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A Half Century of Crop Rotation

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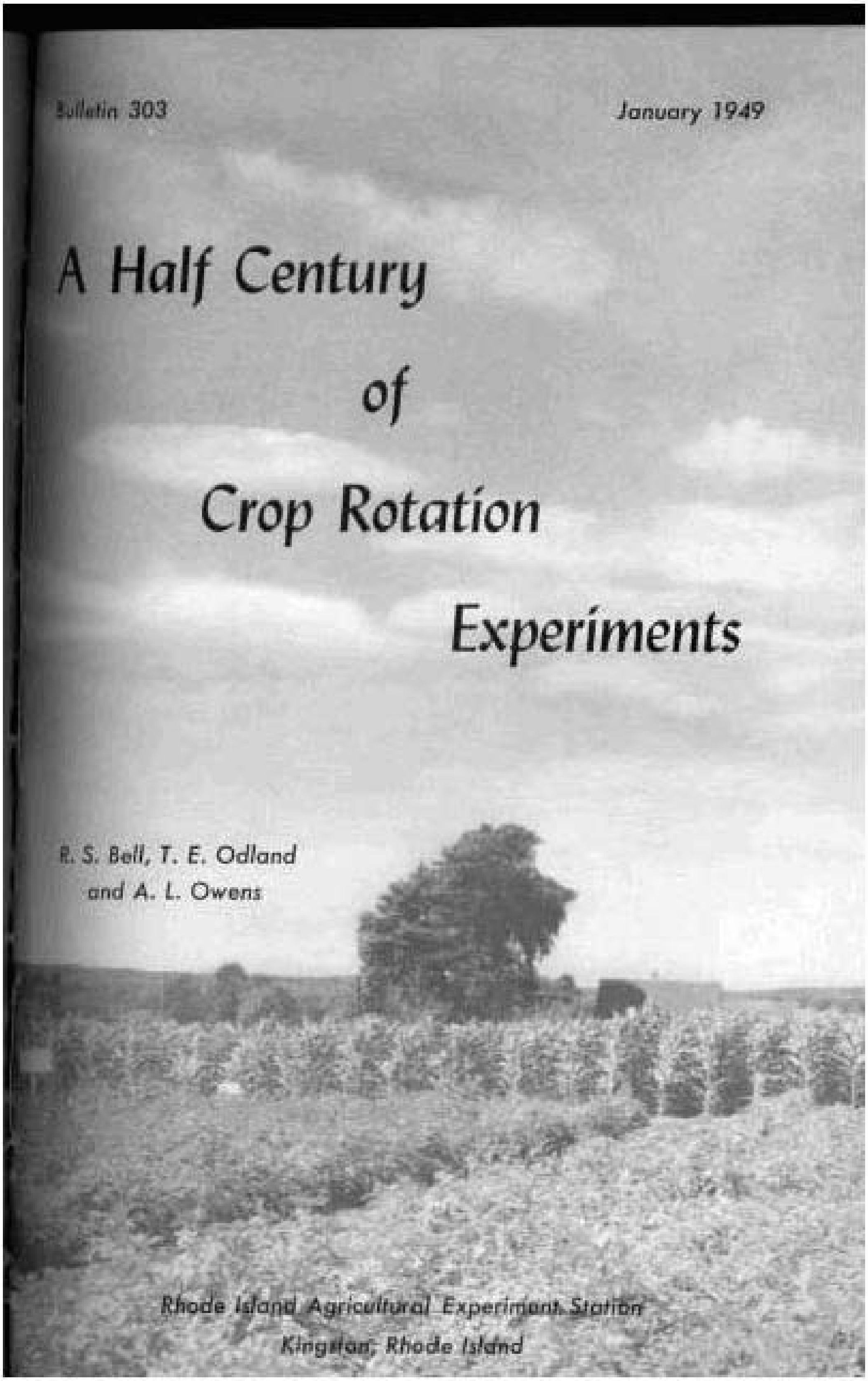

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ABSTRACT

Fifty-three years of crop rotation studies, started in 1894, were concluded in the fall of 1946. These experiments were on Bridgehampton very fine sandy loam soil that was originally acid and produced meager crops. Within a very few years it became evident that the yields of crops could be materially increased by the use of agricultural lime and chemical fertilizers. The records of the last 17 years of the experiments are reported in this bulletin and comparisons are made with results from former years.

The 3 rotations described in this bulletin are known as rotations B, E, and F. B was a 6-year sequence: 1 year of potatoes followed by a year of ensilage corn and 4 years of alfalfa-timothy hay. Rotations E and F were 5-year sequences in which potatoes were followed by Rhode Island White Flint corn and 3 years of hay. Rotation E contained alfalfa, red clover and alsike clover as well as timothy and redtop in the grass seed mixture. The meadow seeding for rotation F consisted of timothy and redtop grasses.

The average yields of Irish Cobbler potatoes were: 222 bushels per acre on the "clover rotation," 246 bushels per acre on the "alfalfa rotation" and 294 bushels per acre on the "timothy-redtop" rotation. The superior yields of potatoes after the non-legume hay is thought to result, in part, from a more favorable supply and balance of potassium, calcium and magnesium left by the grass crop.

Rhode Island White Flint corn yielded slightly more grain when grown after the legume-grass hay rather than grass hay alone. The supply of available nitrogen seemed to be a controlling factor influencing the yield of corn.

The alfalfa-timothy seeding outyielded the general legume hay mixture during the second and third years. The non-legume seeding produced the smallest amount of hay with the least feed value. The general legume mixture usually produced more hay the first year because the biennial clovers that it contained appeared to mature more quickly than the alfalfa.

The average net returns per acre were figured for 2 periods of 5 years, 1935-1939 and 1942-1946. During the first period these net returns per acre were $40.77, $24.46 and $10.93 for rotations B, E, and F, respectively. During the second period the net returns were $61.41, $34.52 and $39.85 respectively for these rotations.

A HALF CENTURY OF CROP ROTATION EXPERIMENTS[1]

By R. S. Bell, T. E. Odland, and A. L. Owens[2]

This bulletin reports the final results of 3 crop rotation experiments for the period 1930 through 1946, with a summary of results obtained in the earlier years of the experiment which began in 1894. These investigations were concluded at the end of the 1946 growing season in order to prepare the land for other urgent experiments.

Previous publications of the Rhode Island Agricultural Experiment Station have recorded the results up to 1930. A full description of these rotations may be found in the earlier reports.[3]

DESCRIPTION OF EXPERIMENTS

The crop rotation experiments were begun to determine whether the yields of the common farm crops could be maintained over a period of years by using commercial fertilizers alone without manure. Two 5-year rotations, known as rotations E and F, received no manure at any time. The 6-year sequence, called rotation B, received stable manure on 3 particular plots preceding the corn. The other 3 received commercial fertilizer only.

The 6-year rotation (B) during 1933-1946 consisted of 1 year of silage corn, 1 year of Irish Cobbler potatoes and 4 years of alfalfa-timothy hay. One 5-year rotation (E) consisted of Rhode Island White Flint corn, Irish Cobbler potatoes and 3 years of hay containing a mixture of alfalfa, red clover, alsike clover, timothy and redtop. The other 5-year rotation (F) contained no legumes and was seeded to a mixture of timothy and redtop grasses. Thus we have a comparison of 3 types of hay mixtures. The mixtures were sown in late summer after the Irish Cobbler potatoes were harvested.

In this experiment each crop in each rotation was grown side by side, so that the whole rotation could be seen simultaneously each year.

The soil on the experimental plots is classified as Bridgehampton very fine sandy loam. In a former classification it was called Merrimac silt loam. Three feet of the loam is underlain by gravel so that the soil is well drained.

[1]Contribution No. 729 of the Rhode Island Agricultural Experiment Station, Kingston, R. I.

[2]The authors gratefully acknowledge the assistance of the following in conducting this experiment during the period 1930-1946: H. C. Knoblauch, G. F. Lea, T. R. Cox, C. H. Moran, A. E. Rich and F. B. Muller. The assistance of Dr. J. L. Tennant is also acknowledged in the preparation of the section on Financial Comparisons.

[3]Rhode Island Agricultural Experiment Station Bulletins No. 74, 75, 76, 99, 135, 167, 185 and 224.

An excellent stand of alfalfa-timothy hay similar to that grown on rotation B.

