THE INFLUENCE OF ACID SOILS VERSUS BASIC SOILS ON THE ASSIMILATION OF MINERALS BY PLANTS

by

MAYNARD HAROLD SOLT

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INTRODUCTION

This investigation was made for the purpose of studying the influence of acid soils versus basic soils on the growth and chemical composition of plants. The soils received manurial treatments of superphosphate for a first crop and calcium carbonate in addition for the second crop. Miller states, "It is common knowledge that plants of different species grown under identical conditions differ in their elemental composition, especially in regard to the proportionate amount of the various elements that compose them" (1). Plants of different species have an optimum soil pH at which each grows best (2, 3, 4,). Because of these facts it was decided to use two different species, lettuce and lima beans, as the test crops in this investigation.

Soil analysis of today includes investigation of the availability of the plant food in the soil, as well as its absolute quantity. Hall says, "Even the poorest soil contains the nutrient material required by any ordinary crop many times over, yet it is known that crops respond vigorously to dressings of fertilizer which only add a fraction to the plant food already stored in the soil" (5). A complete chemical analysis was made on the original untreated acid and basic soils. The pH and available phosphorus of these soils were determined periodically on soil samples taken at 10-day intervals during the two growing periods.

The crops were grown in the greenhouse on large plots of acid and basic soils, fertilized and unfertilized. The crops were harvested when the lettuce in the plots of best growth had reached a marketable stage and the lima beans had ceased blooming and the majority of the pods well filled. Next the crop yields were determined and the dry weights obtained after drying to constant weight. The dried plant residues were ground and analyzed for moisture, ash, phosphorus, nitrogen, calcium, potassium, sodium, magnesium, sand and silica. Analysis of the lettuce and lima beans show liming and phosphating effect the absorption of nutritive elements from the acid and basic soils.

SOILS AND SOIL TREATMENTS

The basic soil used in these investigations, known as Summit silty clay loam, was obtained from the farm of Mr. William Price, near McIntire School House, located eleven miles northeast of Manhattan in Pottawatomie County. The outstanding characteristic of this soil was its high reserve of phosphorus, containing 0.29 per cent P_2O_5. This soil had a pH value of 7.76.

The acid soil, known as Bates fine sandy loam, was furnished by the County Agent of Cherokee County from a farm near Columbus, Kansas. Soils from southeastern Kansas are particularly low in phosphorus; this soil contained 0.05 per cent P_2O_5. A pH value of 4.94 was obtained for this soil.

The disadvantage of these two soils was their wide difference in content of nutritive elements. The analyses are given in Table 1. This fault was obviated to a large extent, however, by using control plots of the untreated soils as well as the treated plots.

Table 1. Chemical Analysis of Soils

Percentage composition on dry basis

	Acid soil	Basic soil		Acid soil	Basic soil
SiO_2	89.51	65.84	CO_2	0.00	0.81
Al_2O_3	4.65	12.40	Org. C	0.85	3.26
Fe_2O_3	1.45	3.78			
Mn_3O_4	0.31	0.15	Ca	0.13	1.74
MgO	0.13	1.52	K	0.54	2.16
CaO	0.18	2.43	P	0.02	0.13
Na_2O	0.19	0.24	N	0.08	0.32
K_2O	0.66	2.59	S	0.01	0.05
P_2O_5	0.05	0.29			
SO_3	0.04	0.13	Acid Sol. Ca	0.07	1.50
NO_3	0.36	1.39			

Each plot, 39 square feet in area, contained 1500 pounds of soil. The depth of these soils in the beds was approximately seven inches.

There were two plots of acid soil and two of basic soil, four in all. In the first experiment commercial 20 per cent superphosphate was mixed with one plot of acid soil and one plot of basic soil at the rate of 500 pounds per acre, based on the surface area of the plots. In the second experiment calcium carbonate was added to the soils of all four plots at the rate of 3000 pounds per acre and mixed thoroughly.

At the beginning of each growing period and at intervals of ten days composite soil samples were taken from each of the four plots. These samples were dried at 110°C for about six hours, then crushed with a mortar and pestle to pass a millimeter sieve. The small stones were removed and not included in the samples proper.

The hydrogen ion concentration was determined on these samples, within two or three days after taking by the quinhydrone electrode. These data are compiled for the entire experiment in Table 2 and graphically in figure 1.

The available phosphorus in these soil samples was determined by the method of Fraps and Fudge (6), known as the Colorimetric 0.2 N Nitric Acid Method. These available phosphorus data are given in Table 2 and figure 2.

Table 2. Reaction and Available Phosphorus of Soils

Period*	Acid Soil				Basic Soil			
	Control		Superphosphate 500 lbs. per acre		Control		Superphosphate 500 lbs. per acre	
	pH	Available PO_4 P.p.m.**	pH	Available PO_4 P.p.m.	pH	Available PO_4 P.p.m.	pH	Available PO_4 P.p.m.
	First crop planted							
0	4.94	0.141	--	--	7.76	13.20	--	--
1	5.12	0.178	4.75	0.613	7.90	14.15	7.76	15.65
2	4.84	0.144	4.80	0.450	7.34	14.85	7.27	16.94
3	4.94	0.129	4.70	0.432	7.44	15.65	7.34	17.15
4	4.70	0.129	4.68	0.444	7.52	14.98	7.32	16.35
5	4.87	0.101	4.72	0.521	7.40	14.79	7.44	15.25
6	5.05	0.107	4.82	0.542	7.44	13.35	7.57	13.94
7	4.88	0.135	4.88	0.340	7.58	14.52	7.44	15.25
8	4.85	0.153	4.87	0.355	7.47	14.79	7.53	15.41
9	5.03	0.092	5.00	0.291	7.43	13.48	7.40	14.55
10	5.05	0.107	5.00	0.306	7.57	14.58	7.49	15.86
	3000 lbs. $CaCO_3$ added per acre -- Second crop planted							
11	7.49	0.086	7.46	0.328	7.77	15.07	7.77	16.11
12	7.17	0.110	7.09	0.355	7.87	14.92	7.90	15.50
13	7.12	0.193	6.91	0.410	7.72	14.95	7.70	16.14
14	6.88	0.165	6.92	0.374	7.60	15.50	7.77	16.39
15	6.99	0.119	6.83	0.315	7.61	14.46	7.66	15.34
16	6.91	0.126	6.76	0.331	7.62	14.79	7.76	15.80
17	6.87	0.153	6.76	0.361	7.67	15.10	7.71	15.74
18	7.32	0.159	7.07	0.306	7.74	16.72	7.89	17.98
19	6.94	0.175	6.99	0.279	7.67	15.53	7.71	16.26

* Samples taken at 10-day intervals during growing periods of crops.

** Soil extracted by 0.2N nitric acid for available phosphorus

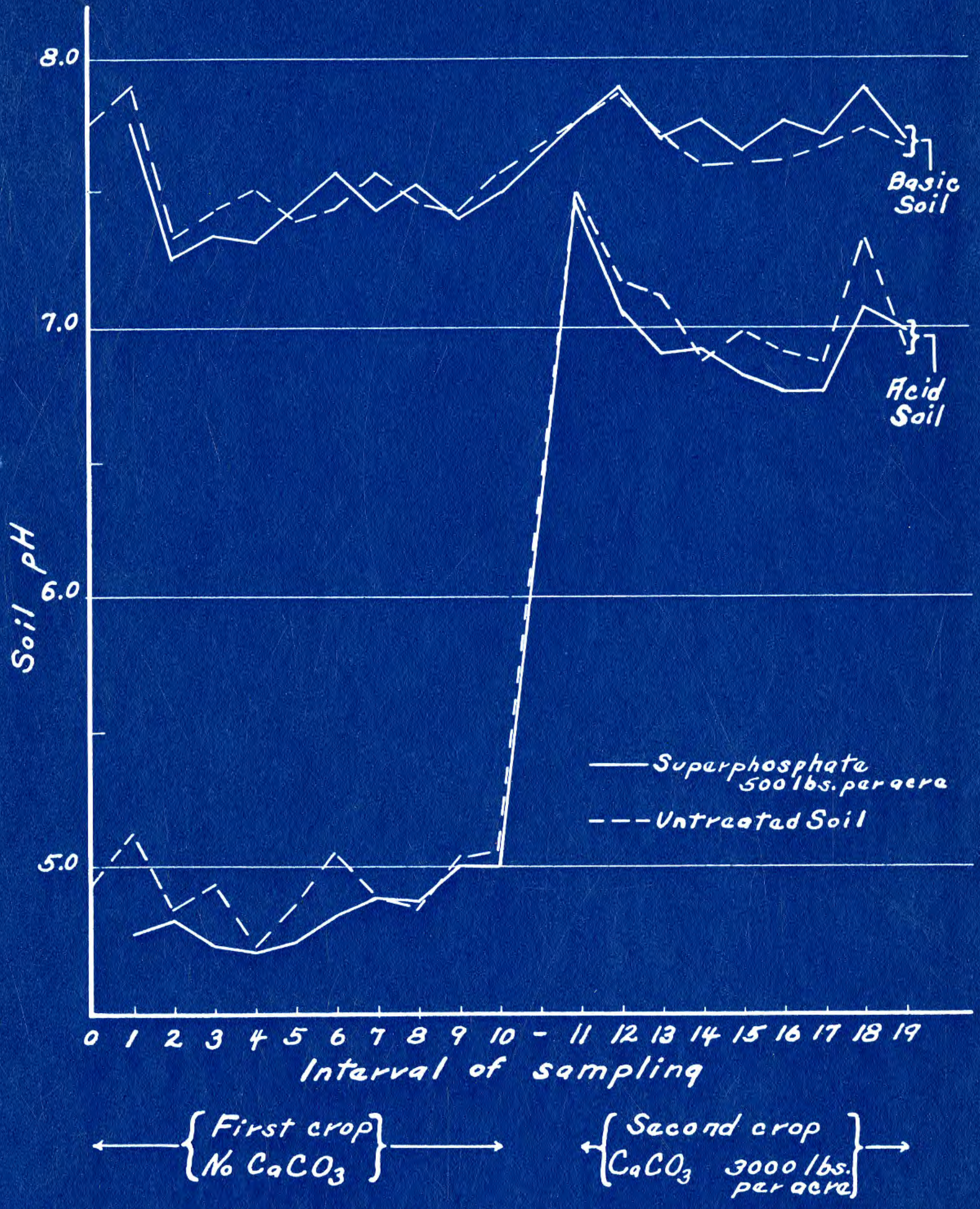

Figure 1. Graph showing the effect of superphosphate and calcium carbonate on soil reaction during the two growing periods. Samples taken at 10-day intervals.

