The Effect of Soil Type and Fertilizer Treatment on the Composition of the Soybean Plant

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The value of the soybean plant for hay is dependent upon the composition of the plant. If the plant has not had access to sufficient amounts of the essential elements of plant food and is deficient in one or more of the essential elements, the feeding value of the plant is less than it would have been normally. A deficiency in the supply of phosphorus or of calcium and phosphorus in the soil available to the plants has resulted in ill effects upon the cattle consuming the plants as hay or as pasture. The hays grown on these soils, which are decidedly low in available phosphorus, are themselves low in their content of phosphorus in comparison to the hays grown on soils of an average or high content of available phosphorus. Some occurrences of the ill effects upon cattle from the consumption of hay or pasture grass that was low in phosphorus or lime and phosphorus are in Minnesota (6), Wisconsin (12), and Montana (39). The supplying of available phosphorus in these soils by the application of soluble phosphates increases the phosphorus content of the hay or pasture grass (12). The deficiency of the other elements has not made itself so apparent as has the deficiency of phosphorus or of lime and phosphorus.

REVIEW OF LITERATURE

A review of the literature bearing upon the effects of soil treatments upon the composition of the soybean plant reveals an apparent contradiction in the results published. Schuster and Graham (31) express the opinion that their results, as well as the results of other investigators, indicate that the composition of the soybean cannot be changed by soil treatments. In an earlier work (30) Schuster reports an increase in yield and in the protein content of soybeans from liming. Hartwell (13) reports that soybean hay from limed plots contains a higher percentage of nitrogen than that from unlimed plots. Lipman and Blair (16, 17, and 18) also obtained an increased nitrogen content on limed soil compared to that on unlimed soil. Stark (37) found that lime and organic matter increased the per cent of protein to a marked degree and that the tendencies were further pronounced by additions of phosphorus. Potassium in addition to this resulted in a decrease in the per cent of protein. Gile and Ageton (8) considered calcium carbonate as having no effect upon the amount of nitrogen contained in soybeans. Lipman et al. (15), found that different fertilizing materials did not greatly influence the per cent of nitrogen in the dry matter but that judicious liming increased the nitrogen content of both the vines and the shelled beans of the soybean. In experiments in pots (14) calcium carbonate gave a higher percentage of nitrogen on an average, than did sodium nitrate. They (15) found also, a difference in the protein content of the soybean with reference to the time of harvesting. The protein content increased with the growth of the plant toward maturity and then it declined. They (14) concluded that if soybeans are to be harvested as forage, harvesting from the end of the tenth to the fifteenth week will result in giving a maximum protein content. MacTaggart (23) reports that phosphorus markedly increased the dry matter and the total nitrogen, and to a less extent the percentage of nitrogen in soybeans. Applications of nitrogen showed no effect on the percentage of nitrogen in the plant. Sulfur in the form of gypsum, used alone and in combination, increased the nitrogen content of alfalfa but appeared not to have any effect upon soybeans. Ginsburg and Shive (10) found that in culture solutions, an increase of nitrogen did not increase the nitrogen in the plant, and that the nitrogen in the plant was not affected by calcium chloride or calcium nitrate but was increased by calcium carbonate in the solutions. Fred and Graul (7) observed that the inoculation of soybeans increased the nitrogen content of the plant.

The Kentucky Station reported that the total ash content of the soybean plant was increased by applications of calcium compounds regardless of any influence upon the growth of the plant (40). Gile and Ageton (8) found that applications of calcium carbonate increased the total carbon-free ash in the soybean plant and also modified the amount of calcium, magnesium and iron present in the ash.

That the magnesium content of the soybean plant was decreased when grown on calcareous soils was reported by Gile and Ageton (8). Hartwell (13) found that an application of lime tended to increase the magnesium and calcium contents of the plant. Magnesic lime increased the magnesium content of the plant more than it did the calcium content of the plant, but calcareous lime affected both the magnesium and the calcium contents of the plant more nearly alike. The Kentucky Station (40) reported that calcium compounds caused an increase in the calcium content of the plant regardless of any increase in growth. Tarr and Noble (38) state that the maximum growth of soybeans was obtained at approximately pH 5, and at a reaction of pH 4, harmful effects upon the seedlings were apparent. Ginsburg and Shive (10) found a definite correlation between the amount of calcium in the culture solution and the calcium content of the plant. The calcium in the plant paralleled that in the solution.

Gile and Ageton (8) found that calcium carbonate apparently had no effect upon the amount of potassium contained in the plant. Hartwell (13) stated that soybeans derived two-thirds of their potassium needs from a soil so deficient in potassium that mangels could only obtain about one-fourth and summer squash only about one-tenth of their requirements of potassium. These results tend to show that the soybean plant possesses a strong feeding power for potassium and would not be greatly affected by any moderate soil treatment.

Shedd (32) found that the sulfur content of soybeans, which responded to applications of sulfur, was in all cases higher than that of soybeans which had not been fertilized with sulfur. This fact suggests that soybeans grown on soils well supplied with sulfur will not be affected by applications of sulfur, and that the sulfur content of the plant will be affected by the soil type as the sulfur content of the soil types vary.

Gile and Ageton (8) found lime also to have no apparent effect upon the amount of phosphorus contained in the soybeans. Hartwell (13) ranked the soybean plant between the carrot and the turnip in its ability to supply its needs for phosphorus where none had been added to the soil for a quarter of a century.

