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Fertility Maintenance By Rotation and Manure[1]

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For several years there has been maintained on the Greenville Farm of the Utah Experiment Station an experiment to determine the relative value of different cropping systems and manurial treatments in maintaining the fertility of the soil.

Conditions of the Experiment

The Greenville Farm is an irrigated farm located about two miles north of the Utah State Agricultural College at Logan on the east side of Cache Valley at an elevation of 4600 feet. The soil is a very calcareous silty loam, quite uniform to a depth of about 50 feet where it overlies coarse gravel. The drainage is perfect to a depth of 100 feet where a permanent water-table is encountered. A chemical analysis[3] shows the soil to consist of about 48 per cent calcium and magnesium carbonate and to contain about 0.17 per cent total phosphate (P_2O_5), 1.82 per cent total potash (K_2O), and 0.11 per cent total nitrogen (N). Experiments on adjacent areas have shown that sugar-beets and alfalfa give good response to phosphate fertilizer on this soil.

The climate is semi-arid. The average annual precipitation at the Experiment Farm is 16.5 inches, of which about one-third comes in March, April, and May, with almost negligible precipitation in June, July, and August. Snow usually covers the ground for several weeks each winter. These conditions are representative of fairly extensive areas in northern Utah.

Previous to these fertility experiments, this particular field had been in irrigation experiments and was cropped rather heavily without manuring. The results indicated that the soil was originally quite productive of most crops, except that it has never produced good crops of sugar-beets without manure.

Description of the Experiment

This experiment on fertility maintenance was so designed as to include several different rotation systems and for comparison the same crops grown continuously year after year. As far as possible each cropping system was repeated both with and without manure and in some cases with several different quantities of manure. Some of the rotations included no leguminous

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[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station.
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[3]"Chemical Studies . . . of . . . Soils . . ." By W. O. Robinson, G. Edington, and H. G. Byers. U. S. Dept. Agr. Tech. Bul. 471:11. 1935.

Final Report on State Station Projects Nos. 5 and 9: Irrigation and Manuring Studies on Greenville Farm and Rotation and Manuring Studies on Greenville Farm, respectively.

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crop, some included only an annual legume (peas), and some included a perennial legume (alfalfa). A detailed description of each cropping system follows:

Rotation "A" was an alternation of spring wheat (Dicklow) and sugar-beets. This rotation occupied eight plats, four being in wheat and four in beets each year. One pair of plats was never manured; one pair received 10 tons of mixed barnyard manure per acre every other year, applied in the fall following the wheat and plowed under; one pair received the 10-ton application of manure every fourth year; and the fourth pair had no manure but a small amount of green manure produced by planting a crop of peas and oats or some similar quick-growing plants as soon as the wheat was removed each year and plowing under the young growth in the late fall.

Rotation "B" was a six-year rotation of potatoes, potatoes, peas, beets, beets, wheat, and repeat. These plats were never manured and they had the benefit of only one annual leguminous crop each six years.

Rotation "C" was an alternation of dent corn and sugar-beets without manure.

Rotation "D" was an alternation of canning peas and sugar-beets. There were three pairs of plats in this series. One pair was unmanured, one pair received 10 tons of barnyard manure every alternate year following the peas, and the third was green-manured by planting a crop of oats and peas (or similar plants) after the crop of canning peas was removed and plowing under the half-grown plants in the fall.

Rotation "E" was a four-year rotation of potatoes, beets, wheat, sweet clover, and repeat. One replicate of this rotation was unmanured and another received a ten-ton application of barnyard manure each fall following the clover and preceding the potatoes. At first sweet clover was used in this rotation because it was thought it would give a better yield than alfalfa for such a short lay, but when it was observed that the yield was no better than alfalfa under these conditions the crop was changed to alfalfa.

Rotation "F" was a seven-year rotation of oats, beets, beets, oats, alfalfa for three years, and repeat. These plats were manured at the rate of 10 tons per acre each fall preceding the beet crops, making two manurings in seven years.

Rotation "G" was a ten-year rotation of potatoes, beets, peas, beets, wheat, alfalfa for five years, and repeat. This rotation was started in 1922 and one replication (marked "heavy manuring," Table 3) received a ten-ton application of manure in the fall preceding each beet and potato crop, making three ten-ton manurings in ten years. Another replication (marked "light manuring," Table 2) received the same manuring treatment for the first ten years, after which time it received no manure. A third replication was never manured. Because the two manured replications had little time to differ in the ten-year period listed in Table 1, they were averaged together as one.

