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CONTENTS

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THAT CONTINUOUS culture of some crops on the same soil usually results in reduction of yield has been known for a long time. Rotation of crops may be nearly as old as agriculture itself, having come into practice through farmers' experience. However, it was about the latter part of the nineteenth century that the reasons for and effects of crop rotation were explained. Only during the last few years has crop rotation been given the recognition it deserves as an effective method of minimizing water runoff and erosion control.

The aims of these studies are to learn: (a) the effect of different cropping systems on crop yields from a 30-year experiment at the agricultural experiment station, University Farm, St. Paul, Minnesota; (b) the effect of precipitation and temperature on crop yields under different cropping systems for the 30-year period.

LITERATURE REVIEW

An extensive literature is available dealing with crop rotation. Only a few selected papers are reviewed briefly here.

Summarizing the results for the first ten-year period, 1895-1904, obtained from the Field C rotations at University Farm, St. Paul, Hays, Boss, and Wilson (12) concluded that any of the systems of cropping that maintained a supply of vegetable matter in the soil, either by manuring or by growing pasture or meadow crops, gave profitable returns. On the other hand, crops grown continuously and crops not properly rotated were less profitable and even resulted in losses.

Snyder (26) sampled the soil of these plots and found that where good rotations were followed or where manure was applied in addition, the percentages of nitrogen and carbon were maintained or increased. Where grain or cultivated crops were

[1] Revised and condensed form of a thesis presented to the faculty of the Graduate School of the University of Minnesota by the senior author, in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1940.

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grown continuously without manure applications, the percentages of both nitrogen and carbon in the soil decreased materially.

Results for the first six years, 1909-14, from various systems of cropping on Field T at University Farm were published in 1917 (2). Manure was applied in all systems of cropping except one, at the rate of 2 tons per acre per year. The yield of corn in the four-year rotation, corn-oats-wheat-hay, was 20.8 per cent higher than the yield of corn grown continuously. For oats and wheat the yields in the rotations were 17.5 and 44.3 per cent higher than for these crops grown continuously.

MATERIALS AND METHODS

Data for this crop rotation study were obtained from 30 years of crop rotation experiments on Field T at University Farm, Minnesota Agricultural Experiment Station. The soil is Hempstead silt loam (25). The surface soil "consists of about 10 to 18 inches of dark-brown to black silt loam, underlain by a subsoil consisting of brown to yellowish brown silty clay loam, which extends to a depth of about 3 feet. Movement of ground water is reasonably free, but nevertheless the moisture conserving qualities appear to be excellent." The substratum consists of a bed of rather clean gravel and sand.

This experiment was started in 1909. The previous cropping of the land over a period of years prior to 1909 tended to keep it in a fairly uniform condition (2). During the ten years before 1909, four applications of barnyard manure were made at the rate of 10 tons per acre over the entire field.

The plots were one tenth of an acre in size. They were so arranged that in each cropping system there were as many plots as there were crops. All plots except three received manure applications at the rate of 2 tons per acre per year. Cropping systems from which yields have been utilized in this study are: 1. continuous wheat, 2. continuous oats, 3. continuous corn, 4. two-year rotation—wheat and oats, 5. two-year rotation—corn and oats, 6. three-year rotation—corn, oats, and hay, 7. three-year rotation—corn, wheat, hay, 8. four-year rotation—corn, oats, wheat, and hay, 9. five-year rotation—corn, oats, wheat, hay, and pasture.

The hay and pasture crops consisted of a mixture of clover and timothy. When stands of clover and timothy were not obtained, the annual hay crop, oats and peas, was substituted.

Few changes were made in the varieties of oats, wheat, and corn utilized for this work during the 30-year period. Only two varieties of corn, both open pollinated and of similar yielding power, were used.

Crop yields from different rotations for the entire period of 30 years have been compared by means of the analysis of variance method, using the average yield of five-year periods. The significances of differences were tested by calculated standard errors. Those exceeding two times the standard error of a difference or odds of about 19:1 are regarded as significant differences. Increase in yield of one rotation over another against the number of years elapsed was studied by the regression coefficient method. The significance of regression coefficients was tested by analysis of variance. Those having an F value exceeding the 5 per cent point or about odds 19:1 have been regarded as significant.

Since the crop yields varied widely from year to year, efforts have been made to find the relationship between yields from different systems of cropping and the climatic factors, precipitation and temperature. Total, partial, and multiple correlation coefficients have been calculated to interpret the relationship between these climatic factors and crop yields. Yields have been correlated with annual precipitation, precipitation during the growing season of the crop, and the precipitation of a particular period for each crop. Since winter precipitation may be important for the growth of the crops the next year, the annual precipitation used here is calculated from October 1 of the previous year to September 30 of the year of harvest.

Two types of accumulative temperature indices through a certain period of time were used in this study. One was the physiological temperature index developed by Livingston (15). This is based upon Lehenbauer's experiment. He determined the average hourly rate of elongation of the shoots of seedling maize plants (10-12 cm. high) when exposed 12 hours to maintained temperatures of from 12° to 43° C. Livingston plotted the results into a smooth curve and then measured the average hourly rates of elongation in hundredths of a millimeter for each degree of temperature considered. Then all the numbers were divided by the value for 4.5° C. or 40° F., thus giving the physiological indices sought. Therefore each index expresses the average hourly growth-rate for its corresponding temperature in terms of growth rate for 4.5° C. as unity. The monthly mean temperature given by the Weather Bureau has been transferred to the corresponding physiological indices and then accumulated for the particular period studied. The other type was the remainder index of temperature efficiency for plant growth. The rate of plant growth at 40° F. was considered as unity and it was assumed that this rate becomes 2 at 41° F., 10 at 49° F., 50 at 89° F., etc. (16). The indices for the period studied were then accumulated and correlated with crop yields.

The significances of these correlation coefficients have been tested by referring to Fisher's VA table (9) with N-2 degrees of freedom. Those giving $P = .05$ or less but greater than .01 were considered statistically significant. Those with over $P = .01$ or less were considered highly significant.

Results from the System of Cropping Studies

COMPARISON OF YIELDS IN BUSHELS AND TONS

Corn

Annual yields of corn from the various cropping schemes are given in table I in the appendix. Average yields of corn by five-year periods, from 1910-1939, inclusive, are summarized in table 1. The year 1934 was very dry and crop yields were extremely low. This brought down the average yield for the period 1930-34; 1938 and 1939, especially the latter, were favorable years. This raised the average crop yield for the period 1935-39.

Table 1. Corn Yields from Different Cropping Systems at University Farm in 5-year Periods for the 30 Years, 1910-1939, Inclusive

Period	Systems of Cropping and Treatments					
	Continuous cropping Manured	2-year rotation C-O Manured	3-year rotation C-O-H No manure	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured
	Bushels per acre					
1910-14	43.16	45.64	47.36	52.70	50.82	50.16
1915-19	37.62	36.98	35.62	48.60	55.94	52.44
1920-24	39.90	37.96	36.44	47.56	50.82	54.98
1925-29	32.56	37.20	32.86	43.48	46.58	45.22
1930-34	21.42	30.70	24.04	27.02	34.16	33.86
1935-39	45.24	52.76	45.28	57.62	53.16	61.40
1910-39	36.65	40.20	36.93	46.16	48.58	49.68
	Per cent with the yields from continuous cropping as 100					
1910-39	100.00	109.69	100.76	125.95	132.55	135.55

C=corn, O=oats, W=wheat, H=hay, and P=pasture.

The data were analyzed by an analysis of variance with the following results:

Variation due to	D.F.	Sum of squares	Mean squares	F	σ
Rotations	5	1021.32	204.2640	19.19*	....
Periods	5	2070.91	414.1820	38.92*	....
Error	25	266.08	10.6432	....	3.27
Total	35	3358.31			

* Highly significant.

The significance of F values was tested by Snedecor's F table. With degrees of freedom 5 and 25 in this case, F values for both rotations and periods exceed the 1 per cent point which corresponds to odds over 99:1. Therefore, taking the 30-year period, 1910-1939, as a whole, some cropping systems were significantly more productive than others; also some periods were significantly more favorable for crop production than other periods. Since the F value for periods, 38.92, is higher than that for rotations, 19.19, the former apparently affected crop yields more than the latter.

Since the standard error of a single determination, i.e., an average for a five-year period was 3.27 bushels, the error of the mean of six periods would be $\frac{3.27}{\sqrt{6}}$ bushels. That for a difference between two means would be $\frac{3.27}{\sqrt{6}} = \sqrt{2}$ or 1.89 bushels. Since twice the standard error of difference gives odds of about 19:1 that an observed difference is not due to chance, any difference above 2 x 1.89 bushels or 3.78 bushels would be due to the effects of different treatments.

Various comparisons from the results summarized in table 1 are made in table 2.

Table 2. Differences in Yield of Corn under Different Cropping Systems

Cropping systems compared	Differences in yield	
	bu.	per cent
C-O and continuous cropping, both manured	3.55	9.69
C-O-H untreated and manured continuous cropping	.28	.76
C-O-H and continuous cropping, both manured	9.51*	25.95
C-O-W-H and continuous cropping, both manured	11.93*	32.55
C-O-W-H-P and continuous cropping, both manured	13.03*	35.55
C-O-W-H and C-O-H, both manured	2.42	5.24
C-O-W-H-P and C-O-H, both manured	3.52	7.63
C-O-H and C-O, both manured	5.96*	14.83
C-O-H manured and C-O-H untreated	9.23*	24.99

* Significant, odds over 19:1.
C=corn, O=oats, W=wheat, H=hay, and P=pasture.

The differences of corn yields from the manured corn-oat two-year rotation, from the untreated corn-oat-hay three-year rotation, and the manured continuous cropping were within the limits of experimental error as defined by odds of 19:1. With manure applied to both under the same treatment, corn in the two-year rotation, corn-oats, yielded 3.55 bushels more than under continuous cropping, which approaches the level of significance of 3.78 bushels but gives odds less than 19:1 that the difference is significant. The effect of the untreated three-year rotation on corn yield was similar to the annual application of 2 tons of manure to the continuous cropping system. Corn responded about equally to the application of manure and to the hay crop in the rotations. This result agrees fairly well with the results from the Missouri investigations (19).

The yields of corn from the manured three-, four-, and five-year rotations were significantly higher than the yields from the manured continuous cropping systems. They produced 25.78, 32.55, and 35.55 per cent more than the continuous cropping, respectively. Corn yields from these three rotations, however, were not significantly different although the difference between the five- and three-year rotation in corn yield was 3.52 bushels which approaches the level of significance.