EXPERIMENTAL PLANS

Fertilizer tests with soybeans were conducted in the field on five soil types in Michigan. The five soil types selected for these experiments were Brookston clay loam near Chesaning, Coloma sand and Kewanee loam near Lowell, Fox sandy loam on the Cass County farm near Cassopolis, and Miami loam near Mason. In addition to these projects receiving fertilizers, another unfertilized plot was located on Hillsdale sandy loam on the College farm at East Lansing. The purpose of this unfertilized plot was to furnish samples for a more detailed study of the changes in the composition of the soybean plant during the growing season.

The fertilizer applications were broadcasted and worked into the soil and the soybeans seeded between the sixth and the tenth of June, 1924. The fertilizer treatments on these plots were made according to the following outlines.

Fertilizer Treatments on Brookston Clay Loam

Plot No.	POUNDS PER ACRE			
	Acid Phosphate*	Gypsum**	KCL	$NaNO_3$***
1	No Treatment	......	......	......
2	400	200	100	100
3	250	......	......	......
4	250	200	......	......
5	250	200	100	......
6	250	200	100	100
7	800	200	100	100

Note: * Anaconda Phosphate was used in amounts equivalent to the acid phosphate.
** Sulfur was used in amounts equivalent to the gypsum.
*** Urea was used in amounts equivalent to the sodium nitrate.

Fertilizer Treatment on Coloma Sand

Plot No.	POUNDS PER ACRE					
	Calcic lime	Magnesic lime	Acid Phosphate*	Gypsum	KCl	$NaNO_3$**
1	No Treat.	....	......	......	......	......
2	5000	....	......	......	......	......
3	....	5000	......	......	......	......
4	....	5000	250	......	......	......
5	....	5000	250	200	......	......
6	....	5000	250	200	100	......
7	....	5000	250	200	100	100

Note: * Anaconda phosphate was used in amounts equivalent to the acid phosphate.
** Urea was used in amounts equivalent to the sodium nitrate.

The fertilizer treatments on Kewanee loam were the same as the treatments on Coloma sand with the exception of the lime treatments, which were 3000 pounds on Kewanee loam instead of 5000 pounds per acre as on Coloma sand.

The fertilizer treatments on Miami loam were the same as the treatments on Coloma sand.

Fertilizer Treatments on Fox Sandy Loam

Plot No.	POUNDS PER ACRE					
	lime Calcic	Acid Phosphate	Gypsum*	KCl	$NaNO_3$	Rock Phosphate
1	No Treat.	......	......	......	......	....
2	6300	......	......	......	......	....
5	6300	200	(86)*	......	......	....
6	6300	200	(86)*	100	......	....
7	6300	200	(86)*	100	100	....
2a	6300	......	......	100	......	....
3a	6300	......	86	......	......	1000
4a	6300	......	......	......	......	1000
8a	6300	......	......	......	100	....
8c	6300	......	......	100	100	....
9a	6300	200	(86)*	......	100	....

Note: * Gypsum in the 200 pounds acid phosphate application.

The object of the several fertilizer plots was to furnish plants for the laboratory studies. Plant samples were taken from the several plots of each project at as nearly the same date as was reasonably possible. The projects on Brookston clay loam, Coloma sand, Kewanee loam, and Miami loam soils were sampled three times during the growing season to represent the early stage of growth, the middle of the period of growth, and the late stage of growth or hay stage. The dates upon which these samples of the growing plants were taken were July 12-14, August 19-22, and September 26 respectively. Only one set of samples was obtained from the Fox sandy loam. This was taken in the middle of the period of growth. The unfertilized project on Hillsdale sandy loam on the College farm was for the purpose of supplying plants for the study of the composition of the plant during the process of growth. Samples were obtained from this plot at intervals of ten or eleven days from June 12th until the time of the first killing frost on September 26th.

The various samples of the soybean plants were air dried in the laboratory. Upon drying they were ground and stored in pint mason jars for analysis.

GREENHOUSE EXPERIMENTS

Some studies on the effect of soil type and fertilizer treatments upon the composition of the cell sap were made upon samples taken from the field plots. In addition to this some projects were conducted in the greenhouse with soybeans in pots of two gallon capacity. Soils for these projects were collected from tilled areas of Coloma sand, Plainfield sand, Fox sandy loam, Berrien sandy loam, Nappanee loam, Miami loam and Kalamazoo muck. A series of pots in duplicate were assembled from each soil, consisting of a check, a light application of phosphorus and potassium, and a heavy application of phosphorus and potassium. Nitrate of soda was applied to all pots in sufficient amount to care for the needs of the plants for nitrogen. The phosphorus and potassium treatments for the pots were as shown in the following outline.

Treatment of Pots

Pot No.	GRAMS PER POT	
	$CaH_4(PO_4)_2$	KCl
1	None	None
2	0.2	0.1
3	2.0	1.0

Where the plants were sufficient in number, samples of the plants (above ground portion) were taken from each pot at three periods during the growth of the plants, to represent the early, the middle, and the late stages of growth. These samples were taken on the 16th, 33rd, and 51st days after seeding. The samples were immediately placed in mason jars surrounded by cracked ice, and the juice pressed out (25), for analysis as soon as possible, this being accomplished within two or three hours after the time of sampling.

