.1 bushels per acre less than for the complete period.

The net result of this special treatment thus far obtained has appeared to have even a more adverse effect on the productivity of the soil than wheat grown continuously without this treatment. It was found that in rotations 3, 5, and 7, where wheat is continuously produced on the same land, wild oats has been an important factor in reducing the yields over what otherwise would have been the case. Consequently the low yield recorded for the last six years in these three rotations may be attributed to both a reduction of the productivity of the soil and to the weed problem.

The yields of corn are given in Table 5. No total crop failures have been experienced during the course of the rotations. The yields have proved to be more consistently uniform than those of any of the crops heretofore presented, largely because the crop is less susceptible to plant diseases, insect pests, and other crop hazards.

Both for the 6-year and the 15-year mean, a simple rotation with potatoes (No. 26) has given the highest yield. The lowest for both periods is that from the continuously cropped plot in rotation 6. This rotation has fallen 10.2 bushels below the 15-year mean and 15 bushels below the last 6-year mean.

TABLE 5.—*Acre yields of corn (bushels) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1920	Mean, 1921–1926
6	32.0	36.7	31.6	31.6	35.9	30.3	34.8	26.1	27.5	23.7	31.7	28.6	19.4	23.2	16.0	28.5	23.8
6-a					44.7	40.6	50.4	43.9	42.7	53.3	40.8	43.9	32.2	34.8	24.4	41.1	38.2
16	42.8	33.9	41.4	36.1	31.5	25.2	50.2	22.2	40.0	28.3	43.3	53.8	37.6	40.7	25.0	35.8	38.1
26	41.8	48.5	55.1	41.3	41.8	35.0	48.3	38.1	45.4	48.8	53.9	58.8	55.4	45.5	37.6	46.4	50.0
32	29.1	48.7	43.5	38.7	37.0	31.7	45.6	36.2	45.7	37.9	48.7	61.4	38.2	42.0	34.4	41.3	43.8
Annual mean	36.4	41.9	42.9	36.9	38.9	32.6	45.9	33.3	40.3	38.4	43.7	49.3	36.6	37.2	27.5	38.7	38.8
Maximum	42.8	48.7	55.1	41.3	44.7	40.6	50.4	43.9	45.7	53.3	53.9	61.4	55.4	45.5	37.6	-----	-----
Range	13.7	14.8	23.5	9.7	13.2	15.4	15.6	21.7	18.2	29.6	22.2	32.8	36.0	22.3	21.6	-----	-----

The yield of flax in rotations 9 and 67 is given in Table 6. The crop is grown to a very limited extent under irrigation on the project, but it was included in the rotation program because flax is extensively produced where dry-land farming is practiced and seems to have some possibilities when irrigated. No total crop failures have been experienced, and the yields have been relatively consistent throughout the 15-year period.

TABLE 6.—*Acre yields of flax (bushels) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1926	Mean, 1921–1926
9	9.9	12.1	13.0	14.5	7.5	7.6	8.5	1.3	6.0	3.4	10.9	9.0	8.0	6.4	2.6	8.0	6.6
67	19.4	31.3	24.3	28.1	27.0	30.3	31.8	15.6	18.1	12.8	24.3	24.1	26.7	22.1	22.6	24.0	22.1
Annual mean	14.6	21.7	18.6	21.3	17.7	18.9	20.1	8.4	12.0	8.1	17.1	16.5	17.3	14.2	12.6	15.9	.....

The yields of alfalfa are given in Table 7. Alfalfa was not incorporated in the series primarily for the purpose of measuring the effect of crop sequences on the yields for this crop, but rather largely to obtain information as to the value of this crop when grown two or three successive years in rotations as compared with other similar rotations in which alfalfa is not included. As alfalfa is a perennial and was grown either as a 2-year or a 3-year crop in the rotations except in the continuously cropped plots 8 and 8–a, the yields in the different years are tabulated separately. The age of the alfalfa on any one plot may be determined by noting the figure following the rotation number, for example 40–1 indicates the yield of rotation 40 for the first year; 40–2 indicates the yield the second year it was in alfalfa; and 64–3 implies the third-year yield in rotation 64. In computing the annual mean for 1912 all yields for that year were used in arriving at the first-year results, as all plots were in alfalfa one year irrespective of designations. In 1913 first and second year annual means only appear, as the yields from the rotations where the crop was to be grown for three years were utilized in arriving at the 2-year mean for that year. This procedure was followed throughout. In the case of the continuously cropped plots first year results were used in arriving at the first year annual means, second year yields in the second year annual means, and thereafter the results of these plots were utilized in arriving at the 3-year annual means for the period covered, as the returns from alfalfa the third year are usually comparable with the results obtained from fields continuously cropped for a long period. Alfalfa following a grain crop is fall seeded in the stubble as soon as practicable after the grain is harvested. Therefore, alfalfa in rotations 44, 46, 64, and 69 is fall seeded. In rotations 40, 60, 61, and 67 following a cultivated crop it is spring seeded.

Yields are included for the full 15-year period with the exception of rotations 8–a, 46, 64, and 69, which were introduced in 1916. Fall seeding, when possible, has been practiced for the purpose of determining the merits of this method as compared with spring planting. Fall-seeded alfalfa is somewhat subject to winterkilling the first year, depending upon the severity of conditions. All alfalfa plots seeded in the fall of 1918 were winterkilled, a fact which necessitated reseeding in the spring of 1919.

The same condition existed during the winter of 1925–26, when all fall-sown plots were reseeded in the spring of 1926. Hail and grasshopper injury in 1921 notably reduced the second and third year mean yields, which are the lowest recorded.

The annual mean yield for the first-year alfalfa has been 2.33, second year 5.51, and third year 5.33 tons per acre. Alfalfa serves a dual purpose under irrigated conditions, which its use at this station

illustrates. It is used as a forage crop for feeding the livestock on the project and for the purpose of maintaining the productivity of the soil when used in a rotation with other crops. When produced on farms devoted largely to livestock production it often is grown for several years on the same land. But when planted wholly or in part for its beneficial effects on succeeding crops it may be plowed under at the end of the second or third year. When used in this capacity it is of practical interest to note that these results indicate that approximately maximum production may be expected the second season of growth. Although it is decidedly questionable whether the maximum benefit to the soil is obtained in this short period, considering the first cost and returns, it might be desirable in actual practice to continue alfalfa for a period of at least four or five years.

