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D. W. Pittman

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Maintaining The Productivity of Irrigated Land

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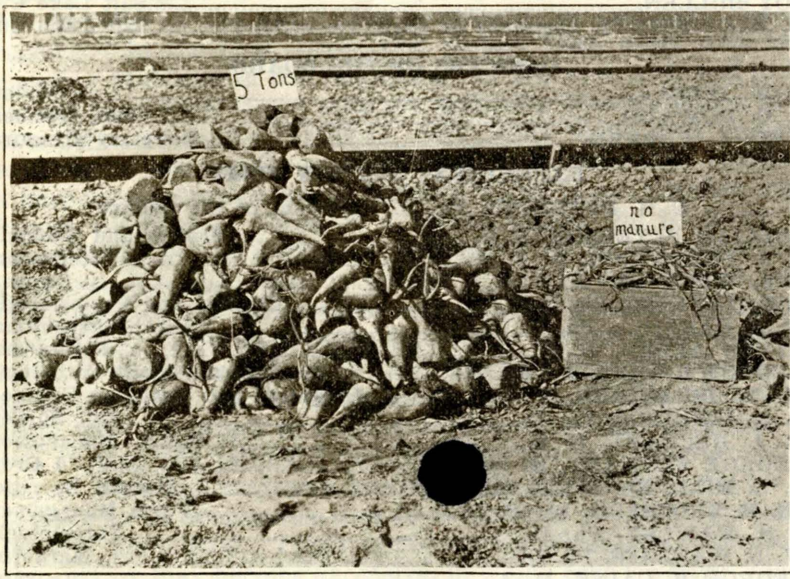

UTAH AGRICULTURAL EXPERIMENT STATION

LOGAN, UTAH

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MAINTAINING THE PRODUCTIVITY OF IRRIGATED LAND

By

D. W. PITTMAN[1]

It is almost universal history that in farming a newly developed region no attention whatever is paid to maintaining the fertility of the soil. This is natural for two very obvious reasons. In the first place the pioneer has other and more pressing problems in the "subduing" of the new land, and in the second place such virgin soils are generally blessed with a great abundance of native fertility. New lands in an arid or semi-arid region are usually especially fertile because they represent a long-time accumulation of fertility which is not possible under humid conditions. Since in a humid region the tendency for evaporation is not sufficient to remove all of the water that goes into the soil, there is always a certain excess that seeps downward to the water-table and is later removed by springs and rivers. This seep water constantly carries away a certain amount of the soluble salts that serve as food for plants. In an arid climate, on the other hand, the evaporating tendency is more than sufficient to remove all the water that goes into the soil so that the ultimate movement of the soil moisture is upward. This soil moisture leaves all its soluble material at the surface as it evaporates, and thus there is an accumulation of mineral plant-food. (This accumulation of soluble material at the surface may become excessive, in which case we have "alkali" —but that is another problem.) On the other hand, the organic matter or "humus" of the soil contains most of the nitrogen (one of the most important plant-foods), and this does not move with the water but rather is lost by slow oxidation or burning up, so that this element of plant-food is lost more rapidly from the well-aerated soils of the arid region than from soils in a humid climate.

It is the purpose of this bulletin to show by results of experiments conducted at the Greenville Experiment Farm that under the typical pioneer system of farming, i. e., cropping the land continuously without manure, even our best irrigated soil rapidly loses its productivity, but that with reasonable manuring it may be maintained in a productive condition for a great many years to come or may even be built up when "run down".

[1]This work being in the nature of a summary, the author has drawn freely from the work of everyone who has ever been connected with the Greenville Experiment Farm.

CONDITIONS OF THE EXPERIMENT

These experiments were conducted on the Greenville Experiment Farm two miles north of the Utah Agricultural College at Logan in Cache Valley. The climate is temperate and semi-arid. The mean precipitation of 16.78 inches occurs mostly as winter snow and in the month of May. The summers are quite dry. The evaporation from a free water surface is about 25 inches during the summer corresponding to a yearly evaporation of probably from 50 to 60 inches. The mean annual temperature is 47.4 degrees F. with a minimum of -30 degrees and a maximum of 101 in twenty-nine years. The average length of the frost-free season is 144 days. The precipitation at Logan for the time of the experiment and the average for the last thirty-two years is given in Table 1 which is compiled from the U. S. Weather Bureau reports.

TABLE 1.—PRECIPITATION AT LOGAN DURING THE YEARS OF EXPERIMENTS

	MONTH												
Year	Nov.	Dec.	Jan.	Feb.	Mch.	Apr.	May	June	July	Aug.	Sep.	Oct.	Total
1901-02	0.35	1.32	0.28	0.95	2.53	2.52	2.19	0.74	0.52	0.27	0.00	0.51	12.18
1902-03	1.80	1.02	2.62	0.33	0.52	2.01	2.89	0.25	0.35	0.12	0.90	1.01	13.82
1903-04	2.29	0.68	1.23	2.25	3.13	1.61	0.85	0.47	0.52	0.82	0.17	1.57	15.59
1904-05	0.00	0.90	0.40	1.22	2.22	1.60	2.13	0.63	0.20	0.73	2.07	0.37	12.47
1905-06	0.64	0.30	2.28	2.02	2.61	2.47	5.05	1.43	0.71	4.55	1.62	0.60	24.28
1906-07	1.07	1.99	4.85	2.69	3.54	1.58	2.80	2.44	0.00	0.90	0.12	1.45	23.43
1907-08	0.13	1.46	0.78	0.81	1.76	0.34	3.71	2.60	0.87	1.07	1.32	4.01	18.86
1908-09	1.37	0.13	2.97	2.59	2.04	0.56	2.51	0.22	0.94	1.08	2.28	1.53	18.22
1909-10	3.21	2.38	1.87	1.90	1.25	0.20	1.08	0.00	0.79	0.05	0.65	1.73	15.11
1910-11	0.87	1.45	5.76	1.46	2.72	1.48	1.77	0.29	0.12	0.00	1.92	1.14	18.98
1911-12	1.70	0.71	0.95	0.93	2.02	2.25	2.22	0.91	1.98	1.31	0.54	3.04	18.56
1912-13	2.40	0.35	0.69	0.92	3.09	1.65	1.25	2.09	1.98	0.14	1.47	2.14	18.17
1913-14	1.84	0.56	3.80	1.40	1.73	2.32	0.86	3.15	1.98	0.08	1.51	2.21	21.44
1914-15	0.00	0.55	1.06	1.32	0.59	1.94	3.28	1.12	0.22	0.00	3.44	0.05	13.57
1915-16	1.37	0.78	2.61	2.62	2.17	1.73	0.91	0.88	0.08	0.20	0.10	3.78	17.23
1916-17	0.80	2.89	0.91	4.51	1.88	2.84	4.21	0.48	0.48	0.00	1.34	0.07	20.41
1917-18	0.77	0.65	3.15	2.33	1.80	0.80	1.82	0.44	1.14	0.36	1.22	2.56	17.04
1918-19	0.94	0.35	0.02	1.88	0.74	1.62	1.20	0.00	0.31	0.40	2.88	4.43	14.77
1919-20	0.73	1.49	0.26	1.24	2.73	3.08	0.94	0.28	0.19	1.38	1.57	4.70	18.59
1920-21	1.36	1.51	1.48	1.22	2.77	3.64	1.50	0.01	0.00	0.74	0.34	1.28	15.85
1921-22	0.72	4.63	1.45	1.85	1.70	2.12	1.65	0.70	0.77	1.28	0.17	0.27	17.31
1922-23	0.55	2.55	2.71	0.48	0.96	3.10	1.53	1.81	0.58	0.64	1.30	2.14	18.35
32-year Avg.....	1.18	1.65	1.64	1.49	1.95	1.84	2.11	0.85	0.59	0.67	1.18	1.63	16.78

The soil is a uniform deep, rich loam, largely of limestone formation and quite fairly representative of the better soils of the Great Basin.

