THE LIME FACTOR IN PERMANENT SOIL IMPROVEMENT

II. ROTATIONS WITH LEGUMES

J. G. LIPMAN AND A. W. BLAIR

New Jersey Agricultural Experiment Station

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In the preceding paper, the authors have discussed the influence of lime on crops grown in a rotation which, so far as possible, excludes all legumes. In this paper, an attempt is made to show the influence of lime in four different rotation systems, all of which include some legume crops.

The soil on which this work was carried out is of the same character as and adjacent to that which was described in the preceding paper. It is a loam inclining to a sandy or gravelly phase and previous to 1908 when the work was started, had been badly neglected.

Twenty-eight $\frac{1}{8}$ -acre plots were laid out and these divided into 4 sections of 7 plots each, each section being devoted to a different rotation but all sections having the same lime treatment. The rotations for the different sections are as follows:

	ROTATION 1 PLOTS 21-27	ROTATION 2 PLOTS 28-34	ROTATION 3 PLOTS 35-41	ROTATION 4 PLOTS 42-48
1913	Corn (rye, vetch, crimson clover)	Corn (rye, vetch, crimson clover)	Corn (rye, vetch, crimson clover)	Corn (rye, vetch, crimson clover)
1914	Oats (soybeans and cowpeas)	Potatoes	Potatoes (rye)	Oats and peas, mil- let
1915	Wheat	Rye	Tomatoes (rye, vetch, crimson clover)	Rye and vetch, rape
1916	Timothy and clover	Timothy and clover	Lima beans (rye, vetch, crimson clover)	Rye, cowpeas (rye)
1917	Timothy and clover	Timothy and clover	Cucumbers (rye and vetch)	Oats and peas, cow- peas

The first plot in each section is the check plot, that is, it receives no lime treatment. The second, third and fourth plots in each section received in 1913, $\frac{1}{2}$, 1 and 2 tons, respectively, of finely ground calcium limestone per acre, and the fifth, sixth and seventh plots received $\frac{1}{2}$, 1 and 2 tons, respectively, of magnesian limestone per acre. This lime treatment was intended to last throughout the 5-year rotation, 1913 to 1917.

Samples of soil were not collected when the work was begun but samples which were taken from three of the plots in 1909 showed an average nitrogen content of a little over 0.10 per cent. In 1913 and again in 1918, samples were collected from all plots for lime-requirement and total nitrogen and carbon determinations. The results of the determinations on the two sets of samples are shown in another place in this paper.

It should be explained here that the results of this work for the first five years, 1908 to 1912, have been published (1, 2), and will not be included in this paper except in so far as they may be needed to make clear the work of the second 5-year period.

In summarizing this work, it was stated that with comparatively few exceptions, both forms of lime increased the yield of dry matter and nitrogen

TABLE 1

Average increase in yield of nitrogen, in pounds per acre, over the check plots, for the non-magnesian and magnesian limestone sections, 1908-1912

		1908	1909	1910	1911	1912
		lbs.	lbs.	lbs.	lbs.	lbs.
Plots 21-27 (Rotation 1)	Non-magnesian limestone.....	7.95	1.97	5.95	2.00	2.67
	Magnesian limestone.....	14.91	9.70	11.23	10.47	11.70
Plots 28-34 (Rotation 2)	Non-magnesian limestone.....	10.27	0.00	9.74	2.79	8.55
	Magnesian limestone.....	3.33	0.00	17.17	4.06	5.97
Plots 35-41 (Rotation 3)	Non-magnesian limestone.....	5.57	3.93	*	8.51	*
	Magnesian limestone.....	7.21	5.93	*	6.77	*
Plots 42-48 (Rotation 4)	Non-magnesian limestone.....	7.71	2.75	52.65	16.74	27.89
	Magnesian limestone.....	6.41	12.73	70.00	0.00	20.05

* Nitrogen determinations not made.

over the yields given by the check plots. It was also pointed out that in the majority of cases, the dry matter of crops from the limed plots showed a higher percentage of nitrogen than dry matter from the unlimed plots.

The influence of the lime is clearly brought out by the figures given in table 1 which show the average increase, in pounds of nitrogen per acre, over the check plots, for the two limestone treatments. With only slight exception, a fair gain is shown for all rotations. The most pronounced exception is the potato crop on plots 28 to 34 in 1909.

It is significant that the largest gains are shown for the forage crops rotation, plots 42 to 48. In 1910, on these plots there was a gain of 52.65 pounds of nitrogen per acre for the non-magnesian limestone and 70 pounds per acre for the magnesian limestone. In some cases, the gain is greater for the one form of lime and in other cases for the other form.

The average percentage of nitrogen in the soil samples collected in 1913 is somewhat less than the average of the three samples taken in 1909. This, it is pointed out, appears to indicate a gradual loss of nitrogen even though the plots had received a moderate application of nitrogenous fertilizers and had had the benefit of two or more leguminous crops during the rotation. The land, however, was producing good crops which were with one exception being taken off the land, and thus more nitrogen was being removed in the crops than was being applied in the form of commercial fertilizers.

The second 5-year period embraces the years of 1913 to 1917 and the results are reported for the two forms of lime as yield of dry matter, per cent of nitrogen in the dry matter, and total nitrogen removed in the crop. This plan is carried out for the four rotations and it is thus possible to note the influence of the lime on the yield of dry matter and nitrogen and also to compare the two forms of lime as used in the different quantities.

ROTATION 1—GENERAL FARM CROPS

Plots 21-27—1913 to 1917

This rotation consisted of one year of corn, one of oats, one of wheat and two of timothy and clover. Since this was the beginning of the second 5-year period, there was a timothy and clover sod to be plowed under for corn. Notes made May 1, 1919, state that on the check plot (plot 21, no lime) there was a poor stand of clover in scattered weak bunches and that on the limed plots the stand was fair to good.

The land was fitted for corn and finely ground limestone applied in accordance with the plans already outlined. Fertilizers also were applied on the acre basis as follows:

Acid phosphate, 300 pounds

Muriate of potash, 100 pounds

A mixture of fish and tankage equivalent to 200 pounds of fish

This, it will be noted furnished nitrogen equivalent to about 100 pounds of nitrate of soda.

Reed's Yellow Dent corn was planted on June 2 and this received the usual cultivation during the season. In late September, the corn was harvested, weighed and samples dried and prepared for analysis.

A cover crop of rye, vetch and crimson clover was seeded in the corn at the last cultivation. Notes made in the early spring of 1914 state that the rye on the no-lime plot was about 4 inches high but that there was no vetch or crimson clover on this plot. The rye was thicker on the other plots and there was also more vetch and crimson clover.

On April 14 this cover crop was plowed under and about one week later fertilizers were applied and the plots seeded to oats. The fertilizers were the same as those used for the corn the previous year, except that dried fish was used at the rate of 200 pounds per acre.

In July it was noted that the oats on plot 21 (check) were more mature but the crop was not so heavy as on the lime-treated plots.