EARLY HISTORY

Wheeler and Adams (14) reported in 1904 that preparation of the area for the experiments started in 1889. The area was cropped uniformly for 4 years to study the initial productivity of the plots. At this time the land yielded scarcely a quarter of a ton of hay per acre, or half a ton of corn stover. During the first 3 years of the rotation (1894-1897) it was not realized that the soils were acid and needed lime. As soon as the need was realized, lime was added. The policy since has been to lime once in the rotation, immediately after harvesting potatoes, so that the new legume seedings can benefit by the liming.

In 1916 Hartwell and Damon (4) published a 20-year comparison of 5 rotations. The best yield of potatoes was from the rotation where tubers were grown only once in 6 years (rotation B). The average yields of hay were largest in this 6-year rotation, regardless of years removed from seeding. This 6-year rotation also produced slightly larger yields of rye grain and hard corn than the 5-year sequences.

Odland, Damon, and Tennant (7) in 1930 showed that the yields of corn in rotations B and E were superior to those from rotation F in which no legumes were grown. They also pointed out that rotation E (legume hay) produced approximately 1 ton more of hay than F (non-legume hay). The production of digestible protein was nearly twice as great from the legume rotation. Potatoes, however, yielded slightly higher in the non-legume rotation (F). Rotation F showed the least net annual returns per acre. The computed net annual returns per acre were $18.97 for F; $26.34 for E; and $40.78 for B.

CROPPING PLAN CHANGES AND CULTURAL METHODS

Few changes in the cropping plans have been made since 1930. In rotation B, West Branch Sweepstakes corn was substituted for the Rhode Island White Flint in 1933 and grown for silage corn until 1946, when Ohio K-24 was used.

The potato variety for rotations E and F was changed to Irish Cobbler in 1930 to correspond to rotation B where Cobblers have been grown since 1923. Before 1930, late varieties of potatoes were grown on E and F.

In 1946, the last year of the experiment, 10 varieties of corn were grown in place of the White Flint in rotations E and F. The figures representing bushels of corn for 1946 are the average yields of all the the varieties on each plot.

FERTILIZER INGREDIENTS APPLIED

The annual average application per acre of the various fertilizer ingredients in rotations B, E, and F are shown in Table 1. The amount of fertilizers used was changed slightly from time to time as it seemed advisable. On rotation B, magnesium was added to the potato fertilizer after 1939 at the rate of 30 pounds of MgO per acre. Additional magnesium was not applied to rotations E and F until 1941. A small amount of complete fertilizer was used in 1930 before the new seeding and again from 1937-1946.

The nitrogen for the corn and potato crops was applied as nitrate of soda and sulfate of ammonia in equal proportions at first. From 1940-1946, potatoes received more nitrogen from sulfate of ammonia than from sodium nitrate. The latter was used as the source of nitrogen for the hay crops. On rotation F from 1930 through 1938 there was a graduated application of nitrogen to the hayfields. First-year hay received the least nitrogen and third-year hay the most nitrogen. After 1938 the amount of nitrogen applied was the same for each year of hay in the rotation. More nitrogen was used on the non-legume than on the legume rotations.

Superphosphate was the source of phosphoric acid (P_2O_5). The potash (K_2O) was derived from muriate of potash for most crops. During the period 1930-1938, sulfate of potash was used in the fertilizer for potatoes.

The lime applied to rotations E and F averaged 875 and 825 pounds of CaO per acre, respectively, once in 5 years and to rotation B 1,467 pounds once in 6 years.

The average annual applications of nitrogen, phosphoric acid and potash shown in Table 1 can be expressed only approximately in terms of modern fertilizer ratios. For example, the average annual application of fertilizer to the potatoes in rotation B was approximately equivalent to a 1,600-pound application of a 5-10-10 fertilizer.

Table 1 shows that the amounts of N, P_2O_5 and K_2O applied to corn and potatoes on rotations E and F were the same. In rotation F, approximately 3 times as much nitrogen was used for the grass hay as for the legume rotations. More P_2O_5 and K_2O were used on the legume hay than on the non-legume hay.

Table 1. Average Annual Application of Fertilizers in Pounds per Acre for Rotations B, E and F (1930-1946)

	Nitrogen			Phosphoric Acid			Potash		
Crop	B[a]	E	F	B	E	F	B	E	F
Corn	35	42	42	85	104	104	56	68	68
Potatoes	86	87	87	172	175	175	178	181	181
Hay	18	20	56	90	84	80	92	84	67

[a]On rotation B (1930-1932) 10 tons of stable manure were used on corn without the addition of commercial fertilizer. During 1936-1938 and 1942-1944, both commercial fertilizer and manure were used before corn. Nutrients in the manure are not included in this table.

AMOUNT OF RAINFALL AT KINGSTON, RHODE ISLAND

Weather conditions are often a deciding factor in the results obtained from experiments. The amount of precipitation during the growing season has a marked effect on the yields of corn. The average precipitation by months at Kingston, Rhode Island for the growing seasons from 1930-1946 is shown in Appendix Table 1.

The average monthly precipitation at Kingston from April through September over a period of 40 years was 3.9 inches. During the past 17 years the average monthly precipitation was 3.5 inches. The extreme variability of the precipitation from year to year is illustrated by comparing August 1940, when less than 1 inch of rain fell, with August 1946, when nearly a foot of rain fell.

Relatively low average precipitation during the growing season had little effect on yields of hay and potatoes, provided the rainfall was fairly evenly distributed during the season. A very dry month during the growing season, with rainfall below an inch, greatly reduced the yields

Low rainfall in the spring reduced hay yields, while lack of rain during the summer had more influence on the potato and corn crops.

EXPERIMENTAL RESULTS

CORN ON ROTATIONS B, E AND F

For the 17-year period 1930-1946, rotation E produced an average yield of 6 bushels more per acre than rotation F. The amount of stover averaged slightly higher on rotation F. This same relationship has held true through the other periods of the rotation, as can be seen in Table 2.

These data indicate that as far as Rhode Island White Flint corn is concerned, the preceding hay crop makes little difference as long as adequate fertilizer nutrients are applied. During 6 of the 17 years there was practically no difference between yields of corn on the 2 rotations. Some years (1934-1935 and 1942-1943) corn in the legume rotation produced much better than corn in the non-legume rotation. Analysis of the results by Student's Method (6) shows odds of 68:1 that the small difference in bushels of corn in favor of the legume rotation is significant.

Table 2. Yields of Corn per Acre on Rotations B, E and F

Year	Rotation B[a]			Rotation E		Rotation F	
	Silage Green Wt. Tons	Corn Dry Wt.[b] Tons	Grain Bu.	R. I. White Flint Grain Bu.	R. I. White Flint Stover Tons	R. I. White Flint Grain Bu.	R. I. White Flint Stover Tons
1930	—	5.07	90	51	3.56	52	4.43
1931	—	2.51	73	69	2.21	71	2.36
1932	—	2.85	89	73	2.63	71	2.71
1933	19.8	5.23	—	62	3.37	62	3.19
1934	16.7	4.08	—	53	3.34	55	3.49
1935	17.4	3.51	—	60	3.34	45	3.67
1936	22.7	4.56	—	71	2.36	70	2.33
1937	19.2	4.52	—	67	4.01	63	3.94
1938	17.9	4.16	—	44	2.10	40	1.91
1939	14.3	3.27	—	46	2.17	44	2.04
1940	15.8	3.23	—	45	2.85	53	3.15
1941	20.1	3.73	—	60	3.00	56	3.11
1942	20.4	4.57	—	74	3.30	40	2.62
1943	19.7	3.90	—	54	3.90	40	3.90
1944	10.7	3.80	—	44	1.91	35	2.17
1945	13.5	2.16	—	38	—[c]	37	—[c]
1946	19.4	2.81	—	80[d]	4.72	77[d]	4.70
Averages:							
1894-1913	—	2.99	66	60	2.67	59	2.75
1914-1929	—	3.44	66	66	3.32	62	3.48
1930-1946	17.7	3.76	—	58	3.05	52	3.12
1894-1946		3.37		61	2.99	58	3.09

[a]Rhode Island White Flint corn 1930-1932, and West Branch Sweepstakes 1933-1945.
[b]Stover 1930-1932.
[c]No weights of stover were taken due to damage by cows.
[d]Average of 10 varieties of hybrid corn.