The soil was probably first broken about 1875, but its history is not known in detail before 1894 except that it was probably cropped to wheat almost exclusively. In 1894 it was seeded to alfalfa which remained on the land till 1901. The Experiment Station bought the land in 1901, and there is a detailed record of every plat of it since that time. It is very doubtful if any manure was ever applied to the soil before 1901. Table 2 gives a complete chemical analysis (strong acid digestion) of the soil made in 1902. As compared with estimates of the average contents of fertile soils for nitrogen, phosphorus acid, and potash, it is seen that it was a good fertile soil tho rather low in nitrogen and quite low in organic matter. Recent analyses made by a method of complete digestion[2] bear out these same relationships.

TABLE 2.—CHEMICAL COMPOSITION OF SOIL AT GREENVILLE FARM*

Determination (%)	Depth in Feet								Average Soils from Various Sources
	1	2	3	4	5	6	7	8	
Insoluble + silicia	42.18	36.51	32.15	41.65	28.72	29.64	31.14	30.75	
Potash (K_2O)	0.67	0.89	0.59	0.82	0.61	0.74	0.79	0.75	0.3 to 2.0
Soda (Na_2O)	0.35	0.47	0.47	0.62	0.37	0.42	0.45	0.74	
Lime (CaO)	16.88	17.80	21.34	15.60	22.62	23.15	22.24	21.78	0.1 to —
Magnesia (MgO)	6.10	9.46	7.57	7.48	9.36	5.89	6.06	5.63	
Iron Oxide (Fe_2O_3)	3.03	2.69	3.46	2.95	2.17	2.42	2.47	2.54	
Alumina (Al_2O_3)	5.64	4.69	3.40	6.09	5.33	8.07	7.90	9.03	
Phosphoric Acid (P_2O_5)	0.41	0.29	0.34	0.19	0.12	0.06	0.07	0.11	0.03 to 0.11
Carbon dioxid (CO_2)	19.83	23.11	26.67	20.88	29.31	29.57	28.80	28.13	
Volatile	5.60	3.38	3.93	4.23	0.91	0.95		0.24	
Total	100.69	99.29	99.93	100.51	99.52	100.91	99.92	99.68	
Humus	0.53	1.00	0.61	0.47	1.13	0.60	0.44	0.57	0.25 to 5.0
Nitrogen (N)	0.14	0.12	0.08	0.18	0.07	0.07	0.06	0.07	0.1 to 0.3

*From Utah Experiment Station Bulletin 115.

The relative crop-producing power of the land at the time of purchase is shown in Table 3. In this table the average production on the experiment field of corn, spring wheat, oats, alfalfa, potatoes, and sugar-beets for 1902, 1903, 1904, and 1905 is compared to the state's average for those years. The figures for the state's average were obtained from the Yearbooks of the Department of Agriculture and the figures for the experiment farm were obtained by averaging together the yields of all the unmanured plats of a certain crop where the yield had not been noticeably decreased by intentional faulty irrigation. It must be remembered that the state's average yield always includes much poor land that is farmed on a narrow margin because it is

[2]Thomas, M. D. "Aqueous Vapor Pressure of Soils" II. *In* Soil Science, Vol. XVII (1924), p. 3.

cheap and that therefore any piece of "good" land should produce from one and a half to two times the state's average yield. It will be noted that this field produced approximately two and three-tenths times the average yield of corn, one and nine-tenths times the average yield of spring wheat and oats, one and three-fourths times the average yield of alfalfa, two times the average yield of potatoes, and only about one-third the average yield of sugar-beets. It was "good" soil for most crops, but it was not "sugar-beet land".

TABLE 3. YIELD OF VARIOUS CROPS (unmanured) ON THE GREENVILLE FARM AT ABOUT THE TIME OF PURCHASE COMPARED WITH STATE'S AVERAGE (all crops irrigated)

Year	Ear Corn bu.acre[1]	Spring Wheat bu. acre	Oats bu. acre	Alfalfa tons acre	Potatoes bu. acre	Sugar-beets tons acre
1902	66.6	40.2	68.3		258	4.81
1903	61.7	42.3	67.6	5.295	269	3.48
1904	76.2	50.4	68.4	5.736	340	
1905	49.9	50.9	....	5.929	380	
Average on Farm......	63.6	46.0	68.1	5.653	312	4.15
Average of State........	27.7	24.2	36.5	3.250	151	12.25*
Farm Yield as *per cent* of state's average	230	190	187	174	207	33 *

[1]Corrected to normal moisture.
*Approximate.

Since we have later demonstrated that this soil will produce large crops of sugar-beets when well manured, it was probably the lack of organic matter or nitrogen or both that held down the growth of sugar-beets at the start. It would be interesting to know whether this soil would have produced sugar-beets in its virgin condition and had been depleted by excessive cropping to wheat and subsequently alfalfa or whether it never did possess the necessary elements for a beet soil until manured; but this we can never know. In order to prevent the old alfalfa roots from interfering with the experimental work in 1902 they were as far as possible pulled and hauled away in the early spring which may have deprived the soil of any advantage it might have had from the growth of the alfalfa.

RESULTS WITH SUGAR-BEETS

As before mentioned, at the time the farm was purchased after probably nineteen years' continuous cropping to wheat followed by eight years in alfalfa with all the hay and finally even the roots removed the farm would only produce about one-third of the state's average yield of sugar-beets in 1902 and 1903. No more sugar-beets were planted on the place again until 1910. By that time, due to the varied cropping treatments (but always without manure), the soil had improved until the average yield of sugar-beets for 1910 and 1911 was 7.116 tons, or about one-half of the state's average for that time. This was also 34 per cent of the yield of plats of manured beets that were grown just across the road. Since there were always from this time on numerous plats of beets on this field across the road which received identical cultural treatment with those on the Greenville Field they will serve as a better standard of comparison than the state's average.

TABLE 4. YIELD OF SUGAR-BEETS ON GREENVILLE FARM GROWN CONTINUOUSLY WITHOUT MANURE

A. Average of 12 plats for 6 years				B. Average of 3 plats for 8 years			
Year	Yield (tons acre)	(%) Manured	(%) State Avg.	Year	Yield (tons acre)	(%) Manured	(%) State Avg.
1916	8.08	43	78	1916	6.64	36	64
1917	6.90	34	80	1917	8.32	41	96
1918	7.85	36	64	1918	9.96	45	81
1919	4.78	30	49	1919	5.89	37	60
1920	5.01	26	40	1920	6.60	34	53
1921	1.10	8	11	1921	1.65	12	16
				1922	5.04	31	43
				1923	8.15	38	....