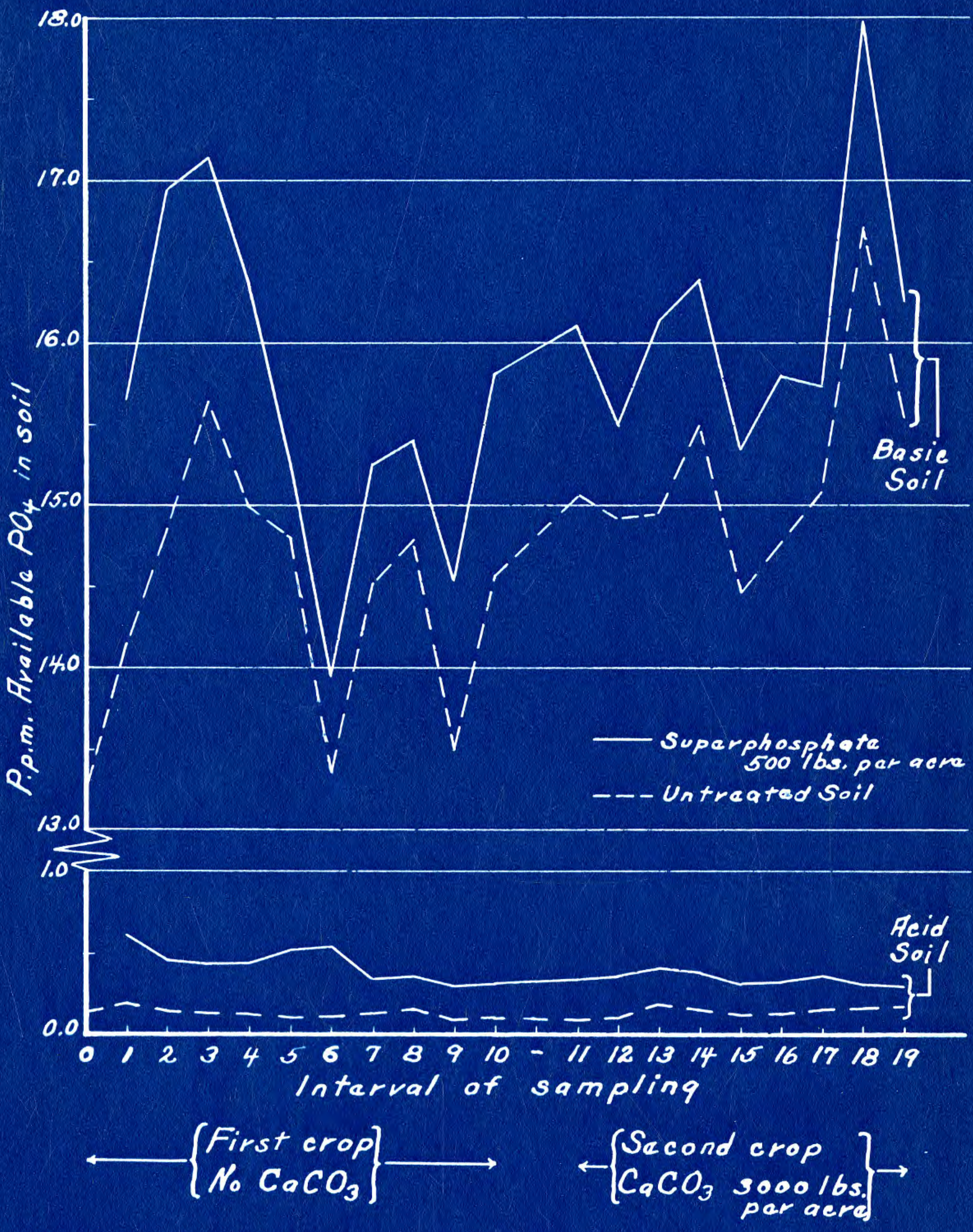

Figure 2. Graph showing the effect of superphosphate and calcium carbonate on the available phosphorus in soils during the two growing periods. Samples taken at 10-day intervals.

GREENHOUSE EXPERIMENT

First Crop

On October 5, 1932, the lettuce and lima beans were planted, one-half of each plot to lettuce and the other half to lima beans. The lettuce was transplanted at this time, having been previously started in flats. The lettuce plants had several leaves and were about two inches in height when transplanted. In transplanting, all the soil was removed from the lettuce roots. The lima beans were thinned to one plant per hill when they had grown to a height of several inches. The distance between the hills was nine by six inches for both lettuce and lima beans allowing each plant 54 square inches of soil surface. Distilled water was used for watering all the crops grown in this investigation.

The lettuce was harvested December 3, 1932, 59 days after transplanting in the plots. At this time the lettuce in the plots of best growth was ready for market. The plants were cut off near the surface of the ground and the green weight of each plot of lettuce determined. The root systems of all the plants, consisting of those roots that came out intact, were removed and washed free of soil. The lettuce tops and roots were then dried to constant weight and the dry weights obtained. The tops were ground to pass through a millimeter sieve and samples taken for chemical analysis.

The lima beans were harvested January 4, 1933. The plants had stopped blooming and the pods were filling out at this time after a growth period of 91 days. The tops were cut off near the surface of the ground and the root systems removed and handled like those of the lettuce plants. The green weights of the lima bean tops were obtained. Samples were prepared for chemical analysis in the usual manner.

Crop yields are compiled in Table 3.

Second Crop

The same varieties of lettuce and lima beans were planted in this second experiment. The new factor influencing the growth of this crop was the application of calcium carbonate which affected the assimilation of the plant nutrients and the soil reaction.

The details of planting, care during growth, harvesting and drying of the crops were performed the same as for the preceding experiment. Crop yields are compiled in Table 3. The lettuce and lima beans had the same number of days growth as the first crops, respectively, the lima beans being planted February 13, 1933, and harvested May 15, 1933, and the lettuce planted February 27, 1933, and harvested April 28, 1933.

Table 3. Crop Yield and Moisture Content of Lettuce and Lima Beans

	Acid soil		Basic soil		Acid soil		Basic soil	
	Control	SP	Control	SP	$CaCO_3$	$CaCO_3$+SP	$CaCO_3$	$CaCO_3$+SP
	Lettuce -- First crop				Lettuce -- Second crop			
No. of plants in plot	44	44	48	47	44	48	48	48
No. of plants dried	44	44	10	11	44	48	12	12
Green wt. of plants dried (gms)	387.0	870.0	1008.0	1007.0	147.5	544.0	899.0	648.5
Dry wt. of plants dried (gms)	19.7	44.8	40.0	40.5	15.5	47.3	66.4	54.2
Moisture of plants dried (gms)	367.3	825.2	968.0	966.5	132.0	496.7	832.6	594.3
Moisture (per cent)	94.91	94.85	96.03	95.98	89.50	91.31	92.61	91.64
Dry matter (per cent)	5.09	5.15	3.97	4.02	10.50	8.69	7.39	8.36
Green wt. of total plot (gms)	387.0	870.0	3499.0	2821.0	147.5	544.0	3105.0	2252.5
Dry wt. of total plot (gms)	19.7	44.8	138.8*	113.3*	15.5	47.3	229.4*	188.0*
Av. green wt. per plant (gms)	8.796	19.750	72.895	60.021	3.352	11.333	64.687	46.927
Av. dry wt. per plant (gms)	0.4478	1.0184	2.8940*	2.4138*	0.3520	0.9850	4.7804*	3.9232*
	Lima Beans -- First crop				Lima Beans -- Second crop			
No. of plants in plot	48	47	44	44	44	44	44	44
No. of plants dried	48	47	44	44	44	44	44	44
Green wt. of plants dried (gms)	1663.0	1286.0	2437.0	2243.0	1492.5	2302.0	2998.0	3105.0
Dry wt. of plants dried (gms)	209.0	222.0	290.0	271.0	271.0	509.0	591.0	548.0
Moisture of plants dried (gms)	1454.0	1064.0	2147.0	1972.0	1221.5	1793.0	2407.0	2557.0
Moisture (per cent)	87.43	82.74	88.10	87.92	81.84	77.89	80.29	82.35
Dry matter (per cent)	12.57	17.26	11.90	12.08	18.16	22.11	19.71	17.65
Green wt. of total plot (gms)	1663.0	1286.0	2437.0	2243.0	1492.5	2302.0	2998.0	3105.0
Dry wt. of total plot (gms)	209.0	222.0	290.0	271.0	271.6	509.0	591.0	548.0
Av. green wt. per plant (gms)	34.645	27.361	55.386	50.977	33.920	52.318	68.136	70.468
Av. dry wt. per plant (gms)	4.3550	4.7226	6.5910	6.1582	6.1598	11.5676	13.4296	12.4552

* Calculated

Crop Yields

Some of the factors that affect growth are soil nutrients, soil reaction, oxygen supply, moisture, light and temperature. Such factors as the above influenced the growth of the lettuce and lima beans grown in this experiment. The crop yields are tabulated in Table 3, giving green weights as well as dry weights.

The addition of superphosphate to the acid soil increased the dry weight yield of lettuce 127.4 per cent and lima beans 8.44 per cent over the crops from the untreated acid soil. With the addition of calcium carbonate to these same plots, the lettuce and lima bean yields increased on the superphosphate treated plot 179.6 and 88.8 per cent, respectively.