The three-year rotation produced significantly higher yields than the two-year rotation. Since they were equally treated with manure, the only differences between them is the presence of legumes in the former. Therefore, the significantly higher yield from the three-year rotation may be credited to the beneficial effect of the hay crops.

The yields from the manured three-year rotation were significantly higher than those from the untreated rotation. It appears that the effects of manure and crop rotation on yields were separate, and their effects cumulative.

The results with corn from the different systems of cropping for the 30-year period may be summarized as follows: The yields from the manured continuous cropping and the three-year rotation without manure were not significantly different. The yield from the manured corn-oat rotation averaged 3.55 bushels more than the manured continuous cropping. This difference approached the level of significance of 3.78 bushels but gave odds of less than 19:1 that the difference is significant. The yields from the manured three-, four-, and five-year rotations were significantly higher than those from the manured corn continuous, the manured corn-oat rotation, and the three-year rotation without manure. Comparison of the yields from the two- and three-year rotations, both manured, showed that introduction of a hay crop into the rotation increased corn yields significantly. Also the corn yields in the manured three-year rotation were higher than in the same rotation without manure application. The effects of the hay crop and of manure application in the rotation on corn yields were cumulative.

Oats

Yields of oats from the different cropping systems for each year of the 30-year period are given in table II, in the appendix. Average oat yields from the different cropping systems by five-year periods, 1910-39, and for the entire 30-year period, inclusive, have been summarized in table 3.

Table 3. Oat Yields from Different Cropping Systems at University Farm in 5-year Periods for the 30 Years, 1910-1939, Inclusive

Period	Systems of cropping and treatments						
	Continuous cropping Manured	2-year rotation C-O Manured	2-year rotation W-O Manured	3-year rotation C-O-H No manure	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured
	Bushels per acre						
1910-14	46.62	54.88	51.10	57.76	60.24	59.22	56.50
1915-19	57.92	80.50	62.26	78.64	82.62	76.08	78.98
1920-24	43.16	59.66	41.04	57.86	59.62	66.90	63.42
1925-29	50.68	67.60	53.88	70.08	81.20	71.26	65.56
1930-34	41.80	53.66	42.20	55.78	58.06	63.36	61.22
1935-39	50.38	60.26	54.52	57.34	57.88	57.26	61.70
1910-39	48.43	62.76	50.83	62.91	66.60	65.68	64.56
	Per cent with the yields from continuous cropping as 100						
1910-39	100.00	129.59	104.96	129.90	137.52	135.62	133.31

C=corn, O=oats, W=wheat, H=hay, and P=pasture.

The analysis of variance was used to analyze the data as in corn. The F value for cropping systems is 19.50, and that for periods, 25.86. They exceed the 1 per cent point and therefore are highly significant. Two times the standard error of difference used for comparing significant yield differences is 4.75 bushels.

The oat yields from the wheat-oat rotation and from oats grown continuously were not significantly different although

Table 4. Differences in Yield of Oats under Different Cropping Systems

Cropping systems compared	Differences in yield	
	bu.	per cent
C-O and continuous cropping, both manured	14.33*	29.59
W-O and continuous cropping, both manured	2.40	4.96
C-O-H untreated and continuous cropping, manured	14.48*	29.90
C-O-H and continuous cropping, both manured	18.17	37.52
C-O-W-H and continuous cropping, both manured	17.25*	35.62
C-O-W-H-P and continuous cropping, both manured	16.13*	33.31
C-O-W-H and C-O-H, both manured	—.94	—1.43
C-O-W-H-P and C-O-H, both manured	—2.04	—3.16
C-O and W-O, both manured	11.93*	23.47
C-O-H and C-O, both manured	3.84	6.12
C-O-H, manured, and C-O-H, untreated	3.69	5.91

* Highly significant.

there was an average difference of 2.4 bushels in favor of the rotation. Since the culture of oats and wheat was similar, any effect of one crop on the other would need to be a direct effect and not due to a difference in method of handling. The oat yields in the corn-oat rotation averaged 14.33 and 11.93 bushels, respectively, higher than those from the continuous cropping and from the wheat-oat rotation. Both of these differences are significant. Since manure was applied at the same rate in each system of cropping, these large differences may be credited to the wide differences between the grain crops and corn, and to the tillage of the corn crop preceding the oats. Cultivation of the corn crop resulted in less weeds in the oat crop following it. Any other effects of tillage of the corn or that of a widely different crop on the grain crops that followed were not investigated.

The effect of legumes in rotations on oat yields may be examined by comparing the yields from the corn-oat and the three-year rotation. Both received applications of manure. The average yield per acre difference for these two rotations was 3.86 bushels, which approaches but does not reach the level of significance with odds of 19:1. More lodging of oats grown in the manured three-year rotation than in the two-year rotation reduced yields to some extent. This tended to offset the beneficial effect of the hay crops in the manured three-year rotation.

The difference in oat yields between the manured and untreated three-year rotations was 3.72 bushels per acre which approached but did not reach the level of significance necessary for odds of 19:1. The three-year rotation without manure has maintained an adequate soil productivity for oats. Too high soil productivity for the oat crop resulting from the application of manure in addition to the inclusion of the hay crop in the rotation caused lodging and lowering of yields.

Oat yields from the three-, four-, and five-year rotations receiving equal amounts of manure were not significantly different. However, oats in these rotations all yielded higher than in the continuous cropping system. The significantly higher oat yields in these three-, four-, and five-year rotations over the continuous cropping system are probably due partially to the presence of corn in the rotation.

The untreated three-year rotation produced significantly more than the manured continuous cropping scheme. Apparently inclusion of a hay and a corn crop in the cropping scheme was more effective in increasing oat yields than the application of manure in the continuous cropping scheme at the rate of two tons per acre per year.

A brief summary for oat yields in the different cropping systems follows: Oat yields from the continuous cropping scheme, and from the wheat-oat rotation, both manured, showed no significant difference. However, they were significantly lower than those from the corn-oats rotation, the two three-year rotations, either manured or untreated, and the four- and five-year rotations. There was no significant difference between yields in the three-, four-, and five-year rotations. It appears that oat yields in these manured rotations were increased more by the inclusion of a cultivated crop than by the inclusion of a hay crop. Since corn is able to utilize high soil productivity, it produced more in the manured rotations than either manured or rotated systems of cropping alone. Oats, on the other hand, lodged frequently when the soil productivity was high. Therefore, oats did not show higher production from the manured than from the untreated rotation, both including a cultivated crop. Oat yields appeared to be more responsive to the effects of rotation than to the application of manure.

Wheat

Yields of wheat from the different cropping systems for each of the 30 years are given in table III in the appendix. The average yields of wheat by five-year periods, 1910-1939, inclusive, from different rotations have been summarized in table 5.

Table 5. Wheat Yields from Different Cropping Systems By 5-year Periods for the 30 Years, 1910-1939, Inclusive

Period	Systems of cropping and treatments				
	Continuous cropping Manured	2-year rotation W-O Manured	3-year rotation C-W-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured
	Bushels per acre				
1910-14	15.14	20.15	25.20	24.12	22.12
1915-19	22.96	24.18	31.10	28.90	28.78
1920-24	15.08	15.38	21.46	19.74	21.10
1925-29	15.30	18.10	28.68	28.24	26.68
1930-34	17.94	17.48	25.10	21.90	23.92
1935-39	15.56	15.16	19.68	23.46	19.26
1910-39	17.00	18.41	25.20	24.39	23.64
	Per cent with the yields from continuous cropping as 100				
1910-39	100.00	108.29	148.24	143.47	139.06

C=corn, O=oats, W=wheat, H=hay, and P=pasture.

Table 6. Yield Differences of Wheat under Different Cropping Systems (Manured)

Cropping systems compared	Differences in yield	
	bu.	per cent
W-O and continuous cropping	1.41	8.29
C-W-H and W-O	6.79*	36.88
C-O-W-H and W-O	5.98*	32.48
C-O-W-H-P and W-O	5.23*	28.41
C-O-W-H and C-W-H	—.81	—3.32
C-O-W-H-P and C-W-H	—1.56	—6.60
C-O-W-H-P and C-O-W-H	—.75	—3.08

* Highly significant.

From an analysis of variance, the F value for cropping systems was found to be 27.46, and that for periods, 17.22. They are both highly significant.

Yield differences between wheat in the different rotations are summarized in table 6. Two times the standard error of difference for testing the significance of difference of two means is 2.02 bushels.

The average wheat yield during the 30-year period in the wheat-oats rotation was only 1.41 bushels higher than that from the continuous wheat, which was not a statistically significant difference. The similar results when oat yields from the continuous cropping were compared with that in the wheat-oats rotation have been pointed out previously.

Wheat yields from the three-, four-, and five-year rotations were significantly higher than those from the continuous wheat or wheat-oats rotation. Whether this was due to the effect of corn or hay or part from each cannot be interpreted since no comparisons can be made.

Wheat yields from the three-, four-, and five-year rotations were not significantly different. Similar results have been pointed out for corn and oats. The three-year rotation was as efficient in maintaining soil productivity as the longer ones, and the yields were somewhat higher than from the four- or five-year rotations.

The results for wheat may be briefly summarized as follows: The yields from rotations which included a cultivated crop and a mixed leguminous and grass hay were significantly higher than those from the continuous cropping or the wheat-oats rotation.

Hay

Annual yields of hay from the different cropping systems for each of the 30 years are given in table IV of the appendix. The

Table 7. Hay Yields from Different Cropping Systems by 5-year Periods for the 30 Years, 1910-1939, Inclusive

Period	Systems of cropping and treatments			
	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured
	Tons per acre			
1910-14	2.45	2.59	2.37	2.56
1915-19	2.31	2.67	3.29	2.99
1920-24	1.86	1.94	2.29	2.02
1925-29	1.90	2.36	3.04	2.39
1930-34	1.09	1.19	1.44	1.55
1935-39	2.19	2.37	2.82	2.41
1910-39	1.97	2.98	2.54	2.32
	Per cent with yield from untreated 3-year rotation as 100.0			
1910-39	100.00	110.65	128.95	117.77

C=corn, O=oats, W=wheat, H=hay, and P=pasture.

average yields of hay by five-year periods, from the different rotation systems, 1910-1939, inclusive, are summarized in table 7.

From the analysis of variance, the F value for cropping systems was found to be 6.03 and that for periods, 20.69. They are both highly significant. Yield differences between rotations are summarized in table 8. Two times the standard error of difference for testing the significance of difference for two means is 0.27 ton.

