APPROVAL FOR CONSTRUCTION

Following this approval for planning, the State Conservationist arranges to provide planning assistance to the local organization. The planning assistance takes the form of a work plan described in the *Interim Watershed Protection Handbook* as follows: "The watershed work plan will describe the watershed and its problems and set forth clearly and concisely a plan, a schedule of operations, the estimated cost, proposed cost-sharing arrangements and other responsibilities of those participating in the project, and economic justification for installing, operating, and maintaining those measures needed for protection and improvement of that watershed."

Preparation of the work plan is fundamentally a joint responsibility of the local sponsoring organization and the United States Department of Agriculture. In practice, the State Conservationist selects and sends out a watershed work-plan party, and in cooperation with the local organization, determines possible solutions. The local organization is then free to accept any approved combination of the alternatives. It may accept part of a plan and reject the rest of the parts that are not interdependent.

When a tentative agreement has been reached between the work-plan technical party and the local agency, the State Conservationist is responsible for review. When the plan is mutually acceptable to the Conservationist and the local organization, it is forwarded to the Administrator. Upon his approval it is sent back to the State Conservationist for final negotiation. At this time, the Conservationist obtains a firm commitment from the local sponsor. This commitment relates to both the nature of the program and its financial arrangements.

The proposal is then sent to the Administrator for final review by all concerned federal agencies and final approval by the Secretary of Agriculture. The Secretary's policy provides that there shall be the fullest possible cooperation with other federal agencies concerned with land and water management. Customary procedure of the Federal Inter-Agency Committee on Water Resources will be followed in notifying appropriate field representatives of concerned federal agencies when an investigation is to be initiated.

Whenever the estimated federal contribution to the construction cost of works of improvement shall exceed $250,000 or the works of improvement include any structure having a total capacity in excess of 2,500 acre-feet, the Secretary transmits a copy of the plan and the justification therefor to the Congress through the President.

The amended Act provides that any such plan "(a) which includes reclamation or irrigation works or which affects public or other lands or wildlife under the jurisdiction of the Secretary of the Interior, or (b) which includes federal assistance for floodwater detention structures, shall be submitted to the Secretary of the Interior or . . . Army, respectively, . . . at least 30 days prior to transmission of the plan to the Congress through the President."

Under the law, no appropriation shall be made for any such plan unless it has been approved by resolutions adopted by the appropriate committees of the Senate and House of Representatives. If there is no single structure larger than 4,000 acre-feet, the appropriate committees are the Committee on Agriculture and Forestry of the Senate and the Committee on Agriculture of the House. If there is a single structure larger than 4,000 acre-feet the law specifies that the appropriate committees shall be the Committees on Public Works of the Senate and House of Representatives.

The Administrator of the Farmers Home Administration is responsible for carrying out the loan provisions of the amended federal act, but the procedures to be followed had not been announced at the time this bulletin was completed.

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SOIL MANAGEMENT STUDIES on the *Webster Soils* OF SOUTHERN MINNESOTA

C. O. ROST
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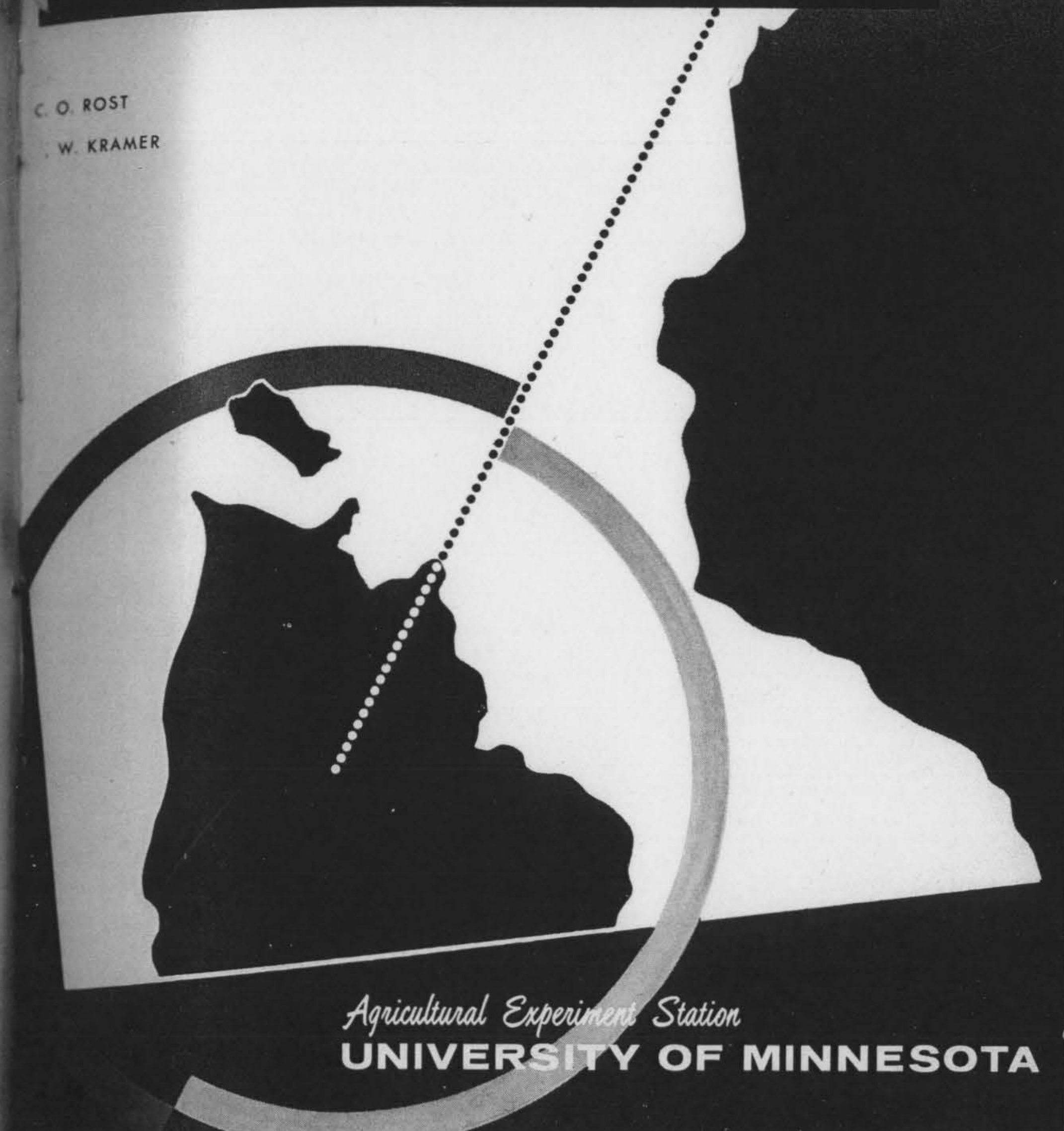

Agricultural Experiment Station
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Soil Management Studies on the Webster Soils of Southern Minnesota

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"WHAT COMBINATIONS OF SOIL MANAGEMENT PRACTICES PRODUCE THE BEST RESULTS ON WEBSTER SOILS?"