Whereas, with the basic soil the application of superphosphate decreased the lettuce yield 16.64 per cent and the lima bean yield 6.56 per cent. The addition of calcium carbonate to the basic soil plots changed these percentage decreases very little. The dry weight yield of both the lettuce and lima beans was greatly increased upon the addition of calcium carbonate to the basic soil, with and without superphosphate. Figure 3 shows the dry weight yield of the average plant in grams.

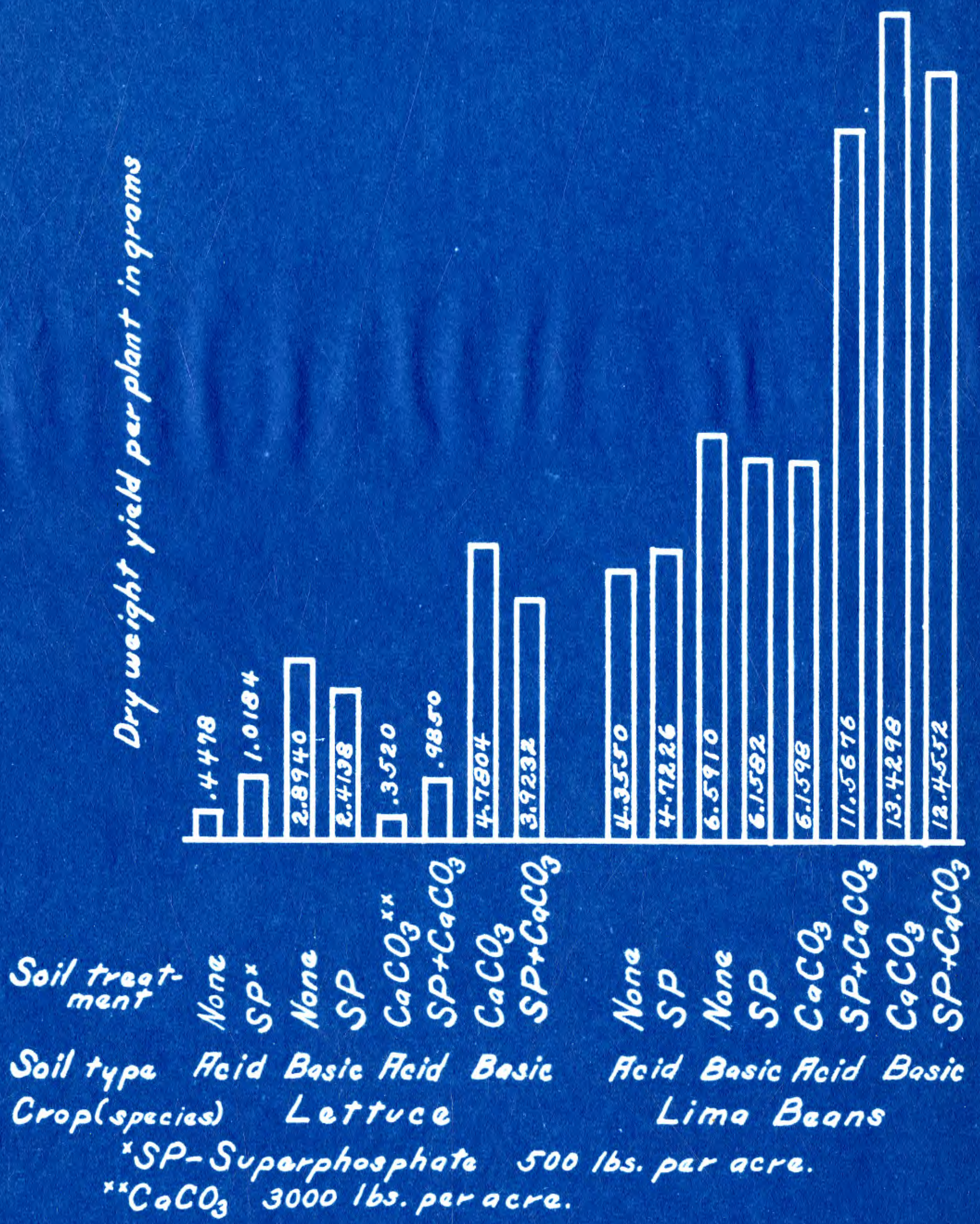

Figure 3. Chart showing the yield in dry weight in grams per plant, as indicated by soil treatment, soil type and plant species.

It will be noted that the moisture content of the second crop of lettuce and lima beans was considerably lower than the first crop (see Table 3). The average decrease in moisture content of the four plots of the second crop of lettuce was 4.18 per cent of that of the first crop. For the lima beans the moisture content averaged 5.98 per cent less for the second crops. This would indicate that calcium carbonate applied to the soil decreased the percentage of water in the plants.

Inspection of the lima bean roots of both the first and second crops showed some nitrogen fixation to have taken place. However, the seed had not been inoculated prior to planting. The greatest number of nodules were found in the basic soil plots. An interesting thing noted about the nodules was that some nodules from the same root system were pale green inside while others were nearly black. Both types produced colonies of bacteria on nutrient media in the laboratory. The root systems of the second crop of lettuce had quite a bad nematode infection. Possibly this affected the growth of these plants.

METHODS OF ANALYSIS

The methods used in determining the chemical composition of the soils and the plant tissue are in general use so will not be described in detail.

The chemical composition of the untreated soils was determined as follows: nitrogen by the method of Kjeldahl (7), total phosphorus by the magnesium nitrate method (7), sulphur by the magnesium nitrate method of Swanson and Latshaw (8), potassium and sodium by the J. Lawrence Smith method, determining as sulphates and separation by the Lindo-Gladding method (7). Silica, iron, aluminum, manganese, calcium and magnesium were determined on soil samples fused with sodium carbonate; silica was determined by dehydration (7), iron by reduction and titration (7), aluminum by difference (7), manganese by oxidation with bromine (9), calcium by the volumetric method (7), magnesium by the gravimetric method (7), moisture by the method given in the U.S.D.A. Circular No. 139 (10), total carbon by the sodium peroxide fusion method (7), carbonates by decomposition with hydrochloric acid (7), acid soluble calcium by a method outlined by Swanson, Gainey and Latshaw (11), available phosphorus by the colorimetric fifth normal nitric acid method (6), and soil reaction with the quinhydrone electrode.

The methods of the Association of Official Agricultural Chemists were used for the plant material analyses (7). The determinations made were moisture, ash, sand, silica, nitrogen, calcium, magnesium, phosphorus, sodium and potassium.

CHEMICAL ANALYSIS OF THE SOILS

To get a general idea of the composition of these soils a complete chemical analysis was made of each. These results calculated on a dry basis are tabulated in Table 1.

In the essential plant nutrients these two soils vary considerably. The nitrogen content of the acid soil was only 0.08 per cent while for the basic soil it was 0.32 per cent. The organic carbon of the acid and basic soils was 0.85 and 3.26 per cent, respectively. An interesting thing is noted in the organic carbon-nitrogen ratio, it is approximately 10.3 for both soils. According to Hall (5) and others the carbon-nitrogen ratio for cultivated soils is 10.1.

One of the most widely studied soil constituents is phosphorus. The total phosphorus of the basic soil was exceedingly high, being 0.29 per cent P_2O_5, while it was only 0.05 per cent P_2O_5 for the acid soil. The potassium content of the acid and basic soil was 0.66 and 2.59 per cent K_2O, respectively. Clarke (12) reports the average analysis of 466 soils from the humid region of the southern States, in the U. S. Geological Survey Bulletin No. 330. The average soil has 0.113 per cent P_2O_5, and 0.216 per cent K_2O as shown by this bulletin.

Total calcium was very low in the acid soil, being 0.13 per cent Ca, but was 1.74 per cent Ca in the basic soil. The acid soluble calcium content of the acid and basic soils was 0.07 and 1.50 per cent Ca, respectively. This would indicate that the carbonate content of the acid soil was very low, none was found, but the carbonate as CO_2 was 0.81 per cent for the basic soil. Hall says, "The importance of free calcium carbonate in the soil lies not in the calcium that it supplies for the nutrition of plants, but in its use as a base to maintain the neutrality of the soil" (5). The results show that there is no calcium carbonate in the acid soil to take care of any acids that might form in that soil by the decomposition of organic matter or by plant growth.

Sulphur is essential to plant growth. The total sulphur in the acid soil was 0.01 per cent which was less than the minimum of 0.015 per cent found in Kansas soils by Swanson and Latshaw (8). The basic soil had a sulphur content of 0.05 per cent which was above the average of the Kansas soils found by these investigators.

Soil Reaction and Available Phosphorus

Soil samples were taken from the four plots every ten days during the growing periods to ascertain any changes in the soil reaction and content of available phosphorus.

In general, the superphosphate treatment did not increase the acidity of the soils to any extent. Shortly after the first growing period had started the pH curves for the treated and untreated plots of the acid and basic soils, respectively, had touched or crossed each other as shown in figure 1. There were fluctuations in the curves but no marked changes.

After the application of calcium carbonate at the rate of 3000 pounds per acre the acid soil became alkaline in reaction, changing the pH from approximately 5.0 to 7.5. As the second growing period advanced the pH of the two plots of acid soil dropped to the acid side of pH 7, remaining between pH 6.7 and 7.0 for the rest of the growing period with one exception as shown in Table 1 and figure 1.

The calcium carbonate treatment decreased the acidity of the basic soil. There were no wide changes in the pH values of these two plots of soil during the second experiment.

The available phosphorus data are reported as parts per million PO_4 in the dry soil (Table 2). These results are shown graphically in figure 2. There are many fluctuations in the available phosphorus results obtained from the basic soil samples, whereas in the acid soil samples there were no pronounced changes.

The addition of calcium carbonate had no clear cut effect on the available phosphorus of either soil. It increased the available phosphorus to some extent in the basic soil as shown by figure 2.