Comparing hay yields from the manured three-year rotation with the untreated three-year rotation gave a difference of .21 tons in favor of manure. These differences are close to a significant level at the .05 per cent point. The hay yield from the five-year rotation was lower than that from the four-year rotation by .22 tons. Both manured four-year and five-year rotations produced higher yields than the untreated three-year rotation. Only the four-year rotation produced significantly higher yields of hay than were produced by the manured three-year rotation.

Table 8. Yield Difference of Hay under Different Cropping Systems

Cropping systems compared	Differences in yield	
	tons	per cent
C-O-H, manured, and C-O-H, untreated	.21	10.66
C-O-W-H, manured, and C-O-H, untreated	.57*	28.93
C-O-W-H-P, manured, and C-O-H, untreated	.35*	17.77
C-O-W-H and C-O-H, both manured	.36*	16.51
C-O-W-H-P and C-O-H, both manured	.14	6.42
C-O-W-H-P and C-O-W-H, both manured	—.22	—9.48

* Significant.

COMPARISON OF YIELDS OF CRUDE PROTEIN AND TOTAL DIGESTIBLE NUTRIENTS

Average annual production of protein and total digestible nutrients in feeds produced per acre under the different cropping systems were compared. The results from the five-year rotation were not included since the yields of pasture were not available. The results are summarized in table 9.

Table 9. Average Pounds of Protein and Total Digestible Nutrients in Feeds Produced Per Acre Annually under Different Cropping Systems, 1910-1939, Inclusive

Cropping systems compared	Digestible protein	Total digestible nutrients
	lbs.	lbs.
Continuous corn, manured	150.26	1671.24
Continuous oats, manured	159.82	1075.15
Continuous wheat, manured	90.10	807.50
W-O rotation, manured	132.66	1001.46
C-O rotation, manured	185.97	1613.20
C-O-H rotation, untreated	186.64	1674.27
C-O-H rotation, manured	210.82	1914.25
C-W-H rotation, manured	180.79	1806.67
C-O-W-H rotation, manured	201.07	1834.08

The standard error of protein production in pounds per acre from different cropping systems is 12.60. Two times the standard error of difference is 35.64 pounds. A larger difference than this may be considered significant. Although the 30-year average yield per acre of wheat was 17.0 bushels per acre, production of feed protein from this cropping system was significantly lower than from the other systems. The protein production from the wheat-oats rotation was low also. There was no significant difference in feed protein production from the two-year rotation, corn-oats, and the continuous cropping of corn or oats. Rotations containing corn or both corn and hay, however, produced significantly more protein per acre than any of the continuous cropping schemes or the wheat-oats rotation. No significant difference in protein production was found in comparing results from the two-year rotation of corn and oats, and the three- and four-year rotations.

Two times the standard error of the difference of the production of total digestible nutrients per acre in different cropping systems is 388.34 pounds. Continuous oats and wheat and the two-year rotation of wheat and oats produced significantly lower yields than any of the other systems. Since corn is usually a highly productive crop, its total digestible nutrient production when grown continuously was not significantly lower than the yields produced in the three- and four-year rotations.

DIFFERENCES IN YIELDS OF CROPS IN DIFFERENT SYSTEMS OF CROPPING

To determine the trend of the variation in yield under different systems of cropping during various periods in the experiment, regression coefficients were used. When differences in yield were correlated with years, a significant positive regression coefficient indicated an increasing difference in yielding ability during the period.

Corn

Results during the first five-year period comparing corn yields from the corn-oats rotation with continuous corn may be illustrated as follows:

X (years)	Y (gain in yield from C-O rotation over continuous cropping)
1	5.6
2	—5.8
3	8.7
4	—2.4
5	6.3

The calculated regression of differences in yield for years was then:

$$b_{YX} = \frac{S\ (XY) - S\ (X)\ \overline{Y}}{S\ (X^2) - S\ (X)\ \overline{X}} = .4800\ \ (14).$$

Analysis of variance was then used to test the significance of the coefficient by means of deviations from regression (9). The regression coefficients computed for corn are summarized in table 10.

During the first ten-year period, the regression coefficient for yield differences comparing the four-year rotation and the continuous cropping system for years is 2.0776. Analysis of variance showed that this is a significant value. This is due to the fact that under crop rotation with manure applications, soil productivity was maintained during the first several years, while it was being reduced under continuous cropping. The same was true for the five-year rotation compared with the continuous cropping scheme.

Table 10. Regression Coefficients of Corn Between Yield Differences of Cropping Systems and Years

Cropping systems compared	First 5 years	First 10 years	Last 20 years	30 year period
C-O rotation vs. continuous cropping	.4800	—.3200	.6267	.3497
C-O-H rotation, untreated, vs. manured continuous cropping	—.2200	—1.3103	.3241	—.0085
C-O-H rotation, manured, vs. continuous cropping	2.2000	.2329	—.1994	—.1002
C-O-W-H rotation vs. continuous cropping	2.2900	2.0776*	—.4759	—.1004
C-O-W-H-P rotation vs. continuous cropping	3.4400	1.9321*	—.2280	.0855
C-O-H, manured, vs. C-O-H, untreated	2.4200	1.5321*	—.1288	—.0206
C-O-H vs. C-O, both manured	1.7200	.5576	—.4359	—.3297
C-O-W-H-P rotation vs. C-O-H rotation	1.2400	1.1527	—.1086	.8013
Average of manured 3-, 4-, and 5-year rotations vs. continuous cropping	2.5300	.9879	.1006	.0578
Average of 3-, 4-, and 5-year rotations, manured, vs. C-O rotation, manured	2.0500	1.3115	—.4310	—.2085
Average of 3-, 4-, and 5-year rotations, manured, vs. C-O-H rotation, untreated	2.7500	2.2861	—.2205	.0650

* Significant; odds over 19:1.

That this did not hold true for the manured three-year rotation appeared to be due to greater variation of yields from this rotation compared with the others. The manured three-year rotation tended to show a progressive difference in yield compared with that from the same rotation without manure application. This is indicated by the significant regression coefficient of 1.5321. None of the other regression coefficients was significant. However, a general tendency may be observed. Except for the corn-oats, two-year, and the untreated three-year rotation, all other coefficients were comparatively high for the first five-year and ten-year periods. Differences between the yields from these rotations and the yields from cropping systems tended to increase during the first five or ten years. The very small negative regression coefficient of corn yield differences for the untreated three-year rotation compared with the manured continuous cropping scheme indicated that the differences in yield between these two cropping systems were relatively constant over the first few years. The positive significant regression coefficient of 1.5321 for the difference between corn yields from the manured three-year rotation compared with those from the manured two-year rotation showed that during the first ten-year period these tended to diverge.

All coefficients for the last 20 years are small. Therefore, the differences in corn yields between those cropping systems remained rather stable during this period.

Since yield differences from the three-, four-, and five-year rotations were not significant, their yields were averaged and then compared with those from the continuous cropping system, etc. Regressions of these averages are presented in the last part of table 10. The large regressions of these averages for the first five- and ten-year periods and small regressions for the last 20- and for the entire 30-year periods emphasize the point already brought out that divergences in yields tended to appear early.

Oats

The regression coefficients for oats are summarized in table 11.

Table 11. Regression Coefficients for Oats Between Yield Differences in Cropping Systems and Years

Cropping systems compared	First 5 years	First 10 years	Last 20 years	30 year period
C-O rotation vs. continuous cropping	9.3300	2.9564	.0180	.0413
W-O rotation vs. continuous cropping	2.1800	.2727	.2935	.0282
Untreated C-O-H rotation vs. continuous cropping	5.4200	1.5297	—.5367	—.0875
C-O-H rotation, manured, vs. continuous cropping	5.0300	2.1915	—.8357	—.2770
C-O-W-H rotation vs. continuous cropping	4.2000	1.9309	—.6779	.1106
C-O-W-H-P rotation vs. continuous cropping	2.5900	1.9576	—.6547	.0774
C-O-H rotation vs. C-O rotation	1.6100	.4182	—.2085	—.0084
C-O-H rotation, manured, vs. C-O-H rotation, untreated	—4.3000	—.7591	—.2109	—.0785
C-O-W-H-P rotation vs. C-O-H rotation	—4.7300	—.0047	—.1792	.1561
Average of 3-, 4-, and 5-year rotations vs. continuous cropping	3.1400	1.8412	—.8417	—.1717
Average of 3-, 4-, and 5-year rotations vs. C-O rotation	—6.1900	—1.1152	—.3872	—.0078
Average of 3-, 4-, and 5-year rotations vs. W-O rotation	.9600	1.5673	—1.1119	—.1279
Average of 3-, 4-, and 5-year rotations vs. C-O-H rotation, untreated	—.3000	.2509	—.2680	.0425

Most regression coefficients for oat yields in the first five-year period when rotations were compared with continuous cropping are rather high. Due to only three degrees of freedom in these cases, no statistically significant differences are shown. However, these high regression coefficients do indicate a general tendency for oat yields grown in rotation to diverge from the yields produced in the continuous cropping system. The regression coefficient for the three-year rotation compared with that for the corn-oats two-year rotation indicates a divergence in yield. The coefficient for the manured compared with the untreated three-year rotation is negative. The application of manure in one of these rotations did not tend to make the yields of oats diverge materially. Yields from the five-year rotation did not tend to deviate materially from those in the manured three-year rotation. The regression coefficient of oat yield differences between the four-year rotation and the continuous cropping, 1.9309, is close to the significant level.

The results for the first ten-year period generally agree with those for the first five-year period. Except for the wheat-oats rotation, the coefficients indicate a divergence of the yields produced by the rotations and by continuous cropping.

Regression coefficients for the last 20 years are low. These results are similar to those obtained for corn.

Wheat

The regression coefficients for wheat are summarized in table 12.

Table 12. Regression Coefficients for Wheat Between Yield Differences of Cropping Systems and Years

Cropping systems compared	First 5 years	First 10 years	Last 20 years	30 year period
W-O rotation vs. continuous cropping	—.1000	—.6327	—.1695	—.1870
C-O-W-H rotation vs. continuous cropping	.3600	—.5333	.0495	—.0074
C-O-W-H-P rotation vs. continuous cropping	.1500	—.2715	—.1669	—.0427
C-O-W-H-P rotation vs. C-O-W-H rotation	—2.9100	.2618	—.1991	—.0166
Average of 4- and 5-year rotations vs. continuous cropping	.2700	.4000	—.0522	—.2389

Due to the fact that annual variation of wheat yields within cropping systems were large, the regression coefficients for wheat between yield differences of rotations are not conclusive.