METHODS OF ANALYSIS

SOYBEAN PLANT

Ash:—Official Method, Association of Official Agricultural Chemists, 1924 (3).
Total Nitrogen:—Official Method to include nitrates (3).
Calcium, magnesium, sulfur and phosphorus:—Official Method (3).
Potassium:—Cobalti-nitrite method, Adie (1).

CELL SAP OF SOYBEAN PLANT

Phosphorus:—Coeruleo-molybdate reaction of Deniges, Atkins (4).
Potassium:—Cobalti-nitrite method, Adie (1).
Calcium:—Official Method (3).
Freezing Point Depression:—Bouyoucos and McCool (5).

VARIATIONS IN THE COMPOSITION OF THE SOYBEAN DURING GROWTH

Small variations in the composition of the soybean plants during growth are shown in the analysis of the plants grown on the five types of soil fertilized and unfertilized and one other type of soil unfertilized. Many of these variations, however, though small numerically, are appreciably large.

Moisture. The data of the moisture content are not complete for the growing season because of a frost at the time the last samples were taken (110 days after seeding). The moisture content of the plants 35 days after seeding varied between 3.3 and 4.6 grams of water for each gram of dry matter. At 73 days after seeding it varied from 3.1 to 4.9 grams of water for each gram of dry matter. These data show a tendency to less variation in the moisture content of the younger plants than in the older plants (73 days after seeding). The amount present became greater as the plants grew older on Brookston clay loam (table 2) and Miami loam (table 5), with the exception of the plants on Miami loam re-

TABLE 1

Soybeans. Hillsdale sandy loam, College farm. Unfertilized. Analysis based on dry weight.

Days after seeding	Water gm. per gm. dry plant	Ash %	Ca %	Mg %	N %	S %	P %	K %
30	4.03	10.70	2.702	0.586	4.414	0.232	0.234	0.695
41	......	10.97	2.801	0.756	4.414	0.253	0.331	0.677
52	5.08	12.53	2.547	0.923	4.542	0.277	0.329	0.775
62	4.35	10.54	2.415	0.893	4.423	0.277	0.316	0.626
72	4.32	9.23	2.050	0.846	3.833	0.283	0.287	0.722
83	3.58	8.19	1.879	0.780	3.349	0.265	0.272	0.609
93	3.39	8.27	1.905	0.756	3.219	0.251	0.287	0.627
104	......	8.13	1.865	0.719	3.167	0.249	0.329	0.576

ceiving the complete fertilizer treatment. There was less moisture present in the older plants grown on Hillsdale sandy loam (table 1), Coloma sand (table 3), and Kewanee loam (table 4) respectively.

Ash. The ash content of the soybean plant was greater in many cases 73 days after seeding than it was either 35 or 110 days after seeding. This increase was greatest in the plants grown on Coloma sand (table 3) receiving either calcic lime or magnesic lime. The plants on Coloma sand (table 3) receiving no fertilizer treatment and on Miami loam (table 5) receiving a fertilizer lacking only nitrogen, showed less pronounced increase in the ash content of the plants for the same period. In a greater number of cases the ash content was greater in the plant 35 days after seeding than it was 73 days after seeding. In every case the ash content on the plants was lowest 110 days after seeding for each soil and fertilizer treatment respectively. The plants have by this time, larger amounts of the carbohydrates and proteins, etc., than in the earlier stages of growth.

Calcium. The calcium content of the soybean plants, as a whole, decreased with the age of the plants. The plants grown on Coloma sand (table 3) receiving no fertilizer, or calcic lime alone had a higher calcium content 110 days after seeding than they had 73 days after seeding. Very little or no change took place in the calcium content during the period from 73 to 110 days after seeding, for those plants grown on Brookston clay loam* (table 2) receiving phosphorus, phosphorus and sulfur, phosphorus, sulfur, and potassium, and a complete fertilizer, (table 2, plot 7).

Magnesium. The magnesium content was not as uniform as the calcium content. However, a general decrease in the magnesium content of the plants occurred as they became older. Less difference occurred between the plants of the different soils for the period from 73 to 110 days after seeding, than for the period from 35 to 73 days after seeding. There were some exceptions to this statement, namely, an increase in the magnesium content of the plants receiving no fertilizer on Hillsdale sandy loam (table 1) during the period from 35 to 73 days after seeding, a small increase throughout the season in the plants on Coloma sand (table 3) receiving magnesic lime, and increases during the period from 73 to 110 days after seeding in the plants on Brookston* clay loam (table

* No lime was applied on Brookston clay loam.

TABLE 2

Soybeans. Brookston clay loam, near Chessening, Michigan.