The corn crop in rotation B was changed from a grain to a silage crop in 1933, so only a 3-year grain average is available in this period. The green weight of silage corn varied from 22 tons in 1936 to a low of 10 tons in 1944. This low yield was partly due to hurricane damage to the corn. The figures for dry weight show that the weight of green corn may vary several tons without appreciable differences in the actual dry weight of material.

At the bottom of Table 2 is a summary of the yields of corn for 5 periods and the annual average from 1894-1946. The averages for bushels of corn produced are similar in all rotations. On the 53-year average the legume rotation outyielded the non-legume rotation by 3 bushels of corn. Apparently corn will do well in a non-legume rotation if it is supplied with adequate nitrogen.

POTATOES

The comparative yields of potatoes are shown in Table 3. For 16 out of the 17 years the non-legume rotation outyielded the potatoes grown on rotation E by an annual average of 72 bushels per acre. The non-legume rotation also outyielded the potatoes grown on rotation B by 48 bushels per acre. Rotation B, with alfalfa-timothy hay 4 years, produced an annual average of 24 more bushels of potatoes per acre than rotation E on which the clover hay mixture was grown.

Analysis of the results shows that the increase in yields of potatoes from the non-legume rotation over those from the legume rotations was highly significant, the odds being greater than 2400:1. The differences in yields between the 2 legume rotations were found to be significant by odds of 216:1. The per cent of U. S. No. 1 potatoes was usually a little greater for the non-legume rotation.

The more favorable effect of the non-legume rotation on potatoes has been noted before. In 1934 Odland, Smith and Damon (9) pointed out that in their crop sequence studies, larger yields of potatoes were obtained following redtop or timothy than following red or alsike clover.

WATER-STABLE AGGREGATES AND ORGANIC MATTER CONTENT OF THE ROTATIONS

No clear explanation is available for the apparently beneficial effect of the non-legume rotations on potatoes. Rynasiewicz (12) published a summary of the water-stable aggregates under crops in rotations E and F. He found very little difference in aggregation between the legume and non-legume rotations. In listing the relative state of aggregation he rated the non-legume slightly better than the legume rotation.

Table 3. The Yield of Potatoes in Bushels per Acre from Rotations B, E and F

	Rotations		
Year	B	E	F
1930	323	332	401
1931	203	223	267
1932	291	276	382
1933	213	226	323
1934	224	218	248
1935	269	264	351
1936	272	236	355
1937	295	244	321
1938	366	274	320
1939	212	194	254
1940	274	200	391
1941	234	201	281
1942	232	283	220
1943	220	134	189
1944	152	152	213
1945	144	102	169
1946	251	201	306
Averages:			
1894-1913	260	231	249
1914-1929	300	307	327
1930-1946	246	222	294
1894-1946	268	251	287

Table 4 shows the soil organic-matter determinations for these rotations which Salomon and Smith (13) made by the dry combustion method. These determinations were made on soil samples taken in 1912 and preserved in a dry condition and on other samples taken in 1939 from the same plots. These data show that the 6-year rotation contained the most organic matter and nitrogen per acre-foot at both sampling dates. Also, the plots receiving approximately 10 tons of stable manure once in 6 years maintained a slightly higher level of organic matter. Over the 28-year period the 5-year legume rotation lost the least organic matter of the 3 systems. The loss of organic matter from the grass rotation is similar to the average loss for the 6-year rotation.

Table 4. Tons of Organic Matter and Nitrogen per Acre-foot of Soil, for Rotations B, E and F

	Organic Matter		Nitrogen		Loss	
Rotation	1912	1939	1912	1939	O.M.	N
B	92.50[a]	74.50	3.72	3.25	18.00	0.47
	93.90[b]	79.20	3.91	3.27	14.70	0.64
E	78.53	67.13	3.34	2.84	11.40	0.50
F	81.57	64.10	3.37	2.81	16.47	0.60

[a]No manure was applied during the course of the experiment.

[b]Approximately 10 tons of stable manure were applied once in 6 years preceding the corn crop.

The striking fact brought out by these determinations is that the crop rotations and fertilizer programs failed to maintain the organic matter content of the soil. As the quantity of organic matter decreased, the nitrogen reserve also dwindled.

It is obvious that neither the organic matter determinations nor the aggregate analyses explain why the non-legume rotation has produced superior yields of potatoes. While these analyses and determinations do not show any conclusive benefit in favor of the redtop-timothy system, it has been observed that the soil "fluffs up" more where redtop and timothy are grown in rotation. The soil appears a little more friable than in the other plots. The supposition can be made that this fluffy or friable condition is associated with better aeration. If so, it might be a partial answer to the higher potato yield on this plot.

The soil in the concrete frame where potatoes were rotated with redtop "fluffed up" higher than the edges of the frame. The soil in the frame where potatoes alternated with corn became compact and was one inch or more below the edge of the frame.

Bushnell (2) of the Ohio Experiment Station has demonstrated "that the potato plant is peculiarly sensitive to soil aeration, and that insufficient aeration may be frequently a limiting factor in potato yields on silt loam and heavier soil types." The Bridgehampton very fine sandy loam at the Rhode Island Experiment Station is high in silt and was formerly classified as a silt loam. Although no evidence is presented to demonstrate that aeration was more favorable in the grass rotation, it is believed that it may have been, and that the better aeration in the non-legume rotation favored the greater production of potatoes.

EFFECT OF VARIOUS AMOUNTS OF NITROGEN, POTASSIUM, MAGNESIUM AND CALCIUM ON THE YIELDS OF IRISH COBBLER POTATOES

From 1939-1943 an experiment was inserted on a quarter section of the potato plots in rotations E and F to see what influence variations in nitrogen, potash, magnesium and calcium might have on the yields of potatoes. It is a well-known fact that legumes remove more of these nutrients than grasses do. Growing legumes before potatoes might aggravate the deficiencies of these nutrients. The amount of N, P_2O_5, K_2O, MgO and CaO used, as well as the average yields for the 5-year period, are shown in Table 5. The average yields of potatoes from the rest of rotations E and F are shown also for comparison.

Varying the quantity of nitrogen from low to high made little difference in the yields of potatoes on rotation E. Additional potash, magnesium and calcium produced small increases over the average yields on the main part of rotation E.

It is outstanding that for all treatments, the yields of potatoes from the non-legume plots are a great deal higher than those from the clover rotation.

Another striking fact is that varying the nitrogen, potash, magnesium, and calcium on the non-legume rotation produced lower yields than those from the standard treatment. The poorest crops of potatoes were obtained from the high-potash treatment on this non-legume rotation, while from the clover rotation the best yield occurred on the high-potash treatment.

The results of this experiment suggest the correctness of the theory that some additional basic materials such as calcium, magnesium, and potassium may be needed for potatoes when large crops of legume hay are removed during the rotation.

The low yields of potatoes produced by the high potash treatment on rotation F are similar to those reported by Knoblauch and Odland (5) who found that excessive amounts of potash were associated with magnesium deficiency of potatoes. When magnesium sulfate was applied to

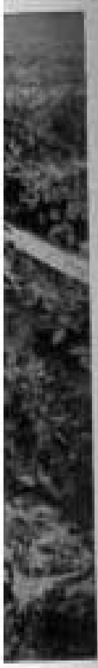

Table 5. Five-Year Annual Average Application of Fertilizer Nutrients and Yields of Potatoes for Special Potato Experiment on Rotations E and F

Treatment	Pounds of Fertilizer Ingredients Per Acre					Yields in Bushels	
	$NaNO_3$	$(NH_4)_2SO_4$	Super-phosphate	KCl	MgO[a]	Legume Rotation	Non-legume Rotation
Low N	22	29	194	210	12	206	276
High N	63	80	194	210	12	210	288
Low K	42	55	194	110	12	208	288
High K	42	55	194	310	12	235	254
High K + high Mg	42	55	194	310	42	222	289
High K + high Mg + Ca[b]	42	55	194	310	42	217	285
Standard + Ca	42	55	194	210	12	227	310
					Average	218	284
Rotation E	42	55	192	210	18	203	—
Rotation F	42	55	192	210	18	—	313

[a]Actually magnesium was added to all those plots only the last 2 years of the experiment (1942-1943) at the rate of 30 lbs. MgO per acre annually. Only the high magnesium plots received MgO for the entire 5 years.