These changes in the pH and available phosphorus might be due to reactions of the superphosphate and calcium carbonate with the soil complex or to the different requirements of the plants for the soil nutrients at various stages of their growth. The soils when received for the greenhouse experiment were abnormally dry. This would affect the equilibrium of the soil and it would take some time to reach equilibrium after water was applied. These factors and possibly many others have caused the fluctuations in the pH and available phosphorus content of these soils.

Sewell and Latshaw (13) observed that superphosphate had no effect on soil reaction if allowance was made for some slight variations in pH value determinations.

McGeorge and Breazeale (14) in their experiments found that the presence of calcium carbonate greatly reduces the solubility of phosphate in phosphate rock as well as in soils, while they found that the solubility of phosphate from materials like superphosphate is less affected by calcium carbonate in soils. Nemec (15) reported that soils with adequate calcium should have more available phosphorus than soils lacking in calcium.

CHEMICAL ANALYSIS OF THE PLANT MATERIAL

Miller (1) says, "The proportion of the various elements that may be found in plants depends upon numerous and varied factors such as the species of the plant, the type of the soil, the distribution of the roots, the rainfall, and the general climatic conditions as well as the methods of cultivation."

In the following discussion the author has attempted to show the relationship between the different constituents of the plants grown under the several soil treatments, as found by analysis.

Nitrogen, being an important constituent of the proteins, amino acids, chlorophyll, the alkaloids and the protoplasm of the plant, was determined on the plant material.

The percentage of nitrogen on the dry basis in the lettuce and lima beans is tabulated in Table 4. The nitrogen content ranges from 2.36 to 4.85 per cent. In figure 4 and Table 5 the weight of nitrogen assimilated by each plant is tabulated, clearly showing the effects of the soil types and various soil treatments. As previously mentioned, each plant whether lettuce or bean was allowed 54 square inches of soil surface.

Table 4. Composition of Lettuce and Lima Beans (Dry Basis)

Soil		Percentage of the dry weight							
Type	Treatment	N	P	Ca	Mg	K	Na	SiO_2	Ash
					Lettuce				
Acid	None	4.85	0.523	1.49	0.86	3.42	3.22	0.66	22.79
Acid	SP*	3.76	0.597	1.42	0.77	4.25	2.86	0.58	21.66
Basic	None	3.39	0.899	1.85	0.42	9.06	0.53	0.13	24.42
Basic	SP	3.50	0.944	2.00	0.46	9.49	0.55	0.19	25.13
Acid	$CaCO_3$**	3.37	0.241	1.98	0.49	2.24	1.66	1.10	18.33
Acid	$CaCO_3$ + SP	3.40	0.377	1.55	0.53	2.05	2.46	0.55	16.99
Basic	$CaCO_3$	2.44	0.545	1.14	0.29	7.56	0.24	0.18	17.87
Basic	$CaCO_3$ + SP	2.40	0.534	1.43	0.32	7.06	0.62	0.20	18.99
					Lima Beans				
Acid	None	2.97	0.309	2.96	0.50	1.63	0.71	1.65	13.05
Acid	SP	2.65	0.346	2.62	0.51	1.59	0.73	1.46	11.83
Basic	None	3.33	0.491	3.46	0.35	2.61	0.44	1.86	15.24
Basic	SP	3.45	0.503	3.59	0.33	2.91	0.44	2.11	16.66
Acid	$CaCO_3$	2.82	0.282	2.57	0.45	1.42	0.42	0.73	10.73
Acid	$CaCO_3$ + SP	2.43	0.317	2.37	0.51	0.93	0.62	0.55	9.74
Basic	$CaCO_3$	2.36	0.379	2.21	0.24	2.12	0.23	0.88	10.84
Basic	$CaCO_3$ + SP	2.44	0.424	2.34	0.21	2.40	0.31	1.31	12.38
Seed					Lima Bean Seed				
First crop		3.97	0.442	0.315	0.28	1.73	0.38	0.00	4.55
Second crop		3.93	0.470	0.219	0.24	2.08	0.15	0.00	5.01

* SP -- Superphosphate 500 lbs. per acre.

** $CaCO_3$ 3000 lbs. per acre.

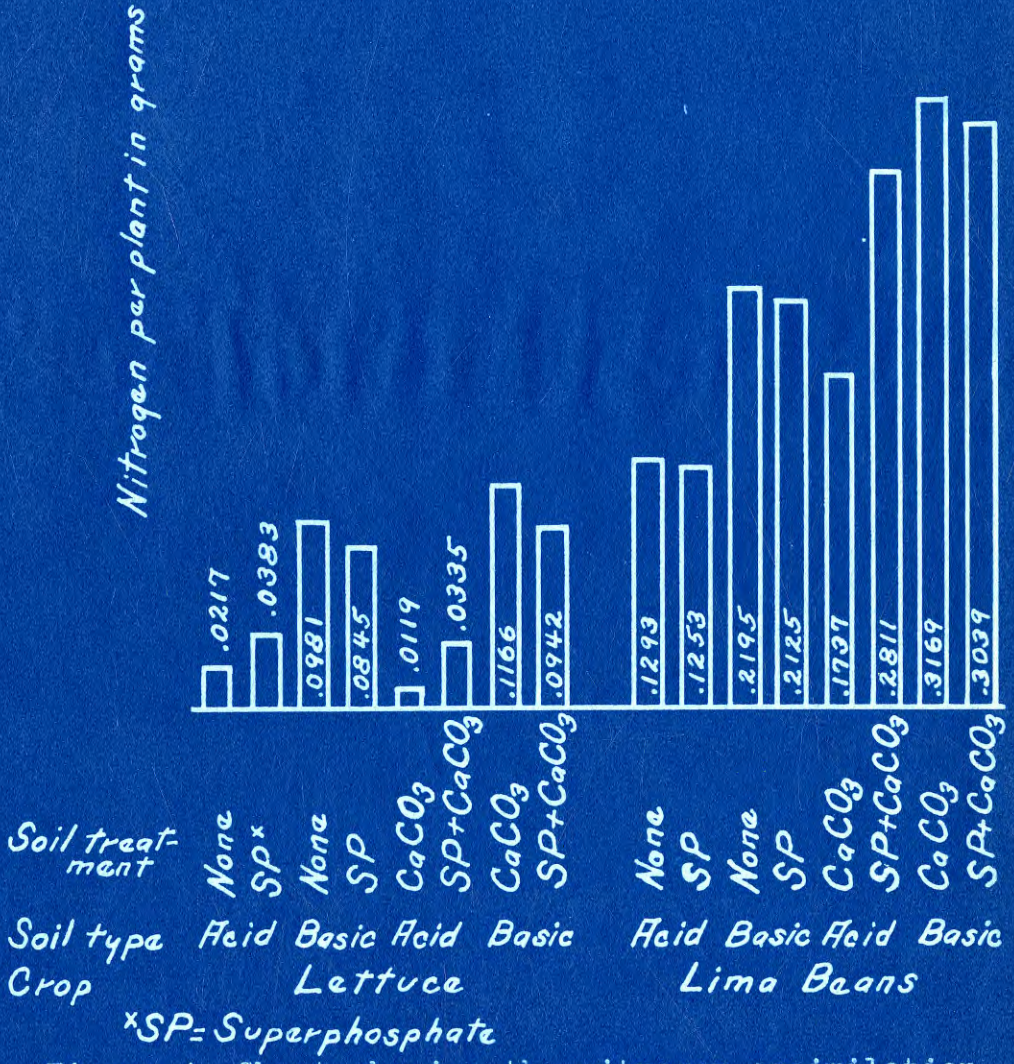

Figure 4. Chart showing the nitrogen assimilation in grams per plant, as indicated by plant species, soil type and treatment.

Table 5. Composition of Lettuce and Lima Beans (Grams per Plant)

Soil		Av. Plant Weight**	Grams per plant							
Type	Treatment		N	P	Ca	Mg	K	Na	SiO_2	Ash
						Lettuce				
Acid	None	0.4478	0.0217	0.0023	0.0067	0.0039	0.0153	0.0144	0.0030	0.1021
Acid	SP*	1.0184	0.0383	0.0061	0.0145	0.0078	0.0433	0.0291	0.0059	0.2206
Basic	None	2.8940	0.0981	0.0260	0.0535	0.0122	0.2622	0.0153	0.0038	0.7067
Basic	SP	2.4138	0.0845	0.0228	0.0483	0.0111	0.2291	0.0133	0.0046	0.6066
Acid	$CaCO_3$***	0.3520	0.0119	0.0008	0.0070	0.0017	0.0079	0.0058	0.0039	0.0645
Acid	$CaCO_3$ + SP	0.9850	0.0335	0.0037	0.0153	0.0052	0.0202	0.0242	0.0054	0.1674
Basic	$CaCO_3$	4.7804	0.1166	0.0261	0.0545	0.0139	0.3614	0.0115	0.0086	0.8543
Basic	$CaCO_3$ + SP	3.9232	0.0942	0.0210	0.0561	0.0126	0.2770	0.0243	0.0079	0.7450
						Lima Beans				
Acid	None	4.3550	0.1293	0.0135	0.1289	0.0218	0.0710	0.0310	0.0719	0.5683
Acid	SP	4.7226	0.1252	0.0163	0.1237	0.0241	0.0751	0.0348	0.0690	0.5587
Basic	None	6.5910	0.2195	0.0324	0.2281	0.0231	0.1720	0.0290	0.1226	1.0045
Basic	SP	6.1582	0.2125	0.0310	0.2211	0.0203	0.1792	0.0271	0.1299	1.0260
Acid	$CaCO_3$	6.1598	0.1737	0.0174	0.1583	0.0277	0.0875	0.0259	0.0450	0.6610
Acid	$CaCO_3$ + SP	11.5676	0.2811	0.0367	0.2742	0.0590	0.1076	0.0717	0.0636	1.1267
Basic	$CaCO_3$	13.4298	0.3169	0.0509	0.2968	0.0322	0.2847	0.0309	0.1182	1.4558
Basic	$CaCO_3$ + SP	12.4552	0.3039	0.0528	0.2915	0.0262	0.2989	0.0386	0.1632	1.5420
Seed						Lima Bean Seed				
First crop		0.3554	0.0141	0.0016	0.0011	0.0010	0.0061	0.0014	0.0000	0.0162
Second crop		0.3036	0.0119	0.0014	0.0007	0.0007	0.0063	0.0005	0.0000	0.0152

* SP -- Superphosphate 500 lbs. per acre.