On July 27 the oats were harvested and samples prepared for analysis. Following the oats the land was disked and seeded to a mixture of soybeans and cowpeas as a cover crop. The beans and peas grew finely and on September 14 were plowed under preparatory to seeding the wheat. The plants were 6 to 7 inches high and appeared to be well inoculated. Fertilizers were applied as follows:

	<i>lbs. per acre.</i>
Acid phosphate.....	300
Muriate of potash.....	100
High-grade tankage.....	200

On September 30, wheat was seeded at the rate of $7\frac{1}{2}$ pecks per acre. Notes made April 15, 1915, and again on May 1 state that the wheat on plot 21 was not so good as on the other plots. The wheat was harvested July 9, weighed, and samples prepared for analysis. The land was then fitted for timothy and clover and fertilizers applied on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	400
Muriate of potash.....	100
Nitrate of soda.....	50

The full application of nitrate was 200 pounds per acre, but 150 pounds of this was reserved for a top-dressing to be applied in the spring. The timothy and clover were seeded on September 2 and this seeding resulted in a good stand. On April 13, 1916, the remainder of the nitrate of soda was applied as a top-dressing. A note made June 1 states that there was practically no clover on plot 21. The crop was harvested July 5, weighed and sampled. On August 22, a second cutting of this crop was made, and it was noted at this time that the timothy was too short to be a factor and that there were only a few bunches of clover on plot 21. The plots that received 2000 pounds of limestone were about three-quarters covered with clover, while those that received 4000 pounds were entirely covered. The crop was weighed and samples prepared for analysis.

On November 9, acid phosphate and muriate of potash were applied to the timothy and clover at the rate of 300 pounds and 100 pounds per acre, respectively.

The following spring nitrate of soda was applied as a top-dressing at the rate of 200 pounds per acre.

On June 1 it was noted that there was not very much clover on any of the plots. This is shown by the low nitrogen content of the hay, analysis of which is reported in table 3. The crop was harvested July 5, weighed and sampled for analysis. As already indicated, samples of all these crops were carefully dried and the yield of dry matter calculated on an acre basis. Nitrogen determinations were made on all samples, thus providing for the calculation of the total nitrogen in the crops.

The yields of dry matter and total nitrogen per acre and the percentage of nitrogen in the dry matter for the various crops for the 5-year period are shown in tables 2, 3 and 4.

Considering first the yields of dry matter as shown in table 2, it will be noted that with only slight exception, the plots receiving the lime treatment have given better yields than the check plots. The most notable exception is the oats crop of 1914, where the check plot yielded more grain than any of the treated plots. In the case of the other crops the check plot invariably yielded less than the treated plots.

TABLE 2

Rotation 1—Yield of dry matter, in pounds per acre, for 5 years, 1913-1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914		1915		1916		1917	TOTAL		ANNUAL IN- CREASE OVER CHECK	
		Corn		Oats		Wheat		Timothy and clover	Red clover	Timothy and clover	Grain	Stover straw hay	Grain	Stover straw hay
		Grain	Stover	Grain	Straw	Grain	Straw							
21	Check	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
		850	2650	660	860	1040	1240	3600	200	2620	2550	11,170		
Calcium-limestone section														
22	1000	1225	2800	480	800	1200	1440	3680	980	3520	2905	13,220	118.3	410
23	2000	1400	2950	600	1040	1260	1640	4380	1420	3640	3260	15,070	236.7	780
24	4000	1675	3150	600	1020	1240	1480	4400	1660	3500	3515	15,210	321.7	808
Average		1433	2967	560	953	1233	1520	4153	1353	3553	3227	14,500	225.6	666
Magnesian-limestone section														
25	1000	1850	3500	620	1040	1240	1600	4440	1100	3520	3210	15,200	220.0	806
26	2000	1875	3500	600	1120	1260	1680	4620	1920	3800	3735	16,640	395.0	1094
27	4000	2000	3200	640	1040	1220	1600	4540	1800	4220	3860	16,400	436.7	1046
Average		1742	3400	620	1067	1240	1627	4533	1607	3847	3602	16,080	350.6	982

With very slight exception, there is some increase in yield with each increase in the amount of calcium limestone applied, and likewise an increase from the 1000 to the 2000-pound application of magnesian limestone. On the other hand, there is not so often an increase in yield from the 2000 to the 4000-pound application in this section. It is to be noted, however, that the average yields on the magnesian-limestone section are without exception, larger than the corresponding yields for the calcium-limestone section.

The average *annual* increase for the check plots for the calcium-limestone section is for the grain 225.6 pounds, and for the straw, hay, etc., 666 pounds, whereas the corresponding figures for the magnesian-limestone section are

TABLE 3

Rotation 1—Yield of nitrogen, in pounds per acre, removed by crops for the years 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914		1915		1916		1917	TOTAL NITRO- GEN GRAIN, HAY, ETC.	ANNUAL INCREASE OF NITROGEN OVER CHECK
		Corn		Oats		Wheat		Timo- thy and clover	Red clover	Timo- thy and clover		
		Grain	Stover	Grain	Straw	Grain	Straw					
21	lbs. Check	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
		10.31	15.30	13.36	6.29	20.47	3.66	31.18	4.32	19.91	124.80	

Calcium-limestone section

22	1000	15.35	17.76	10.48	6.56	24.30	3.96	41.29	25.03	28.51	173.24	9.69
23	2000	18.37	21.90	13.27	8.90	25.16	6.30	52.74	35.87	30.90	213.41	17.72
24	4000	24.12	25.21	13.16	7.64	24.63	4.07	52.58	44.97	29.72	226.10	20.26
Average		19.28	21.62	12.30	7.70	24.70	4.78	48.87	35.29	29.71	204.25	15.89

Magnesian-limestone section

25	1000	17.17	23.99	13.60	7.88	25.13	5.34	45.78	28.90	27.81	195.60	14.16
26	2000	25.71	26.57	13.10	10.28	24.80	4.79	54.79	51.30	32.26	243.60	23.76
27	4000	29.78	24.40	15.12	8.90	24.24	5.50	52.16	47.61	34.56	242.27	23.49
Average		24.22	24.99	13.94	9.02	24.72	5.21	50.91	42.60	31.54	227.16	20.47

TABLE 4

Rotation 1—Per cent of nitrogen in dry matter of crops for the years 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914		1915		1916		1917
		Corn		Oats		Wheat		Timo- thy and clover	Red clover	Timo- thy and clover
		Grain	Stover	Grain	Straw	Grain	Straw			
21	Check	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
		1.213	0.573	2.024	0.731	1.968	0.295	0.866	2.161	0.760

Calcium-limestone section

22	1000	1.253	0.652	2.184	0.820	2.025	0.275	1.122	2.554	0.810
23	2000	1.312	0.761	2.211	0.856	1.997	0.384	1.204	2.526	0.849
24	4000	1.440	0.820	2.193	0.749	1.987	0.275	1.195	2.709	0.849
Average		1.335	0.744	2.196	0.808	2.003	0.311	1.174	2.596	0.836

Magnesian-limestone section

25	1000	1.272	0.711	2.193	0.758	2.027	0.334	1.031	2.627	0.790
26	2000	1.371	0.790	2.184	0.918	1.968	0.285	1.186	2.672	0.849
27	4000	1.489	0.810	2.362	0.856	1.987	0.344	1.149	2.645	0.819
Average		1.377	0.770	2.246	0.844	1.994	0.321	1.122	2.648	0.819

for the grain 350.6 pounds, and straw, hay, etc., 982 pounds. Attention should be called to the very wide difference between the yield of red clover on the check plot and the treated plots for 1916. This crop, as is well known, is especially susceptible to the unfavorable soil condition brought about by the deficiency of lime.

