Ten Years' Results from the Ferden Rotation and Crop Sequence Experiment[1]

L. S. ROBERTSON, R. L. COOK, P. J. ROOD AND L. M. TURK[2]

The results of the first cycle of crop rotation and the field layout of the Ferden experiment were published in the 1946 Proceedings of the American Society of Sugar Beet Technologists. The experiment was started in 1940 for the purpose of obtaining answers to certain questions regarding soil management for sugar beets. It seemed particularly important to determine the role which legumes might play in the production of maximum yields. Seven cropping systems, involving three legumes, alfalfa, sweet clover and red clover, are arranged in such a way that all crops appear each year and plots are replicated four times.

All cropping systems are arranged as five-year rotations. Since the end of the first cycle of the rotations, brome grass has been seeded with the alfalfa and a mixture of alsike, June, mammoth and sweet clover was substituted for pure sweet clover as a green manure crop.

The soil where the experiment is located is classified as Brookston sandy clay loam. It contains 25 to 28 percent clay and 50 to 58 percent sand. The field is tiled but the structure of the soil is such that drainage is slow. The shape of the sugar beet roots indicates poor aeration during years of intensive spring rainfall.

The seven five-year rotations are as follows:

1. Barley, alfalfa-brome, alfalfa-brome, corn, beets.
2. Barley, alfalfa-brome, alfalfa-brome, beets, corn.
3. Barley, alfalfa-brome, alfalfa-brome, beans, beets.
4. Barley, oats, alfalfa-brome, corn, beets.
5. Barley, oats, red clover-timothy, corn, beets.
6. Barley, beans, wheat, corn, beets.
7. Barley-green manure, beans, wheat-green manure, corn, beets.
   (green manure is grown from alsike, June, mammoth and sweet clover seeded with barley and is plowed under the next spring for beans. The second crop of the same mixture is seeded in the spring on wheat and is plowed under the next spring for corn.)

All plots are divided into high and low fertility sub-plots. The high fertility sub-plots have received a total of 2,000 pounds of 2-16-8 fertilizer during the 10 years of the experiment. The low fertility sub-plots have received 800 pounds during that time. One-half of the fertilizer was applied at the time beets were planted. The remainder was applied to the grain crops.

[1] Contribution from the Department of Soil Science, Michigan State College, East Lansing, Michigan. Approved for publication by the Directors of the Michigan Agricultural Experiment Station as Journal Article No. 1331. The field experimental work is cooperative between the Michigan Experiment Station and the Farmers and Manufacturers Beet Sugar Association. The writers express thanks to R. W. Bell, Farm Crops Department, Michigan State College, for assistance with the field work and for the presentation of this paper at the National meeting of the Society.

[2] Assistant Professor, Professor, Extension Specialist and Head, Respectively, Department of Soil Science, Mich. State College.

The reader is urged to refer to the first report (1)[3] on this experiment for details of plot technique and field lay-out.

Experimental Results

The second cycle of these rotations started with the 1946 season. Seedling loss due to black root resulted in failure of the sugar beet crop in 1947. The yields obtained during the other four seasons of the five year period are recorded in Table 1. The 1946 yields were high for that area. They

Table 1.—The Effect of Rotations at Two Levels of Fertilizer Application on the Yield of Sugar Beets.

Rotation[2]	Crop Sequence[1]	Yield Per Acre—tons 1946	1948	1949	1950	1941-45 Mean	Diff In Mean	1946-50 Mean	Diff In Mean	1941-50 Mean	1941-50 Rotation Mean
1H	Ba, A ,A, C, SB	11.7	12.68	8.99	11.15	10.34	1.66	11.13	1.99	10.70	9.78
1L		12.8	10.51	6.49	6.74	8.68		9.14		8.86	
2H	C, Ba, A, A, SB	17.1	8.33	8.32	8.08	10.88	1.72	10.44	2.22	10.69	9.72
2L		14.6	7.32	6.21	4.74	9.16		8.22		8.74	
3H	Ba, A,A, Bc, SB	15.6	11.75	10.09	10.68	10.24	1.22	12.01	2.05	11.56	10.39
3L		14.1	10.83	6.75	8.14	9.02		9.96		9.42	
4H	Ba, O, A, C, SB	15.6	11.65	8.69	9.81	10.45	1.86	11.44	2.45	10.89	9.82
4L		13.1	9.96	5.67	7.21	8.59		8.99		8.77	
5H	Ba, O, Cl, C, SB	15.7	11.49	10.05	9.15	10.04	1.44	11.85	3.11	10.84	9.75
5L		12.4	9.29	7.13	5.14	8.60		8.74		8.66	
6H	Ba, Bc, W, C, SB	11.7	9.72	8.77	8.81	9.64	1.71	9.75	1.51	9.69	8.88
6L		10.9	9.04	5.47	7.54	7.95		8.24		8.07	
7H	Bagm, Bc, Wgm, C, SB	12.9	12.27	8.79	10.48	10.08	1.39	11.11	2.42	10.53	9.61
7L		11.5	8.96	6.23	8.08	8.69		8.69		8.69	
Significance Rotation[3]		*	**	-	*			**		**	**
L.S.D. 5%		2.56	1.81	1.37	1.76			1.8		0.59	0.59