Hay

The regression coefficients for hay yields from the different systems of cropping are given in table 13.

Table 13. Regression Coefficients of Hay Between Yield Differences of Rotations and Years

Cropping systems compared	First 5 years	First 10 years	Last 20 years	30 year period
C-O-H rotation, manured, vs. C-O-H rotation, untreated	.094	.044	.003	—.0023
C-O-W-H rotation vs. C-O-H rotation, both manured	*—.001*	*.140*	*—.007*	*.0139*
C-O-W-H-P rotation vs. C-O-H rotation, both manured	—.133	—.017	—.006	—.0014
C-O-W-H rotation, manured, vs. C-O-H rotation, untreated	.093	.184	—.001	—.0125
C-O-W-H-P rotation, manured, vs. C-O-H rotation, untreated	—.039	.027	.004	—.0021

Since no continuous hay data were available and hay yields from the different rotations did not deviate from each other greatly, the regression coefficients for differences of hay yields between different rotations on years are all very small.

Summarizing the results obtained from the study by regression coefficients of differences in yields of crops by years, indications are that the main yield differences in different cropping systems were brought out during the first several years. After this period yields varied from year to year with weather conditions, but the averages for the crops in the different rotations were maintained largely in the same order.

INFLUENCE OF CLIMATE ON VARIATIONS IN YIELDS

In addition to studying the effects of cropping systems on yields, it appeared important to learn to what extent weather influenced results from the different rotations.

Two methods were followed in studying this phase of the subject. The first consisted of observations on the relation of rainfall and temperatures during the growing season to yield for each year studied. Correlation of yields of all crops for the entire 30-year period with annual rainfall and that for particular periods during which most rapid development of the plants take place and with temperatures for different periods was the second method employed. The correlation method was expected to show the general trend of the relation between weather and yield over the 30-year period.

To facilitate the study of yields for certain years in relation to rainfall and temperature for the different months of the growing season, data largely from Appendix tables 24-29 have been assembled in table 14. A column has been added giving the per cent of increase of the average yields from the three-, four-, and five-year rotations over the yields from the continuous cropping.

In 1919 corn yields averaged the highest in the 30-year period; hay yields were higher than average and oat and wheat yields were about average. Temperatures were not far from average for each month except for September which was higher than average. The higher than average rainfall in April gave the hay crop a good start. The high rainfall of July with somewhat below average precipitation in August and September favored the development and proper ripening of the corn crop. With favorable weather conditions, increases for the rotations over the continuous

Table 14. Effect of Rainfall and of Temperature During the Growing Season on the Yields of Crops for Certain Years

Period or year	Crop	Continuous cropping Manured	2-year rotation W-O Manured	2-year rotation C-O Manured	3-year rotation C-O-H No manure	3-year rotation C-O-H Manured	Average 3-, 4-, and 5-year rotation Manured	Per cent increase average for 3-, 4-, and 5-year rotation over continuous crop	Apr.	May	June	July	Aug.	Sept.
30-year average	Corn	36.7	....	40.2	36.9	46.2	48.1	31.1	Rainfall in inches					
	Oats	48.4	50.8	62.8	62.9	66.6	65.6	35.5	2.0	3.2	4.2	3.0	3.0	2.8
	Wheat	17.0	18.4	....	....	25.2	24.4	43.5	Temperature, monthly mean in °F.					
	Hay	....	....	....	2.0	2.2	2.4	....	45.9	58.5	68.5	73.9	70.6	62.0
1919	Corn	69.6	....	68.0	65.5	82.3	85.9	23.4	Rainfall in inches					
	Oats	44.1	50.0	53.1	54.4	57.6	56.6	28.3	3.4	1.7	4.0	6.2	1.9	1.5
	Wheat	19.3	19.0	....	....	28.0	23.9	23.8	Temperature, monthly mean in °F.					
	Hay	....	....	....	3.4	3.8	3.1	....	45.2	58.2	70.2	74.6	69.8	64.3
1934	Corn	5.1	....	12.9	10.7	17.6	25.6	40.2	Rainfall in inches					
	Oats	10.8	11.0	14.8	11.0	19.1	19.4	33.3	1.6	0.2	2.3	1.4	1.6	4.9
	Wheat	6.0	4.7	....	....	3.8	4.1	—31.7	Temperature, monthly mean in °F.					
	Hay	....	....	....	.7	.8	.9	....	46.0	68.6	84.0	76.2	70.1	57.2
1930	Corn	18.8	....	22.2	14.8	19.4	29.6	57.4	Rainfall in inches					
	Oats	57.2	68.1	82.5	98.1	108.5	106.6	86.4	0.6	3.4	6.7	0.9	0.7	4.1
	Wheat	25.0	28.1	....	....	50.0	44.3	77.2	Temperature, monthly mean in °F.					
	Hay	....	....	....	.8	1.0	1.6	....	49.4	58.4	68.6	75.3	75.2	62.4
1931	Corn	13.0	....	15.6	18.6	13.8	13.5	3.8	Rainfall in inches					
	Oats	46.0	53.3	63.4	33.3	37.4	52.3	13.7	1.2	1.4	4.8	1.1	3.0	2.4
	Wheat	17.7	18.9	....	....	18.1	16.9	—4.5	Temperature, monthly mean in °F.					
	Hay	....	....	....	1.5	1.5	1.6	....	50.0	56.1	73.7	76.8	70.6	68.6
1915	Corn	7.2	....	7.2	11.3	29.7	31.0	430.5	Rainfall in inches					
	Oats	61.9	64.7	90.0	92.2	91.8	78.9	27.5	1.9	4.0	4.9	5.9	3.5	2.6
	Wheat	24.2	25.2	....	....	30.7	31.0	28.1	Temperature, monthly mean in °F.					
	Hay	....	....	....	3.0	3.2	3.1	....	56.0	52.2	62.5	67.2	65.8	60.6
1917	Corn	20.8	....	12.5	22.0	29.0	30.7	47.6	Rainfall in inches					
	Oats	51.8	64.7	87.2	86.9	98.5	96.8	67.5	1.7	4.2	3.8	4.1	2.8	2.2
	Wheat	23.7	24.7	....	....	34.5	34.0	43.5	Temperature, monthly mean in °F.					
	Hay	....	....	....	1.9	2.6	3.5	....	41.9	54.6	63.3	73.0	67.3	60.0

cropping schemes were all in the same direction but materially lower in 1919 than for the entire 30-year period.

Data for 1935 and 1939 are not included in table 14, but reference to the Appendix tables will show that weather conditions were favorable for good yields of all crops. May precipitation for 1935 was somewhat higher than for 1919 and temperatures somewhat lower in June. Under these conditions, oat and wheat yields were about as high in the continuous cropping schemes as in the three-, four-, and five-year rotations. In 1939 oat yields in all the systems of cropping were high and not far different, while wheat yields were low with a considerable advantage in favor of the rotations. In these good years, the weather brought about differences in relationships between yields from the different cropping systems.

The 1934 yields of each of the crops except corn averaged the lowest of any year during the 30-year period. Rainfall was deficient each month of the growing season. The May rainfall, two tenths of an inch, was the second lowest for any month during the growing season for the 30-year period. Temperatures were unusually high during May and June and somewhat higher than average for August. Corn yields in the rotations showed about the usual relationship. All wheat yields were extremely low, with no advantage in favor of the three-, four-, and five-year rotations.

With favorable temperatures for each month of the growing season in 1930 for each of the four crops, the low yields of hay for the year may be attributed to the deficient April rainfall, and the low yields of corn to the deficient July and August rainfall. For this year, yields from the rotations were much higher relatively compared with those from the continuous cropping schemes than they were for the 30-year period.

Weather conditions in 1931 were in general similar to those in 1930, differing mainly in that deficient rainfall continued over both April and May and rainfall in August was about normal. Temperatures in June and July were somewhat higher than in 1930 and higher than average. Average corn yields from the three-, four-, and five-year manured rotations were the lowest for any year of the 30-year period, and this average was not materially higher than the yield from the continuous cropping system. Wheat yields were similar from all systems of cropping. Yields of both corn and wheat in the different cropping systems varied from the usual relationship. Average oat yields from the three-, four-, and five-year rotations were only 13.7 per cent higher than the yield from the continuous cropping compared with the 30-year average of 35.5 per cent. All hay yields were low, due to the deficient rainfall in April and May.

In 1915 rainfall was near to or above average for each month of the growing season and water supplies were ample for good crop yields. Monthly mean temperatures were far below average for each of the months—May-August, inclusive. Corn yields for this coldest growing season during the 30-year period resemble most those for 1934, the driest, hottest season in the same period of years. A cool growing season with ample water supply resulted in high yields of oats, wheat, and hay. The increase in yields of oats and wheat from the rotations compared with those from the continuous cropping were somewhat lower than average.

Another year with about average rainfall each month of the growing season and with abnormally low temperatures occurred in 1917. The main difference was that the mean temperature for July was higher than for 1915, being about average. Yields of corn from all systems of cropping were low again, but this year they varied less from their average relationship than in 1915. Again, as in 1915, oat, wheat, and hay yields were high. Oat yields from the rotations were high in relation to yields from the continuous cropping system.

Variations in rainfall and in temperature during the growing season of the years selected for study were responsible for large differences in yields of the same crops from year to year and of different crops the same season. Some years they also affected the same crops differently in the several cropping systems.

Precipitation and Yields

Corn

Total correlation coefficients calculated between corn yields in different rotations and precipitation for particular periods of the year are summarized in table 15.

That the correlation coefficients between yields of corn for the 30-year period from the different systems of cropping and precipitation did not deviate from each other greatly indicates that corn in these systems of cropping reacted, in general, similarly to the precipitation of different periods.