TABLE 7.—*Acre yields of alfalfa (tons) from the irrigated rotations, Huntley Field Station, 1912–1926*

Rotation No.	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean
8	0.72	4.51	4.62	4.72	3.86	3.99	4.87	4.61	4.39	3.40	5.55	4.66	5.42	3.76	3.66	4.18
8–a					1.52	5.95	6.54	6.83	5.14	2.47	6.35	5.12	6.26	4.78	5.24	5.11
40–1	.43	2.07	2.33	2.22	2.02	1.92	2.02	.47	1.76	1.24	2.08	1.46	3.64	1.78	2.88	1.89
40–2	.20	5.25	5.65	6.61	4.75	5.44	4.96	5.80	4.30	3.78	5.84	4.84	6.52	5.90	5.80	5.05
42–1	1.02	2.31	2.40	2.33	2.12	1.98	2.38	1.03	1.60	1.12	2.26	1.60	3.20	2.38	3.22	2.06
42–2	.94	6.22	6.26	7.47	5.31	5.72	5.12	5.76	3.79	3.66	6.61	4.69	6.20	5.00	6.08	5.26
44–1	.90	2.07	1.47	1.80	1.71	1.84	2.49	.96	2.91	1.96	2.52	2.48	2.62	3.06	3.06	2.13
44–2	.93	5.52	4.46	6.16	4.92	4.77	4.92	4.22	3.49	2.54	5.22	4.04	5.92	5.08	4.56	4.45
46–1					1.73	3.73	3.39	2.73	3.25	1.86	3.09	2.98	3.14	3.54	2.52	2.91
46–2					1.87	5.88	6.45	6.36	5.04	2.32	6.05	4.86	6.30	5.46	5.34	5.08
60–1	.88	2.51	2.45	2.46	1.99	2.11	2.15	.73	1.95	1.16	2.42	1.36	2.98	2.06	2.88	2.01
60–2	.76	6.29	5.25	7.38	5.32	5.09	4.94	6.11	4.08	3.92	6.48	4.74	6.56	5.16	5.42	5.17
60–3	.82	5.92	5.72	6.58	5.92	4.86	5.10	4.18	5.69	2.86	6.51	5.74	7.10	5.70	5.88	5.24
61–1	.76	1.79	2.59	2.52	2.37	2.39	2.43	2.28	2.22	1.67	2.96	1.84	4.32	2.82	3.34	2.42
61–2	.51	5.99	5.53	7.92	5.83	6.28	5.06	6.64	5.00	4.62	5.87	5.58	6.58	6.32	6.70	5.63
61–3	.64	4.78	5.98	7.43	6.60	5.90	6.22	4.31	6.08	3.53	6.70	6.11	7.37	6.04	6.32	5.60
64–1					1.88	3.17	3.29	2.40	3.54	1.72	3.50	3.19	2.86	3.58	2.40	2.87
64–2					1.91	6.18	5.97	6.12	5.23	2.81	5.69	4.07	6.34	4.84	4.88	4.91
64–3					1.86	5.92	6.54	2.20	5.27	2.56	6.12	5.14	6.48	5.78	5.54	4.86
67–1	.71	2.46	2.06	2.64	2.19	1.97	2.13	1.10	1.82	1.18	2.26	1.53	4.04	2.32	2.86	2.08
67–2	.60	5.86	5.24	7.29	5.42	5.58	4.40	6.81	4.71	3.76	5.82	4.73	6.42	5.58	6.04	5.22
69–1					1.87	3.37	3.49	2.77	3.82	1.98	4.17	2.82	3.28	4.46	3.00	3.18
69–2					2.00	5.99	6.18	6.76	5.67	3.08	6.05	3.80	6.52	5.04	5.82	5.18
Annual mean:																
First year	.72	2.20	2.22	2.34	1.94	2.50	2.64	1.61	2.54	1.54	2.81	2.14	3.34	2.89	2.91	2.29
Second year		5.59	5.40	7.14	5.26	5.71	5.33	6.06	4.59	3.39	5.96	4.59	6.37	5.37	5.63	5.46
Third year			5.44	6.24	5.46	4.92	5.85	4.43	5.31	2.96	6.25	5.35	6.53	5.21	5.33	5.33

The foregoing tables giving detailed yields of oats, sugar beets, potatoes, wheat, corn, flax, and alfalfa indicate clearly that the land where these crops were grown was quite productive at the outset, and this is further shown by the satisfactory yields often occurring during the latter part of the period covered by these data from the continuously cropped plots as well as from those including such cropping practices as are believed to have an adverse effect on crop yields when practiced continuously. It seems reasonable to suppose that more striking results would have occurred if the experiments at the outset had been located on land of low productivity rather than to serve what is an equally valuable purpose of demonstrating how crop yields may be maintained.

ANNUAL FLUCTUATIONS OF YIELDS

Throughout the period covered by these tabulated results the crops have been subjected to varying degrees of injury which have had a more or less marked influence on the yields. These have been storm, insect, disease, and accidental injuries, which have not always uniformly affected all plot yields in any one season. So far as practicable this is noted in the text when it has been particularly obvious at the time it occurred and when it was of sufficient magnitude to result in a material lowering of yields.

Seasonal conditions have usually tended to operate uniformly on the different crops each season, some seasons being favorable and others unfavorable. For the purpose of ascertaining the seasonal variation in yields, Table 8 is included, in which the mean annual yield for each crop except alfalfa and flax is compared with the mean of these annual yields for the entire period and expressed as a percentage of the mean for the 15-year period.

TABLE 8.—*Seasonal mean acre yield of each crop, except alfalfa and flax, in the irrigated rotations, expressed as a percentage of the mean yield of all plots, in each of such rotations, at the Huntley Field Station, 1912–1926*

Crop	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1921–1926
Oats	65	113	120	106	95	101	122	71	85	91	119	109	119	106	77	103
Sugar beets	90	113	97	83	100	85	106	88	66	94	116	165	117	101	85	113
Potatoes	107	93	73	132	100	95	161	109	80	102	84	93	92	99	101	95
Wheat	96	153	123	130	100	101	91	104	100	80	103	78	71	97	73	84
Corn	94	108	111	95	98	84	119	86	104	99	113	127	95	96	71	100
Mean	90	116	105	109	99	93	120	92	83	93	107	114	99	100	81	99

The mean percentage of all these crops for the first six years of the period is 102 and for the last six years 99, which is a further indication of the original productivity of the land. In the last column the mean for the last six years is given, and during this period the yields of sugar beets and oats have been above normal, the yield of corn has been normal, while yields of potatoes and wheat have been below normal. Wheat shows the lowest percentage for the 6-year period, but as 5 rotations are involved, 3 of which are continuously cropped, it is not unnatural to suppose that the percentages would be less than with oats, for which 21 rotations are reported, only 2 of which are continuously cropped.

In connection with ascertaining the annual mean of the crops where all rotations are included it is possible to compare the effect of the different rotation treatments by crops. For making this comparison three crops are included—oats, sugar beets, and potatoes—for each of which there is a sufficient number of rotations to justify their inclusion. In this comparison the plots that are untreated, including those continuously cropped, are compared with those that were manured or on which alfalfa was grown or both. For oats there are 6 untreated and 8 treated plots. Six untreated and 8 treated plots of sugar beets and 5 untreated and 7 treated plots of potatoes were included in arriving at the results given in Table 9.