A.
35 Days After Seeding (July 15). Analysis based on dry weight.

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
111	none	4.29	9.72	2.162	1.083	4.815	0.289	0.469	0.635
112	400-P S K N	4.35	9.67	2.345	1.230	4.523	0.300	0.440	0.584
113	250-P	4.35	10.00	2.282	1.376	3.914	0.280	0.335	0.579
114	250-P S	4.08	9.57	2.265	1.366	4.057	0.291	0.372	0.600
115	250-P S K	4.23	9.98	2.242	1.352	4.221	0.250	0.363	0.711
116	250-P S K N	4.16	10.27	2.311	1.394	4.097	0.269	0.360	0.692
117	800-P S K N	4.37	10.30	2.227	1.343	4.032	0.282	0.395	0.701

B. 71 Days After Seeding. (Aug. 20).

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
151	none	4.88	10.61	1.792	1.086	3.463	0.291	0.374	0.627
152	400-P S K N	4.69	11.28	1.809	1.105	3.514	0.307	0.375	0.561
153	250-P	4.50	8.96	1.739	1.026	2.544	0.291	0.291	0.631
154	250-P S	4.63	9.38	1.954	1.066	2.366	0.294	0.282	0.569
155	250-P S K	4.48	9.24	1.726	0.965	2.771	0.280	0.247	0.621
156	250-P S K N	4.27	9.01	1.874	0.976	2.725	0.283	0.243	0.612
157	800-P S K N	4.28	10.75	1.822	1.017	2.847	0.286	0.376	0.659

C. 110 Days After Seeding. (Sept. 26).

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
181	none	......	8.56	1.581	0.795	2.291	0.326	0.390	0.713
182	400-P S K N	......	8.82	1.610	0.884	2.316	0.296	0.394	0.634
183	250-P	......	7.06	1.724	1.061	1.595	0.365	0.329	0.555
184	250-P S	......	9.00	1.993	1.004	1.645	0.418	0.329	0.556
185	250-P S K	......	8.72	1.746	0.911	2.004	0.331	0.318	0.635
186	250-P S K N	......	8.07	1.766	1.065	1.610	0.289	0.290	0.592
187	800-P S K N	......	8.36	1.817	1.096	1.823	0.379	0.428	0.754

2) receiving the complete fertilizer, and on Coloma sand (table 3) receiving lime, phosphorus, sulfur, and potassium.

Nitrogen. The nitrogen content of the soybean plants showed a general decrease with the age of the plants. However, the nitrogen content of the plants on Coloma sand (table 3) on all plots increased during the period from 73 to 110 days after seeding. The nitrogen content at 73 and 110 days after seeding was practically the same for the plants grown on Miami loam (table 5) receiving the complete fertilizer, and a fertilizer lacking only nitrogen, and for the plants grown on Kewanee loam (table 4) receiving no fertilizer and a fertilizer lacking only nitrogen.

Sulfur. The sulfur content was the most uniform of the elements studied in these experiments. It was the most uniform in the plants receiving no fertilizer and complete fertilizer. The only variations of any significance were in the plants on Coloma sand (table 3). Here all fertilizer treatments increased the sulfur content of the plants in the latter half of the period of growth but decreased it in the first half of the period of growth, with the one exception of the treatment of magnesic lime on plot 3.

TABLE 3

Soybeans. Coloma sand, near Lowell, Michigan.

A. 35 Days After Seeding (July 16). Analysis based on dry weight.

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
211	none	3.76	10.12	2.799	0.694	4.173	0.318	0.411	0.504
212	Ca-lime	3.64	9.73	2.162	0.824	3.432	0.377	0.427	0.532
213	Mg-lime	3.33	9.06	1.993	0.815	3.393	0.293	0.297	0.488
214	*Mg P	4.12	10.38	2.603	0.884	3.883	0.377	0.451	0.656
215	Mg P S	4.11	10.70	2.428	1.008	3.676	0.451	0.407	0.596
216	Mg P S K	4.41	10.66	1.957	0.729	3.405	0.398	0.390	0.816
217	Mg P S K N	4.43	10.79	1.815	0.742	3.996	0.288	0.318	0.813

B. 73 Days After Seeding (Aug. 23).

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
251	none	3.34	11.38	1.760	0.644	2.163	0.321	0.403	0.729
252	Ca-lime	3.22	14.83	1.754	0.575	1.973	0.326	0.404	0.629
253	Mg-lime	3.09	11.53	1.766	0.960	1.800	0.393	0.416	0.727
254	*Mg P	3.28	9.05	2.036	0.928	1.889	0.361	0.392	0.784
255	Mg P S	3.33	9.11	2.036	1.007	1.548	0.385	0.397	0.798
256	Mg P S K	3.44	8.30	1.633	0.629	1.422	0.345	0.409	0.835
257	Mg P S K N	3.29	7.69	1.486	0.585	1.566	0.243	0.302	0.692

C. 109 Days After Seeding (Sept. 27).

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
281	none	......	8.37	2.115	0.607	2.441	0.386	0.462	0.591
282	Ca-lime	......	8.15	2.080	0.457	2.324	0.420	0.477	0.548
283	Mg-lime	......	8.12	1.173	1.035	2.708	0.536	0.509	0.647
284	*Mg P	......	8.09	1.406	0.787	2.308	0.518	0.490	0.518
285	Mg P S	......	7.50	1.428	0.785	2.139	0.476	0.451	0.641
286	Mg P S K	......	9.04	1.414	0.800	2.119	0.503	0.547	0.698
287	Mg P S K N	......	7.56	1.336	0.590	1.818	0.379	0.489	0.723

* Magnesic lime.

Phosphorus. The phosphorus content was lower 73 days after seeding than it was at either the 35th or 110th day after seeding. On Kewanee loam the phosphorus content of the unfertilized plants was found to have increased with the age of the plants (table 4). This increase in the phosphorus content was greatest in the plants on Coloma sand receiving magnesic lime (table 3). The phosphorus contents of these plants were 0.29%, 0.39%, and 0.53% respectively for the three periods of study. The phosphorus content of the plants on the unfertilized Hillsdale sandy loam (table 1), which was sampled at 10 or 11 day intervals, increased a small amount in the second sample (41 days after seeding) and then decreased, though to a less degree to and including the sixth sample (83 days after seeding). It increased again in the eighth sample (104 days after seeding). The results of these experiments suggest a tendency for the phosphorus content of the soybean plants to increase during the latter half of the growing season.