With large acreages of Webster soils in southern Minnesota, the question is important. In fact, nearly 10 percent of Minnesota's land area of 51.2 million acres is in the Webster soil series (2.2 million acres) or the closely related Nicollet series (2.7 million acres). Both soils are very productive; tend to be fairly level, with erosion usually not a problem; and can be cropped and managed in much the same manner.

To help answer the question, the University of Minnesota established the Nicollet Soils Experimental Field in 1948. Located on the Sidney Johnson farm on an area of typical Webster clay loam, northwest of St. Peter in Nicollet County, the field was the site of 6 years of experimentation from 1949 through 1954. Purpose of the experiments was to test the effectiveness of specific soil management practices on crop yields—such as different cropping systems, the effect of barnyard manure, and the effect of different kinds and amounts of commercial fertilizer. This is a report of the results.

In addition to the obvious factors of existing conditions of the soil and weather over 6 years, the problem had three general aspects.

1. **Cropping systems** have a varying impact upon a soil. Such properties as the organic matter content, soil tilth, soil aeration, infiltration of water, internal drainage, and moisture relationships are affected differently by the particular crops in the rotation. Likewise, the different tillage operations for seedbed preparation and cultivation required by each crop may affect soil tilth, aeration, water infiltration, and internal drainage.

Including legumes or legume-grass mixtures in the rotation can also have a beneficial influence on soil properties. In addition, the legumes fix atmospheric nitrogen to make it available to other crops through the action of soil microorganisms.

2. **Commercial fertilizers** can supply plant nutrients when they are lacking—primarily nitrogen, phosphorus, and potash, alone or in combination. But except as they stimulate crop growth—which in turn may benefit the soil—commercial fertilizers produce no effect on soil properties comparable to that

[1] Special acknowledgment is due to Sidney Johnson, on whose farm the experimental plots were located and who also prepared the seedbeds and planted and cared for the crops; to Fred Wetherill, Nicollet County agricultural agent, who helped in the project; and to Paul Burson, professor of Soils, University of Minnesota, for helpful suggestions in planning the experiments.

of a sound cropping system. Mere addition of commercial fertilizer is not a substitute for good soil management.

3. **Barnyard manure** can, on the other hand, improve such soil properties as the organic matter supply, tilth, water infiltration, and aeration. Manure also supplies some plant nutrients.

The experiments covered all of these aspects, always taking into consideration the existing conditions of the soil.

Soil Tests

Existing levels of plant nutrients on the area were determined by soil testing. Tests on samples of the surface soil (0-6 inches) from 28 control or "check" plots at the Nicollet Experimental Field showed the available phosphorus to be low to very low.[2] The amounts ranged from 5 to 17 pounds per acre, with the average being 10 pounds. Available phosphorus in the subsurface layer (7-12 inches) varied between 2 and 18 pounds per acre, with an average of 7 pounds.

The soil tested medium in exchangeable potassium—between 110 and 315 pounds per acre in the surface 6 inches, with an average of 163 pounds. In the second 6-inch layer, the potassium varied from 90 to 220 pounds, the average being 156 pounds per acre.

Weather Conditions

Weather conditions obviously could not be controlled. Those were somewhat variable during the growing season of the 6 years, 1949-54, of experimentation.[3]

The first year, 1949, saw drought conditions. Precipitation was below normal and below average in every month of the growing season (table 1). Temperatures from May to August averaged 5.4 degrees above normal. Crop yields were noticeably affected, and there was little effect from any treatment tried.

In 1950, precipitation was again below normal. The growing season showed 5 inches below average. However, temperatures were also slightly below normal. This tended to reduce the effects of the moisture shortage because of reduced evaporation.

For the next four seasons, conditions were more favorable to crop growth. The season of 1951 was wet and cool, with precipitation above normal by 8.6 inches and temperatures about 2 degrees below the average. Except for the precipitation in 1953 being 7.16 inches above normal, conditions were near normal and generally favorable for 1952, 1953, and 1954.

[2] According to the method of Bray and Kurtz. (See Bray, R. H. and Kurtz, L. T., "Determination of total, organic, and available phosphorus in soils," *Soil Science*, 59:39 (1945).)

[3] Data for the St. Peter area, taken from the U. S. Weather Bureau, Climatological Data—Minnesota.

Table 1. Variation from normal of precipitation in inches and temperature in degrees during the growing season in the 6 years, 1949-54.

Year	April	May	June	July	August	September	Total
				Precipitation			
1949	−0.13	−1.39	−0.60	−2.10	−1.11	−1.15	−6.48
1950	−0.02	+0.34	−3.49	+0.83	−1.19	−1.47	−5.00
1951	+0.16	+0.07	+3.04	+0.75	+4.12	+0.47	+8.61
1952	−1.29	−1.78	+1.49	+0.35	+1.61	−2.91	−2.53
1953	+1.23	+2.49	+3.55	+1.81	+0.95	−2.87	+7.16
1954	−0.06	+1.01	+1.40	−0.93	−1.13	−0.19	+0.10
				Temperature			
1949	+2.0	+5.5	+6.3	+5.0	+4.8	−3.4	
1950	−6.9	−0.8	+1.5	−2.0	−1.9	0.0	
1951	−5.2	+3.8	−4.0	−1.6	−1.9	−4.4	
1952	+2.8	−0.4	+3.2	+1.1	−0.9	+1.2	
1953	−5.4	+0.6	+3.4	+0.2	+1.6	+0.4	
1954	+2.4	−5.1	+3.7	+1.9	−0.7	−0.1	

Cropping Systems Tested

Three cropping systems were used in the experiments: (1) corn-oats, (2) corn-oats with sweet clover as a green manure crop, and (3) a 4-year rotation of oats, hay, corn, and corn.