What has been said with reference to the yield of dry matter will apply in most cases to the yield of total nitrogen shown in table 3. With very few exceptions, the lime treatments have resulted in an increase of total nitrogen over the check plot. The 2000-pound application of both forms of lime, in nearly all cases, shows an increase over the 1000-pound application. In a number of cases, on the other hand, the 4000-pound application shows no increase over the 2000-pound application. The total yields of nitrogen for the 5 years are as follows:

	LIMESTONE APPLIED	YIELD
	<i>lbs. per acre</i>	<i>lbs. per acre</i>
Check.....		124.8
Calcium limestone.....	1000	173.2
	2000	213.4
	4000	226.1
Magnesian limestone.....	1000	195.6
	2000	243.5
	4000	242.3

From these figures it will be noted that with the calcium limestone 4000 pounds gave a slightly higher yield than 2000 pounds. With the magnesian limestone, the yields with the 2000 and 4000-pound applications are practically the same.

The annual increase for the calcium limestone plots over the check plots ranges from 9.69 pounds, with the 1000-pound application to 20.26 pounds with the 4000-pound application. In the case of the magnesian limestone the increase is 14.16 pounds with the 1000-pound application, 23.76 pounds with the 2000-pound application, and 23.49 pounds with the 4000-pound application. Excluding the 1000-pound applications, the increases per acre will average above 20 pounds per year. Thus the increase for one year would more than pay the cost of the limestone.

The percentage of nitrogen in the dry matter as reported in table 4 is of especial interest. With very few exceptions, it is higher in the samples from the limed plots than in those from the check plots. This is true of the grain and also of the straw, corn stover and hay. In earlier publications we have called attention to this effect of lime and have suggested, in the case of the legume crops, that the lime tends to establish soil conditions favorable to the development of those organisms which aid the plant in storing up atmos-

pheric nitrogen. The higher percentage of nitrogen in non-leguminous plants is no doubt in part an indirect effect of the stimulation of the symbiotic organisms, that is, the utilization of nitrogen which was secured through leguminous plants, and in part the result of the stimulation of those organisms which nitrify organic matter in general.

To increase the crop yield means much, but to increase also the nitrogen content of the crop adds still further to its total value.

The average percentages of nitrogen in the crops from the two sections differ but slightly, that is, the average percentage of nitrogen in the crops from the magnesian-limestone section is not appreciably greater than the average in crops from the calcium-limestone section.

Referring again to the total yield of nitrogen (table 3) it may be pointed out that with 2000 pounds per acre of magnesian limestone, the timothy and clover crop of 1916 removed slightly more than 100 pounds of nitrogen per acre. In comparison with this, it will be noted that the corn crop of 1913—grain and stover—removed about one-half as much nitrogen. The smallest amount of nitrogen was removed by the oat crop of 1914. This was somewhat below the normal, because the oats shattered badly at the time of harvesting.

The fertilizers which were applied during the 5 years carried a total of about 108 pounds of nitrogen. The crops on the calcium-limestone section removed an average during the same period of a little more than 200 pounds per acre, and those on the magnesian-limestone section removed an average of nearly 230 pounds per acre. There is good reason for believing that this excess over the amount applied is being drawn from the atmosphere largely through the legume crops. If it is not being thus secured then the soil is gradually being depleted of its nitrogen supply. This question will be further discussed in connection with the table showing the percentage of nitrogen in the soil.

ROTATION 2—GENERAL FARM CROPS WITH POTATOES

Plots 28-34—1913 to 1917

This rotation consists of one year of corn, one of potatoes, one of wheat and two of timothy and clover. As in the case of rotation 1, plots 21 to 27, the timothy and clover sod preceded the corn and the corn crop was fertilized and cared for in the same way as in rotation 1. Early in August a cover crop of rye, vetch and crimson clover was seeded in the corn. Notes taken April 8, 1914, show that the rye was thin on plots 28 and 29, and also that there was not much vetch and crimson clover on these plots. This cover crop was plowed under about the middle of April, 1914, and fertilizers applied on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	300
Muriate of potash.....	100
Dried fish.....	200

Early in May the plots were planted to Green Mountain potatoes. After these had been planted, it was decided that the first application of fertilizers was not sufficient and the following additional application was made per acre—100 pounds of acid phosphate and 200 pounds of muriate of potash, thus making the total application 400 pounds of acid phosphate, 300 pounds of muriate of potash and 200 pounds of dried ground fish. This fertilizer was spread broadcast.

The crop was cultivated and sprayed in the usual way throughout the season. Potatoes were dug about the twenty-fifth of August and later the plots were disked preparatory to seeding to rye. Fertilizers were applied on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	300
Muriate of potash.....	100
High-grade tankage.....	200

The plots were seeded to rye at the rate of 6 pecks per acre (vetch and crimson clover were not included in this seeding).

Notes taken April 15, 1915, state that the rye was 8 to 10 inches high at that time. The rye was harvested as grain the last of June and about the last of August the land was prepared and seeded to timothy and clover. For this crop fertilizers were applied on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	400
Muriate of potash.....	100
Nitrate of soda.....	50

On April 13, 1916, these plots received a further top-dressing of nitrate of soda equivalent to 150 pounds per acre. On June 6, the timothy on these plots was about 22 to 24 inches high. There was very little clover on the check plot (no. 28), though there was a fine stand on the other plots. On July 5 the crop was harvested and weighed and the samples prepared.

On August 1 the second growth of clover on these plots was reported as about 12 to 15 inches high, but it was noted that there was very little on plot 28. This second growth was cut and weighed and samples prepared August 23. On November 9 the plots were fertilized at the following rate per acre:

	<i>lbs.</i>
Acid phosphate.....	300
Muriate of potash.....	100

On April 12, 1917, nitrate of soda was applied at the rate of 200 pounds per acre, no nitrate having been applied the previous fall. The effect of this top-dressing was soon apparent, and the timothy made a good growth. The clover was poor. The crop was harvested and weighed July 5 and samples prepared for analysis. The yield of dry matter and total nitrogen from these plots and the percentage of nitrogen in the dry matter are reported in tables 5, 6 and 7.