** Each plant grown on area of 54 square inches.

*** $CaCO_3$ 3000 lbs. per acre.

Table 6 demonstrates the real effect of the application of superphosphate or calcium carbonate on the acid and basic soils. Considering superphosphate as the variable factor, its application changed the nitrogen content of the plants grown on the basic soil only a very small amount, while with the acid soil the superphosphate treatment decreased the percentage of nitrogen 11 to 22 per cent in three cases, while in the fourth case there was practically no change in nitrogen content. The application of calcium carbonate in all cases caused a decrease in the percentage of nitrogen in the dry matter of 5.05 to 31.4 per cent.

The mineral constituents of the plant are found in the ash. Some interesting changes are noted in the percentage of ash and the percentage differences in ash in the lettuce and lima beans grown under the various soil treatments (Tables 4 and 6). The acid soil crops, in general, have a slightly lower ash content than those grown on the basic soils. The addition of superphosphate increased the percentage of ash of both lettuce and lima bean dry matter 3 to 14 per cent on the basic soil plots, but decreased it 5 to 9 per cent on the acid soil plots. When calcium carbonate was added the ash decreased 17 to 27 per cent in the dry plant material from both types of soil. The actual weight of ash per plant (figure 5) which represents the total minerals taken from unit areas of the soils however

Table 6. Difference in Mineral Assimilation Produced by Soil Treatments

Comparisons		Variation from control in per cent							
Control Soil	Treatment	N	P	Ca	Mg	K	Na	SiO_2	Ash
Variable factor superphosphate						Lettuce			
Acid soil	SP*	-22.40	+14.30	- 4.70	-10.50	+25.40	- 11.20	-12.10	- 4.95
Basic soil	SP	+ 3.25	+ 5.00	+ 8.10	+ 9.52	+ 4.74	+ 3.77	+46.10	+ 2.90
Acid soil + $CaCO_3$**	SP	+ 0.89	+ 5.64	-21.70	+ 8.16	- 8.48	+ 48.20	-50.00	- 7.30
Basic soil + $CaCO_3$	SP	- 1.64	- 2.02	+25.40	+10.30	- 6.61	+158.00	+11.10	+ 6.26
						Lima Beans			
Acid soil	SP	-10.80	+11.90	-11.50	+ 2.00	- 2.45	+ 2.82	-11.50	- 9.35
Basic soil	SP	+ 3.60	+ 2.44	+ 3.75	- 5.71	+11.50	0.00	+13.40	+ 9.31
Acid soil + $CaCO_3$	SP	-13.80	+12.40	- 7.78	+13.30	-34.40	+ 47.60	-24.60	- 9.22
Basic soil + $CaCO_3$	SP	+ 3.39	+11.90	+ 5.88	-12.50	+13.20	+ 34.80	+48.80	+14.20
Variable factor calcium carbonate						Lettuce			
Acid soil	$CaCO_3$	-30.50	-53.90	+32.80	-43.00	-34.50	- 48.40	+66.60	-19.50
Basic soil	$CaCO_3$	-28.00	-39.40	-38.40	-30.90	-16.50	- 54.70	+38.50	-26.80
Acid soil + SP	$CaCO_3$	- 9.57	-36.80	+ 9.15	-31.10	-51.70	- 14.00	- 5.17	-21.50
Basic soil + SP	$CaCO_3$	-31.40	-43.40	-28.50	-30.40	-25.60	+ 12.70	+ 5.26	-24.40
						Lima Beans			
Acid soil	$CaCO_3$	- 5.05	- 8.73	-13.20	-10.00	-12.90	- 40.80	-55.70	-17.80
Basic soil	$CaCO_3$	-29.10	-22.80	-36.10	-31.40	-18.80	- 47.70	-52.70	-28.80
Acid soil + SP	$CaCO_3$	- 8.32	- 8.37	- 9.50	0.00	-41.50	- 15.10	-62.30	-17.60
Basic soil + SP	$CaCO_3$	-29.20	-15.70	-34.80	- 3.63	-17.50	- 29.50	-37.90	-25.70

\+ indicates increase over control plot.
\- indicates decrease under control plot.
*SP -- Superphosphate 500 lbs. per acre.
**$CaCO_3$ 3000 lbs. per acre.

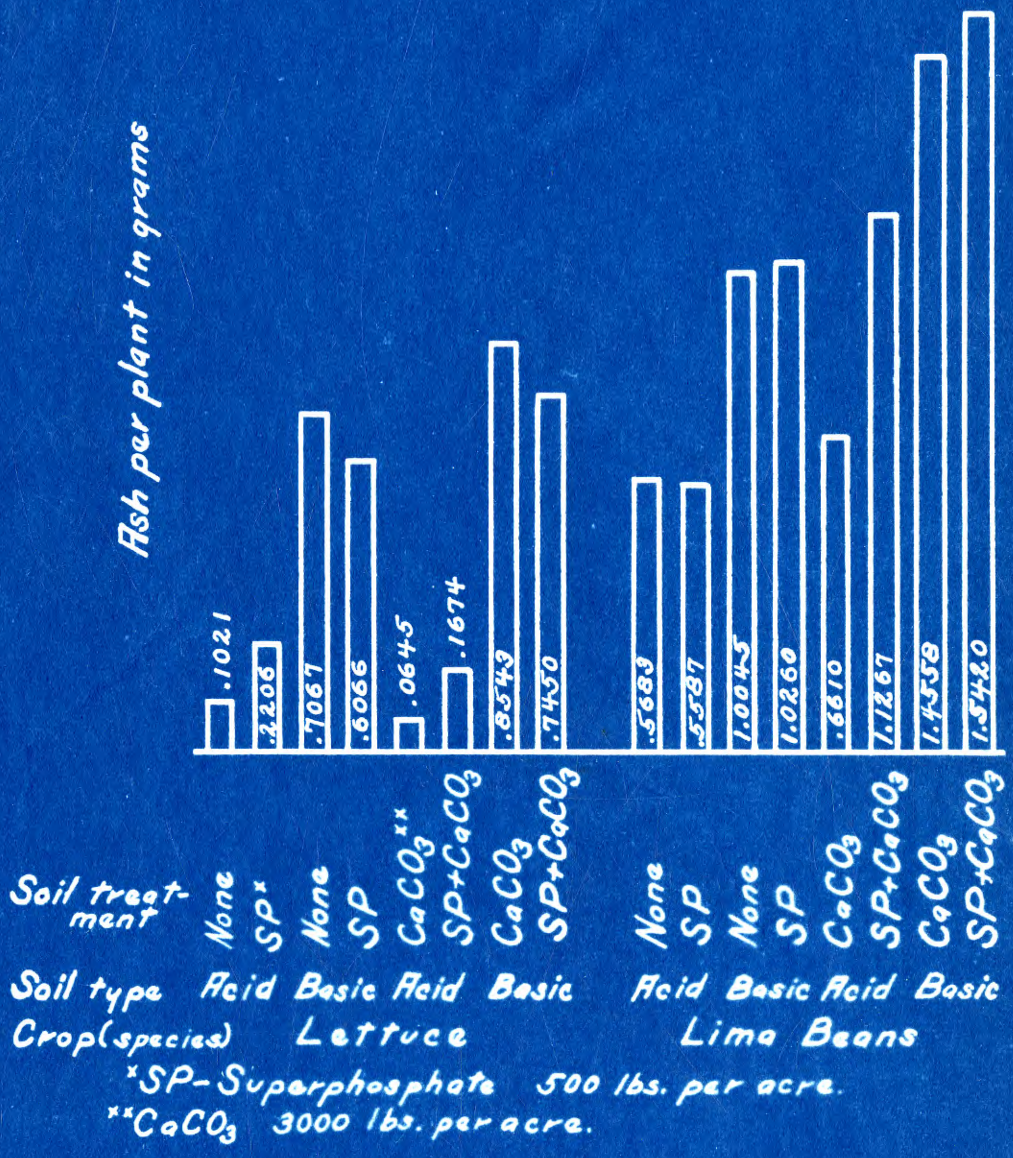

Figure 5. Chart showing the ash content in grams per plant, as indicated by soil treatment, soil type and plant species.

show some different relations. Applications of calcium carbonate increased the weight of ash per plant in every case except for lettuce grown on the acid soil, with and without superphosphate treatment. Application of the superphosphate gave varied results.

Sewell and Latshaw (13) found that light applications of calcium carbonate and superphosphate decreased the percentage of ash in alfalfa a small amount.

Phosphorus plays an important part in the physiological processes of plant growth. It was found to range from 0.24 to 0.94 per cent of the dried lettuce and lima bean plants (Table 4). This range compared to that found in plants in general (1). Superphosphate treatment increased the percentage of phosphorus in lettuce and lima beans as shown in Table 6, on the other hand calcium carbonate decreased the percentage considerably as shown in the same table. Sewell and Latshaw (13) in their work with alfalfa found no consistent indication that superphosphate treatments without lime increased the percentage of phosphorus in the dry matter produced. With lime, however, they found the application of superphosphate increased the amount of phosphorus in the plant.