In the corn-oats rotation these two crops were grown in alternate years. Where sweetclover was seeded in oats, it was plowed down as a green manure crop in the fall of the same year. Four series of plots were used for these systems of cropping, two in oats and two in corn. Thus each crop appeared each year. No manure was used in the 2-year rotations, but nutrients (N, P, K) were supplied in the form of commercial fertilizers.

The 4-year rotation included 2 consecutive years of corn since erosion is usually not a problem on Webster and Nicollet soils. Barnyard manure was applied for first-year corn, a common practice in the area. Other treatments included application of commercial fertilizers on different crops in the rotation.

CORN-OATS AND CORN-OATS (SWEETCLOVER)

FOUR SERIES of plots involved corn and oats were tested, each for 6 years. These series of plots included:

1. Oats without sweetclover (O-C-O-C-O-C).
2. Oats with sweetclover (O[SC]-C-O[SC]-C-O[SC]-C)
3. Corn following oats without sweetclover (O-C-O-C-O-C).
4. Corn following oats, with sweetclover plowed down in the fall as green manure (O[SC]-C-O[SC]-C-O[SC]-C).

The rotations above all started in 1948, so that in 1949 oats followed corn and corn followed oats, both with and without sweetclover. Consequently the first year of the experiment could show the effects of the sweetclover.

All four series received the same fertilizers treatments. Remember that the fertilizer in these experiments, except for the plots applied in the corn hill, was applied to the land before the oats were seeded.

Oat Yields

Some increases in oat yields in individual years were not great enough to be significant. However, the average yields over the 6-year period showed significant increases for all except two treatments—0-60-0 applied for oats and 10-20-20 (120 pounds of 8-16-16) in the hill as a starter for corn.

While seeding sweetclover with oats produced significant increases in only 3 of the 6 years, the 6-year average yield increase was 9 bushels. In only 2 years, 1949 and 1950 when drought conditions prevailed, did the sweetclover seeding fail to substantially increase yields.

Increases in the yield of oats from application of commercial fertilizers were similar under the two systems. Nitrogen alone (20-0-0) was less effective when sweetclover was sown in the oats since the crop was already bene-

NOTE: In this bulletin fertilizer formulas are frequently used. Unless otherwise noted, when a formula such as 0-20-20 is mentioned, it means that the equivalent of 100 pounds of this fertilizer was applied per acre. For example, the bulletin may state that 10-20-20 was applied. Actually it may have been that 120 pounds of 8-16-16 was applied, but this is the equivalent of 100 pounds of 10-20-20.

fiting from the legume-fixed nitrogen and probably from improved physical condition of the soil.

Phosphate alone (0-60-0) had no effect on the oat yield on plots without sweetclover but was highly effective when accompanied by sweetclover green manure indicating that more nitrogen was needed. This is also shown by a 6-year average increase of 21.8 bushels when the fertilizer contained nitrogen and phosphorus (20-60-0). No further increase in the yield of oats was obtained by including potash (20-60-60).

Table 2 gives complete results of the various treatments on oat yields.

Corn Yields

The other part of this oats-corn sequence experiment measured the effect of fertilizer on the corn, usually in the year following application (table 3).

When grown on land which had no green manure, all fertilizer treatments, except 20-0-0 on oats, were effective on corn in 2 years, 1950 and 1954. They had little or no effect in the other years.

When grown on land on which sweetclover had been plowed down, all fertilizer treatments, except nitrogen alone, gave highly significant increases in corn yields in 5 of the 6 years. An application of 130 pounds per acre of 0-46-0 (0-60-0) applied for oats was the only treatment producing significant increases in corn yields in every year.

The benefits of sweetclover as a green manure were more marked on the yield of the following corn crop than on the yield of oats.

Sweetclover seeded with the oats in the spring and plowed down as green manure in the fall produced increases in the yield of corn in all years although they were significant in only three. The average yield increase for the 6-year period was 14.1 bushels.

All fertilizer treatments applied for oats, with the exception of 20-0-0, produced substantial increases in corn yields in the following year. The fertilizer was somewhat more effective on the sweetclover plots except for 20-0-0.

Fertilizer applied in the hill as starter for corn was highly effective for that crop but had little residual or carryover effect on the oat crop following.

Table 2. Effect of different fertilizer treatments on oat yields in an oats-corn sequence, with and without sweetclover as green manure, Nicollet Experimental Fields, 1949-54.

Treatment	Year 1949	1950	1951	1952	1953	1954	6-year average	Percentage of time effective
				Yield in bushels				
None without sweetclover (check)	39.0	30.9	44.2	33.9	28.1	31.2	34.5	
Oats without sweetclover			Increase over check in bushels					
20-0-0 for oats	−0.8	7.9	8.2	13.8	13.8	15.8	9.8	50
20-60-0 for oats	5.8	11.9	6.3	7.5	26.4	18.7	12.8	50
20-60-60 for oats	11.7	13.5	9.8	15.4	25.1	15.6	15.2	50
0-60-0 for oats	−0.5	0.3	−2.1	5.6	5.4	4.6	2.1	0
10-20-20 row for corn	2.7	2.0	−1.3	3.1	2.7	3.2	2.1	0
Oats with sweetclover								
Sweetclover only	−4.1	−1.8	22.0	11.4	13.8	12.9	9.0	50
20-0-0 for oats	−6.0	11.1	20.9	15.3	18.8	14.5	12.4	83
20-60-0 for oats	9.6	18.2	25.4	24.4	21.7	31.3	21.8	100
20-60-60 for oats	3.0	11.0	22.0	21.6	40.6	31.3	21.6	83
0-60-0 for oats	1.5	4.4	28.1	19.0	16.4	24.6	15.7	67
10-20-20 row for corn	1.7	−0.8	15.5	16.2	14.2	11.7	9.7	50
L.S.D., 5 percent level *	7.6	8.9	14.6	9.0	11.4	13.9	4.6	
L.S.D., 1 percent level	10.4	12.1	19.9	12.3	13.8	18.9	6.1	

* Note: The terms L.S.D., 5 percent level and L.S.D., 1 percent level, are research terms which indicate how significant or reliable research results are. Scientists must use these statistical devices to check their results to see if they really are significant or if the results are more or less accidental and mean very little. In the L.S.D. 5 percent level column, the increase indicated here is significant 19 out of 20 times. In the L.S.D. 1 percent level column, it is significant 99 times out of 100.