The yields of dry matter for the 5-year period are summarized in table 5. For the corn and the timothy and clover the lime treatment shows fair increases over the check plots. For the potatoes and rye—1914 and 1915—the yields on the treated plots are slightly less than those on the check, with the exception of the potatoes on the calcium limestone section. The failure of these crops to respond to the lime treatment was probably due to the partial failure of the cover crop which preceded the potatoes, and the absence of any legume cover crop preceding the rye. Or to express the matter an-

TABLE 5

Rotation 2—Yield of dry matter, in pounds per acre, for the 5-year period, 1913–1917*

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914	1915		1916		1917	TOTAL†		YEARLY IN- CREASE OVER CHECK	
		Corn		Potatoes	Rye		Timothy and clover	Red clover	Timothy and clover	Grain	Forage, hay, etc.	Grain	Stover, hay
		Grain	Stover		Grain	Straw							
28	lbs. Check	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
		1050	2425	6200	1400	2680	3920	660	3500	2450	13,185		

Calcium-limestone section

29	1000	1850	2575	7040	1360	2600	4320	960	3680	3210	14,135	380	238
30	2000	1900	2425	7100	1400	2700	4820	1160	4440	3300	15,545	425	590
31	4000	2025	2725	6560	1280	2560	4520	1580	4500	3305	15,885	428	675
Average		1925	2575	6900	1347	2620	4553	1233	4207	3272	15,188	411	501

Magnesian-limestone section

32	1000	2000	2700	5960	1440	2600	4620	1080	3960	3440	14,960	495	444
33	2000	2050	2700	5620	1520	2800	4440	1760	3840	3570	15,540	560	589
34	4000	2200	2525	5240	1320	2560	4200	1660	3580	3520	14,525	535	335
Average. ...		2083	2642	5607	1427	2653	4420	1500	3793	3510	15,008	530	456

* Field weight of potatoes.

† Potatoes not included in total.

other way, the lime could not exert its full benefit in the partial or complete absence of those crops through which it manifests itself most readily. The most notable increases occur with the mixed timothy and clover and clover alone. The latter shows an increase of more than 100 per cent with the magnesian limestone and almost as much with the calcium limestone.

The yields of total nitrogen which are shown in table 6 follow quite closely the yields of dry matter. In the case of the corn (grain) and the red clover the increase amounts to over 100 per cent. The potatoes and rye on the check plot yielded very nearly the same amount of nitrogen as on the treated plots.

On the calcium-limestone plots, there was recovered an average of nearly 228 pounds of nitrogen per acre for the 5-year period and on the magnesian-limestone plots an average of about 234 pounds for the same period, or more than 45 pounds per acre per annum. During the 5 years, there was applied to these plots about 108 pounds of nitrogen, or 22 pounds per year. Apparently we have here a loss of about 24 pounds per acre annually, but undoubtedly this loss was more than made up by the nitrogen secured through the legume crops.

Table 7 shows the percentage of nitrogen in the dry matter of the different crops. It will be noted that, with very few exceptions, the crops from the lime-treated plots—both sections—show a higher percentage of nitrogen than the crops from the check plots. This is in accord with the results secured in rotation 1.

ROTATION 3—CORN, POTATOES AND MARKET GARDEN CROPS

Plots 35-41—1913 to 1917

The corn in this rotation was preceded by the timothy and clover sod and received the same treatment as that in rotations 1 and 2, and the potatoes the same treatment as those in rotation 2. Following the potatoes, the plots were disked, fertilizers applied and rye seeded at the rate of 6 pecks per acre. The fertilizer treatment was the same as that given to plots 28 to 34 at this time.

On April 15, 1915, the rye on these plots was about 8 to 10 inches high. On May 3, the plots were disked preparatory to plowing under the rye as a green manure. The plots were plowed on June 2 and fertilizers applied for the tomatoes on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	600
Muriate of potash.....	300
Nitrate of soda.....	200
Dried blood.....	160

Chalk's Early Jewel tomatoes were set out and later in the season received the usual cultivation and other attention. Picking began about the middle of August and continued until the middle of September, five pickings being made.

Unfortunately, samples were not saved from each plot but a composite sample was made. Thus it is necessary in calculating the nitrogen removed by the tomatoes to base the calculations on the analysis of this composite sample.

Following the tomatoes, the land was disked and seeded to a mixture of rye, vetch and crimson clover. The amount of rye in the mixture was small and consequently a thin stand was secured. Notes made on April 1, 1916,

TABLE 6

Rotation 2—Yield of nitrogen, in pounds per acre, removed by crops for the years 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914	1915		1916		1917	TOTAL NITRO- GEN	YEARLY IN- CREASE OVER CHECK
		Corn		Potatoes	Rye		Timo- thy and clover	Red clover	Timo- thy and clover		
		Grain	Stover		Grain	Straw					
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
28	Check	14.29	19.00	22.47	19.96	8.23	38.96	14.93	27.30	165.14	

Calcium-limestone section

29	1000	28.29	22.31	23.84	19.53	7.20	38.62	23.03	29.44	192.26	5.42
30	2000	32.98	28.17	20.90	21.21	8.29	56.25	26.45	39.03	233.28	13.63
31	4000	35.37	35.06	20.34	20.15	8.60	62.24	39.63	36.00	257.39	18.45
Average		32.21	28.51	21.69	20.30	8.03	52.37	29.70	34.82	227.64	12.50

Magnesian-limestone section

32	1000	31.36	25.16	21.72	21.40	7.98	52.67	26.49	34.41	221.19	11.21
33	2000	31.92	30.20	21.14	21.98	8.60	46.18	44.62	37.52	242.16	15.40
34	4000	34.06	26.79	19.26	19.87	8.60	55.15	41.48	34.65	239.86	14.94
Average		32.45	27.38	20.71	21.08	8.39	51.33	37.53	35.53	234.40	13.85

TABLE 7

Rotation 2—Per cent of nitrogen in dry matter of crops for the 5-year period, 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914	1915		1916		1917
		Corn		Potatoes	Rye		Timothy and clover	Red clover	Timothy and clover
		Grain	Stover		Grain	Straw			
	lbs.	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
28	Check	1.361	0.751	1.783	1.426	0.307	0.994	2.262	0.780

Calcium-limestone section

29	1000	1.529	0.830	1.703	1.436	0.277	0.894	2.399	0.800
30	2000	1.736	1.097	1.560	1.515	0.307	1.167	2.280	0.879
31	4000	1.746	1.235	1.614	1.574	0.336	1.377	2.508	0.800
Average.		1.670	1.054	1.626	1.508	0.307	1.146	2.396	0.826

Magnesian-limestone section

32	1000	1.568	0.889	1.872	1.486	0.307	1.140	2.453	0.869
33	2000	1.557	1.067	1.854	1.446	0.307	1.040	2.535	0.977
34	4000	1.548	0.998	2.006	1.505	0.336	1.313	2.499	0.968
Average		1.558	0.985	1.911	1.479	0.317	1.164	2.496	0.938

state that the cover crop on these plots was fair. Later notes show that the vetch and crimson clover were poor on plot 35 and very good on plot 41.