TABLE 9.—*Mean annual acre yields of oats, sugar beets, and potatoes in untreated rotations and in manured and alfalfa rotations, at the Huntley Field Station, 1912–1926*

[The mean acre yield of each crop is expressed as a percentage of the mean annual yield of such crop in all rotations]

Crop	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Mean, 1912–1926	Mean, 1921–1926
Oats:																	
Untreated	98	87	90	95	89	82	86	80	81	87	88	85	79	73	65	84	80
Treated	103	115	112	106	108	116	112	116	117	112	111	113	119	125	132	114	119
Sugar beets:																	
Untreated	93	88	84	73	89	95	89	93	79	79	84	82	75	66	60	82	75
Treated	105	109	112	120	103	102	108	105	111	115	111	113	118	125	124	112	118
Potatoes:																	
Untreated	91	86	83	85	86	88	87	87	83	84	78	81	76	68	60	82	75
Treated	107	112	115	113	112	111	112	111	115	114	120	117	121	129	135	116	123

The trend of the yields throughout the 15-year period for the untreated plots is downward in the case of all three crops considered, as is indicated by comparing the 15-year means with the means for the last six years. On the other hand, the trend in yield for the treated plots is upward. For the last 6-year period the difference in favor of the treated plots over those untreated is for oats 39 per cent, for sugar beets 43 per cent, and for potatoes 48 per cent; whereas for the 15-year period it is for oats 30 per cent, for sugar beets 30 per cent, and for potatoes 34 per cent.

COMPARISON OF EFFECTS OF THE ROTATIONS ON CROP YIELDS

In order to afford a more direct comparison of the effect of the different rotation treatments on crop yields, the following tables are included according to crops, with the various treatments and crop sequences grouped. This permits a direct comparison of the effect on yields. Continuous cropping of oats is compared with oats in a 2-year rotation with corn, with sugar beets, with potatoes, and with wheat. A further comparison is made where oats appear in an untreated 3-year rotation with sugar beets and potatoes, with sugar beets and corn, and with potatoes and sugar beets. The 2-year untreated rotations where the companion crops with oats are sugar beets and potatoes are compared with two where the same crops are used but a treatment of 12 tons of stable manure is applied preceding the oat crop. The same comparison is made where sugar beets and potatoes are incorporated in a 3-year rotation with oats, two untreated and the other two having an application of stable manure applied every third year, in one case following the sugar beets and preceding the potatoes and in the other following the potatoes and preceding the sugar beets. For purposes of ascertaining the value of alfalfa as a possible substitute for manure, 4-year and 6-year rotations are included; where alfalfa appears in one group it is grown for two years, and in the other it is a 3-year crop. It is possible to compare the joint effect of both manure and three years of alfalfa as included in the treatment of rotation 61 with rotation 60, which has the same crop sequences but no manure. The same general comparisons are made with the other crops.

In considering the summary of results in these rotation experiments, which have been in effect for a series of years, there are three primary factors to be taken into consideration: (1) The annual differences and mean yield variations, largely influenced by the kind of rotation; (2) the uniformity of the differences in the annual yields; and (3) the measure of the effect of the treatment on other crops in the same rotation, by means of which the full value of the complete rotation may be estimated and compared in the same manner as are the annual and mean yields of the several crops as they appear in the different rotations. The data presented in Tables 10 to 14 permit a discussion of the first two, while the third will be presented under the heading "Comparative values of the different rotations."

The following tables give the rotation numbers, the treatment they received, the mean actual yield from 1912 to 1926, and the mean actual yield from 1921 to 1926, together with the probable error computed, which is included for the purpose of determining the degree of the dependability of differences in yield. There are several methods of computing this probable error. The one here used is to multiply the sum of the departures from the mean by the quotient of $n\sqrt{n-1}$ into 0.8453, where n equals the number of yields involved.[5]

The value of determining the probable error is illustrated in Table 10, giving the results with oats in rotation 44, which is compared with those in rotation 24. For the 15-year period there is an actual mean increase in yield in rotation 44 over the yield in rotation 24 of 6 bushels per acre, but with a probable error of 2.9. This relatively large probable error indicates that the increase in the yield of oats, brought about in this rotation by incorporating two years of alfalfa for the 15-year period, is not significant. But when the yields in the last six years are compared, where there is an increase of 18 bushels per acre with a probable error of 2.6, the increase may be considered significant, indicating the cumulative effect of incorporating alfalfa in a rotation of this kind as compared with one in which no alfalfa is included.

A system of crop rotation or special treatment of the soil adjusted to the conditions existing in a given locality is fundamental to continued productivity of the land. It has been repeatedly demonstrated that the continuous growing of crops like sugar beets, potatoes, etc., on the same land year after year develops a soil condition unfavorable to continued satisfactory yields. Planning the cropping system so that crops similar to those under discussion are rotated usually results in the productivity of the soil being maintained for a longer period than it would otherwise. By including a leguminous crop like alfalfa in the rotation, the productivity of the soil is often increased and usually is maintained for a long period of years. By incorporating a special treatment like the application of stable manure, a favorable effect on crop yields is usually secured immediately and continues. Stable manure is not always available, and in that event alfalfa or a similar crop becomes essential where crops of a nature comparable to potatoes or sugar beets are featured in the planting program. The continued success of the farmers on irrigation projects is predicated upon their ascertaining and adopting

[5] MERRIMAN, M. METHOD OF LEAST SQUARES. Ed. 8. New York. 1913.

a plan of farm management which keeps the productivity of the soil at a high standard; yields must be greater when crops are grown under irrigation with the attendant higher production costs, which include such items as leveling the land, cost of water and its application, as well as often high delivery costs to the market, if the irrigation farmers are to compete successfully with those engaged in farming where such expenses are not necessary.

However, the sole benefit to be derived from a proper crop rotation is not confined entirely to maintaining or increasing the productivity of the soil. Continuous cropping of the land often results in excessive weed growth, and not infrequently it intensifies the injury done by certain plant diseases and insect pests, or increases the expense of their control. As crop rotation is essentially diversification, which permits a farmer to be engaged in more than one enterprise, he is able to use his time and equipment more effectively than would be the case were he largely, if not wholly, confining his activities to one crop. When he is producing two or more crops his business is on a much more stable basis in that a failure of one crop, brought about by either low yields or depressed prices, does not necessarily mean that he will operate at a loss that season. Obviously, the added value of a constructive cropping system, aside from maintaining or increasing yields, is not reflected in the preceding or following pages, but its value is apparent and should be considered in weighing the merits of the different cropping systems.

YIELDS OF OATS

The average annual yields of oats as this crop has appeared in the various rotations are given in Table 10. They are recorded for the period 1912 to 1926 and also for the last 6-year period, 1921 to 1926. In arranging the table the rotations are divided into five groups: (1) Plots continuously cropped, (2) untreated plots as compared with those continuously cropped, (3) manured rotations as compared with those untreated, (4) alfalfa rotations as compared with those untreated as well as with those having an application of stable manure, and (5) a rotation in which both manure and alfalfa are included as compared with similar untreated rotations.

A further division permitting additional comparisons has been made. The mean yield of oats in four simple 2-year rotations is given and may be compared with oats in three 3-year untreated rotations. The mean yield of oats in the 2-year rotations, 23 and 25, which have manure applied preceding the sugar beets and potatoes, may be compared with the two 3-year rotations which are manured. Also, the mean yields in the three 4-year rotations may be compared with those in the 6-year rotations, 60 and 64.

Rotation No. 1 was started in 1912, whereas No. 1–a was included in the series in 1916. This also applies to No. 2–a. These two rotations, 1–a and 34, are compared because they were started the same year and are side by side in the same field. This same explanation applies to 2–a and 34 in Table 11.