Table 3. Effect of different fertilizer treatments on corn yields in an oats-corn crop sequence, with and without sweetclover as green manure, Nicollet Experimental Field, 1949-54.

Treatment	Year 1949	1950	1951	1952	1953	1954	6-year average	Percentage of time effective
				Yield in bushels				
None without sweetclover (check)	55.4	33.1	28.9	56.0	44.3	52.6	45.0	
No sweetclover preceding			Increase over check in bushels					
20-0-0 for oats	1.9	3.9	1.4	−3.6	4.6	4.9	2.2	0
20-60-0 for oats	7.0	10.8	7.2	2.4	7.9	19.4	9.1	50
20-60-60 for oats	−4.0	17.0	4.1	7.0	7.8	17.5	8.2	33
0-60-0 for oats	7.0	17.5	6.7	5.3	5.5	18.0	10.0	50
10-20-20 for corn	7.8	10.9	4.3	6.3	21.8	31.5	13.8	50
Sweetclover preceding								
Sweetclover only	6.8	8.2	28.0	5.4	25.9	10.3	14.1	50
20-0-0 for oats	4.5	5.1	32.4	3.6	31.0	8.2	14.1	33
20-60-0 for oats	10.7	26.4	38.5	23.5	30.3	22.0	25.2	83
20-60-60 for oats	6.7	31.0	42.3	27.4	36.7	27.0	28.5	83
0-60-0 for oats	17.4	26.2	37.5	18.7	36.8	24.6	26.9	83
10-20-20 for corn	10.3	21.0	40.6	30.1	40.0	31.0	28.8	83
L.S.D., 5 percent level	15.1	8.2	6.8	13.6	10.3	12.9	6.0	
L.S.D., 1 percent level	......	11.3	9.2	18.6	14.4	17.6	8.0	

THE 4-YEAR ROTATION

THE 4-YEAR rotation studied was oats-hay-corn-corn, and yield figures for every crop except hay are available for all 6 years. Owing to a much lower than normal rainfall and above normal temperatures in 1949 and 1950 there was little or no growth for hay so data for hay are limited to four years.

Since hay was left down for only one year, the seedings consisted of a mixture of red clover and timothy. The first crop was harvested for hay, and the second crop was plowed down for soil improvement. Because of this practice, hay yields are somewhat lower than when two or more cuttings are taken and when a mixture such as alfalfa-brome is used.

Treatments with commercial fertilizers applied to the oat crop with the legume seeding were designed not only to increase oat yields but also to stimulate and improve the yield of hay and have some residual effect on corn. Most of these treatments gave significant increases in the yield of hay. The oat yields were not generally benefited, except by the nitrogen-phosphate (20-40-0) and the complete fertilizer (20-40-40).

Effects on Manured Land

First-year corn received the most benefit from applications of manure although there were some residual effects from fertilizer applied for the oats. Manure applied for first-year corn gave significant increases in the yield of second-year corn in only 3 of the 6 years. When the manure was accompanied by a hill application of phosphate, second-year corn was increased significantly in only 2 years. After growing two crops of corn on manured land, the oat and hay crops were benefited in one-third of the years.

Oat Yields

Two treatments, 20-40-0 and 20-40-40, applied directly to the oat crop gave an average annual increase of about 10 bushels per acre of oats which was highly significant. While other treatments gave average increases of from 1 to 3 bushels over the checks, this

Table 4. Yield of oats in bushels per acre in a 4-year rotation of oats, hay, corn, corn, and increases from different fertilizer treatments, Nicollet Experiment Field, 1949-54.

Treatment	1949	1950	1951	1952	1953	1954	6-year average
	Year						
None (check)	35.9	38.4	42.0	50.8	34.0	39.8	40.1
			Increase over check				
0-40-0 for oats	2.8	6.6	2.0	−0.4	−5.2	8.0	2.3
0-40-40 for oats	3.5	1.6	0.3	−1.7	8.7	4.7	2.9
20-40-0 for oats	5.6	14.8	15.8	−1.8	13.5	15.3	10.6
20-40-40 for oats	10.9	13.3	10.1	−0.9	13.7	11.9	9.9
0-40-0 for oats and 0-40-0 (broadcast) first-year corn	3.3	−0.2	10.5	−0.4	−0.3	4.0	2.9
Manure 8 tons first-year corn	7.9	−1.2	0.2	−1.8	1.9	6.2	2.2
Manure 8 tons first-year corn and 0-20-0 (hill) first-year corn	3.9	−1.0	−1.5	−6.0	10.9	7.2	2.5
Manure 8 tons first-year corn and 10-20-20 (hill) second-year corn	3.7	2.2	4.1	1.5	−0.8	3.6	2.4
0-60-0 (broadcast) second-year corn	5.8	2.5	−4.6	−2.0	−3.2	7.6	1.0
L.S.D., 5 percent level	7.4	5.8	5.4	5.6	7.6	4.3	4.5
L.S.D., 1 percent level	10.00	7.9	7.2	7.6	10.2	5.8	6.3

was not large enough an increase to be considered significant (table 4).

Hay Yields

Commercial fertilizers applied for oats were very effective on the succeeding hay crop (table 5). In only one year, 1952, did they fail to produce highly significant increases in yield.

The most effective treatment was the phosphate-potash mixture, 0-40-40, which gave an average increase of .68 tons per acre, showing that the inclusion of potash was beneficial. The next highest yield was from a double application of phosphate where the increase was .60 tons.

Applying manure for first-year corn had little effect on the yield of hay 3 years later. If fertilizer was used with the manure, there was some carryover to the hay crop with a small but distinct increase in yield.

Table 5. Yield of hay in tons per acre in a 4-year rotation of oats, hay, corn, corn, and increases from different fertilizer treatments, Nicollet Experimental Field, 1951-54.