On May 8 this cover crop was plowed under and on the nineteenth fertilizers were applied on the acre basis as follows:

	lbs.
Acid phosphate.....	600
Muriate of potash.....	300
Nitrate of soda.....	100

About one week later, Burpee's bush lima beans were planted. Notes made July 1 show that the beans were somewhat irregular in growth. On August 1 they were in bloom. On the tenth of August the cover crop consisting of rye, vetch and crimson clover was seeded in the beans. Between September 11 and October 20, four pickings of beans were made. Notes made April 12, 1917, show that there was a good cover crop on these plots. On May 15 the cover crop was plowed under and fertilizers applied on the acre basis as follows:

	lbs.
Acid phosphate.. ..	400
Muriate of potash.....	100
Nitrate of soda.....	160
Tankage.....	200

On the twenty-fifth of May the plots were planted to White Spine cucumbers. These received the usual cultivation and other attention during the summer. A number of pickings were made between July 27 and August 31. Samples were taken from each plot for nitrogen determinations.

After the cucumbers were off the plots were disked and seeded to rye and vetch.

The yields of total dry matter (or marketable vegetables), the total nitrogen and percentage of nitrogen in the dry matter (or marketable vegetables) are shown in tables 8, 9 and 10.

From the figures given in table 8 it will be noted that the limestone-treated plots, in nearly all cases, show a distinct increase over the check plots. This is true for both forms of limestone and if we may judge from the averages, one form does not have much advantage over the other. The cucumbers on the limed plots show notable increases over the check plots. The yield of potatoes on the calcium-limestone section is greater than the yield on the magnesian-limestone section. This is true also of the potatoes grown in rotation 2. It is doubtful, however, if the differences are sufficient to have any particular significance.

It should be noted that the yields of potatoes, tomatoes and cucumbers are the yields at the time of harvesting and not the yields of dry matter.

Table 9 shows the total yield of nitrogen for the various crops. With only one exception (lima beans on plot 41) the lime-treated plots show pronounced increases over the check plots.

TABLE 8

Rotation 3—Yield of dry matter (or harvesting weights), in pounds per acre, for the years 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914	1915	1916		1917	TOTAL		
		Corn		Potatoes	Ripe tomatoes	Lima beans		Market- able cu- cumbers	Grain	Stover	Potatoes tomatoes cucum- bers
		Grain	Stover			Seeds	Pods				
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
35	Check	1475	2650	4800	24,080	480	260	8,138	1955	2910	37,018
Calcium-limestone section											
36	1000	1675	2850	6320	28,550	660	332	11,618	2335	3182	46,488
37	2000	1750	3125	6300	27,860	860	448	13,536	2610	3573	47,696
38	4000	2025	3325	5740	25,610	720	360	11,688	2745	3685	43,038
Average		1817	3100	6120	27,340	747	380	12,281	2563	3480	45,741
Magnesian-limestone section											
39	1000	1775	2975	5680	25,454	540	300	13,432	2315	3275	44,566
40	2000	2100	3275	6260	27,720	660	288	13,482	2760	3563	47,462
41	4000	2200	3200	5100	28,924	360	200	13,496	2560	3400	47,520
Average		2025	3150	5680	27,366	520	263	13,470	2545	3413	46,516

NOTE: Potatoes, tomatoes and cucumbers weighed as harvested.

TABLE 9

Rotation 3—Yield of nitrogen, in pounds per acre, removed by crops for the years 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914	1915	1916		1914	TOTAL NITROGEN	YEARLY INCREASE OVER CHECK
		Corn		Potatoes	Ripe tomatoes	Lima beans		Market- able cu- cumbers		
		Grain	Stover			Seeds	Pods			
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
35	Check	22.11	20.87	15.42	40.55	14.52	2.17	9.50	125.14	
Calcium-limestone section										
36	1000	25.61	23.50	16.20	48.08	19.97	2.46	14.82	150.64	5.1
37	2000	27.27	26.12	19.14	46.92	26.33	3.03	18.34	167.15	8.4
38	4000	30.76	24.62	20.74	43.13	20.51	2.30	14.96	157.02	6.4
Average		27.88	24.75	18.69	46.04	22.27	2.60	16.04	158.27	6.6
Magnesian-limestone section										
39	1000	24.51	22.01	16.41	42.86	16.74	2.56	16.94	142.03	3.4
40	2000	30.87	25.41	19.25	46.68	20.76	2.40	16.94	162.31	7.4
41	4000	34.06	27.99	16.34	48.71	11.43	2.88	15.86	157.27	6.4
Average		29.81	25.14	17.33	46.08	16.31	2.61	16.58	153.87	5.7

The averages for the two sections run very close together, though the average of the potatoes for the calcium-limestone section has a slight advantage over the corresponding average for the magnesian-limestone section.

Attention should be called to the fact that the total amount of nitrogen recovered in the crop is less, by more than fifty pounds, than the total amounts recovered from the two preceding rotations. This calls attention to the fact that market garden crops, although generally giving larger and more profitable yields than general farm crops, take from the land less nitrogen than the latter.

TABLE 10

Rotation 3—Per cent of nitrogen in dry matter of crops for the 5-year period, 1913–1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914	1915	1916		1917
		Corn		Potatoes*	Ripe tomatoes	Lima beans		Marketable cucumbers†
		Grain	Stover			Seeds	Pods	
	lbs.	per cent	per cent	per cent	per cent	per cent	per cent	per cent
35	Check	1.499	0.820	1.676	0.1684‡	3.025	0.835	0.121
Calcium-limestone section								
36	1000	1.529	0.860	1.373	0.1684	3.025	0.742	0.133
37	2000	1.558	0.879	1.569	0.1684	3.062	0.677	0.141
38	4000	1.519	0.769	1.819	0.1684	2.849	0.640	0.130
Average		1.535	0.836	1.587	0.1684	2.979	0.686	0.135
Magnesian-limestone section								
39	1000	1.381	0.771	1.578	0.1684	3.100	0.854	0.135
40	2000	1.470	0.810	1.631	0.1684	3.146	0.835	0.128
41	4000	1.548	0.939	1.738	0.1684	3.174	1.438	0.124
Average		1.466	0.840	1.649	0.1684	3.140	1.042	0.129

* Potatoes dried.

† Tomatoes and cucumbers sampled as harvested.

‡ Composite sample.

The total amount of nitrogen applied to these crops during the 5 years was about 150 pounds, or 30 pounds per acre, while the average amount removed on the lime-treated sections was about 155 pounds, or a yearly average of about 31 pounds per acre.

Table 10 shows the percentage of nitrogen in the different crops. The increase in percentage due to the lime treatment is not so consistent as in rotations 1 and 2, but there are as many plots for which the percentage of nitrogen is above that of the check as there are plots with the percentage below the check. The nitrogen determinations were made on the potatoes after they had been thoroughly dried but, as already explained, they were made on the tomatoes and cucumbers as harvested.