Potassium. The potassium content of the soybean plants was the most irregular of the elements studied in these experiments, but the majority of the variations were small. Some of the largest of these variations were increases occurring with the growth of the plants during the period from 35 to 73 days

TABLE 4

Soybeans. Kewanee Loam, Near Lowell, Michigan.

A. 35 Days After Seeding (July 16). Analysis based on dry weight.

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
311	none	4.10	9.87	2.081	0.663	5.063	0.275	0.345	0.812
312	Ca-lime	4.23	10.22	2.290	0.802	5.089	0.282	0.346	0.653
313	Mg-lime	4.18	10.39	2.210	0.800	5.059	0.279	0.340	0.690
314	*Mg P	4.23	10.78	2.256	0.843	5.076	0.272	0.340	0.764
315	Mg P S	4.53	10.37	2.007	0.754	5.323	0.284	0.364	0.843
316	Mg P S K	4.30	11.05	1.990	0.723	4.783	0.270	0.325	0.774
317	Mg P S K N	4.42	11.26	1.906	0.688	4.833	0.279	0.356	0.835
B.	73 Days After Seeding (Aug. 23).								
351	none	3.58	9.41	1.813	0.643	3.556	0.236	0.383	0.623
352	Ca-lime	3.82	9.73	1.812	0.644	3.678	0.253	0.270	0.717
353	Mg-lime	4.16	10.25	1.710	0.702	3.901	0.275	0.289	0.721
354	*Mg P	4.09	9.02	1.814	0.732	3.658	0.274	0.308	0.703
355	Mg P S	4.50	9.86	1.719	0.648	3.722	0.304	0.349	0.817
356	Mg P S K	4.36	9.63	1.814	0.733	3.422	0.284	0.331	0.757
357	Mg P S K N	4.20	9.74	1.765	0.782	3.910	0.285	0.322	0.703
C.	109 Days After Seeding (Sept. 27).								
381	none	......	6.92	1.294	0.536	3.528	0.277	0.423	0.738
382	Ca-lime	......	6.93	1.187	0.522	3.424	0.260	0.390	0.776
383	Mg-lime	......	6.48	1.418	0.672	3.103	0.282	0.357	0.728
384	*Mg P	......	6.40	1.362	0.624	3.028	0.258	0.374	0.688
385	Mg P S	......	6.66	1.210	0.509	3.147	0.257	0.376	0.678
386	Mg P S K	......	6.32	1.260	0.513	3.449	0.270	0.388	0.794
387	Mg P S K N	......	6.37	1.239	0.530	3.351	0.251	0.365	0.693

* Magnesic lime.

after seeding, on Coloma sand receiving no fertilizer, magnesic lime alone, and a treatment of magnesic lime, phosphorus, and sulfur. Some were also decreases occurring with the age of the plants during the same period with the use of the complete fertilizer. The general tendency seemed to be a small increased potassium content when the plants were half grown and a decrease in the plants when older.

The results obtained in these experiments show that the content of ash, calcium and magnesium decreased with the age of the plant. There were some exceptions, but these may be considered as the exception resulting from some unseen condition. In the sulfur content there was a striking uniformity throughout the growth of the plant except in the case of those plants grown on Coloma sand. In those plants receiving fertilizers there was a small decrease in the first half of the season and an increase in the latter part of the season of growth. The nitrogen content of the plants on Coloma sand was an exception to the general results obtained. In general, there was a decrease in the nitrogen content with the age of the plants. It is possible the increase which occurred in plants on Coloma was due to the inefficient utilization by the plants of the elements available in an unbalanced proportion. This is logical, for plants do include in their structure

TABLE 5

Soybeans. Miami Loam, near Mason, Michigan.

A. 36 Days After Seeding (July 14). Analysis based on dry weight.

Sample No.	Treatment	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
511	none	4.09	9.46	2.370	0.832	4.977	0.258	0.312	0.663
512	Ca-lime	4.02	9.34	2.049	0.828	4.781	0.262	0.278	0.795
513	Mg-lime	3.46	9.06	2.167	0.842	4.740	0.243	0.246	0.745
514	*Mg P	4.01	9.03	2.112	0.910	4.633	0.245	0.273	0.661
515	Mg P S	3.82	9.09	2.333	0.894	4.510	0.247	0.265	0.592
516	Mg P S K	3.70	8.96	2.115	0.836	4.545	0.238	0.250	0.654
517	Mg P S K N	4.52	9.30	2.300	0.908	4.768	0.248	0.258	0.668
B.	73 Days After Seeding (Aug. 19).								
551	none	4.32	8.58	1.834	0.773	4.023	0.260	0.242	0.774
552	Ca-lime	4.14	8.39	1.691	0.781	3.851	0.251	0.226	0.778
553	Mg-lime	4.40	8.70	1.787	0.744	4.054	0.268	0.234	0.684
554	*Mg P	4.37	8.83	1.739	0.873	3.788	0.264	0.235	0.725
555	Mg P S	4.15	8.73	1.869	0.940	3.801	0.272	0.265	0.666
556	Mg P S K	3.93	9.38	1.851	0.882	3.677	0.260	0.256	0.710
557	Mg P S K N	4.17	8.71	1.707	0.777	3.458	0.274	0.261	0.758
C.	111 Days After Seeding (Sept. 26).								
581	none	5.03	6.29	1.291	0.637	3.277	0.229	0.280	0.532
582	Ca-lime	4.48	6.13	1.183	0.552	3.570	0.241	0.273	0.596
583	Mg-lime	4.56	6.44	0.943	0.494	3.697	0.263	0.285	0.575
584	*Mg P	4.18	6.23	1.173	0.682	2.910	0.243	0.285	0.540
585	Mg P S	4.06	5.97	1.193	0.752	3.437	0.240	0.322	0.510
586	Mg P S K	5.37	6.48	1.159	0.629	3.750	0.255	0.352	0.555
587	Mg P S K N	5.18	6.52	1.278	0.733	3.578	0.226	0.305	0.570