[b]The calcium was furnished by 173 lbs. of gypsum per acre.

the high-potash plots, it produced a significant increase in the yields of potatoes.

The yield-depressing effect of high potash in the non-legume rotation was alleviated somewhat by the additional magnesium and calcium. This suggests that the available potash had accumulated over the years so that the high potash treatment produced a concentration of potassium great enough to depress the yield of potatoes by aggravating the magnesium deficiency.

The beneficial effect of high potash on the yields of potatoes from rotation E is evidence that the legumes remove more potassium than is replaced by the standard potato fertilizer. Thus, the potato yields were increased when additional potash was applied. Using calcium and magnesium with the high potash in the legume rotation lowered the yields of potatoes a little. Using calcium and magnesium with high potash in the non-legume rotation increased yields over those from the high-potash treatment.

It is evident from these data that the 2 systems of rotation, legume-grass versus grass alone, must produce widely different potassium-calcium and potassium-magnesium ratios. Another suggestion that may help account for the higher yields of potatoes from rotation F is that the Ca/K and Mg/K ratios were more favorable for the growth of potatoes on the non-legume rotation.

The interrelationships of potassium, calcium and magnesium in plant nutrition are quite intricate. Peech and Bradfield (10) showed that the influence of the K-ion on the availability of the Ca- and Mg-ions depends on such factors as the ratio of the ions to each other, the pH of the soil, and the presence or absence of neutral salts.

Pierre and Bower (11), reporting on potassium absorption by plants as affected by cationic relationships, concluded "that potassium absorption by plants is usually decreased by the presence of high concentrations of other cations in solution. Under certain conditions, however, it may be increased." They also pointed out that K has a higher "competitive ability" than other common cations and the decrease in K from high concentrations of other cations is not so pronounced as is the effect of K on the absorption of Ca and Mg.

Some additional evidence is gained supporting the idea that lower yields of Irish Cobbler potatoes are associated with a greater removal of basic elements by legumes when the soil acidity of the 3 rotations is compared with the lime applications. The average pH for rotations B, E and F for the 5-year period 1940-1945 was 6.25, 5.90 and 6.34, respectively. The average annual lime applications per acre for B, E and F were 244, 175 and 165 pounds of CaO, respectively. The non-legume rotation received the least lime and was the least acid. The alfalfa rotation, which received nearly 80 pounds more CaO per acre annually had about the same pH as the non-legume rotation had. The alfalfa-clover mixture, which received only 10 pounds more per acre annually, was the most acid of the 3 rotations.

The more adequate supply of calcium in rotation B may be one reason why the alfalfa sequence yielded more Irish Cobbler potatoes than the alfalfa-red clover rotation.

Other factors besides those already discussed may also be influential in the production of higher yields of potatoes on the non-legume rotation. The effect of the previous crop on the yields of potatoes will have to be investigated further before a complete answer is obtained.

The evidence in this paper suggests that the greater yields of potatoes from the non-legume rotation are associated with not only a more satisfactory supply of nutrients but also a more favorable balance of the K, Ca, and Mg ions. The supposition is also made that aeration is better in the non-legume rotation. Evidence supporting this point, however, is meager.

HAY

The hay crops have consisted of alfalfa and timothy for rotation B, alfalfa, red clover, alsike clover, timothy and redtop on rotation E; and redtop with timothy on rotation F. Table 6 shows that the annual average yields of alfalfa-timothy hay varied from 5.02 tons of field-cured hay in 1931 to 2.20 tons in 1946. One factor favoring high yields of alfalfa hay was seeding in early August so that the plants were well established before winter.

In rotation E, the annual average yield ranged from a high of 4.31 tons in 1941 to a low of 1.99 tons in 1939. The high yield in rotation F was 3.21 tons in 1940 and a low of 1.58 tons in 1936. Two cuttings, and occasionally 3, were made on the legume meadows. The redtop-timothy produced only one cutting per season. Analysis of the results by Student's Method showed that yields of alfalfa from rotation B were significantly larger than those from rotation E by odds of 20:1. The greater average yields of hay from rotations B and E were highly significant (odds greater than 2000:1) when compared with the yields from rotation F.

In Table 7 the average annual yields of hay for 3 periods have been brought together. The data for former years were collected from pre-

Table 6. Annual Average Tons of Hay per Acre from Rotations B, E and F

	Rotations		
Year	B	E	F
1930	4.09	2.44	2.40
1931	5.02	3.37	2.44
1932	4.02	3.83	2.84
1933	3.41	3.12	2.51
1934	4.00	3.48	2.33
1935	3.37	3.18	2.48
1936	2.81	2.95	1.58
1937	3.83	3.75	2.21
1938	3.18	3.60	2.01
1939	2.40	1.99	2.05
1940	3.66	3.72	3.21
1941	3.54	4.31	3.04
1942	2.86	2.76	2.72
1943	3.72	3.47	3.20
1944	2.60	2.19	1.83
1945	2.86	2.36	2.87
1946	2.20	2.35	2.66
Average	3.39	3.11	2.49

vious bulletins about these rotations. The period from 1894-1913 is 20 years; 1914-1929 is 16 years; and 1930-1946 is 17 years. These periods are of sufficient length to minimize annual variations in weather conditions.

Table 7 shows that the legume rotations have consistently produced more hay than the non-legume rotation. It is a well-established fact that legume hays have higher feeding value than non-legume hay, since the former contain more protein, nitrogen, phosphorus and calcium.

During all 3 periods, the 6-year rotation has outyielded the 5-year rotations on the second- and third-year hays, and on first-year hay during the earlier sequences. With the introduction of alfalfa in the legume mixture in 1924 in rotation B, the average yields of first-year hay during the last 2 periods (1914-1929 and 1931-1946) have been lower than those on rotation E. Perhaps alfalfa, which is a long-lived perennial, does not become established as rapidly as the short-lived clovers. If so, this would account for slightly lower yields from first-year alfalfa hay.

It will be noted that the average for third-year hay from rotation B (1930-1946) was 0.9 ton greater than the third-year hay yield from rotation E. This may be partly due to the loss of much of the red clover and alsike clover from the meadow at the end of the second year. These 2 clovers are largely biennial in growth. Rotation B, however, received a larger amount of CaO than rotation E. This may also have favored larger yields of hay. The fact that high yields of alfalfa-timothy hay can be obtained for a period of 4 or more years by proper management makes this hay superior for the long rotations of grassland agriculture.

Estimates of the per cent legumes in the hay mixtures on rotations B and E were made at haying time. These estimates verified the fact that alfalfa usually lasted longer than clovers. In the third-year hay from rotation E, red clover and alsike clover comprised less than one per cent of the hay mixture. The per cent alfalfa varied from year to year. The 17-year average for alfalfa in third-year hay was 37 per cent for rotation E and 48 per cent for rotation B. The smaller amount of alfalfa on rotation E may be partly due to competition with the vigorous biennial clovers. Alfalfa in the second-year hay averaged 29 per cent when the mixture contained 11 per cent red clover and 9 per cent alsike clover. When these disappeared, the average per cent of alfalfa was 37.

Table 7. Average Tons of Hay from Rotations B, E and F, 1894-1946

Crop	Rotation	1894-1913	1914-1929	1930-1946	1894-1946
First-year hay	B[a]	4.01	3.66	2.91	3.53
	E	3.49	3.76	3.21	3.48
	F	2.53	2.64	2.88	2.68
Second-year hay	B	3.59	3.98	3.49	3.68
	E	3.00	3.76	3.28	3.32
	F	2.65	2.75	2.35	2.58
Third-year hay	B	3.21	3.73	3.77	3.55
	E	—	—	2.87	—
	F	—	—	2.25	—
Fourth-year hay	B	—	4.15[b]	3.45	3.63

[a]Alfalfa hay instead of legume mixture after 1923 in rotation B.
[b]1924-1929, 6-year average.