ROTATION 4—FORAGE CROPS

Plots 42-48—1913 to 1917

The corn which was planted on these plots in 1913 had been preceded in 1912 by oats and peas followed by cowpeas, both of which crops were taken off. As no winter cover crop was seeded, the plots remained bare during the winter of 1912 and 1913. This corn received the same attention and treatment as the corn in the other rotations. On August 6 a cover crop of rye, vetch and crimson clover was seeded in the corn. On April 21, 1914, this cover crop was plowed under, and notes made at that time state that there was a fair crop of vetch and crimson clover on all plots except plot 42 which had none. On April 23, fertilizers were applied to the oats and peas at the following rate:

	<i>lbs. per acre</i>
Acid phosphate.....	300
Muriate of potash.....	100
Fish.....	200

On April 24 oats and peas were seeded at the rate of 3 bushels per acre. On July 6 these were cut as a forage crop and the land immediately prepared for seeding to barnyard millet. The millet was seeded July 8. Notes made under date of August 4 state that there was a thin stand and that weeds were coming in to the detriment of the millet. The millet was cut August 28, the weights recorded and samples prepared for analysis. On August 31, the plots were plowed and prepared for winter vetch. Fertilizers were applied at the following rate per acre:

	<i>lbs.</i>
Acid phosphate.....	300
Muriate of potash.....	100

Notes made April 15, 1915, state that there was a very poor stand of vetch on plot 42. The vetch was good on the other plots. The poor stand on plot 42 was no doubt the result of winter-killing due to adverse soil conditions. On June 1, it was estimated that there was only one-fourth of a stand on this plot. On the other plots, the vetch was 20 to 26 inches high. The vetch was cut June 9 and the ground plowed and seeded to Dwarf Essex rape. Fertilizers were applied on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	300
Muriate of potash.....	100
Nitrate of soda.....	200

The rape was harvested September 15 but was not an entirely satisfactory crop on account of a rather heavy growth of crab-grass. The land was again plowed and seeded to rye, fertilizers being applied on the acre basis as follows:

	<i>lbs.</i>
Acid phosphate.....	400
Muriate of potash.....	100
Nitrate of soda.....	50

On November 1 a good stand of rye was noted on all the plots.

On April 13, 1916, a top-dressing of nitrate of soda was made at the rate of 150 pounds per acre. The rye made a good growth and on June 1 was cut as a forage crop. The land was plowed, fertilized and seeded to Whippoorwill cowpeas. The fertilizer treatment consisted of acid phosphate at the rate of 400 pounds and muriate of potash at the rate of 200 pounds per acre. Notes made August 1 state that there was a thin stand of the cowpeas and that there was much crab-grass among them. On September 19 the cowpeas were cut for hay. The record shows that the crop was about 50 per cent crab-grass. On September 28 the plots were disked and seeded to rye at the rate of 4 pounds per plot. A good stand was secured. On April 17, 1917, the rye was plowed under and fertilizers applied at the following rate per acre:

	<i>lbs.</i>
Acid phosphate.....	300
Muriate of potash.....	100
Dried fish.....	200

Oats and peas were seeded at the rate of 3 bushels per acre. On July 1 the oats and peas were about 8 to 10 inches high but the check plot was noted as being the poorest. They were cut as hay July 12 and the ground disked and seeded to Whippoorwill cowpeas at the rate of 6 pounds per plot. Notes of August 1 state that there was a good stand. The check plot, however, was the poorest. On October 2 they were harvested as hay. The plots were prepared with a spring-tooth harrow on October 12 and rye was seeded at the rate of 4 pounds per plot. The yields for these plots during the 5-year period, together with the total yield of nitrogen and percentage of nitrogen in the crop are shown in tables 11, 12 and 13.

The yield of dry matter for the 5-year period is shown in table 11. Again, with slight exception, the lime-treated plots show a distinct increase over the check plots. In the calcium-limestone section, the oats and peas grown in 1914 show an average increase of 760 pounds per acre and the vetch grown the next year shows a much larger average increase. It may be explained here that the vetch on the check plot was almost an entire failure.

In most cases the averages for the magnesian-limestone section run quite close to those for the calcium-limestone section. However, for the millet the yield on the former is less than on the latter. For the vetch of 1915 the yield is almost twice as much from the magnesian-limestone section as from the calcium-limestone section. The average yearly increase in grain for the calcium-limestone section amounts to 533 pounds and for the magnesian-limestone section to 258 pounds. The corresponding figures for the corn stalks and hay are 1021 and 1073 pounds. This is equivalent to $4\frac{3}{8}$ to $9\frac{1}{2}$ bushels of grain and $\frac{1}{2}$ ton of stalks and hay per acre, which represents the annual gain over the no-lime plot.

The yield of nitrogen for this rotation is shown in table 12. In nearly all cases the lime treatment has resulted in a substantial increase in yield of nitrogen over the check plot. The most pronounced exception is the millet in the magnesian-limestone section in 1914. It should be recalled that this crop came near being choked out by crab-grass, and this accounts in part for the low yields. Attention may be called to the high yield of nitrogen from the vetch crop of 1915. For the calcium-limestone section, there is an average of 48 pounds per acre, and for the magnesian-limestone section an average of nearly 79 pounds per acre.

TABLE 11

Rotation 4—Yield of dry matter, in pounds per acre, for the 5-year period 1913-1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914		1915		1916		1917		TOTAL		YEARLY INCREASE OVER CHECK	
		Corn		Oats and peas	Millet	Vetch	Rape	Rye	Cowpeas	Oats and peas	Cowpeas	Grain	Forage, hay, etc.	Grain	Stover and hay
		Grain	Stover												
42	lbs. Check	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
		1350	2675	1520	400	220	1700	2240	1940	2120	1160	1350	13,975		
Calcium-limestone section															
43	1000	1775	2825	2200	480	840	1840	2660	2240	2600	1240	1775	16,925	425	590
44	2000	1825	3000	2200	620	1400	2120	2780	2540	2820	1600	1825	19,080	475	1021
45	4000	2050	3275	2440	520	2160	2120	3120	2880	2680	2040	2050	21,235	700	1452
Average		1883	3033	2280	540	1467	2027	2853	2553	2700	1627	1883	19,080	533	1021
Magnesian-limestone section															
46	1000	1550	2425	2120	140	2180	1660	2880	2360	3040	1440	1550	18,245	200	854
47	2000	1625	2900	2080	280	2920	2040	2960	2780	2940	1480	1625	20,380	275	1281
48	4000	1650	2550	1920	300	2960	2460	2400	2380	2660	1760	1650	19,390	300	1083
Average		1608	2625	2040	240	2687	2053	2747	2507	2880	1560	1608	19,338	258	1073

The highest yield—nearly 90 pounds—was on the magnesian-limestone plot which received 4000 pounds per acre. Next to the vetch, the oats and peas and the cowpeas gave the largest yields of nitrogen. In 1917, the total nitrogen secured for these two crops on the magnesian-limestone section amounts to more than 100 pounds for each limestone treatment.