The grams of phosphorus assimilated per plant are shown in Table 5 and figure 6. The lima beans were capable of taking more phosphorus from either soil type than the

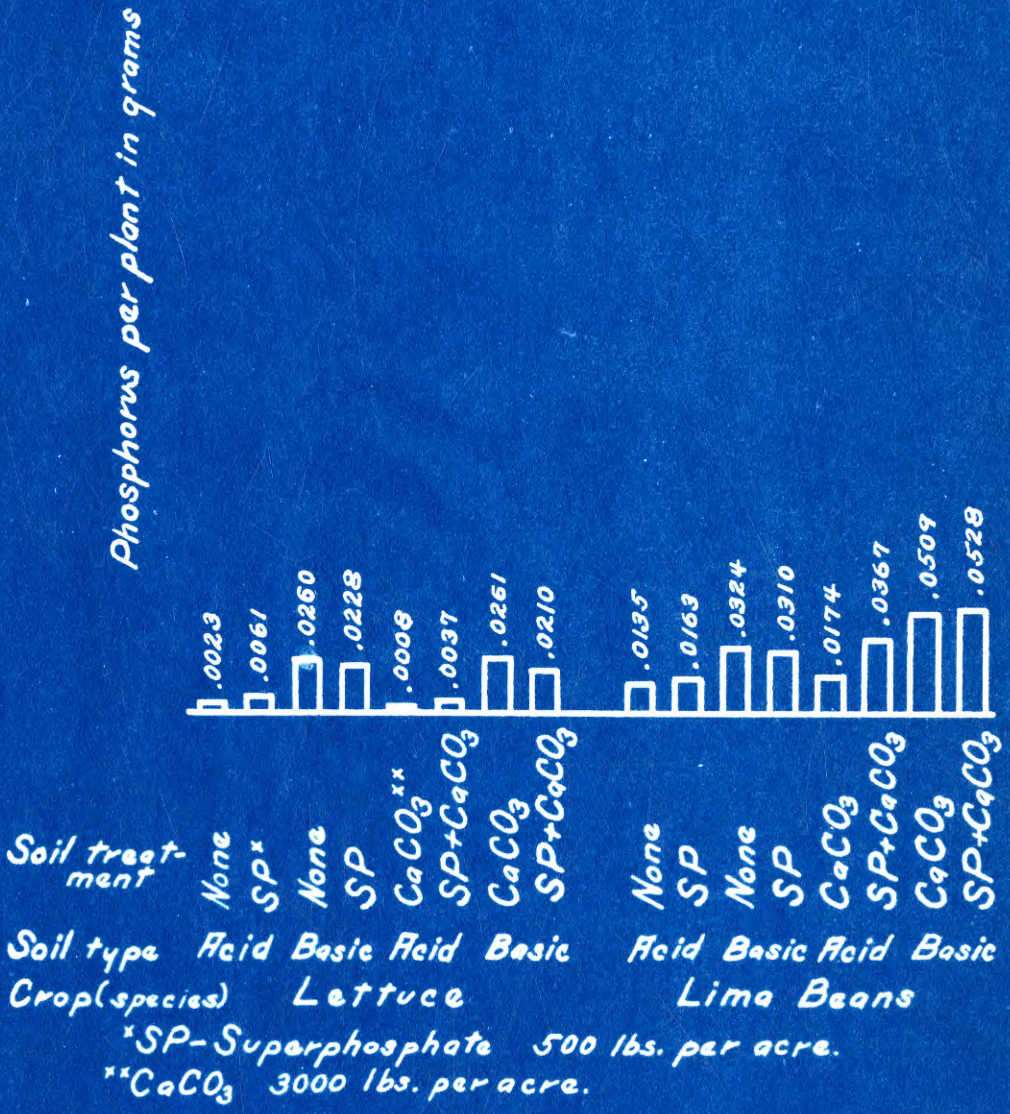

Figure 6. Chart showing the phosphorus assimilation in grams per plant, as indicated by soil treatment, soil type and plant species.

lettuce, the proportionate increase was greater for the acid than for the basic soil.

The nitrogen-phosphorus ratio was higher for the lettuce and lima beans when grown on the acid soil (Table 7). This was probably due to the small amount of available phosphorus in the acid soil. The acid soil without superphosphate treatment had the higher nitrogen-phosphorus ratio. Liming with calcium carbonate always increased this ratio with lettuce and lima beans grown on the acid soil but decreased it with beans grown on the basic soil. The potassium-phosphorus ratio shows it was affected by soil type and treatment as well as plant species. This ratio is fairly constant for the lima bean crops from the variously treated plots, the greatest variation being in the case of superphosphate and lime applications on acid soil. The potassium-phosphorus ratio of the lettuce varies considerably as shown in Table 7.

"Potassium is absolutely essential for plants and cannot be entirely replaced by any other element. Sodium may be substituted for potassium to a certain degree, but by no means entirely" (1), Miller states. The lettuce showed wide differences in assimilation of potassium from the acid and basic soils, however, with the lima beans this was not so marked (Table 4). When calcium carbonate was applied the percentage of potassium in the dry matter of the plants de-

Table 7. Ratios of the Various Elements in Lettuce and Lima Bean Plants

Soil Type	Soil Treatment	N/P	Ca/N	Ca/P	Ca/Mg	K/Ca	K/P	K/N	K/Na
					Lettuce				
Acid	None	9.26	0.31	2.85	1.73	2.29	6.54	0.70	1.06
Acid	SP*	6.30	0.38	2.38	1.84	2.99	7.12	1.13	1.47
Basic	None	3.77	0.55	2.06	4.40	4.90	10.10	2.67	17.10
Basic	SP	3.70	0.57	2.12	4.35	4.75	10.06	2.71	17.20
Acid	$CaCO_3$ **	13.98	0.59	8.21	4.04	1.13	9.28	0.66	1.35
Acid	$CaCO_3$ + SP	9.02	0.46	4.11	2.92	1.32	5.43	0.60	0.83
Basic	$CaCO_3$	4.47	0.47	2.09	3.93	6.64	13.87	3.10	31.50
Basic	$CaCO_3$ + SP	4.49	0.60	2.68	4.47	4.94	13.22	2.94	11.40
					Lima Beans				
Acid	None	9.61	1.00	9.57	5.91	0.55	5.27	0.55	2.29
Acid	SP	7.66	0.99	7.57	5.13	0.61	4.59	0.60	2.18
Basic	None	6.78	1.04	7.04	9.87	0.75	5.32	0.78	5.93
Basic	SP	6.85	1.04	7.13	10.87	0.81	5.78	0.84	6.60
Acid	$CaCO_3$	10.00	0.91	9.10	5.71	0.55	5.03	0.50	3.38
Acid	$CaCO_3$ + SP	7.66	0.97	7.47	4.65	0.39	2.93	0.38	1.50
Basic	$CaCO_3$	6.22	0.94	5.83	9.20	0.96	5.60	0.90	9.21
Basic	$CaCO_3$ + SP	5.75	0.96	5.52	11.14	1.02	5.65	0.98	7.74

* SP -- Superphosphate 500 lbs. per acre.

** $CaCO_3$ 3000 lbs. per acre.

creased 12.9 to 51.7 per cent. There were increases in the percentages of potassium in the lettuce on both acid and basic soil without calcium carbonate when superphosphate was applied but when calcium carbonate was added to these soils there were decreases in potassium content as shown in Table 6. With the lima bean crops superphosphate treatments on the basic soil increased the percentage of potassium but on the acid soil decreased the percentage of potassium in the dry matter.

When the weight of potassium absorbed per plant is considered a different picture is shown (figure 7).

Sewell, Latshaw and Tague (16) observed that liming caused a decrease in the percentage of potassium in the dry matter of alfalfa until a rate of 8000 pounds per acre was exceeded. Above that rate, they found that the percentage of potassium in the dry matter increased. Gaither (17) found that the addition of lime has the effect of diminishing the amount of potash assimilated by wheat grown on the soil.

The potassium-sodium ratio indicates that sodium may to a limited extent take the place of potassium in the plant, because as the percentage of potassium drops the potassium-sodium ratio also drops (Tables 4 and 7).