The effect of growing sugar-beets continuously on the same plats of several years without manure is shown in Table 4 The figures shown are an average of twelve plats for six years, 1916 to 1921, and of three plats for eight years, 1916 to 1923. The low yield in 1921 is due to a severe attack of *Phoma boetae* which had very slight effect on the manured beets but almost totally destroyed those unmanured. Even discounting this effect a slight general decrease is observed, tho the three plats have come back fairly well in 1923.

For eight years previous to this these plats had been continuously cropped (without manure) to different crops in an irrigation experiment. We have therefore a good opportunity to compare the effect of the previous crops and of the previous irrigations averaged together on the subsequent yield of sugar-

TABLE 5. EFFECT OF THE PREVIOUS CROP AND OF THE PREVIOUS IRRIGATION (for 8 years) ON THE SUBSEQUENT YIELD OF SUGAR-BEETS ON UNMANURED LAND

Previous Crop	Average Yield of Sugar-Beets: 1st 3 subsequent years	Average Yield of Sugar-Beets: 1st 6 subsequent years	Amount Previous Irrigation	Average Yield of Sugar-Beets: 1st 3 subsequent years	Average Yield of Sugar-Beets: 1st 6 subsequent years
Fallow	10.84	8.70	None	9.15	6.56
Potatoes ..	10.03	6.65	15.0 in.....	6.23	4.52
Alfalfa	5.88	4.43	25.0 in.....	5.79	4.17
Corn	5.27	4.18	37.5 in.....	5.19	2.88
Oats	5.73	4.14			

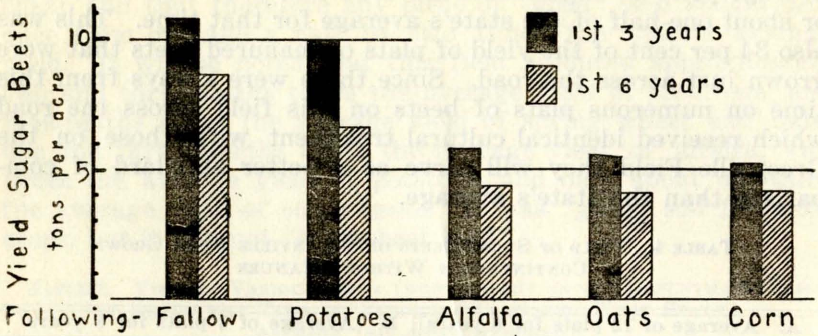

Fig. 1.—Effect of the previous crop on the yield of sugar-beets grown continuously for six years following various other crops grown continuously without manure for eight years

beets. The results are shown in Table 5 and Figure 1. The crop treatments fall into two groups: the land previously left fallow and the land previously in potatoes gave nearly twice the yield of sugar-beets that was obtained from the land previously in alfalfa, corn, or oats. It may seem startling to some that alfalfa was as hard on the land as corn or oats, but it must be remembered that in these experiments nothing was returned to the soil, and alfalfa is a gross feeder drawing heavily on the nitrogen both from the soil and the air. If the manure produced from all of these crops had been returned to the soil the figures would doubtless have been different. Other experiments at this station[3] show that under our conditions alfalfa decreases the soil nitrogen rather than increases it when it is completely removed and nothing is returned to the soil.

In 1922 some sugar-beets were planted on unmanured land that had been in grain continuously for ten years in comparison with similar land in beets for the past six years. The beets following grain yielded 3.7 tons per acre, while those following beets yielded 5.1 tons. The grain plats while in grain had not seemed so badly exhausted as the beet plats, but when planted to the same sensitive crop they proved to be in very bad shape. These figures would probably place sugar-beets in nearly the same group with potatoes and fallow in Table 5. It is notable that cultivated crops (or fallow) left the soil in better condition for several years of succeeding crops than those not cultivated.

The previous irrigation treatments as shown in Table 5 and Figure 2 show consistently that the more irrigation water applied to the previous crop the greater was the exhaustion of the

[3]Greaves, J. E. "Does Crop Rotation Maintain the Fertility of the Soil"? *In* Scientific Monthly, May, 1918, pp. 458-466.

soil for the subsequent crop. The subsequent crop was irrigated uniformly thruout.

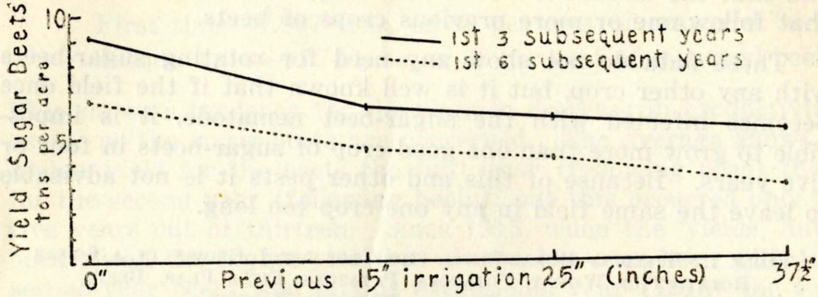

Fig. 2.—Effect on the yield of sugar-beets of different quantities of irrigation water applied to the soil regularly for eight years previous to the growth. of uniformly irrigated sugar-beets for six years (unmanured soil)

An interesting observation was made during the season of 1923 on the effect of manuring and of cropping system on the attacks of the beet blight or *Phoma boetae*. Considering the percentage of the beets diseased, Table 6 and Figure 3 show that

TABLE 6. EFFECT OF MANURING AND OF CROPPING SYSTEM ON *Phoma betae* (blight) OF SUGAR-BEETS (1923)

Treatment of Plats	Diseased Beets (%)
Unmanured—1st-year beets	94
Unmanured—2d-year beets	51
Unmanured—older beet land	46
Well manured—1st-year beets	8
Well manured—2d-year beets	3
Well manured—older beet land	2½

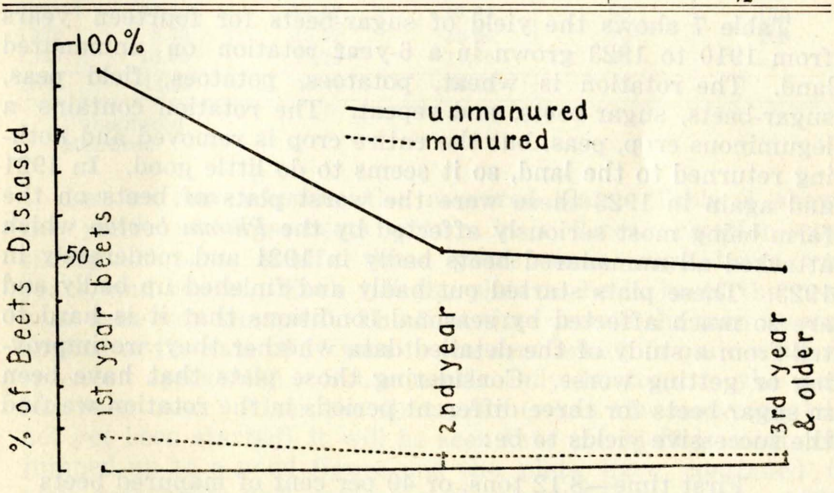

Fig. 3.—Effect of manuring and of cropping system on the proportion of sugar-beets affected by blight (*Phoma boetae*)

manure is one of the principal means of combatting this disease and that the disease is worse on first-year beets than on beets that follow one or more previous crops of beets.