EFFECT OF MANURE APPLIED ONCE IN 6 YEARS

Table 8 summarizes the results of using manure once in 6 years in comparison to no manure in the fertilizer program. On plots 8, 10 and 12 of rotation B, approximately 10 tons of stable manure were applied once in 6 years before corn was planted. Table 8 shows that from 1894-1925 the average yields of marketable potatoes were greater on the plots receiving the manure once in 6 years. From 1926-1935 the average yields of potatoes were practically identical. During the last 11-year period when the manure was supplemented by chemical fertilizer, the average yield of Irish Cobbler potatoes was the lowest of any during the 53-year period. The total average yield of marketable potatoes, however, is greater on the plots receiving manure once in 6 years. Just why the marketable potato yields declined in the manured series is not known. It may be that enough residual nitrogen remained from the previous treatment of the corn crop to promote early and rapid top growth of potatoes. If

Table 8. Average Yields of Crops from Rotation B With and Without Manure

	Potatoes	Corn		Hay					Rye		
	Large Bu.	Grain Bu.	Stover Tons	1st Year Tons	2nd Year Tons	3rd Year Tons	4th Year Tons	Avg. 3 Yrs. Tons	Grain Bu.	Straw Tons	Rowen Tons
1894-1903											
With manure	226	57	2.38	3.30	2.01	2.30	—	2.53	22	1.90	0.88
Fertilizer only	188	67	3.35	3.61	3.52	3.10	—	3.41	18	1.34	0.67
1904-1914											
With manure	320	59	3.12	3.90	4.13	3.60	—	3.88	25	1.90	1.58
Fertilizer only	195	65	3.57	4.04	3.82	3.70	—	3.88	18	1.43	1.22
1915-1925											
With manure	297	57	2.73	3.81	3.79	2.69	—	3.43	27	2.08	1.19
Fertilizer only	239	59	2.76	3.52	3.88	3.21	—	3.54	24	1.69	0.97
1926-1935								Avg. 4 Yrs.			
With manure	261	81	3.52	3.80	3.94	4.86	4.95	4.38	—	—	—
Fertilizer only	258	79	4.58	3.49	4.32	4.24	4.16	4.05	—	—	—
1936-1946											
Manure & fertilizer	231	—[a]	4.25	2.03	2.96	3.68	3.46	3.04	—	—	—
Fertilizer only	254	—	3.04	2.86	3.45	3.35	2.92	3.14	—	—	—
Total average											
With manure	268	63	3.21	3.37	3.38	3.42	4.17	3.45	25	1.96	1.23
Fertilizer only	227	67	3.44	3.50	3.79	3.51	3.51	3.59	20	1.49	0.96

[a]Silage from 1933 through 1946.

hotter, drier weather came, the plants with the larger tops would suffer more from lack of moisture and hence produce a lower yield of marketable potatoes.

The figures in Table 8 indicate that during the first several years corn yielded a few more bushels of grain to the acre when it was fertilized with the readily available chemical fertilizers. Once the fertility of the land was established, it made little difference in the yield of grain whether complete fertilizer or manure was used preceding corn. During the last period, 1936-1946, corn receiving manure plus complete fertilizer yielded more than corn receiving only complete fertilizer. This is not surprising since the manure-fertilizer combination provided more nitrogen for leaf growth.

For 3 periods listed from 1894-1925, during which rye was grown in the rotation, the yields of rye grain averaged slightly higher where manure was used than in those which received only commercial fertilizer.

No clear-cut effect of either treatment is noticeable on the yields of hay for the first 3 years. The 53-year averages show that there was a slightly higher yield of hay on the plots receiving chemical fertilizers only. The fourth-year hay, however, from 1926-1946 averaged higher yields on the manured plots.

It is a well-established fact that farm manure or some other source of additional humus is necessary from time to time in a cropping system to maintain the soil fertility. Odland and Knoblauch (8) have reported that straw bedding manure was compared with sawdust manure and straight chemical fertilization for a period of 18 years on a 3-year crop rotation experiment. The plots receiving chemicals had less total moisture, organic matter, and nitrogen than the manured plots at the conclusion of the study. The average yields of hay and silage corn were greater where straw manure was applied than where 1,000 pounds of fertilizer were used. The results obtained in this auxiliary test of manure in rotation B show it is desirable to use stable manure occasionally in the cropping system.

HAS PRODUCTIVITY BEEN MAINTAINED?

It is difficult to answer the question whether the maximum productivity of the soil has been maintained during the half century commercial fertilizers were used, because of variations in climate, the occasional changes in rate of fertilization and in crop varieties. The data on organic matter and nitrogen from 1912-1939 show a decrease in the soil humus ranging from 15-21 per cent and a consequent decrease in the nitrogen supply ranging from 12-17 per cent. With few exceptions, the average yields of corn, hay and potatoes are lower for the last 17-year period than they were for the preceding 16-year period.

Table 9 shows the average pounds of fertilizer elements and the average yields of corn, potatoes, and 2 years of hay for rotations E and F. These average figures have been determined for a 20-year period, 1894-1913; a 16-year period, 1914-1929; and finally a 17-year period, 1930-1946. The length of the periods is such as to minimize the effects of annual variations in climate.

The impression which may be gained from looking at the table is that fertility was gradually built up toward a maximum during the first 20-year period. During the next 16 years the yields were maintained at a high level, but during the last 17 years there was some decrease in average yields.

The general impression, however, is that the crop yields have held up well through the 53 years of the experiment and that, compared to average yields for New England, they are satisfactory. This means that the productivity of the soil was increased and maintained at a level sufficiently high to produce an economic return from the use of the land, even though the organic matter and total nitrogen have declined a little.

Comparison of the yields from the various fertilizer applications on rotations E and F indicates that the highest returns of corn grain and stover occurred where the greatest amount of nitrogen was used, i.e., during the middle period, 1914-1929. No clear relationship appears between any fertilizer nutrient and the average hay yields on rotations E and F. When sufficient fertilizer is applied, adequate rainfall seems to be a controlling factor for hay yield.

The behavior of the potatoes, of course, was complicated by the change in variety in 1930. The best yields of potatoes occurred during the middle period when the application of complete fertilizer averaged the lowest of the 3 periods. If late potatoes had been grown during the last period, the average yields would probably have been higher. Records on the potato variety trials show that the late Green Mountain potato yields about 45 bushels more per acre, on the average, than the Irish Cobbler. The Irish Cobbler may mature too early to get full benefit from the fertilization which was applied during the last 17-year period.

Table 9. Average Fertilizer Applications and Yields for Rotations E and F

Years	Corn					Potatoes				Hay — 2 years			
	N	P_2O_5	K_2O	Grain	Stover	N	P_2O_5	K_2O	Yield	N	P_2O_5	K_2O	Yield
Rotation E	Lb.	Lb.	Lb.	Bu.	Tons	Lb.	Lb.	Lb.	Bu.	Lb.	Lb.	Lb.	Tons
1894-1913	34	78	61	60	2.67	60	157	151	231	40	63	94	3.25
1914-1929	50	89	70	66	3.32	66	142	111	307	40	78	65	3.76
1930-1946	42	104	68	58	3.05	87	175	181	222	20	84	84	3.26
1894-1946	41	90	66	61	2.99	70	156	148	251	34	74	82	3.41
Rotation F													
1894-1913	34	78	61	59	2.75	60	157	151	249	40	64	96	2.59
1914-1929[a]	47	89	70	62	3.48	62	142	113	327	46	78	66	2.69
1930-1946	42	104	68	52	3.12	88	175	181	294	56	80	67	2.63
1894-1946	40	90	66	58	3.09	70	156	149	287	47	73	78	2.63

[a]Average pounds of commercial nitrogen is less on corn and potatoes in rotation F because more of the nitrogen was applied to the hay crop from 1923-1928.

FINANCIAL COMPARISONS

When selecting any rotation, a farmer should adopt the cropping system which promises to return the largest net profit over the years without depleting his reserve of soil fertility. He should be alert to adjust his system of crop rotations to changing economic conditions, keeping in mind that immediate gain may mean long-time loss if unwise cropping practices are followed.

The crops which can be grown profitably on any farm are determined by soil type, topography, climate conditions, nearness to markets, available labor supply, and many other factors.

It is realized that the rotations reported in this bulletin may not be completely comparable to all rotations used by farmers in this State. Evidence which can help farmers select a cropping system is presented for 3 rotations.

Since the yield data have more meaning to most farmers when expressed in terms of costs and returns, financial comparisons of each rotation have been made for 2 periods of 5 years each.