TABLE 10.—*Average annual acre yields of oats grown continuously on the same land as compared with yields obtained when the crop is grown in simple rotations and the effect of manure and of alfalfa, at the Huntley Field Station, 1912–1926*

Rotation	Crops in the rotation	Average annual yields of oats (bushels)			
		Actual		Increase (+) or decrease (−) as compared	
		1912–1926	1921–1926	1912–1926	1921–1926
Continuous cropping:					
No. 1	Oats	38	38		
No. 1–a	do	57	48		
Average		47	43		
Untreated rotations (compared with continuous cropping):					
No. 16	Corn, oats	65	65	+27±2.1	+27±2.8
No. 22	Sugar beets, oats	82	79	+44±2.2	+41±4.0
No. 24	Potatoes, oats	75	74	+37±2.9	+36±3.9
No. 27	Potatoes, oats (rye)	59	63	+21±2.7	+25±2.1
No. 28	Wheat, oats	47	50	+9±1.7	+12±2.5
Average, not including No. 27.		67	67		
No. 30	Sugar beets, potatoes, oats	65	69	+27±3.4	+31±2.4
No. 32	Sugar beets, corn, oats	50	55	+18±1.4	+17± .8
No. 34	Potatoes, sugar beets, oats	83	77	+26±3.1	+29±3.0
Average		68	67		
Manured rotations (compared with untreated rotations):					
No. 23	Sugar beets (manured), oats	77	84	−5±3.0	+5±4.7
No. 25	Potatoes (manured), oats	86	90	+11±1.9	+16±2.0
Average		81	87		
No. 31	Sugar beets (manured), potatoes, oats.	71	76	+6±1.6	+7±3.0
No. 35	Potatoes (manured), sugar beets, oats.	84	80	+1±4.0	+3±4.0
Average		77	78		
Alfalfa rotations (compared with untreated rotations):					
No. 42	Sugar beets, alfalfa (2 years), oats	87	91	+5±2.0	+12±5.0
No. 44	Alfalfa (2 years), potatoes, oats	81	92	+6±2.9	+18±2.6
No. 46	Alfalfa (2 years), sugar beets, oats	90	98	+8±4.7	+19±5.8
Average		86	94		
No. 60	Sugar beets, alfalfa (3 years), potatoes, oats.	92	100	+27±3.9	+31±4.8
No. 64	Alfalfa (3 years), potatoes, sugar beets, oats.	89	94	+6±3.6	+17±4.8
Average		90	97		
Manure and alfalfa rotation (compared with untreated rotations):					
No. 61	Sugar beets (manured), alfalfa (3 years), potatoes, oats.	94	100	+29±3.8	+[illegible]±5.1

Rotation 27 may be considered as one receiving special treatment, as rye is seeded in the oat stubble in the fall and is plowed under in the spring just preceding the preparation of the land for the potato crop. Yields obtained from this rotation are less than those from rotation 24, which is the same except for the rye; this indicates that this practice has not proved beneficial in its effect on oat yields.

The mean yield of oats in the continuously cropped plots for the last six years is less than for the entire period. Yields from oats in the 2-year and 3-year rotations are nearly the same for the last six years as for the 15-year period, but for both periods they are notably higher than the yields of continuously cropped plots. The yields from the two 3-year rotations receiving applications of manure are higher than those from similar rotations receiving no treatment. The mean yield of oats only one crop removed from an application of manure in rotations 23 and 25, particularly for the last 6-year period, is significantly higher than the yields from rotations 31 and 35, which are two crops removed from the manurial treatment.

Even greater beneficial effects on the yields of oats are to be noted where alfalfa is incorporated as one of the series in a rotation with this crop. In the rotations where alfalfa is included the yields of oats are significantly greater than in any of the others, even including those receiving an application of stable manure. Rotation 61, which has three years of alfalfa and an application of manure during its cycle, has produced the highest average yield both for the 15-year and the 6-year periods, indicating the beneficial effects of this treatment on the yield of oats.

Not only has continuous cropping of oats produced the lowest yield but the tendency is for the yields to be less as the practice is continued, as is indicated when the yields for the last six years are compared with those for the entire period. Untreated 2-year and 3-year rotations have produced definitely higher yields, but are barely sustaining these yields. The value of stable manure is apparent and, as is natural to expect, is more evident when applied once in two years than when applied every third year, with the application two crops removed from the oat crop. The value of alfalfa as a crop to be used in a rotation with oats is apparent if relatively high yields are to be expected. Slightly increased yields of oats, brought about by an application of manure in an alfalfa rotation, are indicated, but these can hardly be considered of importance, particularly when they are compared with other increases.

Oat yields following wheat in rotation 28 have been but little better than those obtained from the continuously cropped plots. In rotations 16 and 32, where corn is the crop immediately preceding the oats, yields have been more satisfactory but are not equal to those resulting from rotations where either sugar beets or potatoes were the preceding crop.

YIELDS OF SUGAR BEETS

The average annual yields of sugar beets for the 15-year and the last 6-year period are given in Table 11. The lowest mean yield for both periods is from the two continuously cropped plots, which for the 6-year period is notably lower than the mean for even the 2-year and 3-year untreated rotations, which are next lowest in order.

TABLE 11.—*Average annual acre yields of sugar beets grown continuously on the same land compared with yields obtained when the crop is grown in simple rotations and showing the effect of manure and of alfalfa, at the Huntley Field Station, 1912–1926*

Rotation	Crops in the rotation	Average annual yields of sugar beets (tons)			
		Actual		Increase (+) or decrease (−) as compared	
		1912–1926	1921–1926	1912–1926	1921–1926
Continuous cropping:					
No. 2	Sugar beets	8.8	9.7		
No. 2-a	do	9.2	7.7		
Average		9.0	8.7		
Untreated rotations (compared with continuous cropping):					
No. 18	Wheat, sugar beets	8.3	8.0	−0.5±0.46	−1.7±0.39
No. 20	Potatoes, sugar beets	12.3	13.6	+3.5± .45	+3.9± .60
No. 22	Oats, sugar beets	9.7	8.3	+.9± .56	−1.4± .41
Average		10.1	10.0		
No. 30	Potatoes, oats, sugar beets	8.0	9.0	−.8± .39	−.7± .45
No. 32	Corn, oats, sugar beets	9.6	11.8	+.8± .52	+2.1± .58
No. 34	Oats, potatoes, sugar beets	11.5	11.4	+2.3± .80	+3.6± .96
Average		9.7	10.7		
Manured rotations (compared with untreated rotations):					
No. 21	Potatoes (manured), sugar beets	15.1	18.1	+2.8± .42	+4.5± .59
No. 23	Oats, sugar beets (manured)	13.2	14.8	+3.5± .63	+0.5± .99
Average		14.2	16.5		
No. 31	Potatoes, oats, sugar beets (manured).	12.3	15.2	+4.3± .44	+6.2± .88
No. 35	Oats, potatoes (manured), sugar beets.	14.2	16.5	+2.7± .70	+5.1± .59
Average		13.3	15.9		
Alfalfa rotations (compared with untreated rotations):					
No. 40	Alfalfa (2 years), potatoes, sugar beets.	12.0	13.4	−.3± .48	−.2± .64
No. 42	Alfalfa (2 years), oats, sugar beets	10.5	11.8	+.8± .65	+3.5±1.07
No. 46	Oats, alfalfa (2 years), sugar beets	10.8	11.9	+1.1± .77	+3.6±1.09
Average		11.1	12.4		
No. 60	Alfalfa (3 years), potatoes, oats, sugar beets.	12.5	15.3	+4.5± .51	+6.3± .72
No. 64	Oats, alfalfa (3 years), potatoes, sugar beets.	13.1	15.3	+1.6± .67	+3.9± .28
Average		12.8	15.3		
Manure and alfalfa rotation (compared with untreated rotations):					
No. 61	Alfalfa (3 years), potatoes, oats, sugar beets (manured).	15.0	17.9	+7.0± .40	+8.9±1.02