[1] SB—sugar beets
C—corn
A—alfalfa-brome hay
Ba—barley
Be—beans
Cl—clover-timothy
W—wheat
Gm—green manure

[2] H—1,000 lbs. 2-16-8 per rotation
L— 400 lbs. 2-16-8 per rotation

[3] *—significant to 5% point
**—significant to 1% point

agree fairly well with the data obtained during the first cycle of the rotations. The highest yields were obtained where beets followed directly after two years of alfalfa-brome and the lowest were recorded from plots where beets followed corn in a rotation without a soil-building crop. By averaging the results from the high and low fertility sub-plots, the respective yields become 15.9 and 11.3 tons.

The second highest yields obtained in the 1946 season were from the plots where beets followed beans. This relative position of that rotation also agrees with the 1941-1945 results previously presented.

During the three years 1948, 1949 and 1950 sugar beets did not do well where they followed directly after alfalfa-brome. Comparing the results only from the sub-plots which received the heavier fertilizer applications, it is seen that the lowest yields in the experiment occurred on plots where that sequence was followed. Such was also true with respect to the yields from the low fertility sub-plots during 1948 and 1950. During the seasons 1943

[3] **Numbers in parentheses refer to literature cited.**

and 1945, beets did very poorly after alfalfa. The spring seasons of those two years were very wet. Planting was late in 1943 and the soil was worked wet.

It was suggested in the earlier publication (1) that beets do well after alfalfa when moisture and aeration conditions are favorable but do poorly in such a crop sequence during wet seasons when soils become puddled. It was further suggested that possibly a lack of soil air resulted in the accumulation of certain toxic decomposition products where fresh alfalfa had recently been turned under.

Smith and Cook (2) have shown by some greenhouse experiments that such a condition might occur. Now, the results from the last three years' studies lend further support to such a theory. When the last four years'

Table 2.—The Effect of Rotations on the Yield of Sugar Beets in the Greenhouse and in the Field.

Rotation	Crop Sequence	[1] Yield roots per pot or per acre Yield roots, percentage of top yield			
		Greenhouse		Field	
		grams	percent	tons	percent
1	Ba, A, A, C, SB	236	79	9.78	94
2	C, Ba, A, A, SB	234	78	9.72	94
3	Ba, A, A, Bc, SB	299	100	10.39	100
4	Ba, O, A, C, SB	214	72	9.82	95
5	Ba, O, Cl, C, SB	187	63	9.75	94
6	Ba, Bc, W, C, SB	149	50	8.88	85
7	Bagm, Be, Wgm, C, SB	202	68	9.61	92

[1] Greenhouse yields are averages of five crops, field yields are averages of nine.

results (the second cycle of the rotations) are averaged, rotation 2, where beets followed alfalfa-brome, becomes the poorest of all, except for number 6, the one without a soil building legume. It is interesting to note what has happened in rotation 3, where beets follow beans which follow the alfalfa-brome crop. Yields in that rotation, with both fertilizer levels, have considerably topped all the others. As the years have passed, evidence has continually pointed to the superiority of that sequence so far as sugar beets are concerned.

It is interesting at this point to present some supporting evidence from the greenhouse. In 1943 pots of soil were taken from the field plots to the greenhouse. During the next five years the same crops were grown in the pots as were grown in the corresponding field plots. The data recorded in Table 2 present a comparison between the five-year average pot yields and the nine-year average field plot yields. To make comparisons easier the yields are in each case reduced to a percentage basis with the highest yield taken as 100.

The highest yields in the pots were obtained where beets followed beans, as was the case in the field. In both greenhouse and field the lowest yields occurred where beets were grown in the rotation without a legume. Rotations 1 and 2 rank almost on an equal basis in both greenhouse and field.