During the 17-year period from 1930-1946, prices dropped from 1930-1932, recovered and were relatively stable from 1935-1939, then rose rapidly following 1940 as a result of the war. Two 5-year periods, 1935-1939 and 1942-1946, are used in the estimated costs and returns of the 3 crop rotations. The first period provides a picture under peacetime prices and the second under conditions encountered during and following the war.

COSTS

The cost items involved in growing and harvesting the crops in these rotations are man labor, tractor and equipment use, fertilizer, lime, manure, seed, spray materials, use of land and interest on the money invested in producing the crop. The costs for each crop are itemized in Table 10.

The prices of fertilizer and seed used in computing these figures are given in Appendix Tables 2 and 4. The average annual cost of the various fertilizer ingredients used for each rotation and crop is given in Appendix Table 3.

The cost of preparing the land for hay and sowing the seed is estimated at $6.00 per acre and pro-rated for the life of the stand. Similar costs for corn and potatoes are included in the estimates of labor and equipment used on those crops.

The cost of spray materials for potatoes is estimated at $6.00 per acre in 1935-1939 and $12.00 per acre in 1942-1946. Since only Irish Cobblers were grown, 4 or 5 sprays were sufficient to bring the crop through the growing season.

Table 10. Estimated Average Annual Costs per Acre By Rotations for the Years 1935-1939 and 1942-1946

	1935-1939 Rotations		
	B	E	F
CORN			
Fertilizer and lime	$34.99	$10.99	$10.99
Seed	1.14	1.03	1.03
Use of land	20.00	20.00	20.00
70 Man hours—grain @ 35c		24.50	24.50
50 Man hours—silage @ 35c	17.50		
15 Tractor hours @ 50c	7.50	7.50	7.50
15 Equipment hours @ 50c	7.50	7.50	7.50
Yield above 52 bu.		.83	
Interest, 3 mo. @ 6%	1.33	1.09	1.07
Total	89.96	73.44	72.59
POTATOES			
Fertilizer and lime	23.29	23.29	23.29
Seed	25.52	25.52	25.52
Use of land	20.00	20.00	20.00
Cover crop[a]	2.00	2.00	2.00
Spray and dust	6.00	6.00	6.00
75 Man hours @ 35c	26.25	26.25	26.25
19 Tractor hours @ at 50c	9.50	9.50	9.50
19 Equipment hours @ at 75c	14.25	14.25	14.25
Yield above 247 bu.	1.33		5.11
Interest, 3 mo. @ 6%	1.92	1.90	1.98
Total	130.06	128.71	133.90
HAY—First Year			
Fertilizer and lime	10.97	9.57	11.82
Seed	1.94	1.25	.63
Preparation of seedbed	1.50	2.00	2.00
Use of land	20.00	20.00	20.00
Man labor @ $1.95/ton	5.04		
Man labor @ $1.75/ton		5.74	4.08
Tractor labor @ $.75/ton	1.96	2.46	1.75
Equipment labor @ $1.13/ton	2.95	3.71	2.63
Interest, 12 mo. @ 6%	2.66	2.65	2.54
Total	47.03	47.38	45.45

	1942-1946 Rotations		
	B	E	F
CORN			
Fertilizer and lime	$49.56	$13.56	$13.56
Seed	1.56	1.42	1.42
Use of land	20.00	20.00	20.00
60 Man hours—grain @ 70c		42.00	42.00
40 Man hours—silage @ 70c	28.00		
15 Tractor hours @ 50c	7.50	7.50	7.50
15 Equipment hours @ 50c	7.50	7.50	7.50
Yield above 37 bu.		3.20	
Interest, 3 mo. @ 6%	1.71	1.43	1.38
Total	115.83	96.61	93.36
POTATOES			
Fertilizer and lime	30.12	31.63	31.63
Seed	45.76	45.76	45.76
Use of land	20.00	20.00	20.00
Cover crop[a]	2.50	2.50	2.50
Spray and dust	12.00	12.00	12.00
70 Man hours @ 70c	49.00	49.00	49.00
19 Tractor hours @ 50c	9.50	9.50	9.50
19 Equipment hours @ 75c	14.25	14.25	14.25
Yield above 174 bu.	2.04		3.60
Interest, 3 mo. @ 6%	2.78	2.77	2.82
Total	187.95	187.41	191.06
HAY—First Year			
Fertilizer and lime	12.01	12.38	16.73
Seed	2.74	2.54	.64
Preparation of seedbed	1.50	2.00	2.00
Use of land	20.00	20.00	20.00
Man labor @ $3.50/ton	8.65		
Man labor @ $3.15/ton		7.59	8.63
Tractor labor @ $.75/ton	1.85	1.81	2.06
Equipment labor @ $1.13/ton	2.79	2.72	3.10
Interest, 12 mo. @ 6%	2.96	2.90	3.15
Total	52.50	51.94	56.51

[illegible]

Table 10 (concluded) Estimated Average Annual Costs per Acre by Rotations for the Years 1935-1939 and 1942-1946.

	1935-1939 Rotations			1942-1946 Rotations		
	B	E	F	B	E	F

Equipment labor @ $1.13/ton	2.95	3.71	2.63
Interest, 12 mo. @ 6%	2.66	2.65	2.54
Total	47.02	47.38	45.45

Equipment labor @ $1.13/ton	2.79	2.72	3.10
Interest, 12 mo. @ 6%	2.96	2.90	3.15
Total	52.50	51.94	56.31

*Rye is used as a cover crop following corn. Since no attempt has been made to separate other costs, the estimates used repre-

Table 10 (concluded) Estimated Average Annual Costs per Acre by Rotations for the Years 1935-1939 and 1942-1946.

	1935-1939 Rotations		
	B	E	F
HAY—Second Year			
Fertilizer and lime	$10.97	$9.57	$11.82
Seed	1.94	1.25	.63
Preparation of seedbed	1.50	2.00	2.00
Use of land	20.00	20.00	20.00
Man labor @ $1.93/ton	6.54		
Man labor @ $1.75/ton		5.27	2.91
Tractor labor @ $.75/ton	2.54	2.26	1.25
Equipment labor @ $1.13/ton	3.83	3.40	1.88
Interest, 12 mo. @ 6%	2.83	2.60	2.40
Total	50.15	46.35	42.89
HAY—Third Year			
Fertilizer and lime	10.97	9.57	11.82
Seed	1.94	1.25	.63
Preparation of seedbed	1.50	2.00	2.00
Use of land	20.00	20.00	20.00
Man labor @ $1.93/ton	6.37		
Man labor @ $1.75/ton		5.25	3.19
Tractor labor @ $.75/ton	2.48	2.25	1.37
Equipment labor @ $1.13/ton	3.73	3.39	2.07
Interest, 12 mo. @ 6%	2.82	2.59	2.43
Total	49.81	46.30	43.51
HAY—Fourth Year			
Fertilizer and lime	10.97		
Seed	1.94		
Preparation of seedbed	1.50		
Use of land	20.00		
Man labor @ $1.93/ton	6.33		
Tractor labor @ $.75/ton	2.46		
Equipment labor @ $1.13/ton	3.71		
Interest, 12 mo. @ 6%	2.81		
Total	49.72		
Grand Total	416.72	342.18	338.34
Average Per Acre	69.45	68.44	67.67

	1942-1946 Rotations		
	B	E	F
HAY—Second Year			
Fertilizer and lime	$12.01	$12.38	$16.73
Seed	2.74	2.54	.64
Preparation of seedbed	1.50	2.00	2.00
Use of land	20.00	20.00	20.00
Man labor @ $3.50/ton	10.85		
Man labor @ $3.15/ton		9.26	8.73
Tractor labor @ $.75/ton	2.33	2.21	2.08
Equipment labor @ $1.13/ton	3.50	3.32	3.13
Interest, 12 mo. @ 6%	3.16	3.06	3.15
Total	56.09	54.77	56.46
HAY—Third Year			
Fertilizer and lime	12.01	12.38	16.73
Seed	2.74	2.54	.64
Preparation of seedbed	1.50	2.00	2.00
Use of land	20.00	20.00	20.00
Man labor @ $3.50/ton	10.78		
Man labor @ $3.15/ton		8.00	7.78
Tractor labor @ $.75/ton	2.31	1.91	1.85
Equipment labor @ $1.13/ton	3.48	2.87	2.79
Interest, 12 mo. @ 6%	3.16	2.93	3.06
Total	55.98	52.63	54.85
HAY—Fourth Year			
Fertilizer and lime	12.01		
Seed	2.74		
Preparation of seedbed	1.50		
Use of land	20.00		
Man labor @ $3.50/ton	9.66		
Tractor labor @ $.75/ton	2.07		
Equipment labor @ $1.13/ton	3.12		
Interest, 12 mo. @ 6%	3.05		
Total	54.15		
Grand Total	522.50	445.36	452.04
Average Per Acre	87.08	88.67	90.41

The land used in these rotation experiments is considered one of the most productive types in Rhode Island; therefore, its value was assumed to be $200 per acre. An annual charge of 10 per cent, or $20, was made for use of the land.