* Magnesic lime.

appreciably large amounts of some elements not now known to be of any definite value to the plant. The selective feeding ability of the plant is exceeded by the unbalanced proportions of available elements in some cases. The function of phosphorus in the plant has been considered one closely associated with the maturity, and fruiting of the plant. The higher content found in the plants near maturity seems to be in conformity with this conception. The results of potassium content do not lend themselves to any definite explanation or conclusion because of the irregularity in the data, though these variations are comparatively small. In the growth of the plant there is a diminishing proportion of the mineral elements and an increasing proportion of those elements contributing largely to the formation of the organic portions of the plant.

EFFECT OF FERTILIZER TREATMENT UPON THE COMPOSITION OF THE SOYBEAN

The effects of the fertilizer treatments upon the composition of the soybeans in the experiments reported in this paper were small. This study was made at three periods during the growing season and the comparisons drawn for each period separately.

THIRTY-FIVE DAYS AFTER SEEDING

The calcic lime treatment increased only the ash and calcium contents of the plants on Kewanee loam (table 4). It decreased the ash, calcium, and nitrogen contents of the plants grown on Coloma sand (table 3, A), the calcium and nitrogen contents of the plants grown on Miami loam (table 5, A), and the potassium content of the plants grown on Kewanee loam (table 4, A).

The application of magnesic lime increased the ash content of the plants grown on Kewanee loam (table 4, A). The calcium and magnesium contents were also increased but to a smaller extent. It decreased the water, ash, calcium, and nitrogen contents of the plants grown on Coloma sand (table 3, A) and Miami loam (table 5, A), and the phosphorus content of the plants grown on Coloma sand. The calcium content of the plants grown on Coloma sand receiving magnesic lime was 1.99% and that of the plants grown on unfertilized Coloma sand was 2.80%. It was 2.16% in the case of the plants on the calcic limed plot. There is in these data an indication of a depressing effect of the magnesic and calcic lime treatments upon the calcium content of the plants.

The treatment of magnesic lime and phosphorus increased the water, ash, and magnesium contents of the plants grown on Coloma sand (table 3, A) and the ash, calcium, and magnesium contents of the plants grown on Kewanee loam (table 4, a). This treatment decreased the nitrogen content of the plants grown on Coloma sand and Miami loam (table 5, A), and the ash, and calcium content of the plants grown on Miami loam. The phosphorus treatment on Brookston* clay loam (table 2, A) increased the ash and magnesium contents of the plants and decreased the nitrogen content of these plants. The effects attributed to the addition of phosphorus to the treatment were increases in the ash, calcium, and water contents of the plants grown on Coloma sand (table 3, A), the ash content of the plants grown on Kewanee loam (table 4, A) and the water content of the plants grown on Miami loam (table 5, A). No appreciable decreases in the plant content of the respective elements were produced by the addition of the phosphorus to the fertilizer treatment.

Magnesic lime, phosphorus, and sulfur on Coloma sand (table 3, A) increased the water, ash and magnesium contents of the plants, while on Kewanee loam (table 4, A) it increased the water, ash and nitrogen contents. This treatment decreased the calcium and nitrogen contents of the plants on Coloma sand, and the water, ash and nitrogen contents of the plants on Miami loam (table 5, A). On Brookston* clay loam, (table 2, A) where the treatment consisted of the phosphorus and sulfur and no lime, the magnesium content of the plants was increased and the water and nitrogen contents of the plants were decreased. The introduction of the sulfur into the fertilizer treatment caused an increased ash content and a decreased nitrogen content of the plants on Coloma sand (table 3, A), and a decreased ash and water content of the plants on Brookston* clay loam (table 2, A).

The fertilizer treatment consisting of magnesic lime, phosphorus, sulfur, and potassium increased the water and ash contents of the plants grown on Kewanee loam (table 4, A), the water, ash and potassium contents of the plants grown on Coloma sand (table 3, A), and the ash and magnesium contents of the plants grown on Brookston* clay loam (table 2, A). The nitrogen content of the plants

* No lime was applied on Brookston clay loam.

on all four soils (Brookston* clay loam, Coloma sand, Kewanee loam, and Miami loam) and the calcium, ash and water contents of the plants grown on Miami loam (table 5, A), and the calcium content of the plants grown on Coloma sand receiving this treatment were decreased. The addition of potassium in this fertilizer treatment caused an increase in the ash content of the plants grown on Brookston* clay loam (table 2, A) and Kewanee loam (table 4, A), and the water and potassium contents of the plants grown on Coloma sand (table 3, A). Decreases in the calcium content of the plants grown on Miami loam (table 5, A), the water and nitrogen contents of the plants grown on Kewanee loam (table 4, A), and the calcium, magnesium and nitrogen contents of the plants grown on Coloma sand are also attributed to the potassium in the fertilizer treatment of these plots.