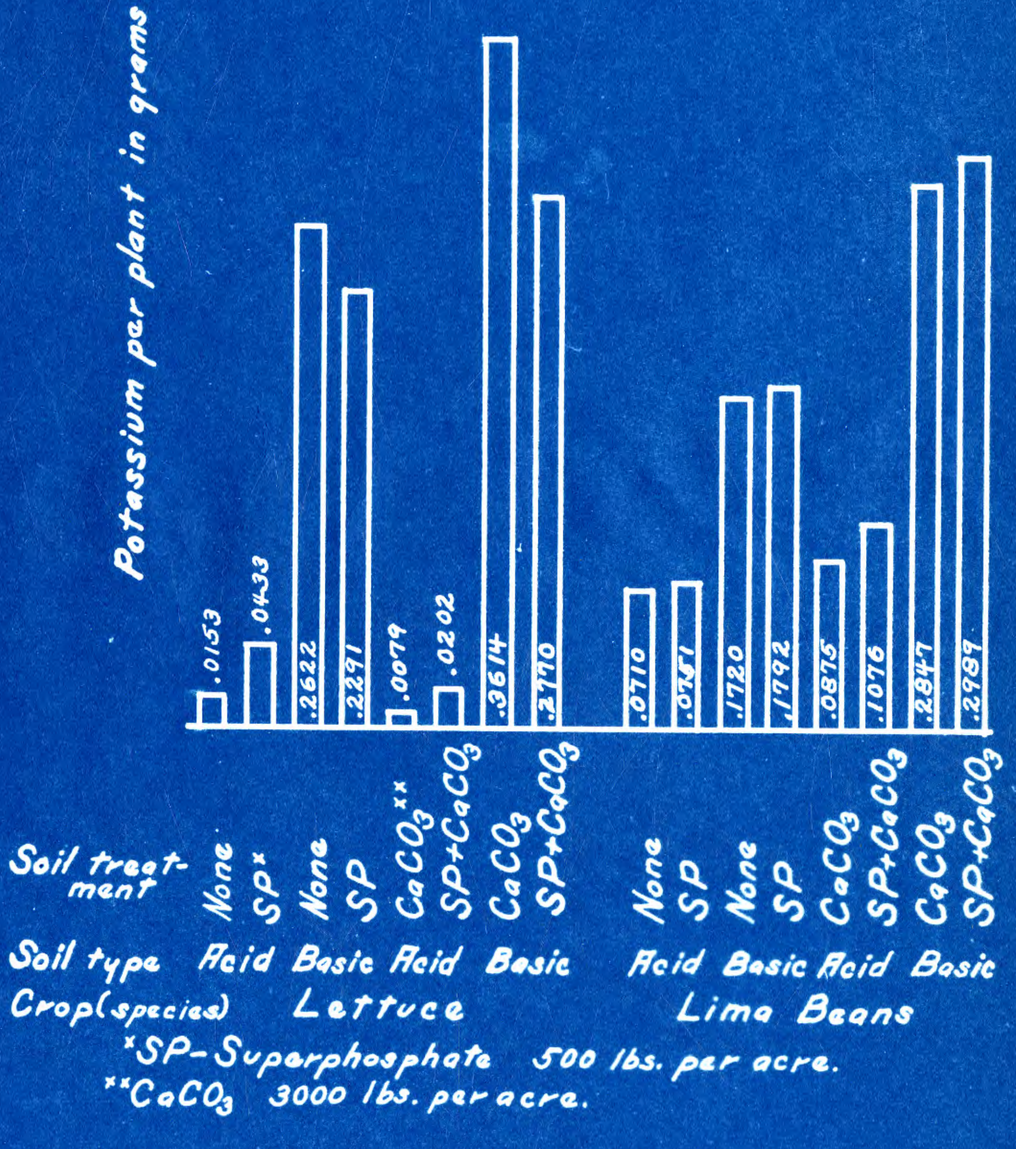

Figure 7. Chart showing the potassium assimilation in grams per plant, as indicated by soil treatment, soil type and plant species.

The potassium-nitrogen was always lower in the dry matter produced on the acid soil than that from the basic soil. Generally, the potassium-nitrogen ratio was increased by the addition of superphosphate to either the acid or basic soil.

Data of the sodium results are compiled in Tables 4, 5, and 6. Figure 8 shows the grams of the element assimilated per plant.

Calcium is an element necessary for plant growth and development, it affects the translocation of carbohydrates as well as entering into the composition of various compounds in the plant. As a rule, the legumes, cabbage, lettuce and tobacco have a high percentage of calcium on a dry basis, while the members of the grass family have a relatively small amount, according to Miller (1). The percentage of calcium on the dry basis ranged from 1.14 to 2.00 per cent for the lettuce and from 2.21 to 3.59 per cent for the lima beans in this investigation. When superphosphate was applied the percentage of calcium in the dried plant material decreased for the acid soil plots but increased when considering the basic soil plots (Table 6). Calcium carbonate applied to the acid and basic soils decreased the percentage of calcium in the dry matter, in general as shown in Table 6. The differences in amounts of calcium taken from the soils of the four plots by the lettuce and lima

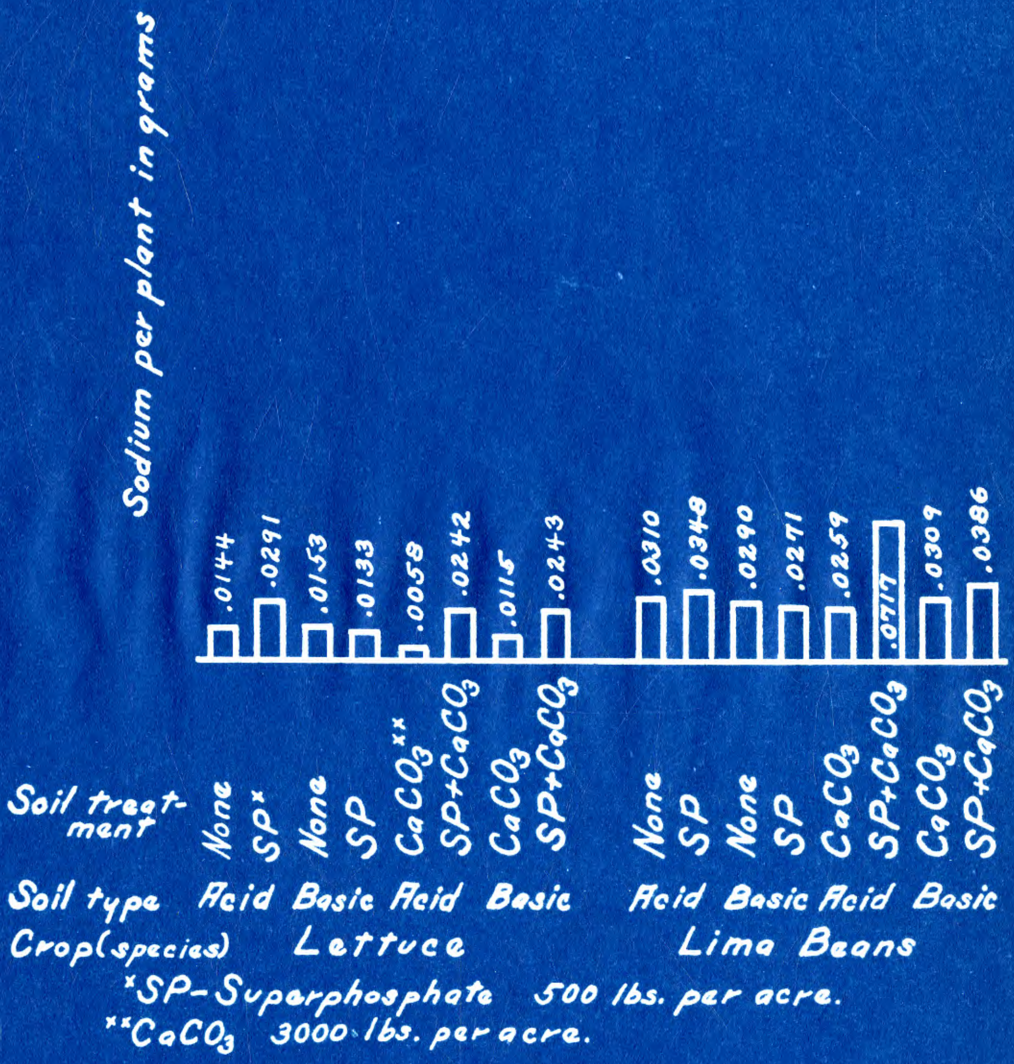

Figure 8. Chart showing the sodium assimilation in grams per plant, as indicated by soil treatment, soil type and plant species.

beans are shown in figure 9.

Parker and Truog (18) observed that there is a close relationship between the calcium and nitrogen content of plants. They state that plants can be divided into two groups, in regard to the calcium-nitrogen ratio. They found that the first group has a calcium-nitrogen ratio of about 0.3 and contain almost entirely members of the grass family which have a low calcium requirement and which are more or less tolerant to soil acidity. They outline a second group that has an average calcium-nitrogen ratio of about 0.55 and includes the legumes and those plants which require a large amount calcium and which are sensitive to soil acidity. The lettuce grown in this experiment had an average calcium-nitrogen ratio of 0.49; for the lima beans it was higher, the average being 0.97 (Table 7).

The calcium-magnesium ratio was higher for the lima bean dry matter than for the lettuce. In general, the calcium-magnesium ratio was lower in the dry matter from the acid soil than from the basic soil (Table 7). The addition of calcium carbonate to the soils did not change these ratios to any extent except in the lettuce grown on the acid soil, both with and without superphosphate.

The percentage of magnesium was always less in the plants grown on the basic soil than those on the acid soil (Table 4). Figure 10 shows the grams of magnesium absorbed

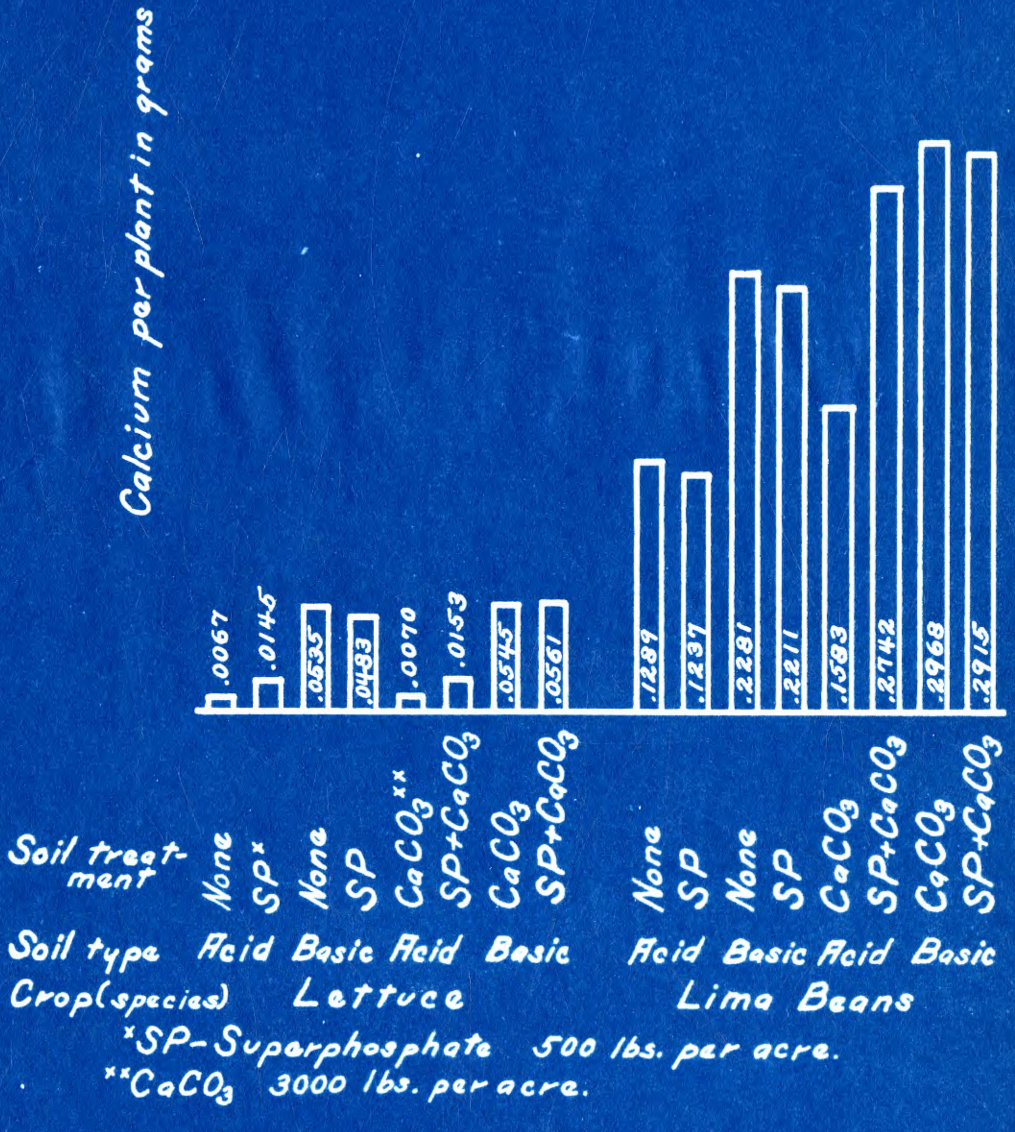

Figure 9. Chart showing the calcium assimilation in grams per plant, as indicated by soil treatment, soil type and plant species.