In the case of the three 2-year rotations the mean yield for the 6-year period is very slightly less than that for the entire period, indicating that up to this time a 2-year rotation has been hardly able to maintain yields. In the case of the 3-year rotations the increase for the last six years over the entire period is 1 ton per acre. Aside

from rotation 61, the most notable increase occurs in the 2-year and 3-year rotations, where manure is applied. In the two 2-year rotations the mean increase in acre yield for the last 6-year period is 2.3 tons and in the two 3-year rotations the mean increase is 2.6 tons. This emphasizes strikingly the value of manure not only in maintaining but also in increasing the yields of sugar beets in the Huntley area.

Alfalfa in 4-year and 6-year rotations not only has maintained the acre yields for the 15-year period slightly more than 3 tons above the 2-year and 3-year untreated rotations, but for the last six years the mean increase over the average yield for the entire period has been 1.3 tons in the 4-year rotation where alfalfa appears two years and 2.5 tons increase in the two 6-year rotations where alfalfa is grown three years out of the six. The beneficial effects of alfalfa on the yield of sugar beets is thus obvious, although the results do not appear to be quite as immediate and as effective as an application of 12 tons of manure in either 2-year or 3-year rotations.

Rotation 21 has produced the highest average yields in both the 15-year and the 6-year periods. The acre yield for the last six years in this rotation was 18.1 tons, which was an increase of 3 tons above that for the total period. In this rotation sugar beets follow potatoes (manured). The next highest yield is from rotation 61, which includes three years of alfalfa followed by potatoes, oats, and beets (manured). The average acre yield in this rotation for the last six years was 17.9 tons, an increase of 2.9 tons over the yield for the 15-year period. Not only are these yields relatively high but it would appear that the full possibilities of this treatment have not yet been exhausted.

In connection with observing the effect of different treatments and crop sequences on the yields of sugar beets, it is particularly pertinent to note the adverse effect on the yield of sugar beets in untreated rotations directly following oats and wheat for both the entire period and the last 6-year period. The average acre yield of sugar beets from rotations 18, 22, 30, and 32 for 15 years is 8.9 tons and for the last 6 years 9.3 tons, which in the former case is 0.1 of a ton less and in the latter instance only 0.6 of a ton more than the mean for the continuously cropped plots. From these results it is evident that both oats and wheat immediately preceding sugar beets in rotations without alfalfa have an effect on the soil detrimental to high productivity.

In comparing rotation 30 with rotation 34, in which the crops are the same but in which the crop sequence is different, it will be observed that beets in the latter rotation produced for the 15-year period an average yield of 3.5 tons higher than the yield in rotation 30, which is further indication that a crop sequence in which beets follow potatoes is much more desirable than one in which beets follow oats.[6]

YIELDS OF POTATOES

The average annual yields of potatoes from 1912 to 1926 and for the last six years, grouped according to treatment given and crop sequences, are given in Table 12. The lowest yield is from rotation 27, where potatoes appear in a rotation with oats, the oats followed by rye, and the rye plowed under just before preparing the land for the

[6] For a more detailed discussion of sugar beets, see the following publication: SAVAGE, D. A., and POWERS, L. EXPERIMENTS WITH SUGAR BEETS AT THE HUNTLEY BRANCH STATION. Mont. Agr. Expt. Sta. Bul. 215, 31 p., illus. 1928.

potato crop. This has proved to be a very undesirable rotation for potatoes, largely owing to the difficulty of properly preparing the land for potatoes where spring plowing is practiced on this heavy soil and where a green-manure crop like rye is plowed under immediately preceding the preparation of the land and the planting of the potatoes. The experience obtained at the Huntley station indicates that this is a very undesirable practice, proving to have an effect on yields even more adverse than continuous cropping.

TABLE 12.—*Average annual acre yields of potatoes grown continuously on the same land compared with yields obtained when the crop is grown in simple rotations and showing the effect of manure and of alfalfa, at the Huntley Field Station, 1912–1926*

Rotation	Crops in the rotation	Average annual yields of potatoes (bushels)			
		Actual		Increase (+) or decrease (−) as compared	
		1912–1926	1921–1926	1912–1926	1921–1926
Continuous cropping:					
No. 4	Potatoes	154	125		
No. 4-a	do	199	179		
Average		177	152		
Untreated rotations (compared with continuous cropping):					
No. 20	Sugar beets, potatoes	220	175	+66±10.1	+50±16.3
No. 24	Oats, potatoes	207	158	+53± 6.2	+33± 9.4
No. 26	Corn,-potatoes	191	137	+37± 8.3	+12± 7.9
Average		206	157		
No. 27	Oats (rye), potatoes	97	102	−57±10.2	−23±13.7
No. 30	Oats, sugar beets, potatoes	184	169	+30± 7.5	+44±12.0
No. 34	Sugar beets, oats, potatoes	264	249	+65± 8.7	+70±18.9
Average		224	209		
Manured rotations (compared with untreated rotations):					
No. 21	Sugar beets, potatoes (manured)	242	218	+22± 8.9	+43±19.2
No. 25	Oats, potatoes (manured)	323	290	+116±10.6	+132±18.2
Average		283	254		
No. 31	Oats, sugar beets (manured), potatoes.	178	167	−6± 6.6	−2±12.1
No. 35	Sugar beets, oats (manured), potatoes.	301	324	+37±11.3	+75±10.5
Average		240	246		
Alfalfa rotations (compared with untreated rotations):					
No. 40	Sugar beets, alfalfa (2 years), potatoes.	268	289	+48±13.2	+114±20.0
No. 44	Oats, alfalfa (2 years), potatoes	202	211	−5±14.0	+53±10.5
Average		235	250		
No. 60	Oats, sugar beets, alfalfa (3 years), potatoes.	289	285	+105±11.1	+116±16.0
No. 64	Sugar beets, oats, alfalfa (3 years), potatoes.	293	300	+29±14.0	+51±22.8
Average		291	293		
Manure and alfalfa rotation (compared with untreated rotations):					
No. 61	Oats, sugar beets (manured), alfalfa (3 years), potatoes.	312	317	+128±11.4	+148± 8.2

The next lowest yield is from the plots continuously cropped to potatoes. Not only is the mean average yield relatively low, but by comparing the last 6-year mean with the mean from 1912 to 1926 it is found that there is a marked tendency for the yields to decrease, the difference between the yield for the complete period and that for the last six years being about 25 bushels per acre. Disease, including scab and blight, has been a factor in adversely affecting yields on the continuously cropped plots and in some of the 2-year rotations in recent years. While the scab disease is not always serious, it does occur to some extent in most seasons, especially on the plots continuously cropped, and the percentage of marketable tubers is frequently materially reduced.