The relationship between the precipitation for different periods and average corn yields for all systems of cropping may be studied by the correlation coefficients given in the last column

Table 15. Correlation Coefficients Between Corn Yields and Precipitation During Different Periods of the Year

Periods	Continuous cropping Manured	2-year rotation C-O Manured	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average of manured 3-, 4-, and 5-year rotations	Average for all systems of cropping
October-September	.3982*	.3195	.3192	.4694*	.4498*	.3731*	.4469*	.4615*
May-September	.2420	.0540	.1153	.2999	.2946	.1900	.2825	.2255
April-September	.2240	.1017	.1741	.3551	.3371	.2510	.3376	.2798
November-March	.3474	.3371	.2592	.1854	.2012	.2392	.2127	.2683
May-June	.2458	.0827	.1675	.2551	.2978	.2334	.3124	.2394
June-July	.2271	.0247	.1179	.3094	.4077*	.2774	.3439	.2537
July-August	.0539	.1338	.0848	.0927	.1844	.0762	.1694	.1876
August-September	—.1508	—.1405	—.1271	—.0424	—.1238	—.2306	—.1384	—.1266
July 1-20	.1457	.1494	.0894	.2557	.2734	.1831	.2537	.2193
July 11-30	.3272	.1717	.2420	.3336	.4396*	.2453	.3506	.3306
July 21-August 10	.0470	—.0632	.0841	.1256	.0643	—.0058	.0800	.0735
August 1-20	—.0527	.0895	—.1159	.0199	—.0620	—.1604	—.0474	—.0406
August 11-31	.0185	.1271	—.0039	.0286	—.0262	—.0665	—.0098	.0382

* Significant, odds over 19:1.

of table 15. Only the coefficient for the period from October of the previous year to September of the succeeding year reaches a significant level. The correlation coefficients for precipitation in winter with corn yields averaged somewhat lower than those for the growing season, May to September.

Corn is usually planted early in May and harvested late in September or early in October at University Farm. May-September is its usual growing season. However, the precipitation during this period of time gave a rather low correlation coefficient with corn yields. That April-September, inclusive, precipitation gave a higher correlation coefficient than May-September figures indicates that April precipitation, falling just before corn planting time, was useful to the crop.

The growing season was divided into successive two-month periods and the precipitation for each was correlated with yields. All correlation coefficients are low in value. They fail to indicate any significant relationship. However, corn appeared to be benefited most by rainfall in the early part of the growing season. In August and September, i.e., after silking time, lower precipitation favored higher corn yields. The explanation may be that low precipitation after silking hastened maturity while high moisture favored delay of maturity.

Corn at University Farm usually silks from the middle of July to the early part of August. These two months have been divided into five 20-day periods, and correlation coefficients computed. From July 11 to 31, just about the silking period, the correlation is only .3306. Though this is higher than any other correlation for the growing season, yet it is smaller than the coefficient between corn yields and annual precipitation from October to September. This indicates that precipitation during silking time influenced corn yields more than that of any other period in the growing season. The correlation coefficient for July 21-August 10 is .0735; that for August 1-20, —.0406; and that for August 11-31, .0382. They are all very small and not significant.

Summarizing the effect of precipitation on corn yields the annual precipitation from October 1 through the succeeding September was significantly correlated with corn yields. No critical period for water requirement during the growing season for the 30-year period was indicated by the correlation coefficients. However, the data included in table 14 show definitely that corn yields were very materially lowered during certain years by deficient rainfall, particularly in July and August, and that excessive temperatures accompanying the moisture deficiency resulted in still lower yields.

Oats

Correlation coefficients between precipitation during different periods and oats yields from different systems of cropping are summarized in table 16. At University Farm, the oat crop is usually planted in April and harvested during the first half of August.

For each period, oat yields in different rotations gave somewhat similar correlation coefficients with precipitation. A considerable number of the correlation coefficients for the June 21-July 10 period and a lesser number for the June-July and July 1-20 period were significant and others approach the level of significance. The correlation coefficients between oat yields and growing season precipitation were higher than the annual ones. This may be due to several reasons. The growing season of oats is relatively short. The precipitation in this period is usually rather abundant. It is this precipitation that is used by oats. On the other hand, the growing season of corn is rather long. It is planted in May and harvested in the latter part of September. It silks during the dry period of the year. The precipitation in this period may be insufficient for satisfactory corn growth. It may need to draw water from a greater depth which was stored from the previous year. According to Weaver (28), roots of a mature oat plant are mostly in the first foot of soil. They attain a working depth of 2.3 feet. In case of the corn plant, the more deeply penetrating roots make a marked development, many extending to 6 or 7 feet deep.

The correlation coefficient between April-May precipitation and oat yield was only .0938. Oat plants are small during this first part of the growing season. They do not need a large amount of moisture for their growth. As the oat plants approached maturity, they used more and more water, and precipitation therefore became increasingly important. This tendency holds true for oats in all the cropping systems investigated. The correlation coefficient for the average yield of all cropping systems increased from .0938 for April-May to .2311 for May-June, and .3547 for June-July.

The time between June 1-August 10 was divided into 20-day

Table 16. Correlation Coefficients Between Oat Yields and Precipitation During Different Periods of the Year

Periods	Continuous cropping Manured	2-year rotation C-O Manured	2-year rotation W-O Manured	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average of manured 3-, 4-, and 5-year rotations	Average for all systems of cropping
Oct.-Sept.	.4114*	.1783	.4088*	.1686	.1658	.1461	.0723	.1460	.2187
April-July	.4539*	.3201	.4268*	.3588	.2977	.1221	.2036	.2456	.3292
Nov.-March	.1429	.0964	.0014	.0839	.1013	.2708	.2574	.1854	.1457
April-May	.2993	.1157	.2604	.0977	.0017	—.0659	.0339	.0034	.0938
May-June	.3212	.2610	.3160	.2674	.1535	.1124	.2131	.1681	.2311
June-July	.3607	.3143	.3576	.4086*	.3897*	.2277	.2513	.3378	.3547
June 1-20	—.1297	—.1085	.0179	—.1184	—.1468	—.2207	—.2240	—.1929	—.1530
June 11-30	.2178	.2033	.2334	.2443	.2605	.2407	.0745	.2211	.2598
June 21-July 10	.3519	.3549	.3381	.4951†	.5349†	.4191*	.3509	.4887†	.4739†
July 1-20	.3722	.3044	.3410	.3675*	.3843*	.1991	.2524	.3189	.3511
July 11-31	.3087	.1610	.2304	.1839	.1822	.0524	.1029	.1416	.1849
July 21-Aug. 10	.2206	.1240	.1716	—.0062	.0247	—.0444	—.1063	—.0237	.0445

* Significant, odds over 19:1.
† Highly significant, odds over 99:1.

periods. The correlation coefficients between June 1-20 precipitation and oat yields were all negative. High precipitation before flowering causes rank vegetative growth and abundant flowering. Unless ample water is available to take care of this lush growth and develop the grain, yields are low. Also heavy vegetative growth is apt to result in lodging with consequent reduction in grain yields if the lodging occurs early. Oat plants usually flower at the end of June to the early part of July. The correlation coefficients between the precipitation for June 20-July 10 and oat yields was highly significant. Apparently this was the critical period of water requirement for the oat crop. After this stage, the correlation coefficients dropped rapidly. The coefficients were .3511 for July 1-20; .1849, for July 11-31; and only .0445 for July 21-August 10.

Summarizing the effect of precipitation on oat yields, growing season precipitation was more closely related to yields than was the annual rainfall. Little relationship between precipitation and yield existed when the oat plants were young. As the crop developed, precipitation became an increasingly important factor until the flowering period, which apparently was the critical stage. After that stage, precipitation appeared to have little effect on yields.

Wheat

Correlation coefficients between wheat yields and precipitation during different periods of the year are summarized in table 17. During the 30-year period at University Farm, the wheat

Table 17. Correlation Coefficients Between Wheat Yields and Precipitation During Different Periods of the Year

Periods	Continuous cropping Manured	2-year rotation W-O Manured	4-year rotation W-H-C-O Manured	5-year rotation W-H-P-C-O Manured	Average of 4- and 5-year rotations	Average for all systems of cropping
October-September	.2434	.3230	.1518	.1610	.1612	.2226
April-July	.3837*	.4237*	.1667	.2139	.1962	.3178
November-March	.1552	.0191	.1550	.0769	.1204	.1754
April-May	.3715*	.3467	.2387	.1389	.1953	.2931
May-June	.3413	.2774	.1696	.2313	.2064	.3073
June-July	.1989	.2761	.0178	.1719	.0972	.1778
June 1-10	.0266	.1536	—.2065	—.0284	—.1223	—.0663
June 11-20	—.0572	—.1100	—.1601	—.1395	—.1682	—.1916
June 21-30	.1819	.1330	.2398	.2405	.2478	.2229
July 1-10	.1418	.2449	.2172	.1830	.2055	.1978
July 11-20	.2137	.3029	.0419	.0925	.0690	.1739
July 21-31	—.1170	—.0974	—.1555	—.1078	—.1358	—.1219

* Significant; odds over 19:1.

crop was usually planted about the middle of April. It produced heads during the latter part of June or the beginning of July. The crop was usually harvested during the latter part of July or the first part of August.

That correlation coefficients between precipitation for a certain period of time and wheat yields from different cropping systems did not deviate from each other greatly indicates that generally wheat in these cropping systems reacted similarly to precipitation.

All correlation coefficients for wheat are rather small. The precipitation during its growing season, April-July, inclusive, had a higher correlation with wheat yields than that of any other period. June and July were divided into ten-day periods, and the precipitation correlated with yields. No significant correlation was found. However, the coefficient for the heading stage, June 21-30, inclusive, is somewhat higher than those for any other ten-day period. Negative correlation coefficients were found between precipitation and wheat yields for the periods June 1-10, and June 11-20. This result is similar to that obtained for oats. It supports the interpretation that heavy precipitation before heading may result in too heavy vegetative growth and reduced yields. The negative correlation coefficients for the period July 21-31 indicated that lower precipitation shortly before the crop ripened had a favorable effect on wheat yields.

Hay

Correlation coefficients between precipitation for different periods and hay yields from various rotations are summarized in table 18.

Table 18. Correlation Coefficients Between Hay Yields and Precipitation During Different Periods of the Year

Periods	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average for all systems of cropping
October-September	.5984†	.6443†	.4112*	.4908†	.6007†
April-August	.5947†	.5977†	.3943*	.5085†	.5738†
November-March	.0710	.1129	.1283	.0599	.1097
April-May	.2978	.2907	.2524	.3571	.3222
May-June	.4270*	.3130	.4582*	.4946†	.4727†
June-July	.6406†	.6336†	.4377*	.4810†	.6996†
July-August	.3168	.3704*	.0752	.1983	.2822

* Significant; odds over 19:1.
† Highly significant; odds over 99:1.

The first crop of clover and timothy hay was cut during the first part of July and the second during the latter part of August. The annual hay crop, oats and peas, used instead of clover and timothy when stands of the latter were not obtained, was harvested during the latter part of July.

For any period of time, hay crops in different rotations gave similar correlation coefficients with precipitation. Both annual and growing season precipitation exhibited highly significant correlation with hay yields. Precipitation during the winter showed no significant correlation with hay production of the succeeding season. Precipitation early in the season was not closely related with hay yields. With one exception, correlation coefficients for both May-June and June-July precipitation with hay yields were important. The correlation coefficients between May-June and June-July rainfall and hay yields are both highly significant. The correlation coefficients for the period July-August are not significant.