These data do not show any need for rotating sugar-beets with any other crop, but it is well known that if the field once becomes infected with the sugar-beet nematode, it is impossible to grow more than one good crop of sugar-beets in four or five years. Because of this and other pests it is not advisable to leave the same field in any one crop too long.

TABLE 7. YIELD OF SUGAR-BEETS (tons per acre) GROWN IN A 6-YEAR ROTATION OF WHEAT, POTATOES, POTATOES, FIELD PEAS, BEETS, BEETS, AND REPEAT—WITHOUT MANURE

Year	Yield Beets after Peas 1st Year	Yield 2d-year Beets after Beets	Average Yield Beets	Average Yield as % of Manured Beets	Average Yield as % of State's Average
1910	.....	.....	7.75	40	60
1911	6.50	10.49	8.50	40	65
1912	9.79	6.09	7.94	40	73
1913	5.77	4.87	5.32	21	44
1914	13.07	9.24	11.15	45	81
1915	6.87	6.72	6.79	44	61
1916	4.20	5.21	4.71	25	55
1917	6.06	6.97	6.51	32	75
1918	9.97	5.78	7.88	36	64
1919	6.35	7.12	6.73	43	68
1920	3.58	4.18	3.88	20	31
1921	0.20	0.21	0.20	1	2
1922	3.25	5.40	4.33	27	37
1923	2.35	3.14	2.74	13	....
Avg.	6.00	5.80	5.90		

Table 7 shows the yield of sugar-beets for fourteen years from 1910 to 1923 grown in a 6-year rotation on unmanured land. The rotation is wheat, potatoes, potatoes, field peas, sugar-beets, sugar-beets, and repeat. The rotation contains a leguminous crop, peas, but the entire crop is removed and nothing returned to the land, so it seems to do little good. In 1921 and again in 1923 these were the worst plats of beets on the farm being most seriously affected by the *Phoma boetae* which attacked all unmanured beets badly in 1921 and moderately in 1923. These plats started out badly and finished up badly and are so much affected by seasonal conditions that it is hard to tell from a study of the detailed data whether they are improving or getting worse. Considering those plats that have been in sugar-beets for three different periods in the rotation we find the successive yields to be:

First time—8.12 tons, or 40 per cent of manured beets
Second time—5.61 tons, or 29 per cent of manured beets
Third time—3.534 tons, or 20 per cent of manured beets

Averaging all the plats for the first and second time round the rotation, we find:

First time—7.907 tons, or 38 per cent of manured beets
Second time—4.974 tons, or 26 per cent of manured beets

This shows a tendency for the plats to decrease in productivity as far as the sugar-beets are concerned. The average shows a higher yield for the beets the first year (following peas) than for the second year (following beets), but this occurred only in five years out of thirteen. Since 1915, when the yields have been lower, the higher yield has always but once been with the second-year beets, and in this exceptional year (1918) the two plats of beets were at opposite ends of the series, the first-year beets probably having the more favored location.

TABLE 8. YIELD OF SUGAR-BEETS (tons per acre) GROWN IN A 7-YEAR ROTATION OF OATS, 3 YEARS ALFALFA, OATS, 2 YEARS SUGAR-BEETS, AND REPEAT (sugar-beets manured)

Year	Yield Beets after Oats 1st Year	Yield Beets after Beets 2d Year	Average Yield Beets	Average as % of Manured Beets	Average as % of State's Avg.
1911[1]	7.68	9.41	8.69	41	67
1912[2]	8.08	16.89	12.50	65	116
1913	12.25	11.05	11.55	45	95
1914	16.14	18.67	17.41	70	127
1915	14.82	18.48	16.65	107	149
1916	18.21	22.34	20.28	108	195
1917	19.47	20.44	19.96	99	230
1918	21.60	25.43	23.52	107	192
1919	17.43	18.42	17.93	113	182
1920	16.18	17.83	17.00	88	138
1921	12.29	14.47	13.38	96	130
1922	9.79	15.52	12.66	79	109
1923	13.60	21.79	17.70	82	......
Avg.	14.99	18.44	16.72	88	

[1]Unmanured
[2]Manured

Let us now consider the manured plats. Table 8 shows the yields of sugar-beets grown in a 7-year rotation consisting of oats, alfalfa three years, oats, sugar-beets two years, and repeat. Each fall the plats to be in beets the next year were well manured. The first time around the manure was applied at the rate of 15 tons to the acre, which is quite a heavy spreader application. Subsequently only 10 tons to the acre has been used. After the first year (when the manuring had not yet been started) it will be seen that the yield immediately jumped up to a good figure and the plats have continued to yield reasonably well even on such a bad disease year as 1921. (Compare Table 6. All the tables for the same years are com-

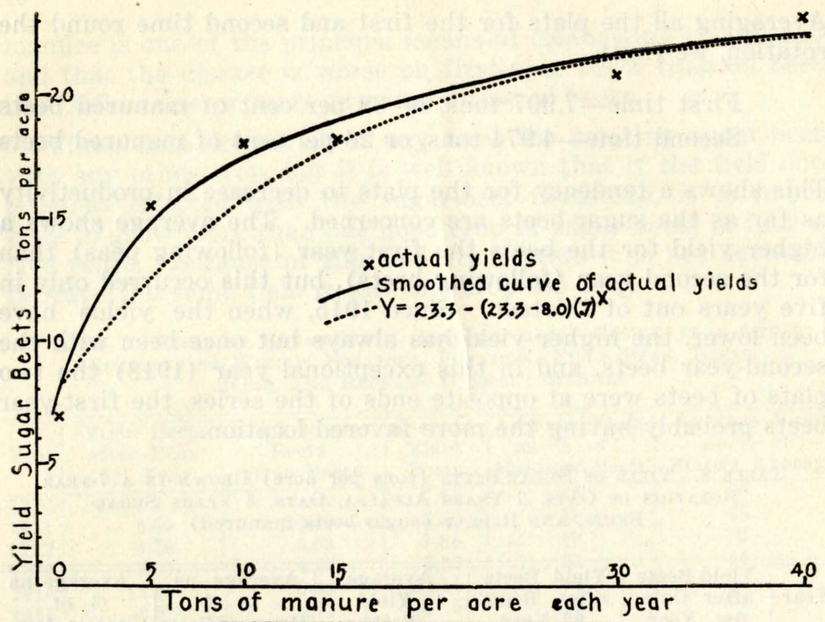

Fig. 4.—Effect of different quantities of manure applied each year on the yield of sugar-beets grown continuously on the same area

parable). Considering those plats that have been around the rotation twice we find the yield to be:

Original unmanured—8.69 tons per acre
1st time around—15.69 tons per acre
2d time around—15.73 tons per acre

This indicates that these plats are holding their own at a level nearly equal to the plats across the road which have been manured every year since 1904. This is during the same period that the plats on the unmanured rotation have been going down, as shown in Table 6.

The figures show that in this rotation the second-year beets are always much superior to the first-year. This may be partly due to some alfalfa plants continuing over into the first-year beets, partly due to the cumulative effect of two years' successive manuring or partly due to the better seed-bed prepared following beets the previous year.