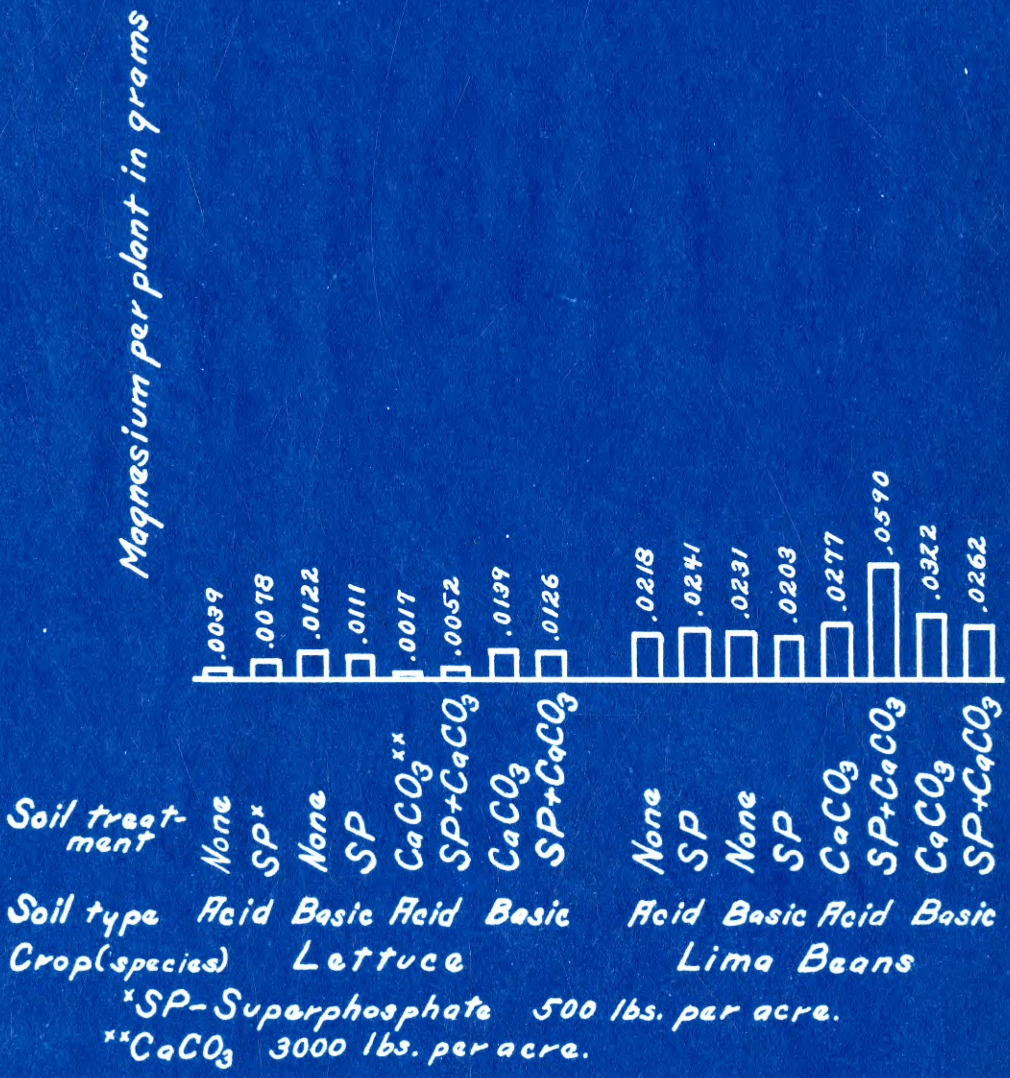

Figure 10. Chart showing the magnesium assimilation in grams per plant, as indicated by soil treatment, soil type and plant species.

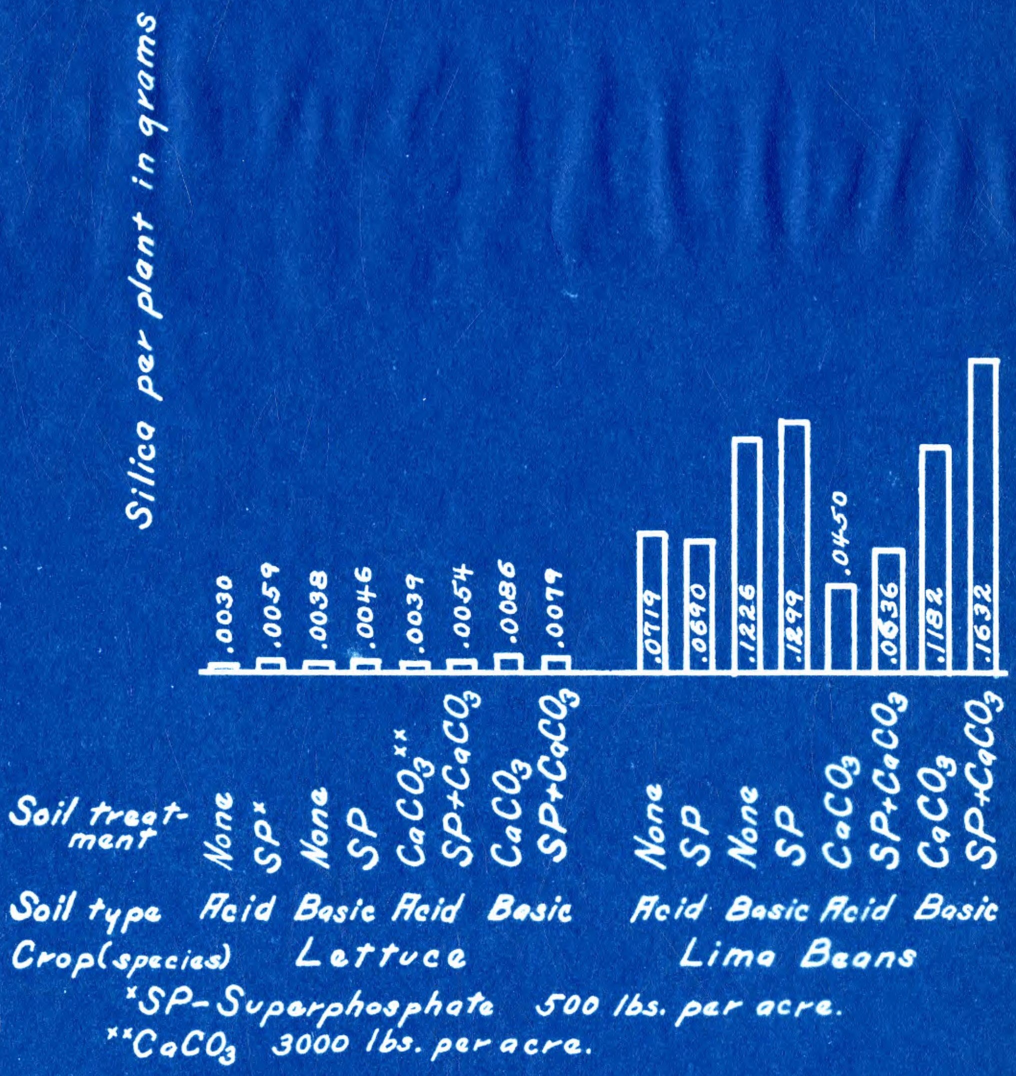

Figure 11. Chart showing the silica assimilation in grams per plant, as indicated by soil treatment, soil type and plant species.

per plant from the soils.

The results of the silica determinations show that lettuce and lima beans assimilate silica in varying amounts both as to percentage of dry matter and grams per plant (Tables 4 and 5 and figure 11). When superphosphate was the variable factor, its application increased the percentage of silica in plants grown on the basic soil but decreased the percentage in the case of the acid soils (Table 6).

SUMMARY

1. Available phosphorus content of the soils was increased by the addition of superphosphate.
2. The addition of calcium carbonate had no clear cut effect on the available phosphorus content of either the acid or basic soil.
3. Calcium carbonate changed the reaction of the acid soil appreciably.
4. Superphosphate treatment had no lasting effect on the soil reaction of the soils.
5. The application of calcium to the acid and basic soils decreased the percentage of ash on the dry basis in the lettuce and lima beans.
6. The superphosphate treatment decreased the percentage of ash in the plants grown on the acid soil but increased it in plants grown on the basic soil.

7. Calcium carbonate applied to the soils decreased the percentage of nitrogen, potassium and phosphorus in the dry matter of lettuce and lima beans.
8. The phosphorus content of the dry matter was increased by superphosphate treatment.
9. The calcium content was decreased in the plants grown on the acid soil by the addition of superphosphate.
10. The calcium content was increased in the plants grown on the basic soil by the addition of superphosphate.

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