The total nitrogen for the 5 years averages $373\frac{3}{4}$ pounds for the calcium-limestone section and $381\frac{1}{2}$ pounds for the magnesian-limestone section, or more than 75 pounds per year. There was applied to these plots a total of about 108 pounds of nitrogen per acre for the 5 years, or nearly 22 pounds per year.

TABLE 12

Rotation 4—Pounds of nitrogen per acre removed by crops for the 5-year period 1913-1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914		1915		1916		1917		TOTAL NITROGEN IN GRAIN, HAY, ETC.	YEARLY INCREASE IN NITROGEN OVER CHECK
		Corn		Oats and peas	Millet	Vetch	Rape	Rye	Cow- peas	Oats and peas	Cow- peas		
		Grain	Stover										
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
42	Check	18.37	18.58	25.20	4.74	7.08	16.68	23.50	28.52	27.41	32.31	202.39	
Calcium-limestone section													
43	1000	25.03	20.29	41.18	6.33	28.67	18.42	29.47	28.34	42.61	34.77	275.11	14.5
44	2000	26.65	25.46	41.58	8.79	49.62	22.09	28.36	41.12	49.01	46.72	339.40	27.4
45	4000	28.52	26.91	46.80	7.28	65.82	24.38	36.07	59.73	56.09	64.87	416.47	42.8
Average.....		26.73	24.22	43.18	7.47	48.04	21.63	31.30	43.06	49.24	48.79	373.69	28.23
Magnesian-limestone section													
46	1000	21.56	18.19	37.91	2.22	60.08	19.24	30.79	54.89	57.64	47.19	349.71	29.5
47	2000	22.44	20.58	35.65	3.79	86.52	23.26	30.49	65.44	54.57	50.35	393.09	38.1
48	4000	24.26	20.52	38.78	4.07	89.63	27.08	23.09	54.91	64.08	55.30	401.72	39.9
Average.....		22.75	19.76	37.45	3.36	78.74	23.19	28.12	58.41	58.76	50.95	381.51	35.83

TABLE 13

Rotation 4—Per cent of nitrogen in dry matter of crops for the years 1913-1917

PLOT	LIMESTONE APPLIED PER ACRE	1913		1914		1915		1916		1917	
		Corn		Oats and peas	Millet	Vetch	Rape	Rye	Cow- peas	Oats and peas	Cow- peas
		Grain	Stover								
	lbs.	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
42	Check	1.361	0.721	1.658	1.186	3.216	0.981	1.049	1.470	1.293	2.785
Calcium-limestone section											
43	1000	1.410	0.751	1.872	1.319	3.413	1.001	1.108	1.265	1.639	2.804
44	2000	1.460	0.899	1.890	1.417	3.544	1.042	1.020	1.619	1.738	2.920
45	4000	1.391	0.860	1.918	1.400	3.047	1.150	1.156	2.074	2.093	3.180
Average		1.420	0.837	1.893	1.379	3.335	1.064	1.095	1.653	1.823	2.968
Magnesian-limestone section											
46	1000	1.391	0.790	1.788	1.587	2.756	1.159	1.069	2.326	1.896	3.277
47	2000	1.381	0.731	1.714	1.355	2.963	1.140	1.030	2.354	1.856	3.402
48	4000	1.470	0.860	2.020	1.355	3.028	1.101	0.962	2.307	2.409	3.142
Average		1.414	0.794	1.841	1.432	2.916	1.133	1.020	2.329	2.054	3.274

Thus there was removed in the crop more than three times as much as was applied in the fertilizers. The average annual increase over the check plot for the calcium-limestone section is 28 pounds per acre and for the magnesian-limestone section 35 pounds per acre. These increases are equal to, and in some cases exceed, the total yields in some of the wheat and rye crops reported in rotation 1.

The percentage of nitrogen in the dry matter is shown in table 13. In the majority of cases there is a higher percentage in samples from the lime-treated plots than in those from the check plots. This is well brought out by comparing the percentage as shown for the check plots with the corresponding averages for the two lime-treated sections. With only two exceptions the latter show a higher percentage of nitrogen in the dry matter than does the check plot. The high percentage of nitrogen in the vetch of 1915 and the cowpeas grown in 1917 is noteworthy, the highest analysis with vetch being 3.54 per cent and the highest with cowpeas 3.40 per cent. The oats and peas show an average close to 2 per cent, while the non-legume crops such as corn, rape and rye show an average of a little over 1 per cent for the rye and rape and 1.4 per cent for the corn and millet.

These figures present a strong argument for growing leguminous crops wherever they can be brought into the rotation to good advantage.

THE INFLUENCE OF THE LIME TREATMENT ON THE NITROGEN CONTENT AND LIME REQUIREMENT OF THE SOIL

Lime requirement

In connection with the foregoing discussion, the figures presented in table 14 are of interest. At the end of each 5-year period, nitrogen and lime-requirement determinations were made on samples of soil from the rotation plots. For these determinations composite samples were taken by making a number of borings to a depth of $6\frac{3}{4}$ inches. The samples were thoroughly mixed and after being dried were passed through a 2-mm. sieve to remove coarse material.

In most cases the soils show a gradual decrease in lime requirement as the amount of limestone was increased. At the end of the first 5-year period, the average lime requirement for the check plots was close to 1200 pounds per acre, while for the plots that received the 2 tons of limestone per acre it was less than 500 pounds. In 1917, at the end of the second 5-year period, the average for the check plots was about 1300 pounds per acre, whereas those plots that received 2 tons of limestone per acre were either alkaline or had a low lime requirement. From this it would appear that the 2-ton application was quite sufficient for a period of 5 years; indeed, where only 1 ton was used the soil had a low lime requirement at the end of the 5 years.

There does not appear to be very much difference in neutralizing power between the calcium limestone and the magnesian limestone.