Temperature and Yields

Accumulated physiological and remainder temperature indices for certain periods of the year were correlated with crop yields to find the relationship between them.

Corn

The coefficients between corn yields from different rotations and temperature are summarized in table 19.

For any one period the correlation coefficients between temperature and corn yields for the different systems of cropping were fairly similar. With one exception, Livingston's physiological temperature index for corn seedling growth gave slightly smaller correlation coefficients than the remainder index. This was not expected. The remainder index was used to compute correlations between corn yields and accumulative heat for all other periods.

All the correlation coefficients in table 19 are very small. The growing period of corn is rather long. Its growth extends through the drouth period of the year. A few days of abnormally high temperatures such as occur frequently during this period may injure the plant very materially. However, this abnormal temperature usually does not influence the average monthly temperature to any great extent. Temperature is such a complex

Table 19. Correlation Coefficients Between Corn Yields and Accumulative Temperature Indices for Different Periods of the Year

Period	Continuous cropping Manured	2-year rotation C-O Manured	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average of manured 3-, 4-, and 5-year rotations	Average for all systems of cropping
May-September, P.I.	.0297	.1238	.1463	.0188	—.0530	.0713	.0454	.0415
May-September, R.I.	.0988	.1715	.1943	.0818	.0117	.1413	.0818	.1046
June-September, R.I.	.0524	.1422	.1954	.0467	—.0479	.1065	.0393	.0727
May-June, R.I.	.0166	.0417	.0571	—.0015	.0373	.0422	.0207	.0041
June-July, R.I.	—.0484	.0031	.1053	—.0210	—.0634	—.0161	—.0345	—.0172
July-August, R.I.	.0828	.2188	.1784	.0965	—.0520	.1216	.0682	.1231
August-September, R.I.	.1770	.3076	.2321	.0909	—.0288	.2047	.0918	.1811

P.I.=Physiological indices.
R.I.=Remainder indices.

Table 20. Correlation Coefficients Between Oat Yields and Accumulative Temperature Indices for Different Periods of the Year

Period	Continuous cropping Manured	2-year rotation C-O Manured	2-year rotation W-O Manured	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average of manured 3-, 4-, and 5-year rotations	Average for all systems of cropping
April-August, P.I.	—.4197*	—.3880*	—.4320*	—.4395*	—.4734†	—.3882*	—.3344	—.4522*	—.4772†
April-August, R.I.	—.3558	—.3593	—.3795*	—.3761*	—.4146*	—.3926*	—.2974	—.4108*	—.4119*
April-July, R.I.	—.4170*	—.4677*	—.4351*	—.4763†	—.5176†	—.4927†	—.4324*	—.5173†	—.5211†
April-May, R.I.	—.2579	—.3075	—.2866	—.2598	—.2947	—.3538	—.2834	—.3217	—.3230
May-June, R.I.	—.4531*	—.5015†	—.5630†	—.5061†	—.5298†	—.4342*	—.4004*	—.5010†	—.5391†
June-July, R.I.	—.4561*	—.4558*	—.4580*	—.5133†	—.5438†	—.4675*	—.4405*	—.5289†	—.5369†

P.I.=Physiological indices. R.I.=Remainder indices.
* Significant; odds over 19:1.
† Highly significant; odds over 99:1.

factor affecting plant growth that Lundegardh made this observation: "The growth curves and respiration curves do not rise regularly with temperature, and the assimilation curve, in some instances, at any rate, has passed its optimum at 20° C. A variation of temperature of one degree, therefore, has very different effect over different parts of the temperature scale" (17).

Summarizing the results for corn: The correlation coefficients between corn yields and both precipitation and temperature are low, the only exception being October to September annual rainfall. While the correlation coefficients indicate that neither precipitation nor temperature during the growing season limited the growth and yields of corn over the 30-year period, examination of the yields and the monthly rainfall and mean temperature for certain years shows that weather during the growing season often materially affected yields of corn.

Oats

The correlation coefficients between oat yields and temperature indices are summarized in table 20. From the similarity of correlation coefficients for each period of time, it appears that generally oats in different rotations reacted similarly to temperature.

All correlation coefficients, including those between the average yields and temperature indices, are negative. Using the average yields, the coefficients for the periods April-July and April-August are all significant. The correlation for the period April-August is somewhat lower, but not significantly so, than that for the period April-July. This is expected since the oat crop usually matured during the latter part of July or early August. Therefore August temperature does not have much opportunity to affect oat yields. The correlation coefficients for the early part of oat growth—April to May—failed to show any significance. For the latter part of the growth period of oats, the correlation coefficients became highly significant. That between oat yields and accumulative temperature indices of May and June was —.5391, while that for the months June and July was —.5369. High temperature became increasingly unfavorable to the oat crop as it approached maturity.

Temperature was a limiting factor for oat production in these cropping systems. It was especially important during the latter part of its growing season. Negative correlation coefficients indicated that the higher the temperature, the lower the oat yield.

The combined studies on precipitation and temperature show that oats yielded highest during cool and moist seasons. Due to the fact that temperature correlation coefficients are in general higher than precipitation coefficients, cool weather appeared to be more important than high precipitation for oats.

Wheat

Correlation coefficients between wheat yields and accumulative temperature indices during different periods of the year are presented in table 21.

Table 21. Correlation Coefficients Between Wheat Yields and Accumulative Temperature Indices for Different Periods of the Year

Period	Continuous cropping Manured	2-year rotation W-O Manured	4-year rotation W-H-C-O Manured	5-year rotation W-H-P-C-O Manured	Average of 4- and 5-year rotations	Average for all systems of cropping
April-July, P.I.	—.4604*	—.3853*	—.5213†	—.5059†	—.5302†	—.5538†
April-July, R.I.	—.4544*	—.2481	—.5320†	—.4791†	—.5214†	—.5175†
April-May, R.I.	—.4131*	—.1310	—.4776†	—.3136	—.3875*	—.3613
May-June, R.I.	—.5212†	—.4349*	—.5627†	—.5159†	—.5570†	—.5660†
June-July, R.I.	—.3601	—.2895	—.4405*	—.4455*	—.4573*	—.4745†

P.I.=Physiological indices. R.I.=Remainder indices.
* Significant; odds over 19:1.
† Highly significant; odds 99:1.

With a few exceptions, these correlation coefficients for any period are fairly uniform, indicating that generally wheat in the different rotations reacted similarly toward temperature. All correlations are negative. Those for the entire period and from May on, with two exceptions, are either significant or highly significant. Apparently high temperatures were unfavorable to wheat yields.

These correlation studies indicate that wheat was similar to oats in its climatic requirements.

Hay

Correlation coefficients between hay yields and accumulative temperature indices for different periods of the year are summarized in table 22.

Since correlation coefficients between hay yields and temperature in each period of time are somewhat similar, hay crops in these systems of cropping appeared to react similarly toward temperature. Like those for oats and wheat, all correlation coefficients are negative. However, they are not as high as those for wheat and oats. The correlations for the entire growing sea-

Table 22. Correlation Coefficients Between Hay Yields and Accumulative Temperature Indices in Different Periods of the Year

Period	3-year rotation C-O-H Untreated	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average for all systems of cropping
April-August, P.I.	—.2926	—.3949	—.2853	—.3212	—.3511
April-August, R.I.	—.2563	—.3397	—.2750	—.2615	—.3206
April-May, R.I.	—.1707	—.2343	—.2240	—.0889	—.2055
May-June, R.I.	—.2716	—.3573	—.3380	—.3573	—.3642*
June-July, R.I.	—.3130	—.4001*	—.3653*	—.3683*	—.4029*

P.I.=Physiological indices. R.I.=Remainder indices.
* Significant; odds over 19:1.

son and for the early part of the season are not quite as high as those for the latter part—June and July. The average correlation coefficient for the periods May-June and June-July are statistically significant. It is during this period the hay crops make their greatest development. High temperatures during all periods were unfavorable to hay production and during the May-July period reduced hay yields significantly.

Summarizing the results for hay: From the correlation coefficients between hay yields and both precipitation and temperature, it appears that hay produces the highest yields when the weather is cool and moist during its growing period. However, contrary to the results for oats, the precipitation, as indicated by higher correlation coefficients, appeared to be more important to hay crops than temperature.

INTERRELATIONSHIP BETWEEN THE EFFECT OF PRECIPITATION AND TEMPERATURE ON CROP YIELDS

When one or both climatic factors had a significant correlation coefficient with the crop yields, partial and multiple correlations between crop yields and climatic factors were computed. They are summarized in table 23.

Partial correlations between corn yields and annual precipitation with temperature for its growing season held constant is larger than that between corn yields and temperature. The indications are that precipitation might have had a closer relationship with corn yields than temperature. The multiple correlation between corn yields and these two climatic factors was highly significant. They influenced corn yields to the extent of about 35 per cent ($.5792^2$ x 100).

For both the growing season and the flowering time of oats

Table 23. Partial and Multiple Correlations Between Precipitation and Temperature and Crop Yields

Items correlated			$r_{yp.t}$	$r_{yt.p}$	$r_{y.pt}$
Corn	October-September	precipitation and			
	May-September	temperature	.5727†	.3944*	.5792†
Oats	April-July	precipitation and	.1744	—.4559*	.5419*
	June-July	temperature	.0764	—.4431*	.5409*
Wheat	April-July	precipitation and	.1615	—.4547*	.5353*
	June-July	temperature	.1081	—.4573*	.4838*
Hay	April-August	precipitation and	.5047†	—.0552	.5755†
	June-July	temperature	.5085†	—.1079	.6155†

y=yield, p=precipitation, t=temperature.
* Significant. † Highly significant.

and wheat, partial correlations of oat yields with temperature, holding precipitation constant, were significant. Those with precipitation, holding temperature constant, were both nonsignificant. The indications are that temperature influenced wheat and oat yields somewhat more than precipitation. The multiple correlation coefficients were significant.

For both the growing season and the flowering period, the partial correlations of yields of hay with precipitation, holding temperature constant, were highly significant. Contrary, the partial correlations of hay yields with temperature, holding precipitation constant, were both nonsignificant. As indicated by the partial correlation coefficients, precipitation was a somewhat more important factor affecting hay yields than temperature. Both multiple correlations for hay were highly significant. Precipitation and temperature were responsible for about 33 and 38 per cent of the hay yields, respectively.

Summary and Conclusions

1. Yields of crops grown continuously and in rotations over a period of 30 years were compared. Also the influence of rainfall and temperature on the crop yields in these cropping systems was studied.