In addition to these rotations most of the crops were also grown continuously, both with and without manure, and in some cases with different quantities of manure.

A list of some of the different cropping and manuring treatments with the abbreviations used in the tables and chart (Fig. 1) follows:

Abbreviation		Treatment
A - O	=	Rotation "A"—no manure
A - 10/2	=	Rotation "A"—10 tons manure every 2 years
A - 10/4	=	Rotation "A"—10 tons manure every 4 years
A - gr.	=	Rotation "A"—green manure
D - O	=	Rotation "D"—no manure
D - m/2	=	Rotation "D"—10 tons manure every 2 years
E - O	=	Rotation "E"—no manure
E - m	=	Rotation "E"—manured
G - 30/10	=	Rotation "G"—10 tons of manure 3 times in 10 years
Cont. 15 T	=	Continuous—15 tons of manure each year, etc.

In the spring of 1934 it was discovered that it would be impossible to continue these experiments for as long a time as had originally been hoped, so it was decided to put the plats into uniform condition and crop them all to the same crop for one year so that a definite comparison could be made of all the plats and all the systems of maintaining fertility. At that time it was too late in the season to plow up the alfalfa and plant sugar-beets, but all of the other plats in the experiment were planted to sugar-beets in 1934. From the alfalfa plats two early cuttings were taken; and then the alfalfa was plowed up and the plats fallowed for the rest of the season to leave them in a condition as similar to the beet plats as possible. Due to the drought and somewhat late planting the yields of sugar-beets in 1934 were quite low. In 1935 all plats were planted to sugar-beets under normally favorable conditions, and reasonably good yields were secured, which seemed to reflect quite accurately the value of the different systems of maintaining fertility. Since all of the rotations had been running since 1922—some much longer—it was decided that the yields of the various crops for the ten-year period 1924-1933, inclusive, would furnish a good basis for comparison of the different treatments insofar as they were comparable. It is, of course, quite difficult to compare yields of different crops.

Results of the Experiment

Table 1 shows the results of the different cropping and manuring treatments on the yield of the various crops while the treatments were in progress. These results show that sugar-beets have the widest variation of any of these crops, being apparently more sensitive to the condition of the soil than any of the others. The sugar-beets were much more responsive to manure than to rotation. In fact, the continuous beets with heavy manuring were the best of all, until they became infested with the sugar-beet nematode near the close of the period when the crop was almost wholly destroyed and it was necessary to change to another crop. With the heavier applications of manure the increased yield was much less per ton of manure than with the lighter applications, but the heaviest application—40 tons of manure per acre each year, which is about three times the ordinary manure-spreader application—gave consistently the highest yield of any of the plats of sugar-beets.

In Table 2 the different cropping and manuring treatments are ranked

Table 1—Average yield of the different crops under the various cropping systems and manurial treatments for the 10-year period, 1924-1933, inclusive.

Treatment Cropping System Manure (tons)		10-Year Average Acre-yield of Various Crops					
		Beets (tons)	Alfalfa (tons)	Peas (lbs.)	Potatoes (bushels)	Wheat (lbs.)	Corn (bushels)
Continuous	**Manure (Amt.)**						
Beets	0	5.22					
"	5	19.17					
"	15	20.72					
"	40	25.31					
Alfalfa	0		4.31				
"	5		7.95				
Potatoes	0				159		
"	10				282		
Wheat	0					19.7	
"	5					27.7	
Corn	0						64.9
"	5						81.0
"	15						91.0
Rotation	**Manure (Amt.)**						
C	0	4.45					64.2
A	0	2.60				35.3	
A	10/4	10.79				43.1	
A	10/2	14.74				47.5	
A	green	3.51				39.8	
B	0	3.61			195	35.5	
D	0	5.39		3160			
D	10/2	17.75		3690			
D	green	7.16		3550			
E	0	2.10			231	39.2	
E	10/4	11.27			340	45.9	
F	20/7	16.89	7.15				
G	30/10	16.67	6.24	3580	330	54.2	

in order of the average yield of the various crops; for each pair of treatments it is shown how many years out of ten the one of higher rank was actually superior to the one of lower average rank. This gives the statistical significance or reliability of this ranking in terms of odds, which show how much credence is to be given to this ranking. For example, if treatment "S" gave a higher yield of sugar-beets than treatment "T" for ten years out of ten, the odds are 1023 to 1 that treatment "S" really is superior to treatment "T." In other words, if this experiment were to be repeated 1024 times, the odds are even that in only one instance

would treatment "T" show better results than "S". On the other hand, if treatment "S" were better than "T" only nine times out of ten, then the odds would be only 92 to 1 that "S" was the better treatment, which is, however, enough to be quite significant. However, if "S" were superior to "T" only five years out of ten, then it is only even odds that either "S" or "T" is superior, and no significance at all can be attached to the the fact that "S" happened to give a somewhat higher average yield for these trials than "T". In general, when one treatment was better than another for less than eight times out of ten (odds of 17 to 1), little or no significance can be attached to the results.