Treatment	1951	1952	1953	1954	6-year average
	Year				
None (check)	1.94	1.45	1.56	1.49	1.61
	Increase over check				
0-40-0 for oats	.64	.21	.46	.64	.49
0-40-40 for oats	.87	.30	.75	.80	.68
20-40-0 for oats	.40	.17	.45	.57	.40
20-40-40 for oats	.53	.20	.60	.38	.43
0-40-0 for oats and 0-40-0 (broadcast) first-year corn	.74	.35	.65	.67	.60
Manure 8 tons first-year corn	.15	−.13	.26	.26	.14
Manure 8 tons first-year corn and 0-20-0 (hill) first-year corn	.34	.05	.52	.36	.32
Manure 8 tons first-year corn and 10-20-20 (hill) second-year corn	.61	.00	.19	.53	.33
0-60-0 (broadcast) second-year corn	.64	.15	.56	.74	.52
L.S.D., 5 percent level	.35	.35	.25	.41	.20
L.S.D., 1 percent level	.47	.47	.34	.51	.26

Corn Yields

The average yield of first-year corn was increased somewhat by fertilizer applied for the oat crop (table 6). The greatest increase was 7.6 bushels per acre from an application of 0-40-40, the inclusion of potash being beneficial to corn as well as to hay. Wherever manure was applied for first-year corn there was a highly significant increase in yield. The increases varied from 15 to 18 bushels per acre.

Phosphate applied for second-year corn had little effect on the next crop the yield of hay by one half ton per acre.

Manure applied for first-year corn was effective on the second corn crop in 2 of the 6 years. Other treatments had no appreciable effect.

Summarizing (table 8) the 6-year results of the four crops grown in rotation, the yield of oats was increased most by the nitrogen-phosphate mixture, 20-40-0; hay by the phosphate-potash combination, 0-40-40; and the two corn crops by treatments which included an application of barnyard manure.

Table 6. Yield of first-year corn in bushels per acre in a 4-year rotation of oats, hay, corn, corn, and increases in yield from different fertilizer treatments, Nicollet Experimental Field, 1949-54.

Treatment	1949	1950	1951	1952	1953	1954	6-year average
	Year						
None (check)	62.9	50.6	61.2	89.5	73.2	73.3	68.4
			Increase over check				
0-40-0 for oats	11.8	4.1	−2.1	9.9	5.9	5.0	5.8
0-40-40 for oats	8.4	6.8	5.3	4.8	10.5	9.7	7.6
20-40-0 for oats	13.0	2.3	0.3	1.8	6.4	1.9	4.3
20-40-40 for oats	6.1	4.8	−3.6	9.8	8.5	10.1	6.0
0-40-0 for oats and 0-40-0 (broadcast) first-year corn	17.1	5.0	−5.8	3.4	9.4	9.5	6.5
Manure 8 tons first-year corn	16.5	16.8	16.7	17.1	13.5	9.9	15.1
Manure 8 tons first-year corn and 0-20-0 (hill) first-year corn	18.7	21.4	17.3	15.0	13.1	15.2	16.8
Manure 8 tons first-year corn and 10-20-20 (hill) second-year corn	19.4	19.6	19.4	15.1	19.1	16.8	18.2
0-60-0 (broadcast) second-year corn	3.2	2.2	0.2	0.0	9.2	10.2	4.2
L.S.D., 5 percent level	10.0	7.7	6.5	10.1	6.4	8.4	4.4
L.S.D., 1 percent level	13.6	10.4	8.7	13.6	8.6	11.4	5.8

of corn which appeared in the rotation 4 years later. The increase of 4.2 bushels per acre over the 6-year period closely approached significance. This was also true for the 20-40-0 treatment for oats.

Only two treatments were applied directly for second-year corn (table 7). Plots receiving 8 tons per acre of manure for first-year corn and 125 pounds of 8-16-16 (10-20-20) in hill for the second corn crop gave significant increases in yield in 4 of the 6 years.

The other treatment on second-year corn was a broadcast application of phosphate (0-60-0) which did not appreciably affect the yield of corn or the oats which followed but did increase

Costs

The different fertilizer treatments vary in cost. Whether they pay or not depends on if they increase the value of the total crop enough. Treatment costs are difficult to calculate since the amount of labor and the machinery costs vary, especially for barnyard manure. The type of machinery used and the distance which manure must be hauled influence the amount of time and labor required.

S. A. Engene, Department of Agricultural Economics, University of Minnesota, estimates that using modern machinery and hauling distances prevail-

Table 7. Yield of second-year corn in bushels per acre in a 4-year rotation of oats, hay, corn, corn, and increases in yield from different fertilizer treatments, Nicollet Experimental Field, 1949-54.

Treatment	Year 1949	1950	1951	1952	1953	1954	6-year average
None (check)	56.9	40.0	27.5	59.9	43.9	70.0	49.7
			Increase over check				
0-40-0 for oats	−1.4	0.2	−2.4	−7.1	3.4	7.9	0.1
0-40-40 for oats	1.0	1.0	−3.4	−.2	1.9	1.3	0.4
20-40-0 for oats	3.5	6.7	−0.5	−4.3	1.1	7.9	2.4
20-40-40 for oats	3.8	−4.5	−3.6	−2.9	2.6	4.7	0.0
0-40-0 for oats and 0-40-0 (broadcast) first-year corn	2.6	5.5	2.4	−4.5	0.0	3.7	1.6
Manure 8 tons first-year corn	−3.3	11.7	−0.2	11.1	7.5	17.2	7.3
Manure 8 tons first-year corn and 0-20-0 (hill) first-year corn	1.7	16.7	2.4	−0.8	2.0	19.3	6.9
Manure 8 tons first-year corn and 10-20-20 (hill) second-year corn	5.0	20.5	5.9	15.7	4.5	26.9	13.1
0-60-0 (broadcast) second-year corn	5.5	4.0	−1.3	−4.3	−1.1	6.7	1.6
L.S.D., 5 percent level	9.2	9.5	4.9	10.5	10.5	7.0	5.4
L.S.D., 1 percent level	12.4	12.9	6.6	14.2	14.3	9.4	7.1

ing on an average Minnesota farm it costs about $1.00 to load, haul, and spread one ton of manure.

To arrive at the return over fertilizer cost per acre from the nine different treatments over the 6-year period the following procedure has been used. The cost of commercial fertilizer was taken from the 1954 fall price lists of several fertilizer manufacturers. Differences in the costs of applications were not taken into consideration. Manure was assigned a cost of $1.00 per ton. Prices used in calculating the value of crops were: oats, $0.70 per bushel; timothy and clover hay, $12.00 per ton; and corn $1.25 per bushel. These prices closely approximate those received and paid by Minnesota farmers in November and December, 1954.

The results are summarized as to yields in table 8 and to costs and returns in table 9. Those treatments which increased the yields of corn were the most profitable.