These greenhouse results serve to support the evidence obtained in the field and the comparison is especially interesting to those who need proof

that greenhouse research may be very valuable when the work is properly conducted.

Reference to the last column in Table 1 shows that where sugar beets followed corn in rotation, where a legume had been plowed under for the corn, it made little difference what the legume was or how it was managed. As a nine-year average, the second highest yields were obtained where alfalfa-brome occupied the land during one year out of five, but yields almost as high occurred where the hay crop was left two years, as *in* rotation 1. Similar yields resulted where the legume was red clover hay or the clover-sweet clover green manure mixture. It should be remembered of course that, in rotation 7, two green manure crops were grown. A single green manure crop, handled as it is *in* this experiment, is probably not equal in soil building value to a hay crop of either clover or alfalfa.

Levels of Fertility

The mean yields reported in Table 1 show clearly that sugar beets are

Table 3.—The Effect of Rotation on the Sucrose Content of Sugar Beets.

Rotation	Crop Sequence	Percent Sucrose			
		1946	1948	1949	1950
1	Ba, A, A, C, SB	19.5	19.0	15.6	18.1
2	C, Ba, A, A, SB	19.0	17.5	15.8	16.9
3	Ba, A, A, Be, SB	20.0	19.0	15.9	17.7
4	Ba, O, A, C, SB	19.3	18.3	16.6	17.6
5	Ba, O, Ci, C, SB	19.7	18.6	16.9	17.7
6	Ba, Bc, W, C, SB	19.8	18.8	17.1	17.8
7	Bagm, Be, Wgm, C, SB	19.7	19.2	16.9	18.1
Significance			**	*	
L. S. D. 5%		N.S.	.78	1.49	N.S.

very responsive to commercial fertilizer and that rates of application should be rather heavy. A comparison of the 1941-45 means with those for 1946-50 shows that, for all the rotations which include a legume, the response to the larger applications of fertilizer was greater during the second cycle of the rotations. This apparent increase in benefit from the fertilizer was greatest *in* rotations 5 and 7, those which included the clovers instead of alfalfa. Where there was no legume in the rotation there was a smaller response to the larger application of fertilizer as time progressed. In other words, as time passes it appears that fertilizers are becoming less effective in the soil-depleting rotation and more effective in those which include a soil building legume.

Sucrose Content

During the first cycle of these rotations, there was some indication that sugar beets grown after alfalfa contained less sucrose than those grown in a non-legume rotation or after sweet clover (1). In 1941 those grown directly after alfalfa contained significantly less sucrose than did those in any other rotation. It was thought, however, that the difference may have been the result of beet size. In 1945 there was some further indication that all the rotations which included two years of alfalfa had brought about reductions in percentage sucrose.

Beets grown after alfalfa in 1948 again contained significantly less sucrose than did those produced in the other rotations. The data presented in Table 3 show further that in 1949, as was the case in 1945, the beets from plots where alfalfa had been grown two years in the rotation were lower than those from any of the other plots. Perhaps it is safe to conclude that alfalfa has somewhat lowered sucrose percentages. The reduction, however, if real, has been very slight.

Rate of fertilizer application has affected sucrose percentages in only one year, 1949. During that year the heavily fertilized beets contained significantly more sugar than did those which were grown on the low fertility plots.

Table 4.—The Effect of Rotation at Two Levels of Fertilizer Application on the Yields of Corn.

Rotation	Crop Sequence	Yield Per Acre—bushels							
		1946	1947	1948	1949	1950	1946-50 Rotation Mean	1941-45 Rotation Mean	1941-50 Rotation Mean
1H	SB, Ba, A, A, C	57.2	52.7	48.8	99.0	63.5	63.7	44.7	54.2
1L		57.3	44.4	46.6	103.4	63.9			
2H	Ba, A, A, SB, C	55.8	32.6	60.1	87.3	58.5	59.7	39.1	49.2
2L		57.4	36.3	62.1	86.8	59.0			
4H	SB, Ba, O, A, C	66.5	48.1	50.0	98.8	63.0	64.6	45.5	55.0
4L		62.0	46.6	52.5	96.2	62.7			
5H	SB, Ba, O, Cl, C	60.0	44.4	33.3	94.7	62.9	59.7	42.3	50.7
5L		60.9	45.8	35.2	90.8	62.8			
6H	SB, Ba, Be, W, C	41.2	30.8	26.0	62.9	50.0	40.6	33.1	36.8
6L		46.0	29.9	20.3	59.7	38.8			
7H	SB, Bagm, Be, Wgm, C	57.4	37.3	42.7	86.2	56.0	56.6	39.5	48.0
7L		64.2	33.1	44.4	85.1	59.9			
Significance (rotations)		**	**	**	**	**	**	**	**
L. S. D. at 5%		7.41	5.43	10.97	12.91	8.71	3.96	2.77	2.77

Other Crops

Michigan sugar beet growers are interested in several other cash crops. Most important among these are corn, wheat and beans. It would be very unwise to adopt a soil management program for sugar beets without considering the requirements of the other crops. One might lose more on the other crops, by some certain practice or crop sequence, than was gained by greater beet yields.