Following the yield of the continuously cropped plots is the mean yield from the three 2-year rotations, Nos. 20, 24, and 26. While the mean yield for both periods is somewhat higher than the mean yield from the continuously cropped plots, yet the same marked tendency exists for the yields to be reduced the longer these rotations are continued, as is indicated when the two periods are compared. Evidently not only are relatively low yields to be expected from potatoes when grown in an untreated 2-year rotation with sugar beets, oats, and corn, but the yields may be expected to decrease progressively the longer such practices are in effect.

Somewhat higher yields have resulted from the 3-year rotations, and the difference between the yields for the entire period and for the last six years is less than either the mean yield of the continuously cropped or the mean yield of the 2-year rotations, indicating that the productivity of the land is better sustained in 3-year untreated rotations than is the case in somewhat similar 2-year rotations. In rotation 34, where potatoes are grown in a 3-year rotation with sugar beets and oats, the yields of potatoes are significantly higher where potatoes follow oats than is the case from rotation 30, which is similar to rotation 34 as to crops, but sugar beets is the preceding crop.

The beneficial effects on the yield of potatoes of manure applied in 2-year and 3-year rotations is evident when the average of the mean yields from rotations 21 and 25 and 31 and 35 are compared with the yields of untreated rotations. These results indicate that manure applied once each cycle directly preceding the potato crop in a 2-year rotation with either sugar beets or oats results in relatively high yields, but may be more frequent than is desirable to obtain the most practical results. In 2-year rotations disease has also been a factor and has been less noticeable in rotations of three or more years.

The apparently favorable effects of an oat crop immediately preceding potatoes on the yield of this crop are well illustrated in rotations 25 and 35 as compared with rotations 21 and 31, where the crop immediately preceding potatoes is sugar beets. The mean average acre yield for the two former rotations is 312 bushels for the entire period and 307 bushels for the last six years. On the other hand, rotations 21 and 31 have produced a mean acre yield of 210 and 192 bushels, respectively, for the same periods.

When oats has been the preceding crop, the use of two years of alfalfa has not been as effective as manure in promoting high productivity as far as potatoes are concerned, although the yields indicate that the full benefits of this rotation have not yet been realized, particularly in 4-year rotations 40 and 44, where alfalfa is grown two

years during the cycle. The beneficial effects of an additional year of alfalfa are strikingly illustrated when the average yields of rotations 40 and 44 are compared with the average of rotations 60 and 64.

Consistently high average yields have occurred from rotation 64 for both periods. Not only are the average yields high for the 15-year period but apparently the full beneficial effects of this rotation have not yet been reached.

YIELDS OF ALFALFA

While alfalfa in point of acreage is one of the major crops under cultivation on the Huntley project and an important source of forage supply for the farmers, its chief value here as well as on similar projects is in sustaining and increasing productivity of the soil for other crops when incorporated in a well-balanced rotation. Therefore, the summary of the detailed yields of alfalfa as recorded in Table 7 are not given, as it was not included in the rotation program to determine the effect of varying crop sequences and treatments on the yield of this crop, but rather to measure its influence on the yields of other crops with which it is associated.

Where proper attention is given the alfalfa, the stand may be maintained after it has become well established. Yields are usually at least sustained if not increased over a long period, and only to a minor extent can the differences in yields of the crop in the various rotations be attributed to rotational influences. This is evidenced when the mean acre yield, 4.64 tons, of the continuously cropped plots is compared with the last 6-year mean acre yield of 4.72 tons. At times there is a tendency for the yield of alfalfa on land continuously devoted to this crop to decline after several years, but there is no evidence that this is a question of productivity, but rather it is attributed to a reduction of stand caused not infrequently by excessive weed growth or winterkilling.

The highest mean acre yield for the 15-year period as given in Table 7 is 5.63 tons from rotation 61. This is nearly 1 ton per acre more than the mean for the two continuously cropped plots for the same period. Other rotations have indicated lesser increases. In the continuously cropped plots injury to the stand by winterkilling has occurred, weed growth has at times been troublesome, and difficulties have arisen in connection with an uneven accumulation of soil deposited by irrigation water and by wind, resulting in difficulties in uniform irrigation. All of these at various times have operated to affect adversely the yields on these plots, but naturally have not been important factors on the plots kept in alfalfa only two or three years.

The third-year alfalfa in rotations 67 and 69 is pastured by hogs. In addition to obtaining information as to the value of this crop when utilized in this manner, the effect of this treatment on other crops in the rotation is also determined. In both of these rotations corn follows alfalfa, and this crop is also pastured. The cumulative beneficial effect on the land after pasturing by hogs for two years is indicated in the high yields of oats in rotation 69 and of sugar beets and flax in rotation 67, as given in Tables 1, 2, and 6, respectively.

YIELDS OF WHEAT

Wheat is a crop of some importance in the Huntley area and is included to a limited extent in the rotation experiments, although oats is largely used for the cereal crop. Oats was used mainly for the sake of uniformity in order that the results at Huntley might be comparable with similar experiments at other stations and not with the thought that it might be more profitable than wheat. (Table 13.)

TABLE 13.—*Average annual acre yields of wheat grown continuously on the same land compared with yields obtained when the crop is grown in simple rotations at the Huntley Field Station, 1912–1926*

Rotation	Crops in the rotation	Average annual yields of wheat (bushels)			
		Actual		Increase (+) or decrease (−) as compared	
		1912–1926	1921–1926	1912–1926	1921–1926
Continuous cropping:					
No. 3	Spring wheat	22	18		
No. 5	do	28	21		
No. 7	Spring wheat (straw returned)	26	17		
Untreated rotations (compared with continuous cropping No. 3):					
No. 18	Sugar beets, wheat	34	31	+12±2.0	+16±3.2
No. 28	Oats, wheat	21	20	− 1±1.3	+ 2±1.7

Although cereals do not necessarily have an important cash value in communities similar to the Huntley area, they often prove to be desirable crops in the general plan of rotation and diversification and are logically included among those in many farm cropping programs, particularly where livestock is kept, thereby permitting the farms to become more nearly self-supporting. So far as the influence on the yields of succeeding crops is concerned, there appears to be but little difference between wheat and oats.

In considering the yields of continuously cropped plots of rotations 3 and 5, there was found to be a definite downward trend of the yields the longer they were continued. The acre yield for the last six years of rotation 3 was 4 bushels less and in rotation 5 it was 7 bushels less than for the complete period. Rotation 7 was continuously cropped, but the straw was returned. This practice, when the decline of yield is considered, proved even less satisfactory than the yields from the two continuously cropped but with no special treatment.

A 2-year simple rotation with sugar beets (No. 18) produced the highest yields for both periods, indicating that sugar beets thus far have not had an unfavorable effect on the yields of wheat, which apparently can not be said of the effect of wheat on the yields of sugar beets.

No appreciable beneficial effects are apparent in the yield of wheat in a 2-year rotation with oats when compared with wheat continuously grown. Such variation as does occur indicates that yields may be maintained at a slightly higher level in this relation than would be the case were wheat grown continuously on the same land.