2. Yields of corn in rotations including clover-timothy hay crops were significantly higher, with few exceptions, than those of cropping systems which did not contain mixed hay crops. The average corn yield from the corn-oat rotation was 3.55 bushels higher than the average yield from the corn continuous system. This difference approaches the significant level. Yields of corn from the three-, four-, and five-year rotations all containing mixed hay crops and receiving applications of manure were not significantly different. Application of manure in addition to rotations further increased yields significantly. The effects of rotation and application of manure were additive.

3. Oat yields were significantly lower in the manured continuous cropping and the two-year wheat-oats rotation than in all other rotations studied. Alternating a cultivated crop with oats increased oat yields significantly. Inclusion of mixed hay crops in rotations receiving manure, however, did not raise oat yields materially. Application of manure in the three-year rotation brought about an increase in yield of 3.69 bushels. This difference approaches the level of significance. The effects of rotation and application of manure on oat yields were not additive.

4. Wheat yields in the three-, four-, and five-year rotations were significantly higher than those for continuous cropping and the wheat-oats rotation.

5. Yields of hay in the rotations were increased by application of manure.

6. Average total digestible nutrients produced per acre by the systems of cropping containing corn or both corn and hay were significantly higher than those produced by grains only, either grown continuously or alternately with each other.

7. Crop yields from the three-, four-, and five-year rotations, all manured, were, in general, not significantly different.

8. Yield differences of crops in these cropping systems were brought about largely in the first ten years or less of operation. After this period, the average yield differences from different cropping systems did not change materially.

9. Deficient rainfall in April resulted in reduced hay yields. If the rainfall deficiency extended over both April and May, hay yields were further reduced and oat yields were lowered also. Deficient rainfall in July or in July and August limited corn yields, and, if temperatures during July and August were also unusually high, there was further reduction in yield. Subnormal temperatures during the entire or major part of the growing season for corn resulted in low yields.

10. Correlation coefficients indicated that on the average the corn, oats, wheat, and hay crops reacted similarly to precipitation and temperature under the different systems of cropping during any given period of time.

11. Average corn yields from all the systems of cropping showed a significantly positive correlation with the annual precipitation ending September 30. No significant correlation coefficient was found between corn yields and precipitation of any other period of the year, or accumulated heat units of any period during its growing season.

12. Oat yields showed a higher correlation coefficient with precipitation for the growing season than with annual rainfall. Neither of these coefficients, however, was significant. The positive correlation coefficient between oat yields and precipitation for the flowering period, June 21-July 10, was highly significant. Apparently this was the critical period of water requirement for the oat crop. Higher temperatures resulted in lower oat yields. The correlation coefficient between temperature during the latter part of the oat-growing season and yield was highly significant. It appears that temperature had more effect on oat yields than precipitation.

13. The reaction of wheat was, in general, similar to that of oats. However, no significant correlation between yield and precipitation in the flowering period was found.

14. Hay yields showed highly significant correlation coefficients with annual precipitation and the rainfall from May to July. All correlation coefficients between hay yields and accumulative heat units at any period of time are negative. That for June to July, the flowering period for the hay crop, is significant. Precipitation appeared to have a greater effect on hay yields than temperature.

15. For oats, wheat, and hay, precipitation and temperature became increasingly important to crop yields as the plants approached the flowering period.

Bibliography

1. Anon. Changes in soil organic matter and nitrogen under long continued cropping. Ohio Agr. Expt. Sta., Bul. 402:20-21. 1927.
2. Arny, A. C. Crop rotation investigations. Field T experiments. Minn. Agr. Expt. Sta., Bul. 170:1-55. 1917.
3. Bear, B. F. Theory and practice in the use of fertilizers, Ed. 2, 360 pp. John Wiley & Sons, Inc., New York. 1938.
4. Cato, M. P., and Varro, M. T. Roman farm management. 365 pp. Macmillan Co., New York. 1913.
5. Chia, S. Y. "Tze Min Yao Szo" (Techniques of Agricultural Production). Commercial Press, Limited, China.
6. Chilcott, R. C. The relations between crop yields and precipitation in the Great Plains Area. U. S. Dept. Agr., Misc. Cir. 81:1-94. 1927.
7. Cole, J. S. Correlation between annual precipitation and the yields of spring wheat in the Great Plains. U. S. Dept. Agr., Tech. Bul. 636:1-39. 1938.
8. Davis, F. E., and Pallesen, J. E. Effect of the amount and distribution of rainfall and evaporation during the growing season on yields of corn and spring wheat. Jour. Agr. Res. **60:**1-23. 1940.
9. Fisher, R. A. Statistical methods for research workers. Ed. 7, 336 pp. Oliver and Boyd, Edinburgh and London. 1938.
10. Hall, A. D. The book of Rothamsted experiments. 332 pp. John Murray & Co., London. 1919.
11. Hays, O. E. Soil and water conservation investigations. Soil Conservation Service, Mimeograph ESR-1:1-57. 1937.
12. Hays, W. M., Boss, Andrew, and Wilson, A. D. The rotation of crops: Report of 10 years on 44 rotation plots. Minn. Agr. Expt. Sta., Bul. 109. Pt. I:281-327. 1908.
13. Hodges, J. A. The effect of rainfall and temperature on corn yields in Kansas. Jour. Farm Econ. **13:**305-318. 1931.
14. Hopkins, C. G., Readhimer, J. E., and Eckhardt, William G. Thirty years of crop rotations on the common prairie soil of Illinois. Ill. Agr. Expt. Sta., Bul. 125:323-356. 1908.
15. Livingston, B. E. Physiological temperature indices for the study of plant growth in relation to climatic conditions. Physiol. Res. **1:**399-420. 1916.
16. ———— and Shreve, F. The distribution of vegetation in United States as related to climatic conditions. 590 pp. Carnegie Institute of Washington, Washington, D. C. 1921.
17. Lundegardh, H. Environment and plant development. 330 pp. Edward Arnold Co., London. 1931.
18. Miller, M. F., and Krusekopf, H. H. The influence of systems of cropping and methods of culture on surface runoff and soil erosion. Mo. Res. Bul. **177:**1-32. 1932.

19. MILLER, M. F., AND HUDELSON, R. R. Thirty years of field experiments with crop rotation, manure and fertilizers. Mo. Agr. Expt. Sta., Bul. 182:1-43. 1921.

20. ROSE, J. K. Corn yield and climate in the corn belt. Geog. Rev. **26**:88-102. 1936.

21. RUSSELL, E. J. Soil conditions and plant growth. Ed. 6, 636 pp. Logmans, Green & Co., London. 1932.

22. SMITH, J. W. Relation of precipitation to yield of corn. U. S. Dept. Agr. Yearbook 1903:215-224.

23. ——— The effect of weather upon yield of corn. Monthly Weather Rev. **42**:78-93. 1914.

24. ——— Agricultural meteorology. 304 pp. Macmillan & Co., New York. 1920.

25. SMITH, W. G., AND KIRK, H. M. Soil survey of Ramsey County, Minn. Bureau of Soils, U. S. Dept. Agr. Advance Sheets—Field Operations. 37 pp. 1916.

26. SNYDER, HARRY. Influence of rotation of crops and continuous cultivation upon the composition and fertility of soils. Minn. Agr. Expt. Sta., Bul. 109. Pt. II:328-358. 1908.

27. WALLACE, H. A. Mathematical inquiry into the effect of weather on corn yield in the eight Corn Belt states. Monthly Weather Rev. **48**:439-446. 1920.

28. WEAVER, J. W. Root development of field crops. 291 pp. McGraw-Hill Co., New York. 1926.

Appendix

Table I. Yields of Corn in Bushels Per Acre from Continuous Cropping and Five Different Rotations Over a 30-year Period, 1910-1939, at University Farm, St. Paul

Year	Continuous cropping Manured	2-year rotation C-O Manured	3-year rotation C-O-H No manure	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average
1910	33.3	38.9	40.2	36.1	31.9	34.7	35.9
1911	47.5	41.7	54.9	64.6	61.1	52.1	53.7
1912	38.9	47.6	35.0	39.9	45.8	44.7	42.0
1913	52.8	50.4	55.0	61.7	57.5	57.4	55.8
1914	43.3	49.6	51.7	61.2	57.8	61.9	54.3
1915	7.2	7.2	11.3	29.7	30.7	32.5	19.8
1916	43.1	41.1	43.0	49.4	51.0	53.6	46.9
1917	20.8	12.5	22.0	29.0	33.3	29.7	24.6
1918	47.4	56.1	36.3	52.6	72.7	62.8	54.7
1919	69.6	68.0	65.5	82.3	92.0	83.6	76.8
1920	53.7	52.9	32.1	51.6	54.6	60.5	50.9
1921	26.6	25.3	27.5	52.0	50.5	50.1	38.7
1922	49.2	60.7	46.4	49.0	57.6	66.7	54.9
1923	43.8	25.7	49.5	51.8	55.7	62.0	48.1
1924	26.2	25.2	26.7	33.4	35.7	35.6	30.5
1925	25.9	28.7	36.2	44.1	38.8	54.0	38.0
1926	35.6	33.5	19.6	39.8	34.7	32.1	32.6
1927	33.9	35.1	34.2	38.9	63.0	51.1	42.7
1928	34.7	41.2	31.3	42.7	42.4	37.8	38.4
1929	32.7	47.5	43.0	51.9	54.0	51.1	46.7
1930	18.8	22.2	14.8	19.4	36.2	33.1	24.1
1931	13.0	15.6	18.6	13.8	15.5	11.1	14.6
1932	21.1	47.0	23.9	30.7	35.3	40.5	33.1
1933	49.1	55.8	52.2	53.6	54.1	55.2	53.3
1934	5.1	12.9	10.7	17.6	29.7	29.4	17.6
1935	51.6	62.9	48.1	65.1	60.7	65.5	59.0
1936	45.1	55.4	54.9	56.6	46.1	56.3	52.4
1937	23.6	24.5	30.5	36.6	33.7	42.2	31.9
1938	47.6	69.2	43.8	64.5	53.5	70.5	58.2
1939	58.3	51.8	49.1	65.3	71.8	72.5	61.5
Average	36.7	40.2	36.9	46.2	48.6	49.7	43.0

C=corn, O=oats, H=hay, W=wheat, and P=pasture.