Corn

In Michigan corn is very important to the beet grower because it is the only other row crop on many farms. That is especially true in the southern beet area where beans are not grown. Six of the rotations in this experiment include corn and in all except number 2, corn precedes sugar beets. The yields of corn, by years for the second cycle, are presented in Table 4. Also presented are the rotation means for the first and second cycles and for the ten-year period. The years 1949 and 1950 were especially good corn years. Averages for the period 1946 through 1950 were considerably greater than for the previous five-year period.

Corn yields have been consistently higher where a legume was included in the rotation than where only soil-depleting crops were grown. Statistical analyses have shown this to be true for the first five-year averages and for each of the last five years. The production of one year of alfalfa in the five-year rotation caused an average increase in corn yield of 12.4 bushels during the first five-year period. The average yields for the last five years show this figure to be increased to 24.0 bushels. Apparently the value of the alfalfa is building up as the years pass.

Yields of corn were not further increased by leaving alfalfa-brome for two years. In fact, the 10-year average yields of corn were slightly higher where the hay was left only one year. Where corn has followed clover-timothy, the crop has yielded 4.3 fewer bushels than where it followed one year of alfalfa-brome.

The sweet clover grown during the first cycle of the rotation caused a 6.4 bushel average increase in yield, whereas the green manure mixture used during the last five years caused an increase of 16 bushels. During that period the difference in the averages from rotations 5 and 7 was not significant. In other words, the two green manure crops were about equal to one red clover-timothy hay crop.

Table 5.—The Effect of Rotation at Two Levels of Fertilizer Application on the Yield of Wheat.

Rotation	Crop Sequence	Yield Per Acre—bushels							
		1946	1947	1948	1949	1950	1946-50 Mean	1941-50 Mean	1941-50 Rotation Mean
6H	C, SB, Ba, Be, W	26.2	32.7	31.9	33.9	37.6	32.5	30.2	29.2
6L		24.7	31.5	27.3	32.9	34.8	30.2	28.1	
7H	C, SB, Bagm, Be, Wgm	25.8	37.8	35.5	38.6	42.7	36.1	33.9	33.2
7L		25.5	42.9	37.4	32.1	39.9	35.6	32.5	
Significance (Rotation)		—	—	—	—	—	**	**	
L. S. D. 5%							2.26	1.20	

In rotation 2, the crop sequence was such that beets followed alfalfa and corn followed the beets. As an average for ten years, corn yields were five bushels lower as a result of that sequence than where corn followed directly after two years of alfalfa-brome as in rotation 1. The sugar beet yield data (Table 1) show that sugar beets did not yield more where they followed the hay crop, so for the benefit of the corn it would seem well to recommend the use of rotation 1 in preference to rotation 2.

Levels of fertilizer application did not affect corn yields. This may have been partly due to the fact that the corn crop was not directly fertilized.

The question has often been asked "In what way does a soil building crop improve soil to result in increased yields of the following crops?" "Is it the result of nitrogen supplied by the legume or perhaps the result of improved soil structure brought about by higher organic matter levels?"

Certain studies not reported in this paper indicate that perhaps two-thirds of the yield increase attributed to the soil-building legume may be due to the nitrogen supplied by the decomposing residues. The remainder is probably the result of improved soil structure. Physical measurements

such as pore space and granule stability have shown that soil structure changes have resulted from the production of the soil building crops.

Wheat

Wheat follows beans in rotations 6 and 7. The only difference in the rotations is a green manure crop, consisting of a mixture of alsike, June, mammoth and sweet clovers, which is seeded twice in rotation 7. The data recorded in Table 5 show that the green manure crops increased wheat yields, as an average for ten years, by four bushels per acre. The wheat served as one of the companion crops for the green manure seeding, so the increase in yield was in spite of the competition offered by the clovers.

Yields of wheat were not appreciably higher on the plots which received the larger applications of fertilizer. This seems a bit strange because in other experiments the most economical rates of fertilizer have been much greater than the rate used on the low fertility side of these plots.