The complete fertilizer treatment increased the ash and magnesium contents of the plants grown on Brookston* clay loam (table 2, A), the water, ash and potassium contents of the plants grown on Coloma sand (table 3, A), and the water and ash contents of the plants grown on Kewanee loam (table 4, A). The only appreciable decreasing effect from the complete fertilizer occurred in the nitrogen content of the plants grown on Brookston* clay loam (table 2, A), Kewanee loam and Miami loam (table 5, A), and in the calcium content of the plants grown on Coloma sand. Effects attributed to the nitrogen in this fertilizer treatment were an increased nitrogen content of the plants grown on Coloma sand and Miami loam, and an increased ash content of the plants grown on Brookston* clay loam, Kewanee loam, and Miami loam.

The foregoing notations of the decreased and increased effects of the fertilizer treatment upon the composition of the plants 35 days after seeding represent only a part of the possibilities. Many cases did not show any effects, and others were too small for consideration. Each fertilizer treatment caused both increases and decreases in some one or more elements but the number of increases was greater than the number of decreases. Each fertilizer treatment decreased the nitrogen content of the plants except the treatment of magnesic lime, phosphorus and sulfur on Kewanee loam. The ash content was increased, by each treatment, on one or more of the soils. Both calcic and magnesic lime exerted a depressing effect upon the calcium content of the young plants. The phosphorus, sulfur, and potassium contents were not affected by the fertilizer treatments. The composition of the young plants (35 days after seeding) was affected by the fertilizer treatment but the changes, for the most part, were comparatively small. The data from one season's work does not lend itself to a more definite conclusion than that drawn.

SEVENTY-THREE DAYS AFTER SEEDING

The calcic lime treatment on Coloma sand (table 3, B) increased the ash content of the plants; on Kewanee loam (table 4, B) it increased the water and ash contents; and on Fox sandy loam (table 6) it increased the calcium and nitrogen contents. The increase in the nitrogen content of the plants on Fox sandy loam from 2.72% for the check plot to 3.74% for the calcic lime application was a very appreciable one. The ash content of the plants grown on Fox sandy loam and the nitrogen content of the plants grown on Coloma sand were decreased by the application of calcic lime. The composition of the plants grown on Miami loam (table 5, B) was not appreciably affected by the calcic lime treatment.

* No lime was applied to Brookston clay loam.

TABLE 6

Soybeans. Fox Sandy Loam, Near Cassapolis, Michigan.
75 Days After Seeding (Aug. 14). Analysis based on dry weight.

Sample No.	Treatment	Ash %	Ca %	Mg %	N %	S %	P %	K %
651	none	10.57	1.894	0.665	2.725	0.347	0.377	0.511
652	Lime	7.72	2.078	0.822	3.740	0.244	0.296	0.487
652a	Lime K	8.35	2.025	0.783	4.246	0.271	0.281	0.521
653a	Lime R-P S	8.80	2.302	0.767	3.940	0.266	0.405	0.436
654a	Lime R-P	8.68	2.288	0.881	4.342	0.287	0.398	0.468
655	Lime A-P	8.63	2.292	0.832	4.112	0.273	0.405	0.484
656	Lime K A-P	8.56	2.315	0.680	3.867	0.273	0.362	0.688
657	Lime K A-P N	7.29	2.152	0.729	3.962	0.234	0.299	0.466
658a	Lime N	8.30	1.999	0.967	4.394	0.252	0.346	0.497
658c	Lime K N	7.93	2.058	0.624	3.609	0.246	0.284	0.564
659a	Lime A-P N	7.72	2.121	0.794	3.948	0.237	0.328	0.464

Lime=6300 pounds of calcic lime per acre.
K = 100 pounds of muriate of potash per acre.
R-P =1000 pounds of rock phosphate per acre.
S =Gypsum equivalent to that in 200 pounds of acid phosphate per acre.
A-P = 200 pounds of acid phosphate per acre.
N = 100 pounds of nitrate of soda per acre.

The magnesium content of the plants grown on Coloma sand (table 3, B) and the water, ash and nitrogen contents of the plants grown on Kewanee loam (table 4, B) were increased by the magnesic lime treatment. The only decreasing effect of the magnesic lime treatment was upon the water and nitrogen contents of the plants grown on Coloma sand. The magnesic lime treatment did not affect in an appreciable way the composition of the plants grown on Miami loam (table 5, B) as was also true of the calcic lime treatment. A comparison of the composition of the soybean plants treated with calcic lime and those treated with magnesic lime indicated a higher content of magnesium in the plants grown on Coloma sand (table 3, B), a higher ash, nitrogen, and water content in the plants grown on Kewanee loam (table 4, B), and a higher water and ash content in the plants grown on Miami loam (table 5, B), receiving the magnesic lime treatment. The ash content of the plants grown on Coloma sand was the only constituent that was higher in the plants receiving the calcic lime treatment.