There are two separate series of plats cropped continuously to beets that have received various quantities of manure each year. Because of different previous history they are not as entirely comparable as could be wished. The 5-, 15-, and 40-ton plats have been manured at this rate since 1910 but have been in sugar-beets only since 1919. The 0-, 10-, and 30-ton plats have been manured and in sugar-beets since 1916. The yields are shown in Table 9 and Figure 4. The largest yield of beets was with the largest application of manure (40 tons per acre), but the greatest value per ton of manure was secured with the smallest application. This means that if a person has not enough manure to cover all his beet land each year, the thinner he spreads it (within reason) the greater will be the returns from each ton of manure; but if he has plenty of manure then the thicker it is spread (up to 40 tons to the acre at least) the greater will be the returns from each acre. In general, it may be said that with the ordinary spreader application of about 10 tons to the acre, each ton of manure will produce nearly an additional ton of beets on land that needs it as badly as this land. A great deal of our soil needs it fully this badly. The smoothed curve of Figure 4 shows the average yield of beets for any quantity of manure applied annually to this soil.

TABLE 9. YIELD OF SUGAR-BEETS (tons per acre) GROWN CONTINUOUSLY ON PLATS RECEIVING VARIOUS QUANTITIES OF MANURE EACH YEAR

Year	Manure Applied per Acre					
	None	5 Tons	10 Tons	15 Tons	30 Tons	40 Tons
1916	5.76	oats	9.25	oats	11.88	oats
1917	8.96	oats	18.51	oats	20.70	oats
1918	9.12	19.06	23.59	22.52	27.22	24.60
1919	6.06	12.97	20.77	15.92	22.16	19.67
1920	4.98	9.99	17.58	13.18	22.46	22.87
1921	1.09	15.34	11.29	16.97	15.56	20.69
1922	5.38	14.83	20.90	16.73	20.49	23.90
1923	6.98	20.57	22.15	23.68	26.08	27.30
Avg. Yield	6.90	15.48	18.00	18.17	20.82	23.17
Additional tons of beets produced per ton of manure added						
	......	1.72	1.11	.75	.46	.41

The dotted curve on the same figure follows the mathematical law of diminishing returns. That is, if the yields followed this curve, the value of the second 5 tons of manure being 70% that of the first, then the value of the third 5 tons would be 70% that of the second, the fourth 70% that of the third, and so forth.

Stated mathematically in Spillman's[4] exponential form:

$Y = M - (M-y) R^x$ where Y = yield with x units of manure

M = maximum possible yield with any quantity of manure (must be approximated from actual curve)

y = yield with no manure

R = ratio of increment produced by any additional unit of manure to increment produced by the previous unit of manure.

[4]Spillman, W. J. "Application of the Law of Diminishing Returns . . ." *In* Jr. Farm Economics, Vol. V, No. 1, pp. 36-52.

The noticeably greater actual value of the manure in small applications over the theoretical curve is possibly due to the relatively greater residual effect of applications of former years in the case of the lighter applications as compared to the heavier applications.

Comparing all the unmanured beets grown on the farm from 1918 to 1923 with all the manured, it is seen that the manured beets yielded on the average 19.52 tons per acre, while the unmanured yielded 4.54 tons or only 23 per cent of the manured. This is the widest difference observed with any crop. The picture on the cover shows the extreme difference in yield in 1921 when the blight was bad. The large pile at the left and the small pile on the inverted apple box at the right were produced by the same sized plats.

RESULTS WTH POTATOES

The experiments with potatoes are not so extensive but show similar tendencies. Table 10 shows the yield of potatoes on the unmanured rotations from 1910 to 1923. The potatoes in the first two columns are in rotation "B", the beets in which have already been considered. The rotation is wheat, potatoes, potatoes, field peas, beets, beets, and repeat. The third-column potatoes are in rotation "C" which is a 4-year rotation of oats, corn, beans, potatoes, and repeat. No manure has ever been applied to these plats. In the next columns the average yields in the unmanured plats are compared with the average yield in manured plats across the road. The unmanured plats yielded 62 per cent as much as the manured. This is a much smaller

TABLE 10. YIELD OF POTATOES (bushels per acre) GROWN IN ROTATIONS WITHOUT MANURE (compared with manured potatoes)

Year	Rotation "B" After Wheat	Rotation "B" After Potatoes	Rotation "C" After Beans	Average Unmanured Plats	Average Manured Plats	Unmanured Plats as % of Manured
1910	87.5	78.0	88.7	84.8	....	....
1911	185.6	126.3	142.6	151.5	....	....
1912	195.9	172.2	122.1	163.4	429.5	38
1913	184.5	184.5	168.0	179.0	318.2	56
1914	121.0	61.0	171.3	117.8	265.1	44
1915	94.9	87.8	110.2	97.7	197.1[1]	50
1916	90.5	103.7	133.5	109.2	202.6	54
1917	167.8	160.8	159.9	162.8	266.1	61
1918	155.4	144.9	137.1	145.8	190.5	77
1919	173.5	176.1	184.0	177.9	300.4	59
1920	128.3	159.0	157.7	148.3	347.2	43
1921	81.7	70.7	104.5	85.6	108.2	79
1922	260.4	296.9	256.9	271.4	233.9	116
1923	246.0	246.4	271.0	254.5	401.4	63
Avg. 1911-23	160.4	153.1	163.0	158.8	271.7	62

[1]By comparison with state's average—no manured potatoes in 1915

TABLE 11. YIELD OF POTATOES ON LAND RECEIVING VARIOUS QUANTITIES OF MANURE EACH YEAR[1]

Manure	Yield in Bushels per Acre				Increase Due to Manure		
	1910	1911	1915	Average	Bushels	Per cent	Bushels for Each Ton Manure
None	140.9	124.7	94.0	119.9	....	....	....
5 Tons	224.0	118.8	140.5	184.4	64.5	53.8	12.9
15 Tons	261.7	218.3	206.4	228.8	108.9	90.8	7.3
40 Tons	328.5	245.5	298.7	290.8	171.0	142.6	4.3

[1]From Utah Experiment Station Bulletin 172

difference than in the case of the sugar-beets, but the soil was never in such bad shape for potatoes as for beets. While the unmanured plats have not decreased in productivity they have only once equalled the manured plats. There are only a few figures for the effect of different quantities of manure on potatoes. These are given in Table 11 and Figure 5. Here again we see that the manure is of more value per ton if applied at a moderate rate of application. For average applications on this soil a ton of manure is worth about 10 bushels of potatoes, the value varying with the need as in the case of the beets.