Estimates of the average hours of man labor and equipment use required to produce these crops cannot be applied readily to individual farms. Differences in soil type, farm layout, kind of equipment, skill of farm labor, and the efficiency of management greatly influence the time necessary to complete the various operations.

The results of a study by the United States Department of Agriculture on labor requirements for crops and livestock (3), and cost account data on 50 New York farms (1) were considered in arriving at the estimated labor requirements shown in Appendix Table 2.

The following rates were the basis for computing costs for equipment use: $.50 per hour for tractor use, $.50 per hour for other equipment used in the production of corn, and $.75 per hour for equipment used in the production of potatoes and hay. All available cost data indicate higher hourly rates for equipment employed on those crops requiring specialized machinery in some phase of production.

With grain corn and potatoes, an extra charge was made for harvesting larger-than-average yields. In 1935-1939, $.15 per bushel was added for corn yields over 52 bushels per acre. In 1942-1946, $.20 per bushel was added for yields above 37 bushels per acre. In 1935-1939, $7.00 per 100 bushels was added for potato yields above 247 bushels per acre. In 1942-1946, $8.00 per 100 bushels was added for yields over 174 bushels per acre.

RETURNS

The annual returns per acre from the crops grown in the 3 rotations are based on the average yields recorded in the experiment during 1935-1939 and 1942-1946, and on the average prices received by Rhode Island farmers during the same periods. These prices for corn, potatoes, and hay are shown in Appendix Table 6.

The average yields and the dollar values of the crops are given in Table 11. The returns for each crop have been tabulated by rotations.

A comparison of the average costs and returns per acre per year is shown in Table 12. In each of the rotations, the net return per acre for 1942-1946 is materially higher than for 1935-1939. The value of the crops grown increased more than production costs. During 1935-1939,

Table 11. Estimated Average Returns per Acre for the Years 1935-1939 and 1942-1946

		1935-1939 Rotations						1942-1946 Rotations					
		B		E		F		B		E		F	
Crop	Unit	Yield	Value	Yield	Value	Yield	Value	Yield	Value	Yield	Value	Yield	Value
Corn, silage[a]	ton	15.41	$99.70		$		$	16.75	$154.27		$		$
Corn, grain	bu.			57.60	50.11	52.10	45.53			52.80	73.92	37.20	52.08
Corn, stover[b]	ton			2.40	9.60	2.78	11.12			3.07	15.35	2.90	14.50
Potatoes	bu.	266.00	242.06	246.80	224.59	320.10	291.29	199.50	353.12	174.40	308.69	219.30	388.16
Hay, 1st year	ton	2.61	66.29	3.28	63.63	2.33	38.21	2.47	83.06	2.41	66.59	2.74	67.49
Hay, 2nd year	ton	3.39	86.11	3.01	58.39	1.66	27.22	3.10	104.25	2.94	81.23	2.77	68.23
Hay, 3rd year	ton	3.30	83.82	3.00	58.20	1.82	29.85	3.08	103.58	2.54	70.18	2.47	60.84
Hay, 4th year	ton	3.28	83.31					2.76	92.82				
Total Returns			661.29		464.52		443.02		891.10		615.96		651.30
Average Per Acre			110.22		92.90		88.60		148.52		123.19		130.26

[a]Value of corn silage in rotation B is estimated as one-third of the value of clover and timothy hay, or $6.47 per ton during 1935-1939 and $9.21 per ton during 1942-1946.

[b]Value of corn stover is estimated at $4.00 per ton during 1935-1939 and $5.00 per ton during 1942-1946.

the returns per acre from rotation B were $16.31 more than from rotation E, and $29.84 more than from rotation F.

During 1942-1946, B returned $26.92 more per acre than E, and $21.59 more than F. Most of this margin is due to the high value of the corn silage and alfalfa hay grown in B relative to the grain corn and mixed hay in E and F.

The obvious difference between rotations E and F is the greater return from potatoes in F. During 1935-1939, potatoes in F returned $66.70 more per acre than E and during 1942-1946, they returned $79.47 more. To a potato farmer, the increased yields following a non-legume hay is an important consideration. To a dairyman who is interested in growing good hay for his herd, the mixed legume hay would be more suitable.

Table 12. Estimated Average Annual Net Return Per Acre By Rotations for 1935-1939 and 1942-1946

	1935-1939 Rotations			1942-1946 Rotations		
	B	E	F	B	E	F
Average returns	$110.22	$92.90	$88.60	$148.52	$123.19	$130.26
Average costs	69.45	68.44	67.67	87.08	88.67	90.41
Net returns	40.77	24.46	10.93	61.44	34.52	39.85

COMMENTS ON ROTATIONS

Of the 3 rotations in the experiment, B, a 6 year sequence, was the most profitable. For the average dairyman, however, an even distribution of labor would be difficult if two-thirds of the cropland were in alfalfa. With uncertain climatic conditions in this area during haying, special machinery to dry hay or to handle grass silage would be needed to supplement the regular equipment to insure harvest at the ideal time.

These estimates of costs and returns are intended to reflect average conditions. Actual returns on any one farm may vary considerably. On some farms, the same yields can be obtained with less labor and equipment use. This would mean greater net returns than those reported here. On other farms, more labor to obtain the same yields would result in lower net returns per acre.

Prices differing from those used would change the net return per acre. Other rates of fertilizer application might have a direct effect on yields and indirectly on net returns. On soils other than Bridgehampton very fine sandy loam, yields might vary from those obtained in this study.

Alternate crops might be more profitable than those included in the rotations. As indicated in rotation B, silage corn would give dairy farmers a higher net return than grain corn. For a dairyman who finds a 5-year rotation such as E or F more suitable to his circumstances, silage corn would be the better crop.

In planning any rotation, crops should be selected which do not require attention simultaneously. The availability of day labor to take care of peak demands should be determined.

SUMMARY

The results obtained with rotations B, E and F for the years 1930-1946 are recorded in this bulletin. Average yields for previous periods are also shown for comparison.

The average yield of corn on rotation E was 58 bushels, and on rotation F was 52 bushels per acre for the period 1930-1946. The yields of dry stover, however, were nearly equal. The corn yield on rotation B averaged 83 bushels for a 3-year period. The change to silage corn on rotation B prevented obtaining a 17-year average of grain from this rotation.

The yield of Irish Cobbler potatoes ranged from 222 bushels on E to 294 bushels per acre on rotation F. Potatoes on rotation B were intermediate with an average yield of 246 bushels.

No complete explanation was found for the higher yields of Irish Cobbler potatoes in the non-legume rotation. Some evidence is presented which indicates that additional potassium, calcium and magnesium may produce small increases in the yields of potatoes grown in rotation with legumes.

The average yield of first-year hay was greatest where the general legume mixture was planted in rotation E. Alfalfa-timothy (rotation B) yielded a little less, while the non-legume rotation gave the lowest yield of first-year hay. The alfalfa-timothy hay outyielded the other hay mixtures for the second, third and fourth years. The yield of hay on rotation E was considerably lower the third year, probably due to the loss of the biennial clovers.

The yields of crops have been satisfactorily maintained over a period of 53 years without the use of stable manure, although evidence gained from rotation B suggests that manure occasionally applied in a rotation is beneficial. The use of manure before corn once in 6 years, during the period 1896-1935, benefited the following potato crop. When both manure and fertilizer were used, this trend was reversed. This may have

been because of too much nitrogen which might produce excessive top growth. Corn usually responded somewhat better to commercial nitrogen than to manure.