In both the continuously cropped plots and the plot in which wheat alternates with oats in a 2-year rotation a large amount of wild oats has appeared each season and has materially decreased the yield of wheat on these plots.

YIELDS OF CORN

Corn is not extensively grown under irrigation on the Huntley and surrounding areas. This is partly due to the distance from the centers of consumption and partly because of the moderate yields obtained. It has not been able to compete successfully with such cash crops as sugar beets. On certain farm units the crop serves a useful purpose when produced largely for consumption on the farms as an essential feed to certain kinds of livestock.

The average yield of corn in the five rotations where it appears is given in Table 14. Continuously cropped plots 6 and 6–a have a tendency to produce lower yields the longer these rotations are continued, as is evidenced by comparing the total with the last 6-year average. On the other hand, when the crop is grown in a rotation with other crops the two periods compared indicate that up to the present time yields are being slightly more than maintained. The most satisfactory yields for both periods as well as the largest increase in both periods are from the 2-year untreated rotation 26, where potatoes is the companion crop. Corn preceded by oats in a 2-year rotation has not produced as well in either rotations 26 or the 3-year rotation 32, which includes oats and sugar beets but where the corn follows the sugar beets. The results are comparable with those obtained from sugar beets where this crop follows oats in untreated rotations, although less definite.

TABLE 14.—*Average annual acre yields of corn grown continuously on the same land compared with yields obtained when the crop is grown in simple rotations, at the Huntley Field Station, 1912–1926*

Rotation	Crops in the rotation	Average annual yields of corn (bushels)			
		Actual		Increase as compared	
		1912–1926	1921–1926	1912–1926	1921–1926
Continuous cropping:					
No. 6	Corn	28	24		
No. 6–a	do	41	38		
Untreated rotations (compared with continuous cropping No. 6):					
No. 16	Oats, corn	37	38	9±1.5	14±2.2
No. 26	Potatoes, corn	46	50	18±1.6	26±1.7
No. 32	Oats, sugar beets, corn	41	44	13±1.4	20±1.6

In addition to the rotations listed in Table 14, corn was also included in rotations 67 and 69. In both these rotations the corn is pastured by hogs, and definite yields were not obtained, although estimated yields were determined by harvesting each year the product from a certain percentage of the plants in each case. These yield estimates indicated that the yield was much higher in these rotations than in any of those listed in Table 14. In both rotations 67 and 69 corn follows the third-year alfalfa, which is also pastured by hogs.

In the former rotation corn is grown one year and in the latter two years. The fact that corn follows alfalfa hogged and corn hogged is no doubt responsible for the increased yields in these rotations. In rotation 69 rape is seeded in the corn following the last cultivation. Hogging off corn has been found to be a profitable and desirable method of harvesting this crop.[7]

COMPARATIVE VALUE OF THE DIFFERENT ROTATIONS

The effects on the yields of several crops for the 15-year period when various rotational and other treatments have been in effect have been given in the preceding pages, but no attempt has been made to ascertain the comparative merits of the different rotations as a whole by obtaining an estimate of the gross returns and deducting therefrom reasonable production costs. Large yields are highly desirable, but of equal importance are the expenses incurred in obtaining these yields. It is obvious that such an intensive cropping program might be adopted whereby the soil-improvement crops and treatments applied were a sufficient liability on the major cash crops included that the combined expenses incurred more than offset the benefits derived and would not prove to be as profitable as others receiving less intensive treatment and where the crop yields were somewhat less.

It is of practical value to determine whether manure can be applied more profitably once in three years rather than in alternate years. Considering the relatively low crop value of alfalfa, together with the initial high first-year cost of seed and seeding with low yield, it is possible to ascertain whether this crop should be in a rotation for a 2-year or a 3-year period. Information is obtained as to the comparative values of rotations with alfalfa or the same major crops included without alfalfa but with manure applied to maintain the soil productivity. Information can be obtained as to the desirability of an application of manure in a 6-year rotation with alfalfa. Thus it appears that the full value of such investigations can not be determined without arriving at the average estimated net returns per acre, permitting comparisons to be made between the different cropping systems.

The comparative crop values of the different rotations are given in Table 15. The production costs of each crop were determined by using for the cultural operations a figure often fixed in the community, such, for instance, as contract labor and the hauling of sugar beets, harvesting grain, plowing, taxes, and irrigation water. Other items of expense, such as disking, harrowing, cultivating, and harvesting alfalfa, were estimated, based partly upon experience in performing these operations at the station as well as on observations made among farmers on the project. The cost of applying manure was estimated to be $8 per acre. The unit value of the different crops is believed to be not far from the average value of these crops for the last five years and is as follows: Alfalfa, $8.50 per ton; corn, $0.90 per bushel; potatoes, $0.60 per bushel; wheat, $1.08 per bushel; oats, $0.48 per bushel, and sugar beets, $8 per ton. In determining the gross returns

[7] The results of pasturing corn with hogs are given in the following publications:
HANSEN, D. GROWING CORN ON IRRIGATED LAND. Mont. Agr. Expt. Sta. Bul. 193, 16 p., illus. 1926.
——— WORK OF THE HUNTLEY FIELD STATION IN 1923 AND 1924. U. S. Dept. Agr. Circ. 360, 42 p., illus. 1926.

per acre the yields for the last 6-year periods were used, as it is believed they more nearly represent the cumulative rotational effects. It is not even implied that the values are in any way actual, owing to the wide differences in production costs on individual farms and the fluctuation in the market prices of the crops. For comparative purposes they are accurate in that unit values are the same throughout and production costs, though estimated, are standardized on all rotations.

TABLE 15.—*Comparative per acre value of the different rotations*

Rotation No.	Crop sequence	Relative value [1]	Rotation No.	Crop sequence	Relative value [1]
21	Potatoes, sugar beets (manure)	$40.80	8	Alfalfa continuously	$10.02
35	Potatoes, sugar beets, oats (manure)	38.68	48	Alfalfa (2 years), sugar beets, oats	9.69
25	Oats (manure), potatoes	24.81	42	Oats, sugar beets, alfalfa (2 years)	6.60
61	Potatoes, oats (manure), sugar beets, alfalfa (3 years)	24.64	44	Potatoes, oats, alfalfa (2 years)	6.60
23	Oats (manure), sugar beets	21.26	30	Potatoes, oats, sugar beets	3.08
40	Potatoes, sugar beets, alfalfa (2 years)	21.25	18	Wheat, sugar beets	3.01
64	Alfalfa (2 years), potatoes, sugar beets, oats	21.18	26	Potatoes, corn	2.66
20	Potatoes, sugar beets	20.91	22	Oats, sugar beets	1.85
60	Potatoes, oats, sugar beets, alfalfa (3 years)	19.82	2	Sugar beets continuously	1.70
34	Potatoes, sugar beets, oats	19.48	24	Oats, potatoes	1.40
31	Potatoes oats (manure), sugar beets	15.39	6	Corn continuously	−1.90
32	Corn, oats, sugar beets	11.65	4	Potatoes continuously	−2.33
			3	Wheat continuously	−8.21
			28	Wheat, oats	−8.53
			1	Oats continuously	−11.41

[1] The minus (−) sign indicates loss.