From Table 2 it thus appears that for sugar-beets all those treatments which included manure were significantly superior to those which did not and the more manure the better—up to 40 tons per acre per year; rotation in itself, with annual legumes, perennial legumes, or no legumes was of no value **as long as the soil was free from nematode.** In interpreting these results it should be noted that in these experiments erosion was eliminated by border dykes completely surrounding each plat and that in actual farm experience on irrigated land erosion losses due to the continuous use of a cultivated crop and the almost inevitable introduction of nematode or some other pests or disease will sooner or later put a stop to a system of growing sugar-beets continuously on the same land.

In the case of wheat it is the rotation or change of crop which was of most importance in maintaining the yield, with manure of distinctly secondary value. In fact, it was nearly impossible to maintain wheat for ten years continuously even on lightly manured land because of wild oats and other weeds. An occasional fallow year would lessen this trouble from weeds. Alfalfa for five years at a time seemed to be distinctly better than a short-lived legume in maintaining the productivity of the land for wheat.

With potatoes, both rotation and manure were shown to be essential to maintain yield, while with alfalfa manure seemed to be the more important under these conditions. The corn and peas did not occur often enough for good comparisons, except that the corn gave a very consistent response to manure.

Table 3 and Figure 1 show by figures and graphically the average fertility of the plats in these various cropping systems as measured by the yield of unmanured sugar-beets on all plats in 1935. Of the various rotation systems, Rotation "G" which had alfalfa five years out of ten, left the soil in the most fertile condition; where manured it was better than the other manured rotations and where unmanured it was better than the other unmanured rotations. It was, however, under the conditions of this experiment, inferior to continuous corn, fallow, or potatoes where unmanured or to any of the continuous cropping systems that were manured each year. This last observation might be explained in part by the relatively small quantity of manure used in Rotation "G"—only three ten-ton applications in ten years.

Table 2—Significance of data of Table 1 as shown by consistency of results. Figures show number of times out of 10 that the treatment to the left was superior to that at the top of the column.[1] (Method suggested by S. R. Miles in his article entitled "A Very Rapid and Easy Method of Testing the Reliability of an Average and a Discussion of the Normal and Binomial Methods." In **Jour. Amer. Soc. Agron.**, 27:21-31. 1935.)

Treatment and Manure (tons)		Sugar-beet Data													
		Cont. 15	Cont. 5	D-M	F-M	G-M	A-M/2	E-M	A-M/4	D-gr.	D-O	Cont. O	B-O	A-gr.	A-O	E-O
Continuous	**Manure (Amt.)**															
"	40	10[1]	10	10	10	10	10	10	10	10	10	10	10	10	10	10
"	15		8	7	8	8	7	10	9	10	10	10	10	10	10	10
"	5			7	8	8	8	10	8	10	10	10	10	10	10	10
Rotation	**Manure**															
D	"				6	6	8	10	9	10	10	10	10	10	10	10
F	"					6	7	9	9	10	10	10	10	10	10	10
G	"						7	9	9	10	10	10	10	10	10	10
A	M/2							9	9	10	10	10	10	10	10	10
E	M								5	9	10	10	10	10	10	10
A	M/4									8	9	9	10	10	10	10
D	green										8	7	8	9	8	8
D	0											7	8	8	8	9
Continuous	**Manure**															
"	0												9	8	10	10
Rotation	**Manure**															
B	0													5	9	8
A	green														7	6
A	0															7

(Continued)

[1]Where figure is 10, odds are 1023 to 1 that treatment is actually superior.
" " " 9, " " 92 to 1 " " " " "
" " " 8, " " 17 to 1 " " " " "
" " " 7, " " 5 to 1 " " " " "
" " " 6, " " 1½ to 1 " " " " "
" " " 5, " " 1 to 1 " " " " "

Table 2.—(Continued).