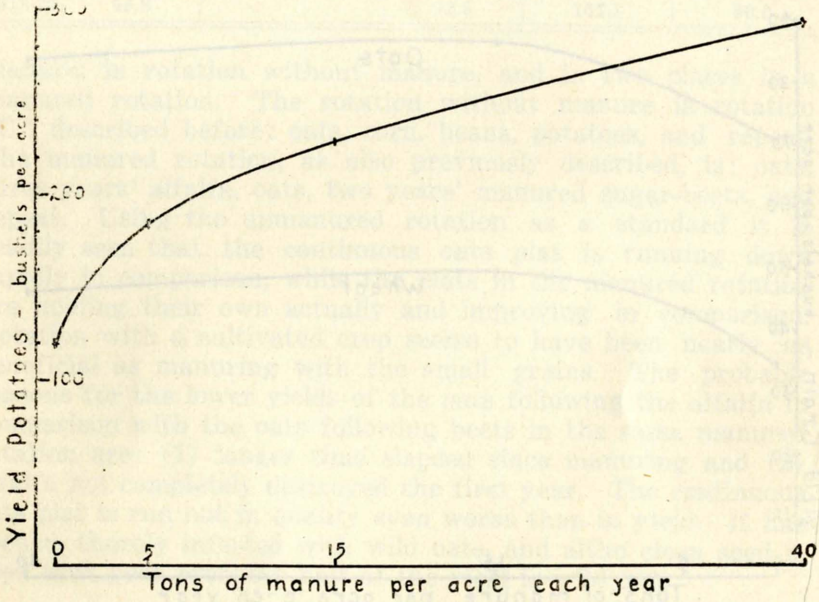

Fig. 5.—Effect of different quantities of manure applied each year on the yield of potatoes

RESULTS WITH GRAIN

The effect of manure on wheat and oats is shown in Table 12 and Figure 6. These show at once that the larger applica-

TABLE 12. YIELD OF WHEAT AND OATS (bushels per acre) ON PLATS RECEIVING VARIOUS QUANTITIES OF MANURE EACH YEAR

Manure Applied (Tons per Acre)	Wheat			Oats		
	Yield Average 3 Years	Increase due to Manure	Increase per Ton Manure	Yield Average 2 Years	Increase due to Manure	Increase per Ton Manure
None	38.1	.....	.....	78.7	.....	.....
5 Tons	48.1	10.0	2.00	86.9	8.3	1.65
15 Tons	55.1	17.0	1.13	96.8	18.2	1.21
40 Tons	51.4	13.3	0.33	93.1	14.4	0.36

tions of manure are harmful to the grain as compared with smaller applications. The damage comes thru the straw growing too rank so that the grain lodges and does not mature properly and cannot be harvested. The smaller applications increase the yield somewhat, but the manure is of not nearly so much value per ton here as with the sugar-beets or potatoes. A ton of manure in light application here gives an increase of about one bushel of wheat or one and one-half bushel of oats. This is why in our rotations we apply the manure to the sugar-beets and potatoes rather than to the grain.

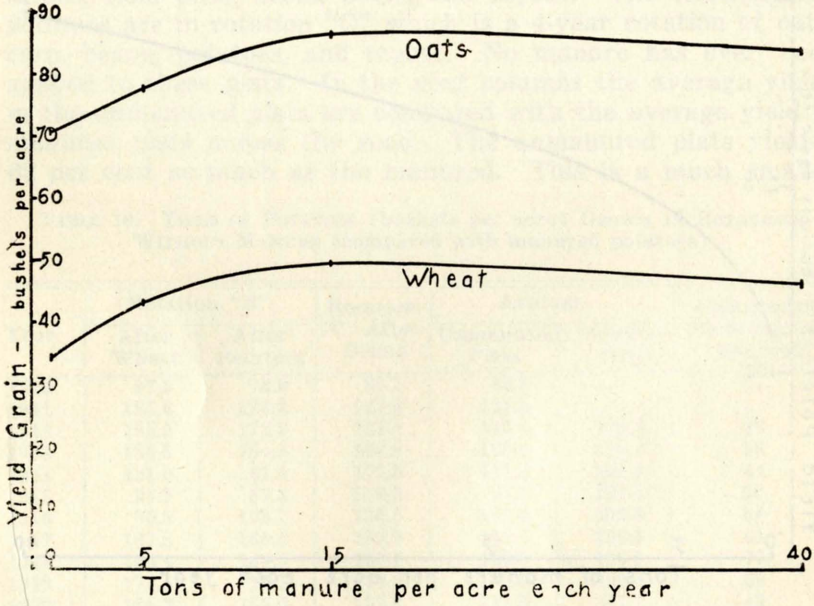

Fig. 6.—Effect of different quantities of manure applied each year on the yield of wheat and oats

Table 13 shows the comparative results of growing oats continuously without manure, with alternate fallow without

TABLE 13. YIELD OF OATS (bushels per acre) IN DIFFERENT FARMING SYSTEMS

Year	Continuous Oats No Manure	Alternate Oats and Fallow No Manure	Rotation Without Manure	After Beets in Manured Rotation	After Alfalfa in Manured Rotation
1908	115.6	....	....	....	....
1909	84.0	....	37.1	....	....
1910	51.9	....	72.5	....	....
1911	61.4	....	71.6	....	....
1912	87.3	....	130.1	123.5	112.0
1913	77.0	....	107.0	116.1	98.0
1914	73.5	....	80.7	59.5	44.6
1915	78.2	....	94.7	117.5	74.9
1916	52.7	74.9	74.5	109.5	59.3
1917	52.7	fallow	76.6	107.1	91.4
1918	53.9	86.5	72.9	109.9	87.8
1919	54.4	fallow	75.8	73.3	85.6
1920	52.7	74.1	79.9	123.5	90.6
1921	22.4	fallow	75.7	54.9	44.4
1922	49.2	66.7	74.1	137.5	93.1
1923	42.0	fallow	57.6	123.5	78.2
Avg. 1908-11	78.2		60.4		
Avg. 1912-17	70.2		93.9	105.5	80.2
Avg. 1918-23	45.8		72.6	103.8	80.0

manure, in rotation without manure, and in two places in a manured rotation. The rotation without manure is rotation "C", described before: oats, corn, beans, potatoes, and repeat. The manured rotation, as also previously described, is: oats, three years' alfalfa, oats, two years' manured sugar-beets, and repeat. Using the unmanured rotation as a standard it is readily seen that the continuous oats plat is running down rapidly in comparison, while the plats in the manured rotation are holding their own actually and improving in comparison. Rotation with a cultivated crop seems to have been nearly as beneficial as manuring with the small grains. The probable reasons for the lower yields of the oats following the alfalfa in comparison with the oats following beets in the same manured rotation are: (1) longer time elapsed since manuring and (2) alfalfa not completely destroyed the first year. The continuous oats plat is run out in quality even worse than in yield. It has become thoroly infested with wild oats, and altho clean seed is used each year probably half of the yield is wild oats.

RESULTS WITH ALFALFA

The results with alfalfa are shown in Table 14. The continuous alfalfa plats show no consistent increase or decrease in yield as yet, tho there is some blue grass sod creeping in especially on the oldest plat. There are no plats on the farm where manure is applied directly to alfalfa, but the three plats of alfalfa occurring in the 7-year rotation already mentioned, which is manured twice in the seven years (when planted to sugar-beets), show the residual effect of this manuring. The unmanured alfalfa plats average only 89 per cent of the yield of these plats. Only the two older of the manured plats were considered in this comparison except where comparing with 1st-, 2d-, or 3d-year alfalfa. The figures show that the 1st-year alfalfa on these rotation plats is not quite so good as the others, but the differences between the other two are probably so small as to be accidental.