An application of 8 tons per acre of manure for first-year corn and 125 pounds of 8-16-16 (10-20-20) in the hill

Table 8. Six-year average yield per acre of oats, hay, first-year corn and second-year corn grown in a 4-year rotation under different treatments, Nicollet Experimental Field, 1949-54.

Treatment	Oats	Hay *	Corn	Corn	Gain over control (check) Oats	Hay	Corn	Corn
	bu.	tons	bu.	bu.	bu.	tons	bu.	bu.
None (check)	40.1	1.61	68.4	49.7	......	......	......	......
0-40-0 for oats	42.4	2.10	74.2	49.8	2.3	.49	5.8	0.1
0-40-0 for oats	43.0	2.29	76.0	50.0	2.9	.68	7.6	0.3
20-40-0 for oats	50.7	2.01	72.6	52.1	10.6	.40	4.2	2.4
20-40-40 for oats	50.0	2.04	74.4	49.7	9.9	.43	6.0	0.0
0-40-0 for oats and 0-40-0 (broadcast) first-year corn	43.0	2.21	74.9	51.4	2.9	.60	6.5	1.7
Manure 8 tons first-year corn	42.3	1.75	83.5	57.0	2.2	.14	15.1	7.3
Manure 8 tons first-year corn and 0-20-0 (hill) first-year corn	42.4	1.94	85.2	56.6	2.3	.33	16.8	6.9
Manure 8 tons first-year corn and 10-20-20 (hill) second-year corn	42.5	1.94	86.7	62.8	2.4	.33	18.3	13.1
0-60-0 (broadcast) second-year corn	41.2	2.13	72.6	51.3	1.1	.52	4.2	1.6

* 4-year average.

Table 9. Average acre returns over fertilizer cost from nine fertilizer treatments on a 4-year rotation of oats, hay, corn, and corn, Nicollet Experimental Field, 1949-54.

Treatment	Value of increase	Cost of treatment	4-year gain	Annual gain	Rank	Gain per fertilizer dollar
0-40-0 (90# 0-46-0) for oats	$14.86	$3.57	$11.29	$2.82	7	$3.16
0-40-40 (200# 0-20-20) for oats	20.06	6.83	13.23	3.31	4	1.93
20-40-0 (200# 10-20-0) for oats	20.47	7.35	13.12	3.28	5	1.78
20-40-40 (250# 8-16-16) for oats	19.59	10.40	9.19	2.30	8	0.88
0-40-0 for oats and 0-40-0 (broadcast) first-year corn	19.48	7.14	12.34	3.08	6	1.72
Manure 8 tons first-year corn	31.22	8.00	23.22	5.80	3	2.90
Manure 8 tons first-year corn and 0-20-0 (45# 0-46-0 in hill) first-year corn	35.23	9.78	25.45	6.36	2	2.37
Manure 8 tons first-year corn and 10-20-0 (125# 8-16-16 in hill) second-year corn	44.93	13.20	31.73	7.93	1	2.40
0-60-0 (135# 0-46-0 broadcast) first-year corn	14.26	5.35	8.91	2.23	9	1.66

for second-year corn gave the highest return, approximately $8.00 per acre per year.

This was followed by manure and phosphate in the hill for first-year corn, $6.36 per acre, and manure alone for first-year corn, $5.80 per acre per year. Gains from commercial fertilizers varied from $3.31 to $2.23 per acre per year.

The treatments are ranked according to the amount of the annual gain, but this does not necessarily mean the greatest return from each dollar invested in the treatment. Under ordinary circumstances the farmer is interested in the treatment which will give him the greatest profit over the cost of fertilizer. There may be those, however, whose funds are limited. Their interest may be in the treatment which gives the largest return for their fertilizer dollar (table 9).

The application of 40 pounds of P_2O_5 per acre for the oat crop ranked first in return for each dollar invested in fertilizer. It was also the lowest in acre cost for treatment. An application of manure gave the second highest return per dollar invested, and all treatments which included manure were almost equal to it.

As the acre fertilizer cost rises, the return from the fertilizer dollar falls. Where funds are available for the purchase of fertilizer, however, the annual gain from the treatment is the more important.

HEAVY FERTILIZATION

BY THE END of the third year it was evident that the treatments being used were not producing yields of crops of oats, hay, and corn which might logically be expected from a soil with the productive potential of Webster clay loam. Consequently the plots in the 4-year rotation were split and half were given a heavier application of fertilizer. The treatments used are given below, the heavier fertilizer treatments being designated by X. Actual applications are given. The formula which would equal this application at 100 pounds per acre is given in parentheses.

1. 90 pounds 0-46-0 (0-40-0) broadcast for oats.

1X. Same as 1 plus 130 pounds 0-46-0 (0-60-0) top-dressed on hay in the spring.

2. 200 pounds of 0-20-20 broadcast for oats.

2X. Same as 2 plus 300 pounds of 0-20-20 top-dressed on hay in spring.

3. 200 pounds of 10-20-0 broadcast for oats.

3X. Same as 3 plus 67 pounds 0-0-60 (0-0-40) broadcast on hay in the spring.

4. 250 pounds 8-16-16 (20-40-40) broadcast for oats.

4X. Same as 4 plus 300 pounds of 0-20-20 broadcast on sod in fall before plowing and 60 pounds of nitrogen broadcast in spring for first-year corn.

5. 0-40-0 broadcast for oats and 0-40-0 broadcast for first-year corn.

5X. Same as 5 plus 67 pounds of 0-0-60 broadcast in spring on hay and 40 pounds nitrogen broadcast for second-year corn.

6. Untreated (check).

6X. 1000 pounds 10-10-10, on sod, fall-plowed for corn.
100 pounds 10-20-0, hill, first-year corn.
125 pounds 8-16-16, hill, second-year corn.
125 pounds 33-0-0 side-dressed second-year corn.
200 pounds 10-20-0 broadcast for oats.
100 pounds 0-0-60 top-dressed on hay, spring.

7. 8 tons manure first-year corn.

7X. Same as 7 plus 8 tons manure for second-year corn.

8. 8 tons manure and 100 pounds 0-20-0, hill, first-year corn.

8X. Same as 8 plus 8 tons manure and 100 pounds 0-20-0, hill, second-year corn.

9. 8 tons manure first-year corn and 125 pounds 8-16-16 hill second-year corn.

9X.8 tons manure and 125 pounds 8-16-16, hill, for both first- and second-year corn.