The costs and returns for each rotation have been compared for 2 periods of 5 years, 1935-1939 and 1942-1946. Because the average prices received by farmers increased faster than average costs, net returns per acre averaged higher in 1942-1946 than in 1935-1939 for the 3 rotations.

During both periods, rotation B produced the largest average net return per acre. The corn silage and alfalfa hay had greater cash value than the grain corn, mixed legume hay, and grass hay in the other rotations. With two-thirds of the land in alfalfa hay, however, B was not very well adapted to an even distribution of labor throughout the year. To insure harvest at the proper stage, considerable investment in specialized machinery would be needed.

Net returns from potatoes in rotation F were higher than from E during both periods because of the consistently greater yields following non-legume hay. In 1935-1939, returns over costs from F were lower than from E. The larger potato yield was not sufficient to overcome the low yields of the less valuable grass hay in F. In 1942-1946, returns over costs from F were higher than from E because of the larger yields of both potatoes and hay. If the feed value of the hay is an important item, clover hay should be considered.

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APPENDIX

Table 1. Rainfall in Inches at Kingston, Rhode Island During the Growing Season, April through September, for the Period 1930-1946

Year	April	May	June	July	August	September	Average
1930	1.70	3.45	2.50	3.35	2.49	1.39	2.48
1931	2.63	3.07	5.36	3.73	3.99	1.03	3.30
1932	2.00	2.76	2.40	2.81	5.40	12.66	4.66
1933	7.63	2.18	2.15	2.03	5.08	8.09	4.48
1934	5.92	4.24	3.19	1.38	1.62	3.23	3.26
1935	4.28	1.95	5.89	3.92	1.49	5.21	3.79
1936	3.41	1.81	4.29	1.56	4.46	7.91	3.91
1937	5.47	3.31	4.36	0.95	4.06	3.24	3.56
1938	3.33	5.84	7.05	4.49	3.51	5.91	5.21
1939	5.39	0.69	3.33	1.00	8.82	2.29	3.59
1940	5.15	4.78	1.93	3.46	0.81	3.59	3.29
1941	1.99	2.48	6.83	4.15	1.87	0.35	2.94
1942	0.72	1.72	2.65	4.26	6.00	2.65	2.93
1943	3.35	3.61	1.40	2.69	2.63	1.20	2.49
1944	3.32	0.76	2.10	0.67	1.82	6.10	2.46
1945	2.59	4.86	2.84	1.22	3.83	1.25	2.77
1946	2.53	4.77	3.21	2.04	11.12	2.24	4.32
Average	3.61	3.07	3.62	2.57	4.06	4.02	3.49

Table 2. Average Prices of Various Fertilizer Ingredients for the Years 1935-1939 and 1942-1946[a]

	1935-1939		1942-1946	
	Per Ton	Per Lb.	Per Ton	Per Lb.
Nitrate of soda	$35.88	$.01794	$38.64	$.01932
Ammonium sulfate	37.40	.01870	36.76	.01838
Superphosphate	18.72	.00936	25.52	.01276
Muriate of potash	39.08	.01954	42.00	.02100
Potassium sulfate	44.48	.02224	47.80	.02390
Magnesium oxide	4.16	.00208	3.86	.00193

[a]Prices were supplied by Fertilizer Section, Eastern States Farmers Exchange, and are F.O.B. Cambridge, except magnesium oxide, which is F.O.B. Canaan, Connecticut.

Table 3. Average Annual Cost of Fertilizer Ingredients Used per Acre, By Rotations and By Crops Grown for the Years 1935-1939 and 1942-1946

	1935-1939			1942-1946		
Ingredient	Corn	Potatoes	Hay[a]	Corn	Potatoes	Hay[a]
			Rotation B			
Nitrate of soda	$2.33	$4.52	$9.46	$2.25	$4.66	$8.69
Ammonium sulfate	1.94	3.78	......	1.97	5.64	......
Superphosphate	4.27	7.56	18.05	7.66	12.76	22.71
Muriate of potash	2.45	1.30	12.57	1.68	7.00	14.70
Potassium sulfate	......	6.13	......	......	......	......
Calcium oxide	......	......	3.79	......	......	1.93
Magnesium oxide	......	......	......	......	.06	......
Cow manure	24.00	......	......	36.00	......	......
Total	34.99	23.29	43.87	49.56	30.12	48.03
			Rotation E			
Nitrate of soda	2.35	4.52	8.28	2.25	4.90	6.76
Ammonium sulfate	1.94	3.78	......	1.97	5.92	......
Superphosphate	4.27	7.56	11.54	7.66	13.40	17.29
Muriate of potash	2.45	1.30	7.15	1.68	7.35	11.17
Potassium sulfate	......	6.13	......	......	......	......
Calcium oxide	......	......	1.73	......	......	1.93
Magnesium oxide	......	......	......	......	.06	......
Total	10.99	23.29	28.70	13.56	31.63	37.15
			Rotation F			
Nitrate of soda	2.33	4.52	15.81	2.25	4.90	26.32
Ammonium sulfate	1.94	3.78	......	1.97	5.92	......
Superphosphate	4.27	7.56	11.54	7.66	13.40	14.42
Muriate of potash	2.45	1.30	6.37	1.68	7.35	7.91
Potassium sulfate	......	6.13	......	......	......	......
Calcium oxide	......	......	1.73	......	......	1.54
Magnesium oxide	......	......	......	......	.06	......
Total	10.99	23.29	35.45	13.56	31.63	50.19

[a] In rotation B, the figures for hay are 4-year totals. In rotations E and F, they are 3-year totals.

Table 4. Average Seed Prices for the Years 1935-1939 and 1942-1946[a]

Crop[b]	Unit	1935-1939	1942-1946
Corn	lb.	$.0517	$.0709
Grimm alfalfa	lb.	.3769	.5380
Medium red clover	lb.	.3167	.4086
Alsike clover	lb.	.2963	.3776
Timothy	lb.	.1055	.0966
Redtop	lb.	.1655	.1896
Potatoes	bu.	1.1600	3.4700

[a]Cash car-door price, Rhode Island, was supplied by Eastern States Farmers Exchange.
[b]Hay seeding rates for rotation B were 20 lb. alfalfa and 2 lb. of timothy; for rotation E, 7 lb. alfalfa, 5 lb. red clover, 3 lb. alsike clover, 3 lb. timothy, 2 lb. redtop; for rotation F, 10 lb. timothy, 5 lb. redtop.

Table 5. Estimated Average Labor Requirements for Corn, Potatoes, and Hay for the Years 1935-1939 and 1942-1946

	1935-1939 Number of Hours			1942-1946 Number of Hours		
Crop	Man	Tractor	Equipment	Man	Tractor	Equipment
		Per Acre			Per Acre	
Corn (silage)	50	15	15	40	15	15
Corn (grain)	70	15	15	60	15	15
Potatoes	75	19	19	70	19	19
		Per Ton			Per Ton	
Alfalfa	5.5	1.5	1.5	5.0	1.5	1.5
Clover and timothy	5.0	1.5	1.5	4.5	1.5	1.5
Timothy and redtop	5.0	1.5	1.5	4.5	1.5	1.5

Table 6. Average Prices Received By Farmers For Corn, Potatoes, and Hay for the Years 1935-1939 and 1942-1946[a]

Year	Corn Per Bu.	Potatoes Per Bu.	All Hay[b] Per Ton	Alfalfa[b] Per Ton	Clover and Timothy[b] Per Ton
1935	$.80	$.70	$15.40		
1936	1.20	1.34	18.60		
1937	.96	.75	15.50		
1938	.68	.77	15.60		
1939	.71	1.00	16.90		
Avg.	.87	.91	16.40	25.40	19.40
1942	.97	1.30	19.00		
1943	1.32	1.30	21.60		
1944	1.45	1.78	31.80		
1945	1.45	2.03	27.75		
1946	1.81	1.85	23.00		
Avg.	1.40	1.73	24.63	33.63	27.63

[a]U. S. Dept. Agr., Agricultural Statistics for 1935-1944, and U. S. Dept. Agr. Bur. Agr. Econ., Agricultural Prices for 1945-1946.
[b]The average of "All Hay" is used in computing returns from hay in Rotation F. Based on monthly price spreads from January 1945 to December 1946, an estimated differential of $9.00 per ton for alfalfa and $3.00 per ton for clover and timothy from the price of "All Hay" is applied to Rotations B and E.