Treatment		Wheat Data								
		A-M/2	E-M	A-M/4	A-gr.	E-O	B-O	A-O	Cont. M	Cont. O
Rotation	**Manure**									
G	0	6	7	8	9	9	10	9	9	10
A	M/2		6	8	9	9	9	9	10	10
E	Manure			6	8	7	9	8	9	10
A	M/4				6	7	7	9	9	10
A	green m.					6	8	9	10	10
E	0						7	9	10	10
B	0							5	7	9
A	0								8	10
Continuous	**Manure**									
"	0									10

Treatment		Potato Data				
		G-M	Cont. M	E-O	B-O	Cont. O
Rotation	**Manure**					
E	"	5	9	10	10	10
G	"		6	10	10	10
Continuous	**Manure**			9	10	10
Rotation						
E	0				9	9
B	0					8

Treatment		Alfalfa Data		
		F-M	G-M	Cont. O
Continuous	**Manure**	7	8	10
Rotation				
F	"		8	10
G	"			10

Treatment		Peas Data		
		G-M	D-gr.	D-O
Rotation	**Manure**			
D	"	6	6	8
G	"		5	6
D	green m.			6

Treatment		Corn Data	
		5 t.m.	O-M
Continuous	**Manure**		
15	"	9	10
5	"		10

(Concluded)

Table 3—Average yield of sugar-beets (tons per acre), in 1935, on the plats that had been under different cropping systems and manurial treatments prior to 1934.

Cropping System Previous to 1934	Manure			
	None	Light	Heavy	Green
Continuous				
Wheat	5.68	13.08		
Alfalfa	6.39	22.20		
Beets	7.81	12.44	20.25	
Potatoes	9.72	14.39		
Fallow	12.42	20.46	23.98	
Corn	14.08	20.43	23.41	
Rotation				
A	6.17	9.09		4.36
D	6.39	10.68		5.93
C	8.89			
B	8.27			
E	5.97	7.38		
F		10.61		
G	9.21	13.16	15.69	

Rotation "F," which had three years of alfalfa in seven and two manurings in seven years, tied with Rotation "D" (alternate peas and sugar-beets manured every other year) for second place. Rotation "D" had the advantage in that it received an average of 5 tons of manure per acre per year, while rotation "F" had an average of somewhat less than 3 tons per year. On the whole the annual legumes seem not to have been the equal of the longer lasting alfalfa in maintaining fertility. In the case of the unmanured treatments the annual legumes seem to have been of no value at all; Rotation "C" (alternate corn and beets) came out second best.

Of the various crops grown continuously without manure, wheat seems to have been the most exhaustive of soil fertility, followed in order by alfalfa, beets, potatoes, fallow, and corn. The relative position of corn and long-continued fallow in this case is probably misleading as these two series of plats were changed to alfalfa in 1932 and the alfalfa gave a higher yield following the fallow than the corn.

That the plat of continuous alfalfa, unmanured, should have so little fertility left is probably due to the fact that this is one of the oldest plats in the experiment, having been in continuous alfalfa without reseeding or manure from 1910 to 1934 and had become quite soddy and infested with bluegrass, orchard grass, and dandelion. The manured plat dated only from 1922 and was a good clean stand of alfalfa. Of the lightly manured plats, those in continuous beets, wheat, and potatoes were much more reduced in fertility than those in continuous alfalfa, corn, or fallow.

Manuring is seen to have been beneficial in every case and the heavy manuring always better than the light manuring; but the green manuring as applied here, with a small catch crop for green manure following a crop of peas or grain and in turn succeeded by sugar-beets, was of no value at all.

Tables 4 and 5 show the average results of analyses of the soils of these plats at the termination of the differential treatments in the spring of 1934, the surface 6 inches of soil from each plat was tested for organic matter,