TABLE 14

Lime requirement and percentage of nitrogen of soils from plots that have received different quantities of lime, 1908-1917

PLOT	LIMESTONE TREATMENT	LIME (CaO) REQUIREMENT PER 2,000,000 POUNDS OF SOIL		NITROGEN	
		1912*	1917†	1912	1917
Rotation 1—General farm crops					
		lbs.	lbs.	per cent	per cent
21	Nothing.....	1200	1200	0.077	0.0794
22	0.5 ton CaCO ₃ per acre.....	1000	600	0.075	0.0798
23	1.0 ton CaCO ₃ per acre.....	600	400	0.075	0.0791
24	2.0 ton CaCO ₃ per acre.....	000	alk.	0.081	0.0901
25	0.5 ton CaCO ₃ MgCO ₃ per acre.....	600	400	0.091	0.0959
26	1.0 ton CaCO ₃ MgCO ₃ per acre.....	700	400	0.093	0.1015
27	2.0 ton CaCO ₃ MgCO ₃ per acre.....	000	alk.	0.092	0.1010
Rotation 2—General farm crops and potatoes					
		lbs.	lbs.	per cent	per cent
28	Nothing.....	800	1400	0.094	0.0994
29	0.5 ton CaCO ₃ per acre.....	800	1000	0.097	0.1019
30	1.0 ton CaCO ₃ per acre.....	600	400	0.094	0.0931
31	2.0 ton CaCO ₃ per acre.....	100	alk.	0.098	0.1041
32	0.5 ton CaCO ₃ MgCO ₃ per acre.....	700	400	0.093	0.1025
33	1.0 ton CaCO ₃ MgCO ₃ per acre.....	400	alk.	0.091	0.0954
34	2.0 ton CaCO ₃ MgCO ₃ per acre.....	300	200	0.089	0.0966
Rotation 3—Corn, potatoes, market garden crops					
		lbs.	lbs.	per cent	per cent
35	Nothing.....	1100	1200	0.093	0.0921
36	0.5 ton CaCO ₃ per acre.....	800	1000	0.094	0.0912
37	1.0 ton CaCO ₃ per acre.....	600	800	0.081	0.0837
38	2.0 ton CaCO ₃ per acre.....	400	alk.	0.075	0.0808
39	0.5 ton CaCO ₃ MgCO ₃ per acre.....	1100	1000	0.077	0.0800
40	1.0 ton CaCO ₃ MgCO ₃ per acre.....	700	400	0.080	0.0837
41	2.0 ton CaCO ₃ MgCO ₃ per acre.....	500	400	0.082	0.0800
Rotation 4—Forage crops					
		lbs.	lbs.	per cent	per cent
42	Nothing.....	1200	1400	0.084	0.0899
43	0.5 ton CaCO ₃ per acre.....	1100	1200	0.095	0.0998
44	1.0 ton CaCO ₃ per acre.....	700	800	0.099	0.1012
45	2.0 ton CaCO ₃ per acre.....	600	400	0.089	0.0864
46	0.5 ton CaCO ₃ MgCO ₃ per acre.....	1100	1200	0.079	0.0773
47	1.0 ton CaCO ₃ MgCO ₃ per acre.....	500	400	0.067	0.0679
48	2.0 ton CaCO ₃ MgCO ₃ per acre.....	300	alk.	0.098	0.0652

* Limestone applied in 1908.

† Limestone applied in 1913.

Percentage of nitrogen in soils

Nitrogen was determined by the Kjeldahl method and in most cases the results reported are an average of four or more carefully made determinations.

It will be recalled that in Part I of this paper, it was pointed out that with the 5-year rotation of non-legumes the limed section was poorer in nitrogen than the unlimed section at the end of both the first and the second 5-year periods. Furthermore, it was shown that the crops on the limed section were only slightly larger than those on the unlimed section. In other words, the lime actually resulted in a considerable dissipation or loss of nitrogen over and above any loss shown by the unlimed plots.

From the figures shown in table 14, it is evident that the lime treatment has not generally resulted in a depletion of the soil nitrogen as compared with the check, or no-lime plot. This may be more clearly shown by comparing the percentage of nitrogen in samples of soil from the check plot for each rotation, with the average percentage of nitrogen in samples from the six lime-treated plots for that rotation.

The figures are as follows:

	1912	1917
	<i>per cent</i>	<i>per cent</i>
Rotation 1 { Check (no. 21).....	0.077	0.079
{ Average, no. 22 to 27.....	0.084	0.091
Rotation 2 { Check (no. 28).....	0.094	0.099
{ Average, no. 29 to 34.....	0.094	0.099
Rotation 3 { Check (no. 35).....	0.093	0.092
{ Average, no. 36 to 41.....	0.082	0.083
Rotation 4 { Check.....	0.084	0.090
{ Average, no. 43 to 48.....	0.088	0.083

It will be noted that for rotation 1 the lime-treated plots, on an average, show a higher nitrogen content than the check plots; for rotation 2 the average percentage for the limed plots is the same as for the check plot. For rotation 3, the average for the lime-treated plot is about 0.01 per cent less than the percentage for the check plot. For rotation 4 the difference is slightly in favor of the lime-treated plots in 1912 and the check plot in 1917. It will be noted that the figures for 1917 run very close to those for 1912 in both cases.

The lime-treated plots show the greatest gain during the 5 years in rotation 1, and the most loss in rotation 4.

Certainly in this case it can not be said that the lime treatment has been a failure. It has, with only few exceptions, resulted in increased yields, which in several instances have been large, and in addition the nitrogen content of

the soil has been fairly well maintained. In the meantime fair crops have been taken from the land. The oats crops, it must be admitted, have been small, partly because of loss from shattering in the field. The potato crops were not fully successful, because the land is not well adapted to potatoes. With these exceptions, and taking the crops for the 10-year period, the yields have probably been above the average for the locality.

It should be pointed out that these results have been secured without the use of farm manure and with only a very moderate amount of commercial nitrogenous fertilizer. Minerals have been applied in generous amounts in order that a deficiency of these might not become a limiting factor.

From the data presented, it is evident that the limestone which was applied has been an important factor in increasing the yields on the rotation plots described here, but it should be remembered that this effect has been more indirect than direct. Its presence in the soil has favored those organisms which associate themselves with the leguminous plants and has thus enabled those plants to get from the air a larger supply of nitrogen than was obtained by plants grown where the conditions are unfavorable for the nitrogen-fixing organisms.

SUMMARY

Four 5-year rotations were carried out on a loam soil. In each rotation there were seven plots; one unlimed and one each that received 1000, 2000 and 4000 pounds per acre of calcium limestone, and one each that received like amounts of magnesian limestone.

In each rotation legume crops were introduced either as one of the main crops or as a green-manure crop between the main crops.

Two 5-year periods for each rotation have been completed.

Acid phosphate and muriate of potash were used in liberal amounts. Light applications of commercial nitrogenous fertilizers were made. No farm manure was used.

During the 10 years the limed plots, with only slight exception, have yielded distinctly larger crops and more total nitrogen than the unlimed plots.

In most cases, the yields were larger with the 2000 and 4000-pound applications than with the 1000-pound application. The two forms of limestone gave results which are quite similar. There appears to be a slight difference in favor of the magnesian limestone.

In the majority of cases, the percentage of nitrogen was higher in crops from the limed than from the unlimed plots.

The use of lime thus resulted in a gain in both quantity of the crop produced and also in the quality.

Analyses of the soil show, in a number of cases, a higher nitrogen content for limed than for unlimed plots; in other cases, the two are about on a level as to nitrogen content and in a few cases, there has apparently been a depletion of the nitrogen in the limed plots.

This work, taken in connection with the work presented in the preceding paper, would seem to indicate that in using lime emphasis should be laid on its power to make conditions favorable for the organisms associated with leguminous crops rather than on its power simply to neutralize soil acids. In other words, its value is more indirect than direct.

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