The four rotations indicating the highest net acre value are those receiving a treatment of stable manure. The one having the highest value, $40.80, is a 2-year rotation (21) of potatoes and sugar beets, with manure applied prior to the potato crop. Closely following this rotation is No. 35, which is similar, except that an oat crop is inserted after sugar beets. The value of manure applied in a rotation is clearly evident. The only crops continuously grown on the same land which do not indicate a loss are alfalfa and sugar beets. Alfalfa grown continuously had a net return of $10.02 per acre. The returns from sugar beets continuously cropped were only $1.70 per acre. Oats continuously has proved least desirable, with a loss of $11.41 per acre.

Partly due to the original high productivity of the soil and in part due to the fact that potatoes have proved to be an excellent crop to precede sugar beets, untreated 2-year rotation (20), where potatoes and sugar beets are the crops included, is in the eighth position in the table.

The favorable influence of two years of alfalfa on crop yields has been recorded in the preceding pages; but of the four 4-year rotations where alfalfa is included for two years, only rotation 40 has proved to be as profitable as the 6-year rotations where alfalfa is retained for three years out of the six. Owing to the high cost of alfalfa the first year, together with low yields, it appears that a rotation in which alfalfa is retained for three years will result in greater returns than when it is retained for only two years.

Rotations 60 and 61 are identical as to crops, and both have three years of alfalfa, the only difference being that rotation 61 has an application of 12 tons of manure once during its cycle preceding the

sugar-beet crop. They are also comparable as to costs except for the $8 charge for the application of manure added to rotation 61. The net return from that rotation is $4.82 in excess of that from rotation 60. From these results it becomes apparent that manure may be profitably applied to a rotation that includes alfalfa.

The effect on values of either wheat or oats as a crop used in an untreated rotation preceding sugar beets is outstanding when yields in such rotations are compared with those in rotations that do not include these crops. A value of $20.91 is given for 2-year rotation 20, which includes a simple rotation of potatoes and sugar beets. In rotation 30, where an oat crop is inserted between potatoes and sugar beets, the value is reduced to only $3.08, or $17.83 less than the value of rotation 20. Next to the continuously cropped plots, wheat and oats in 2-year untreated rotations with sugar beets and potatoes are among the lowest values listed.

The rotations including alfalfa have not given as high comparative net returns as some of the 2-year and 3-year rotations, particularly those receiving manurial treatment. But the beneficial effect, which appears to be cumulative, on the productivity of the soil resulting from incorporating alfalfa in a rotation with such crops as sugar beets and potatoes is clearly evident in the tables giving the details of yields.

The relatively low price of $8.50 per ton for alfalfa makes the net returns for this crop so low as to decrease materially the average return for the alfalfa rotations. The first-year alfalfa, because of low yields obtained and high costs incurred, usually indicates a loss. If alfalfa were valued at its actual worth when utilized for feed for livestock on the farm where produced it is reasonable to believe it would show returns in excess of those given in Table 15.

SUMMARY

The experiments recorded in this bulletin were conducted at the Huntley Field Station, located in southeastern Montana. This station is representative of certain areas of this and adjoining States.

The soil where these experiments were conducted consists of a heavy clay loam relatively productive and representative of the better types on the larger part of the project.

The objectives were to ascertain what rotations and methods of treatment best promoted high productivity on irrigated soils representative of this and similar areas of the Great Plains, and to plan the rotations in such a way as to afford comparisons as to yield between simple rotations and those having a treatment of stable manure. The value of alfalfa was compared in two rotations, both of which included alfalfa and one of which received an application of stable manure.

The original series consisted of 29 rotations begun in 1912, to which 10 more were added in 1916. They were so arranged that each crop involved in each rotation was grown every year. The plan necessitated having as many plots devoted to each rotation as there were years in the cycle.

The cultural practices followed were in keeping with modern practices in vogue and believed to be the most desirable to bring about the best results, and so far as conditions would permit the plan outlined has been followed. The same varieties of crops were always planted each season.

The details of crop yields are given in a series of tables for each crop each year and for each rotation. Mean yields for the 15-year period and for the last six years are given to afford an opportunity of ascertaining the trend of yields.

The annual fluctuations in yields are ascertained. The season showing the highest annual mean percentage was 1918, with 120 per cent, and the lowest was 1926, with a percentage of 81.

The mean annual yields of the untreated plots devoted to oats, sugar beets, and potatoes are compared with yields in rotations containing alfalfa or manure or both. They are expressed in percentages of the mean annual yield. For the last six years the yields in the treated rotations show a percentage increase over those in the untreated, as follows: Oats 39, sugar beets 43, and potatoes 48.

The rotations producing the highest yields of oats are those in which alfalfa appears. The mean of the two 2-year rotations receiving a treatment of stable manure comes second, and the lowest yields are from the continuously cropped plots.

Manure applied in 2-year and 3-year rotations as a stimulant for increasing the yields of sugar beets has been more effective than has alfalfa. All treated rotations indicate a marked tendency to increase the longer these rotations are continued. This is evident when the average yield for the last six years is compared with the 15-year average. Comparatively low yields have resulted from plots continuously cropped, and no better mean yields have resulted from the two 2-year rotations where beets follow wheat and oats.

From a comparison of the yields of potatoes in the various rotations the highest yields are from the mean of the two 6-year rotations in which alfalfa appears three years out of the six. The beneficial effects of manure on the yields of potatoes is apparent, but the yields appear to be better sustained where manure is applied directly preceding potatoes every third year in a 3-year rotation instead of in alternate years in a 2-year rotation. To plant potatoes following oats, with rye used as a green-manure crop and seeded after the oat crop, has not proved satisfactory. Continuous cropping of potatoes not only lowers the productivity of the soil but intensifies the disease problem.

Alfalfa was included in these experiments for the purpose of determining its effect on crop yields when grown in a rotation with other crops. Yields appear to be sustained over a long period if the stand can be maintained. The first-year alfalfa returns low yield, but the second-year yields have been fully equal to the average of the third season.

When grown in a 2-year rotation with oats, wheat has given yields no better than when continuously cropped. Wheat cropped continuously with straw returned (rotation 7) has returned the lowest yield for the last six years. Yields of continuously cropped wheat and of wheat in a 2-year rotation with oats were adversely affected by wild oats.

Corn yields from untreated 2-year and 3-year rotations have been slightly more than maintained, while the yields from the continuously cropped plots have a tendency to become lower the longer the rotations are continued.

Comparative values of the various rotations have been determined. An application of manure in 2-year and 3-year rotations is

well justified and, after the estimated expense has been deducted, holds the first three places. The incorporation of alfalfa in a well-planned rotation has brought a return second only to that when manure was used. As a rule, it appears a better practice to leave alfalfa for a period of at least three years. Adding manure to a 6-year rotation which includes three years of alfalfa much more than pays for the cost of application.

The results recorded in Table 15 emphasize the importance of adopting a well-planned cropping system and show that crop yields are materially increased by the application of manure or the inclusion of alfalfa in a rotation. They show also that after estimated expenses and reasonable values placed on the various crops have been deducted, the net returns amply justify the practices.

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