TABLE 14. YIELDS OF ALFALFA WITH DIFFERENT TREATMENTS

Year	Continuous Alfalfa No Manure		Alfalfa in Manured Rotation			Avg. Yield Old Alfalfa in Manured Rotation	Unmanured alfalfa (6 plats) as % of Manured Rotation
	1 Plat	6 Plats	1st Year	2d Year	3d Year		
1911	5.428	....	....	....	....	....	....
1912	5.508	....	4.820	5.030	4.440	4.735	....
1913	5.218	....	4.680	4.820	3.950	4.385	....
1914	5.890	....	5.200	6.760	5.200	5.980	....
1915	6.520	....	5.340	6.570	6.760	6.665	....
1916	3.083	3.496	3.623	3.558	3.702	3.630	96 (1st year)
1917	4.388	3.942	3.729	4.836	4.282	4.559	82 (2d year)
1918	4.230	4.801	2.121	5.508	5.784	5.646	83 (3d year)
1919	3.926	4.006	3.410	5.113	5.145	5.129	78 (old)
1920	3.466	5.249	4.480	5.732	5.889	5.811	89 (old)
1921	5.547	6.148	6.391	7.549	7.207	7.378	83 (old)
1922	5.321	6.066	4.795	6.679	7.166	6.923	88 (old)
1923	5.138	6.235	6.234	5.423	5.528	5.476	114 (old)
Avg. 1912-15	5.784	....	5.010	5.795	5.088	5.441	...
Avg. 1916-19	3.907	4.061	3.221	4.754	4.728	4.741	86
Avg. 1920-23	4.868	5.925	5.475	6.346	6.448	6.397	93
Gn'd Avg.	4.853	4.993	4.569	5.632	5.421	5.526	89

RESULTS WITH CORN

There are now available 13 years' results on the experiment on the manuring of corn. The corn has been grown continuously on the same plats and has received: no manure, 5 tons of manure per acre per year, and 15 tons of manure per acre per year. There is an irrigation experiment superimposed on this manuring experiment so that the effect of manuring when different quantities of irrigation water are applied can also be

TABLE 15. YIELD OF CORN WITH VARIOUS QUANTITIES OF MANURE EACH YEAR

Year	No Manure Yield (bu. per Acre)	5 Tons Manure per Acre		15 Tons Manure per Acre		Average Yield for Each Irrigation Treatment
		Yield (bu. per Acre)	% Yield Unmanured	Yield (bu. per Acre)	% Yield Unmanured	
1911	38.5	43.3	112	52.0	135	
1912	36.1	52.1	144	57.2	158	
1913	42.8	62.1	145	69.0	161	
1914	36.9	49.8	135	54.7	148	
1915	30.0	45.5	152	44.0	147	
1916	35.9	49.7	139	49.8	139	
1917	47.2	56.6	120	59.5	126	
1918	48.9	61.4	126	64.9	133	
1919	36.1	35.4	98	31.4	87	
1920	46.4	62.8	135	62.1	134	
1921	26.7	25.3	95	30.7	115	
1922	32.9	43.6	132	54.4	165	
1923	40.1	43.3	108	59.3	148	
Average	38.4	48.5	126	53.0	138	
Increase per Ton of Manure	-----	2.0	-----	1.0	-----	
No Irrigation	32.0	44.0	138	44.2	138	40.1
5-inch "	37.1	49.2	132	50.5	136	45.6
10-inch "	39.1	47.9	123	52.6	134	46.6
20-inch "	43.2	51.2	118	57.5	133	50.6
30-inch "	40.7	50.5	124	57.3	141	49.5
40-inch "	38.1	47.9	126	55.9	147	47.3

observed. The results are shown in Table 15 and Figure 7. The corn yields which were obtained in a very moist condition have been reduced by 40 per cent, as before, to obtain the actual yield of dry marketable corn. The results by years show no consistent increase or decrease in productivity of any of the plats. They are all holding their own in about the same relative position. The effect of the manure in increasing the yield of corn is marked. The increase due to each ton of manure is much greater with the 5-ton than with the 15-ton application. When the figures are arranged by irrigation treatments they show very consistently a lower value of the manure with the irrigation treatment that gives the largest yield (20 acre-inches) and a steady increase in the value of the manure as the irrigation becomes more insufficient or more excessive. In other words, manure will somewhat counteract the effect of insufficient or excessive irrigation, and proper irrigation will to a certain extent make up for a lack of sufficient manure.

This entire relationship is shown graphically in Figure 7. In this figure the plats are assumed to be laid out in regular order with the unmanured at the bottom and the most heavily manured at the top and with the unirrigated at the left and the most heavily irrigated at the right. With the yields put in their

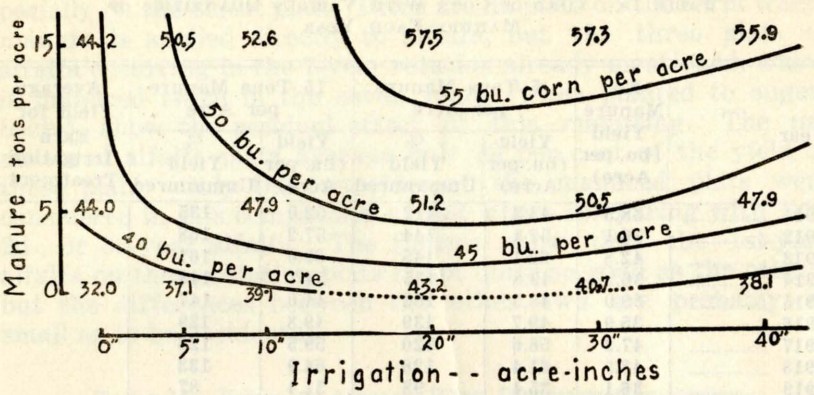

Fig. 7.—Effect of different quantities of manure and irrigation water in various combinations on the yield of corn

proper positions the area was "contoured" for yield, the curved lines passing thru points in this imaginary field that would have the same yield. (In making this chart it was at once evident that the yield of 49.2 bushels of corn per acre with 5 inches' irrigation and 5 tons of manure per acre is too high for its position in relation to the others, so it was necessary to omit this figure, as being due to some accidental condition, in drawing the contours. All the other figures lent themselves just as they were to the drawing ot smooth contours as shown.)

The nearly vertical position of the contours in the left portion of the chart shows that with these small amounts of irrigation lack of sufficient irrigation was almost the only determining factor of these two in the yield. The horizontal position of the contours at the region of 20-inch irrigations shows that manure was the sole limiting factor of these two with this amount of irrigation. The upward turn of the lines in the right of the chart shows that excessive irrigation was here becoming a factor in reducing the yield. The lowest position of the contours being near the 20-inch irrigation line shows that this was about the optimum irrigation. The continued bearing of the 50-bushel and 55-bushel contours to the left at the line of 15 tons of manure shows that more manure would have still further increased the yield with more than 10 inches of irrigation. The nearly vertical position of the 45-bushel curve at the line of 15 tons of manure shows that with less than 10 inches of irrigation more manure would not have materially increased the yield. The proximity of the lower yield curves as compared with the higher yield curves shows the greater efficiency per ton of manure or per inch of irrigation where small amounts of each were used.

WHICH CROP TO MANURE

The foregoing data furnish a basis for rough estimation of the relative response of the different crops to manuring. While, as has been shown, the increased yield due to manure depends wholly on the need of the soil for manure and on the rate of application, still there are some very noticeable differences in the response by the different crops. Roughly, one may say that in these experiments a good standard manuring each year gave an increased yield of 10 tons of sugar-beets, 100 bushels of potatoes, 10 bushels of wheat, 15 bushels of oats, and 15 bushels of corn, while the residual effect of two manurings in seven years gave an increase of over half a ton of alfalfa per acre.