Table II. Yields of Oats in Bushels Per Acre from Continuous Cropping and Six Different Rotations Over a 30-year Period, 1910-1939, at University Farm, St. Paul

Year	Continuous cropping Manured	2-year rotation C-O Manured	2-year rotation W-O Manured	3-year rotation C-O-H No manure	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average
1910	36.6	43.1	40.3	52.8	50.2	53.8	52.8	47.1
1911	50.3	39.1	48.8	52.5	47.2	46.3	47.2	47.3
1912	56.9	35.0	59.4	43.6	58.3	74.7	65.3	56.2
1913	53.4	94.1	61.1	85.8	91.4	65.0	77.2	75.4
1914	35.9	63.1	45.9	54.1	54.1	56.3	40.0	49.9
1915	61.9	90.0	64.7	92.2	91.8	69.6	75.3	77.9
1916	57.6	75.9	62.5	65.9	72.4	72.8	63.1	67.2
1917	57.8	87.2	64.7	86.9	98.5	85.6	103.4	83.4
1918	68.2	96.3	69.4	93.8	92.8	95.0	98.4	87.7
1919	44.1	53.1	50.0	54.4	57.6	57.4	54.7	53.0
1920	53.4	56.1	44.6	64.0	68.9	94.6	85.0	66.7
1921	36.7	42.5	44.5	34.5	31.6	35.6	33.7	37.0
1922	49.9	77.5	42.0	72.3	62.5	79.6	97.1	68.7
1923	39.6	68.4	27.7	68.8	85.1	67.2	57.5	59.2
1924	36.2	53.8	46.4	49.7	50.0	57.5	43.8	48.2
1925	37.4	57.6	47.5	77.5	86.9	51.9	71.6	61.5
1926	43.9	37.2	29.4	44.4	47.4	49.1	32.5	40.6
1927	37.7	50.3	48.1	58.1	62.6	52.8	53.4	51.9
1928	62.2	91.3	63.4	68.8	98.1	90.9	78.1	79.0
1929	72.2	101.6	81.0	101.6	111.0	111.6	92.2	95.9
1930	57.2	82.5	68.1	98.1	108.5	101.5	109.7	89.4
1931	46.0	63.4	53.3	33.3	37.4	62.8	56.7	50.4
1932	43.5	49.9	33.6	71.2	79.3	83.9	68.6	61.4
1933	51.5	57.7	45.0	55.7	46.0	45.2	55.2	50.9
1934	10.8	14.8	11.0	20.6	19.1	23.4	15.9	16.5
1935	70.4	73.5	77.0	78.7	77.0	65.6	76.5	74.1
1936	20.8	35.5	30.7	28.8	34.3	56.4	51.5	36.9
1937	41.5	58.2	42.8	54.6	53.1	52.5	52.6	50.8
1938	44.2	52.9	43.2	52.6	45.9	46.4	45.6	47.3
1939	75.0	81.2	78.9	72.0	79.1	65.4	82.3	76.3
Average	48.4	62.8	50.8	62.9	63.33	65.7	64.6	

C=corn, O=oats, H=hay, W=wheat, and P=pasture.

Table III. Yields of Wheat in Bushels Per Acre from Continuous Cropping and Four Different Rotations Over a 30-year Period, 1910-1939, at University Farm, St. Paul

Year	Continuous Cropping	2-year W-O	3-year C-W-H	4-year C-O-W-H	5-year C-O-W-H-P	Average
1910	15.5	19.3	27.2	26.7	23.5	22.5
1911	13.5	19.3	19.5	17.5	18.9	17.7
1912	11.7	20.0	23.4	22.1	20.3	19.5
1913	22.0	23.8	31.1	30.6	24.9	26.5
1914	13.0	18.3	24.8	23.7	23.0	20.6
1915	24.2	25.2	30.7	28.5	33.9	28.5
1916	20.3	23.2	28.0	28.3	22.7	24.5
1917	23.7	24.7	34.5	35.0	32.5	30.1
1918	27.3	28.8	34.3	32.5	31.3	27.2
1919	19.3	19.0	28.0	20.2	23.5	22.0
1920	20.5	19.9	21.1	28.7	21.9	22.4
1921	11.5	24.5	16.3	13.0	16.6	16.4
1922	13.1	6.2	29.6	18.0	24.9	18.4
1923	7.9	14.1	22.8	16.2	17.3	15.7
1924	22.4	12.2	17.5	22.8	24.8	19.9
1925	21.0	24.8	31.5	25.8	20.2	24.7
1926	4.2	9.1	21.1	14.8	14.9	12.8
1927	18.4	17.8	18.8	20.2	24.0	19.8
1928	20.5	25.0	32.2	36.0	30.0	28.7
1929	12.4	13.8	39.8	44.3	44.3	30.9
1930	25.0	28.1	50.0	36.7	46.3	37.2
1931	17.7	18.9	18.1	15.8	16.9	17.5
1932	18.5	15.8	28.7	24.8	24.9	22.7
1933	22.5	19.9	24.9	28.9	26.3	24.5
1934	6.0	4.7	3.8	3.3	5.3	4.6
1935	20.5	20.3	24.5	21.2	16.8	20.7
1936	9.5	11.0	17.8	21.5	14.6	14.9
1937	18.3	14.8	20.8	36.7	29.0	23.9
1938	21.6	22.8	19.2	24.6	24.5	22.5
1939	7.9	6.9	16.1	13.3	17.4	12.3
Average	17.0	18.4	25.2	24.4	23.6	

C=corn, O=oats, H=hay, W=wheat, and P=pasture.

Table IV. Yields of Hay in Tons Per Acre from Four Different Rotations Over a 30-year Period, 1910-1939, at University Farm, St. Paul

Year	3-year rotation C-O-H No manure	3-year rotation C-O-H Manured	4-year rotation C-O-W-H Manured	5-year rotation C-O-W-H-P Manured	Average
1910	1.00	1.03	1.12	1.40	1.1
1911	2.85	2.90	2.75	3.14	2.9
1912	2.14	2.08	1.45	1.40	1.8
1913	2.74	3.05	2.25	3.26	2.8
1914	3.52	3.89	4.30	3.61	3.8
1915	2.99	3.15	2.41	3.71	3.1
1916	1.96	2.45	3.28	3.69	2.9
1917	1.86	2.62	4.90	2.93	3.1
1918	1.28	1.38	2.33	2.53	1.9
1919	3.44	3.75	3.51	2.11	3.2
1920	3.65	3.53	3.40	3.77	3.6
1921	1.44	1.56	2.47	2.11	1.9
1922	1.63	1.87	3.04	1.62	2.0
1923	1.47	1.37	1.68	1.68	1.6
1924	1.12	1.19	.85	.93	1.0
1925	2.73	2.80	3.74	2.94	3.1
1926	1.43	1.94	2.39	2.02	2.0
1927	1.67	1.96	2.97	1.37	2.0
1928	1.69	2.81	3.04	3.36	2.7
1929	1.99	2.28	3.05	2.25	2.4
1930	.75	1.00	1.93	1.88	1.4
1931	1.46	1.48	1.39	2.01	1.6
1932	1.02	1.14	1.28	1.20	1.2
1933	1.50	1.53	1.43	1.81	1.6
1934	.73	.78	1.17	.88	.9
1935	3.24	3.71	3.91	3.45	3.6
1936	1.34	1.38	1.67	1.43	1.5
1937	1.98	1.78	2.82	2.24	2.2
1938	2.10	2.44	2.42	2.50	2.4
1939	2.30	2.51	3.27	2.45	2.6
Average	1.97	2.2	2.5	2.3	

C=corn, O=oats, H=hay, W=wheat, and P=pasture.

Table V. Annual and Monthly Precipitation in Inches During the Growing Season, 1910-1939, Minneapolis, Minnesota

Year	April	May	June	July	Aug.	Sept.	Oct.	Oct.-Sept. precipitation	Annual precipitation
1910	.64	1.39	1.24	.74	1.56	2.58	.86	17.00	11.59
1911	2.55	4.10	6.93	4.62	3.65	5.83	6.42	32.29	40.15
1912	2.22	4.68	.94	7.08	5.56	1.59	1.23	32.66	26.28
1913	1.86	2.86	2.21	7.75	1.40	4.12	2.55	26.27	26.09
1914	3.69	1.80	8.63	1.17	8.70	2.76	1.58	32.09	31.15
1915	1.87	3.98	4.91	5.92	3.49	2.57	2.59	29.19	33.72
1916	3.07	6.97	4.54	1.27	1.66	2.42	1.60	30.99	27.48
1917	1.70	4.24	3.77	4.06	2.83	2.16	1.70	26.66	25.67
1918	.91	4.32	2.82	5.07	3.73	1.25	2.31	23.08	28.04
1919	3.44	1.71	4.04	6.19	1.88	1.47	1.69	29.15	27.12
1920	2.23	2.67	8.43	1.30	1.14	1.95	2.79	27.83	27.38
1921	2.04	3.49	3.81	3.16	2.03	3.85	.37	26.19	23.75
1922	1.35	2.94	5.63	1.67	1.66	2.16	1.21	23.35	26.07
1923	1.99	2.97	5.04	3.12	1.98	1.61	1.19	24.23	21.35
1924	3.38	1.03	7.35	1.22	7.35	3.43	.76	28.21	28.40
1925	1.21	2.66	4.76	4.03	.20	3.35	.58	19.76	19.41
1926	.58	1.13	3.76	3.49	3.72	5.18	1.61	22.61	25.63
1927	2.48	3.22	6.77	1.86	2.11	4.32	2.30	28.99	30.19
1928	2.33	2.38	2.59	3.68	5.84	2.17	3.17	27.87	25.71
1929	1.62	1.91	4.21	3.33	2.15	3.57	2.17	24.70	23.64
1930	.62	3.38	6.68	.92	.72	4.14	1.14	23.44	24.16
1931	1.20	1.35	4.78	1.12	2.97	2.42	1.87	19.77	22.03
1932	2.15	2.05	1.56	4.36	3.87	.85	.89	24.57	23.39
1933	1.43	7.87	1.31	2.16	1.09	3.44	1.26	25.20	23.05
1934	1.57	.21	2.30	1.40	1.61	4.86	5.64	16.02	22.73
1935	2.32	3.81	4.82	2.59	3.02	1.98	3.95	31.07	27.50
1936	1.48	2.25	2.29	.11	3.48	.78	.66	21.05	18.47
1937	2.62	5.42	3.11	.48	4.10	1.67	1.36	23.29	22.59
1938	3.27	6.97	2.96	3.36	3.45	3.24	.84	29.25	29.75
1939	2.19	3.55	4.95	2.75	3.65	2.31	1.56	24.85	24.50
Average	2.00	3.24	4.24	3.00	3.02	2.80	1.93	25.72	25.57