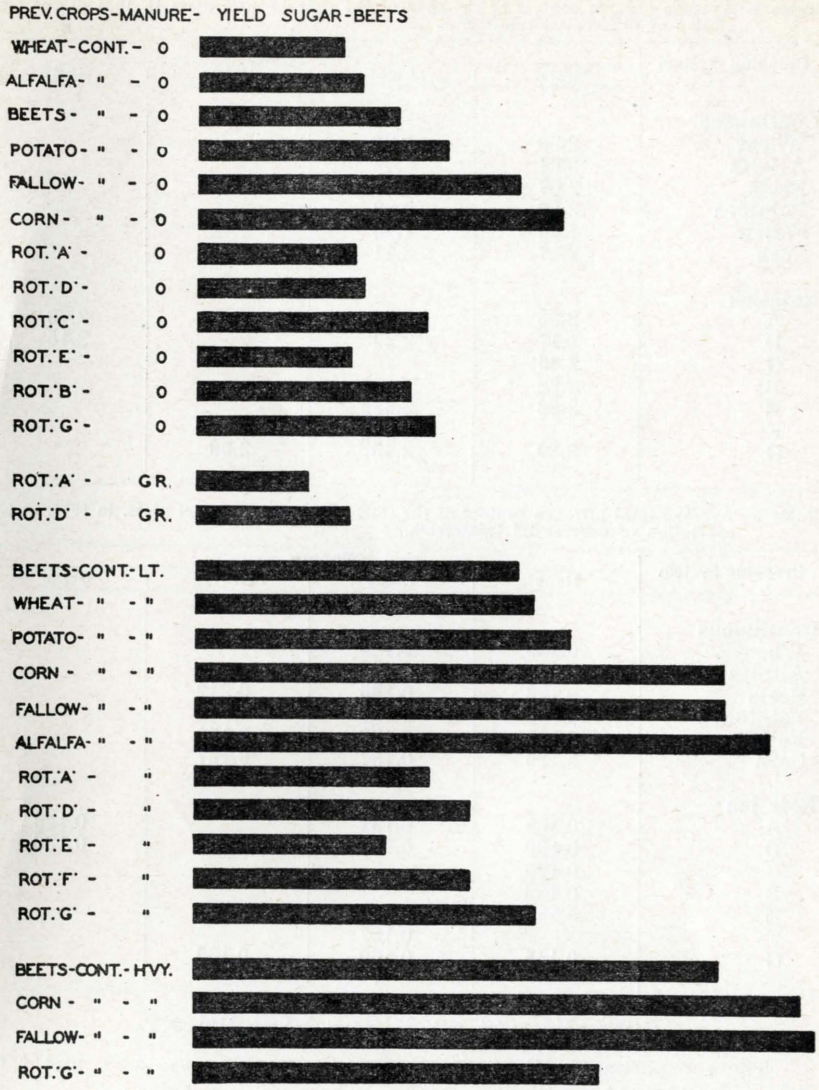

Fig. 1—Chart showing average yield of sugar-beets in 1935 on plats which had received different cropping and manurial treatments from 1924-33, inclusive.

using the rapid approximate test of Schollenberger[4] and for total nitrogen, using a standard kjeldahl test. An inspection of the results shows that either alfalfa or manure, or both, tended to build up both the organic matter and the total nitrogen in the soil, while long-continued fallow or cultivated crops without manure were exhaustive of both organic matter and total nitrogen in the soil. These observations bear out, and to a certain extent help to explain, the results in Table 3.

[4] "A Rapid Dependable Method for Determining Soil Organic Matter." By C. J. Schollenberger. In **Soil Science**, 24:65-68. 1927.

Table 4—Average organic content of the soils of the experimental plats in 1934 at the conclusion of differential treatments.

Cropping System	Manure			
	None	Light	Heavy	Green
Continuous				
Wheat	2.80	2.82		
Alfalfa	3.21	3.44		
Beets	2.07	2.57	4.52	
Potatoes	2.82	2.82		
Fallow	1.93	1.93	2.72	
Corn	2.17	2.11	2.84	
Rotation				
A	2.35	2.56		2.70
D	2.17	2.29		2.15
C	2.45			
B	2.22			
E	2.56	2.38		
F		3.07		
G	2.39	2.45	2.66	

Table 5—Average total nitrogen content of the soils of the experimental plats, in 1934, at the conclusion of differential treatments.

Cropping System	Manure			
	None	Light	Heavy	Green
Continuous				
Wheat	0.160	0.180		
Alfalfa	0.321	0.344		
Beets	0.123	0.155	0.242	
Potatoes	0.158	0.164		
Fallow	0.120	0.133	0.159	
Corn	0.125	0.137	0.167	
Rotation				
A	0.139	0.151		0.143
D	0.130	0.137		0.126
C	0.120			
B	0.136			
E	0.150	0.139		
F		0.167		
G	0.145	0.160	0.163	

CONCLUSIONS FROM THE EXPERIMENT

These experiments show for the crops, cropping systems, and conditions considered here that:

1. Manure is quite essential to maintain productivity of the soil, especially for sugar beets.

2. A good rotation is quite essential to maintain productivity of the soil, especially for the cereal crops.

3. Rotations including alfalfa for several years are superior for maintaining productivity to those with annual legumes or no legumes at all.

4. The nitrogen and organic matter in the soil may be maintained by the use of rotations including alfalfa and the careful return to the soil of the manure produced by feeding the alfalfa.

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