Table 6.—The Effect of Rotation at Two Levels of Fertilizer Application on the Yield of Beans.

Rotation	Crop Sequence	Yield Per Acre—bushels							
		1946	1947	1948	1949	1950	1946-50 Mean	1941-45 Mean	1941-50 Rotation Mean
3H	SB, Ba, A, A, Be	20.5	18.8	21.0	34.6	27.4	24.5	20.5	20.5
3L		19.4	15.2	20.3	32.2	26.7	23.0	19.6	
6H	W, C, SB, Ba, Be	17.1	10.8	19.1	31.0	22.0	20.0	17.1	16.5
6L		14.6	8.7	17.2	28.1	22.8	18.3	15.8	
7H	Wgm, C, SB, Bagm, Be	19.2	9.9	21.9	38.6	28.9	21.7	18.5	17.8
7L		16.5	6.2	18.2	31.8	21.6	18.9	17.3	
Significance (rotation)		—	**	—	—	*	**	**	**
L. S. D. at 5%		4.17	2.55	5.27	5.47	3.50	1.75	1.16	1.16

White Beans

In the Saginaw Valley and Thumb areas, most beet growers include beans in their rotation. This experiment has shown the desirability of growing beets after beans and the importance to the beet crop of a legume in the rotation, so it is well to see what effect the legume has on the beans. The crop occurs after alfalfa-brome in rotation 3 where the ten-year average yield has been 20.5 bushels an acre, four bushels more than that from the rotation where legumes are not grown. So, to the value of the alfalfa-brome in rotation 3 there should be added the value of one and fifty-one one hundredths tons of beets and four bushels of beans. If one adds still further the value of about four bushels of barley which followed the beets, the alfalfa-brome crop becomes a very valuable part of the rotation.

The mixed clover green manure caused a smaller but statistically significant increase in bean yields. Apparently alfalfa-brome is a much better soil building crop for beans than is the clover mixture. Perhaps the grass plays some role in this difference in response.

Heavier applications of fertilizer did have some effect on beans. The heavily fertilized plots averaged about one more bushel an acre than did those which received the lighter application. Over a ten-year period that difference may be significant. The loan data are reported in Table 6.

Summary

A crop rotation and sequence experiment was started in 1940 on Brookston sandy clay loam on the Ferden farm in Saginaw County, Michigan. The study was designed especially to determine the effects of other crops, including legumes and grasses, on the sugar beet crop. Seven five-year cropping systems are being studied. The details of the layout and experimental methods and the first five years' results were presented at the 1946 meeting of the American Society of Sugar Beet Technologists, and were published in the Proceedings of the Society.

The second cycle of this experiment was completed in 1950. The value of soil-building crops was more evident than during the first cycle. The highest beet yields were obtained in the rotation where the crop followed beans which in turn followed two years of alfalfa-brome hay. Lowest yields were obtained where there was no legume in the rotation.

At the end of the first cycle of the rotations, the highest average beet yields were from plots where beets had directly followed alfalfa. During that period, however, there were two years when that rotation did not show up so well. Rainfall was excessive during the growing season of both of those years. The second cycle of the experiment also included several years of high rainfall and the beets which followed alfalfa produced very low yields. As a result the averages for both rotation cycles show that beets directly after alfalfa did not do so well as they did after beans and no better than after corn.

Considering nine-year averages, it made very little difference, so far as beet yields were concerned, what legume was included in the rotation. One year of alfalfa-brome was as good as two and red clover-timothy proved to be almost as good. The two mixed clover green manure crops were just equal to the red clover-timothy hay crop.

Corn and bean yields were markedly increased by the production of legumes in the rotation. They were highest where the crop followed alfalfa-brome. The mixed clover green manure greatly increased corn yields and caused considerable increase in wheat and bean yields. Still higher corn yields resulted where red clover-timothy was grown in the rotation but that rotation was inferior to the one which included alfalfa-brome. As with sugar beets, yields of corn were not increased by leaving the hay for more than one harvest year.

Literature Cited

(1) COOK, R. L., MILLAR, C. E., and ROBERTSON, L. S.
1946. Sugar Beets in Seven Michigan Systems of Crop Rotation. Proceedings American Society Sugar Beet Technologists 4:73-87.

(2) SMITH, F. W. and COOK, R. L.
1946. The Effect of Soil Aeration, Moisture and Compaction on Nitrification and Oxidation and the Growth of Sugar Beets Following Corn and Legumes in Pot Cultures. Soil Science Society of America Proceedings 11:402-406.