10. 90 pounds 0-46-0 (0-40-0) broadcast for oats and first-year corn.

10X. Same as 10 plus 67 pounds of 0-0-60 top-dressed on hay in spring and 40 pounds of nitrogen (125 pounds 33-0-0) broadcast for second-year corn.

The heavier treatments were designed primarily to increase the amount of the nutrient or nutrients over those used when the experiments were started. However, in a number of cases an additional nutrient was included as in 7X, 9X, and 10X. Treatment 6X included the addition of fertilizer for every crop in the rotation with emphasis on the two corn crops. The treatment was included to determine how high yields could be pushed regardless of fertilizer cost.

Treatment 6X produced highly significant increases in yield on all crops in all years except on the oat crop in 1952. Other X treatments were generally more effective than the regular treatment first employed.

One question not fully answered is the effectiveness of larger amounts of nitrogen. At the time the experiments were initiated not all forms of nitrogen now on the market were available and relatively heavy applications, especially for corn, were not then being used. In this connection treatment 4X and 5X, both of which included manure, were highly effective.

The 3-year average yields for the untreated plots, together with the increase or decrease over the controls, are shown in table 10. The data shown here represent average yields without regard to significance.

A number of treatments were superior when their crop producing qualities are considered (table 10). The outstanding treatment in this respect is 6X which represented the heaviest fertilization and the most costly. Next to this was 5X under which 8 tons of manure and 125 pounds of 8-16-16, along the row as starter, was applied for both corn crops. However, neither treatment 5 nor 5X was much more effective than 4X under which no commercial fertilizer was used.

Table 10. Three-year average yields per acre of oats, hay, first-year and second-year corn, grown in a 4-year rotation under 19 fertilizer treatments, Nicollet Experimental Field, 1952-54.

Treatment number	Oats	Hay	First-year corn	Second-year corn	Gain over control: Oats	Hay	First-year corn	Second-year corn
	bu.	tons	bu.	bu.	bu.	tons	bu.	bu.
6 (check)	41.5	1.50	78.7	57.9	......	......	......	......
1	42.3	1.94	85.6	59.3	0.8	.44	6.9	1.4
1X	43.1	2.23	89.7	64.0	0.8	.73	11.0	6.9
2	45.4	2.12	87.0	58.7	3.9	.62	8.3	0.8
2X	43.8	2.49	94.1	61.4	2.3	.99	15.4	3.5
3	50.5	1.90	82.0	59.5	9.0	.40	3.3	1.6
3X	53.8	2.13	89.4	59.4	12.3	.63	10.7	1.5
4	49.8	1.89	88.1	59.4	8.3	.39	9.4	1.5
4X	51.0	2.10	101.5	63.2	9.5	.60	22.8	5.3
5	42.6	2.06	86.1	57.7	1.1	.56	7.4	0.0
5X	45.2	2.21	89.1	68.3	3.7	.71	10.4	10.6
6X	54.0	2.26	101.4	83.3	12.5	.76	22.7	25.4
7	43.6	1.63	92.2	69.9	2.1	.13	13.5	12.0
7X	50.5	1.89	95.1	77.4	9.0	.39	16.4	19.4
8	45.6	1.81	93.1	64.8	4.1	.31	14.4	6.9
8X	48.8	2.13	94.0	71.2	7.3	.63	15.3	13.3
9	43.0	1.79	95.7	73.6	1.5	.24	17.0	15.7
9X	51.0	2.19	101.6	81.1	9.5	.69	22.9	23.2
10	42.3	1.98	85.1	58.4	0.8	.48	6.4	0.5
10X	50.9	2.24	89.0	62.0	9.4	.74	10.3	4.1
L.S.D., 5 percent level					6.2	.22	4.9	7.9
L.S.D., 1 percent level					7.7	.30	6.6	10.6

Supplementing manure with phosphate as in treatments 8 and 8X did not appreciably increase corn yields, but it was effective on the oat and hay crops, especially the latter. Hay responded markedly to top dressing with phosphate and potash (treatment 2X) giving a 3-year average increase of 1.0 ton.

In every case the higher rates of fertilizer produced a higher return over fertilizer costs (table 11). This is clear evidence that heavier rates of fertilization would have been justified.

The treatment showing the greatest gain, $11.54 per acre per year, was 9X which consisted of 8 tons per acre of manure and 125 pounds of 8-16-16 in the hill for both corn crops. This treatment not only increased both corn crops by 23 bushels per acre but also both oats and hay as well.

The treatments ranking 1 to 5, inclusive, included manure for one or both of the corn crops.

With one exception, 10X, all of the heavier rates of fertilization gave gains of more than $5.00 per acre per year Treatment 6X gave the highest value of crop increase, but because of the high cost of the treatment, $57.58, for the rotation, the gain was only $5.13 per acre per year. Treatments 1X, 3X, and 5X which were much less costly gave higher returns. Apparently there are limits in the amounts of fertilizers which can be applied when return over fertilizer cost is considered.

The soil of the Nicollet Experimental Field tested low in available phosphorus. The highest return from a treatment which did not include manure was from 1X which consisted of 0-40-0 for oats and 0-60-0 top-dressed on hay. No treatment containing potash produced a higher return although top-dressing

Table 11. Average returns over fertilizer cost from 19 fertilizer treatments on a 4-year rotation of oats, hay, corn, and corn, Nicollet Experimental Field, 1952-54.

Treatment number	Value of increase	Cost of treatment	4-year gain	Average annual gain	Rank	Return per fertilizer dollar
1	$16.21	$ 3.57	$12.64	$ 3.16	16	$3.54
1X	31.70	5.35	26.35	6.59	6	4.92
2	21.55	6.83	14.72	3.68	14	2.15
2X	37.11	17.07	20.04	5.01	12	1.17
3	17.22	7.35	9.87	2.47	17	1.34
3X	31.42	9.17	22.25	5.56	9	2.42
4	24.11	10.40	13.71	3.43	15	1.32
4X	48.97	28.43	20.54	5.13	10	0.72
5	16.74	7.14	9.60	2.40	18	1.34
5X	37.36	14.40	22.96	5.74	8	1.59
6X	78.10	57.58	20.52	5.13	10	0.35
7	34.90	8.00	26.90	6.72	5	3.36
7X	55.73	16.00	39.73	9.93	2	2.48
8	33.21	9.78	23.43	5.86	7	2.39
8X	48.42	19.56	28.86	7.21	4	1.47
9	44.80	13.20	31.60	7.90	3	2.39
9X	72.55	26.40	46.15	11.54	1	1.75
10	14.95	5.35	9.60	2.40	18	1.80
10X	33.46	17.43	16.03	4.01	13	0.92

hay with potash as in treatments 3X and 6X increased the yields of hay.