APPLICATIONS

These data clearly indicate that it is possible to maintain this soil in a state of high productivity, or build it up when it is run down, and then maintain it by the continued use of moderate applications of manure and a certain amount of crop rotation. To produce the manure it is necessary that the rotation include a feed crop (most generally alfalfa in Utah) and to get the most value from the manure it is generally desirable to have some cash crop such as sugar-beets or potatoes to use it on. Also the rotation should include both cultivated crops and an occasional "seeding down" of the land to make the problem of weed control easier and to maintain the organic matter of the soil.

Since analyses on the plats described here as well as on many other soils have shown that nitrogen (the most important constituent of the organic matter of the soil) is more often than any other one thing the limiting factor in soil fertility, it is also essential that the rotation be so designed as to maintain the nitrogen supply of the soil. This involves the growing of a leguminous crop such as alfalfa, clover, peas, etc., and returning the manure formed from it, since legumes are the only crop plants that can take nitrogen from the air. By knowing the average yield and nitrogen content of the various crops and the approximate return in the manure, it is possible to calculate in a very rough way whether or not a certain rotation will maintain the nitrogen content of the soil. An example will illustrate this point better than a long explanation. Let us assume a 10-year rotation of: alfalfa—5 years, potatoes—1 year, sugar-beets—3 years, and wheat—1 year serving as a nurse crop for alfalfa. This gives half the farm in alfalfa (only one-fifth of it new each year), three-tenths of the farm in sugar-beets, and one-tenth each in potatoes and in wheat. The alfalfa is left for five years as it is not generally considered advisable to plow up a younger stand than this because of the expense of seeding and the lower yield the first year. The potatoes follow the alfalfa because experiments have shown that potatoes or corn yield better proportionately following alfalfa than do other crops, tho grain is frequently used in this position. If the field were infested with nematode it would be impossible to thus leave the sugar-beets for three years in succession.

Considering now the nitrogen removed from the soil in the course of the 10-year rotation we may have:

50 tons sugar-beets	@ .15 per cent N=	150 lbs. N	
300 bu. potatoes......	@ .39 per cent N=	70 lbs. N	
40 bu. wheat..........	@ .27 per cent N=	64 lbs. N	
25 tons alfalfa (estimated).....................		56 lbs. N	from soil
Total removed from soil..............		340 lbs. N	

It is customary to assume that the alfalfa returns as much nitrogen to the soil in its roots as is taken from the soil, the balance in the hay coming from the air. However, since these experiments showed that alfalfa was as exhaustive to this soil as was corn, it is here assumed that the alfalfa left the soil in as poor condition as tho a 40-bushel crop of corn had been removed.

Now considering the return, the 25 tons of alfalfa will contain about 1200 pounds of nitrogen. About two-thirds of this, or 800 pounds, will be returned in the fresh manure when this is fed. Assuming ordinary careless handling of the manure, one-half of this will be lost before reaching the soil, leaving 400 pounds of nitrogen returned. Subtracting the 340 pounds removed, we have still a balance of 60 pounds of nitrogen returned to each acre in the 10-year period, and this rotation is more than maintaining the nitrogen. While such figures are very rough, still it is probably safe to say that if about a third of the irrigated land (on a farm or in a community) is kept in alfalfa and if the hay is fed and the manure carefully returned to the soil, the soil nitrogen will be maintained. Since at present about one-fourth of the irrigated land in Utah grows alfalfa this would not involve any appreciable change in our cropping systems. Probably better handling of the manure or the use of manure produced from the feeding of some of the other crops would make up the deficiency.

A matter of great importance is the prevention of this 50 per cent loss of nitrogen which customarily occurs thru careless handling of the manure. This loss occurs either thru the leaching away of the nitrogen with water that percolates thru the manure and runs away (as drip from the eaves of the barn in a heavy rain for instance) or by escape of the nitrogen into the air, as ammonia (which gives the characteristic odor to manure), and as free nitrogen (odorless). There is also frequently considerable loss thru not saving the liquid portion of the manure (which contains nearly half the nitrogen) because of insufficient absorbent bedding. The methods of preventing these losses are rather obvious. In the first place there should be enough absorbent bedding to retain all the liquid. In the second place it should be seen that no water leaches away from the manure pile. In the third place the escape into the air should be reduced by excluding air from the manure and keeping it cool. To keep the air from the manure it should be thoroly compacted by tramping with stock or otherwise, and if possible kept thoroly moist, without allowing any run-off of water. A shade from the hot sun helps keep it cool and moist.

If it were possible to spread the manure fresh on the land each day this would be a nearly ideal way of preventing the handling loss, but generally this is quite impractical. Where the manure accumulates to considerable depth in a barn or feeding shed and is well tramped by the stock there is relatively little loss, but such a practice cannot be generally commended for sanitary reasons. Where the manure must be piled a large, high, straight-sided pile, slightly hollowed on top rather than full in the middle and watered as much as possible without leaching, is the best. The ordinary loose, sloping pile under the eaves of the barn is probably the worst way to keep manure. Composting the manure with sods is an almost ideal way to preserve it, but is too expensive of labor for any but greenhouse or very intensive truck-farming. Concrete manure pits, especially if provided with a sump and a pump for pumping water from the bottom of the manure on to the top again, are very fine where the expense is justified. Chemical preservatives for manure are as a whole unsuccessful. Lime is worse than useless as it leads to rapid loss of nitrogen. For spreading the manure on the field a spreader is generally worth while for giving a uniform, light application, thus getting the most benefit from the manure. The practice of piling the manure in small heaps in the field to be scattered some time later is a source of appreciable loss. When the manure is applied in the fall or winter, the winter weathering and the melting of the snow will aid materially in getting it thoroly into the soil.

SUMMARY

1. This bulletin reports the results of twenty-one years' experiments and observation of soil fertility conditions on the Greenville Experiment Farm north of Logan, Utah.

2. The soil at this farm is typical of much of our good irrigated land. It produces good yields of all the ordinary crops except that it will not give a good yield of sugar-beets without manure.

3. This soil produces good crops of sugar-beets when well manured. Sugar-beets are much more responsive to manuring than any of the other crops studied.

4. Sugar-beets grown continuously or in rotations without manure tend to decrease slightly in yield.

5. Corn, the small grains, and alfalfa were more exhaustive to the soil, as measured by subsequent sugar-beet production than were potatoes, sugar-beets, or summer fallow.

6. The more irrigation water applied, the more rapid was the exhaustion of the soil.

7. Manure was very effective in enabling sugar-beets to resist the blight (*Phoma boetae*). First-year beets were blighted worse than those on old beet land.

8. The heaviest yearly application of manure (40 tons per acre) gave the largest yield of sugar-beets.

9. The value of the manure per ton was very much greater when it was put on in small (thin) applications.

10. Next to sugar-beets, potatoes gave the greatest returns from the use of manure.

11. The small grains gave only moderate returns from the use of manure and were injured by very heavy applications (40 tons per acre).

12. The continuous growth of small grains without manure was very exhaustive to the soil. Rotation even without manure increased the yield of the small grains.

13. Alfalfa gave good response to the residual effect of manure applied earlier in the rotation.

14. Good increases in the yield of corn were obtained from the use of manure.

15. Manure was relatively somewhat more beneficial with insufficient or excessive than with optimum irrigation.

16. It is possible to maintain the nitrogen content of this soil by a rotation system in which about one-third of the land is kept in alfalfa and the manure produced from feeding this alfalfa is returned to the land.

17. Proper handling of manure will largely reduce important losses.