The use of straight phosphate gave the highest return from the fertilizer dollar. The double application, 0-40-0 for oats and 0-60-0 top-dressed on hay, exceeded the return from the single application of 0-40-0 on oats.

Two applications of phosphate in the rotation (1X) showed a return of $4.92 for each dollar spent for fertilizer as compared to $3.54 for one application (treatment 1). Treatments containing an application of manure gave a somewhat lower return for the fertilizer dollar but were distinctly above the other treatments with the exception of treatments 2 and 3X.

THE VALUE OF MANURE

THE EXPERIMENTS on the Nicollet Experimental Field demonstrate the value of manure as a fertilizer.

Eight tons of manure applied for first-year corn (treatment 7) produced increases in the four crops of the rotation which had a value of $34.90. Thus each ton was worth $4.72.

When 16 tons were used (treatment 7X) the value of the increase was $55.73 or $4.48 each ton. The cost of making application will vary with each field depending on its location in respect to the farmstead. Supplementing manure applied for corn with commercial fertilizer in the hill or along the row was highly profitable. Treatment 9, which included manure for first-year corn and row fertilizer for second-year corn, ranked first in the experiments which ran through six rotations (table 9) and third in heavy fertilization trials (table 11). In the latter it was exceeded only by the two treatments which received 8 tons of manure for both of the corn crops (treatments 7X and 9X).

GENERAL DISCUSSION

UNDER A CROPPING system of growing grain and corn in alternate years, including a leguminous green manure crop with the grain increased the yield of both the grain and the corn. On the grain the yield increase was approximately that obtained with 20 pounds of nitrogen. In such a system grain yields were increased most by an application of a complete fertilizer—one containing nitrogen, phosphate, and potash. The yield of oats on the untreated plots in the two-crop rotation was about 5 bushels less than the yield in the 4-year rotation.

Fertilizers were generally more effective on grain in the oats-corn rotation when sweetclover was seeded with the oats. Increases of 20 bushels per acre of oats were obtained with NP and NPK fertilizers.

The yield of corn in the oats-corn rotation was very considerably increased by the green manure seeded in the oats. Without any fertilizer treatment the 6-year average increase was 14 bushels. This was equivalent to the increase obtained when 20 pounds of nitrogen was applied on the oat crop. As with oats the applications of fertilizer were more effective on corn yields on the land which had a green manure plowed down.

Under the 2-year rotation the average yield of corn was 20 to 25 bushels per acre less than first-year corn and about equal to the yield of second-year corn in the 4-year rotation when no fertilizer was used. Thus in 4 years the oats, hay, corn rotation would produce about 25 bushels more corn than the oats-corn-oats-corn rotation. By seeding sweetclover in the oats the two-corn crops under the two rotations would be approximately the same when no fertilizer was used.

Commercial fertilizers applied for oats were generally more effective on the corn crop in the oats-corn rotation than in the 4-year rotations where the intervening hay crop showed the greatest residual effect from the fertilizer. Hay yields were significantly increased in most cases when fertilizer was applied for the grain with which the legume-grass mixture was seeded.

Manure is a highly effective fertilizer on the Webster soils. In the present experiments either manure alone or manure plus hill (starter) fertilizer for corn produced high yields which exceeded those obtained with commercial fertilizer alone unless very large amounts of commercial fertilizers were used. Even heavy applications of commercial fertilizer did not show the profit obtained by making applications of manure.

SUMMARY OF RESULTS

THE EFFECTS of different soil management practices on Webster clay loam were tested in this research. These management practices involved three different cropping systems. The effects of sweetclover, barnyard manure, use of different kinds of fertilizers at ordinary rates, and use of various fertilizers at heavy rates were measured. The research covered a 6-year period. Some of the more important results are the following.

1. Sweetclover grown as a green manure in a 2-year rotation of oats-corn increased yields of both oats and corn. The yield of corn was increased more than the yield of oats.

2. Commercial fertilizers were more effective on land on which a green manure was plowed down.

3. With the 2-year rotation of oats-corn a complete fertilizer containing nitrogen, phosphate, and potash gave the greatest increase in oat yields. Corn

yields were increased most by a hill application (starter) of complete fertilizer. Oat and corn yields in a 4-year rotation of oats, hay, corn, and corn were approximately 5 and 15 bushels higher, respectively, than those obtained in the 2-year rotation when no manure or fertilizer was applied. When a green manure crop of sweetclover was seeded with oats in the 2-year rotation, yields of both oats and corn were similar to those obtained in the 4-year rotation.

4. Manure applied for first-year corn in the 4-year rotation (oats-hay-corn-corn) increased yields of first- and second-year corn but had little effect on the oat and hay crops.

5. Applying manure for first-year corn plus fertilizing second-year corn in the hill increased corn yields substantially and showed some residual effect on the hay crop. This treatment produced the highest annual return over fertilizer cost in the experiments with ordinary rates of fertilization.

6. All commercial fertilizer treatments applied for oats increased hay yields significantly in the following year. The highest increase, when ordinary rates of application were used, was obtained from a phosphate-potash mixture.

7. Higher than normal rates of fertilization increased yields of all crops in the 4-year rotation. In a few cases oat yields were not increased by heavy fertilization.

8. Applying fertilizer to every crop in the rotation gave the greatest increases in crop yields, but the gain was less than that from some other treatments where the fertilizer cost was less.

9. Making an application of manure and applying hill-dropped fertilizer for both corn crops in the 4-year rotation produced the highest annual gain .

10. All treatments which included an application of manure produced more profit over fertilizer cost for the rotation than those treatments which included only commercial fertilizers.

11. The commercial fertilizer treatment giving the greatest return was the one in which 40 pounds of P_2O_5 was applied for oats and 60 pounds of the same nutrient top-dressed on hay in the spring. Oat yields were not increased, but there was an increase in the yield of hay. Including potash in the fertilizer had little effect on the yield of oats, but increased the yield of hay and first year corn.

12. The experiments demonstrated the value of manure for the corn crop and of commercial fertilizer for hay.

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