The treatment of magnesic lime and phosphorus increased the calcium and magnesium contents of the soybean plants grown on Coloma sand (table 3, B), the water content of the plants grown on Kewanee loam (table 4, B) and the ash content of the plants grown on Miami loam (table 5, B). This treatment decreased the ash and nitrogen content of the plants grown on Coloma sand, the ash content of the plants grown on Kewanee loam, and the nitrogen content of the plants grown on Miami loam. The water, ash and nitrogen contents of the plants grown on Brookston* clay loam (table 2, B) were reduced by the application of phosphorus alone. A comparison of the composition of the plants receiving applications of magnesic lime alone and with phosphorus reveals an increase in the calcium content and a decrease in the ash content of the plants grown on Coloma sand, decreases in the ash and nitrogen contents of the plants grown on Kewanee loam (table 4, B), and decreases in the nitrogen content of the plants

* No lime was applied to Brookston clay loam.

grown on Miami loam (table 5, B) due to the addition of the phosphorus in the treatment. Where calcic lime and phosphorus were used on Fox sandy loam (table 6, sample 654a) the calcium, magnesium, and nitrogen contents of the plants were increased. The nitrogen content was increased from 2.72% in the plants on the check plot to 4.34% in the plants on the plot receiving calcic lime and rock phosphate on Fox sandy loam. This, with a similar increase from an application of lime and nitrogen (table 6, sample 658a), were the largest increases in nitrogen obtained from fertilization. A decrease also occurred in the ash content of the plants on this plot receiving the lime and phosphorus. The ash, calcium, and nitrogen contents of these plants were higher than the ash, calcium, and nitrogen contents of the plants receiving an application of calcic lime alone on Fox sandy loam.

The fertilizer treatment of magnesic lime, phosphorus, and sulfur increased the calcium and magnesium contents of the plants grown on Coloma sand (table 3, B), and the water and ash contents of the plants grown on Kewanee loam (table 4, B). This fertilizer treatment decreased the ash and nitrogen contents of the plants grown on Coloma sand and the nitrogen content of the plants grown on Miami loam (table 5, B). A decrease in the water content of the plants grown on Miami loam was attributed to the addition of the sulfur to this treatment. An increase in the ash and water contents of the plants grown on Kewanee loam was also attributed to the application of sulfur on these plots. The phosphorus and sulfur treatment on Brookston* clay loam resulted in no increases but did result in a decreased water, ash and nitrogen content of the plants. The nitrogen content was 2.36% in the plants treated with phosphorus and sulfur, and 3.46% in the plants given no fertilizer treatment on Brookston* clay loam. The addition of sulfur to the fertilizer treatment increased the ash and calcium contents of the plants on Brookston* clay loam in comparison to those plants getting only phosphorus. A treatment of calcic lime, phosphorus**, and sulfur** on Fox sandy loam (table 6) increased the calcium and nitrogen, and decreased the ash contents of the soybean plants. The increase in the nitrogen content from 2.72% in the plants on the check plot to 4.11% on the plot receiving the lime, phosphorus**, and sulfur** was quite appreciable though not as large as in sample 654a (table 6).

The magnesic lime, phosphorus, sulfur, and potassium treatment increased the water and ash contents of the plants grown on Kewanee loam (table 4, B) and the ash content of the plants grown on Miami loam (table 5, B). The treatment also decreased the ash and nitrogen contents of the plants grown on Coloma sand (table 3, B) and the water and nitrogen contents of the plants grown on Miami loam. On Brookston* clay loam, this treatment which did not include lime, decreased the water, ash, and nitrogen contents of the plants, but did not cause any increases. The calcium and nitrogen contents of the soybean plants were increased by the treatment of calcic lime, phosphorus**, sulfur**, and potassium on Fox sandy loam (table 6, sample 656). The ash content suffered a marked decrease. It was 8.56% in these plants and 10.57% in the plants on the check plot. Only one increase resulted from the addition of potassium to the fertilizer application. This was the nitrogen content of the plants on Brookston* clay loam (table 2, B). Decreases occurred in the calcium content of the plants on Brookston* clay loam, the water content of the plants on Miami loam (table 5, B),

* No lime was applied on Brookston clay loam.
** Supplied in the acid phosphate.

the nitrogen content of the plants on Fox sandy loam, the ash and nitrogen contents of the plants on Kewanee loam (table 4, B), and the ash, calcium and magnesium contents of the plants on Coloma sand (table 3, B).

The application of a complete fertilizer produced increases in the mineral constituents of the plant only on Kewanee loam (table 4, B) and Fox sandy loam (table 6). The water, ash and nitrogen contents of the plants on Kewanee loam were increased. The treatment of calcic lime, phosphorus**, sulfur**, potassium, and nitrogen on Fox sandy loam increased the calcium and nitrogen, and decreased the ash content of these plants. The nitrogen content of the plants on Miami loam (table 5, B) and the ash, calcium, and nitrogen contents of the plants on Coloma sand (table 3, B) were lowered by the application of the complete fertilizer. No increases occurred in the plants on Brookston* clay loam (table 2, B), but decreases did occur in the ash, water and nitrogen contents. The addition of nitrogen in the fertilizer application was accompanied by an increase in the nitrogen content of the plants on Kewanee loam (table 4, B), an increase in the water and a decrease in the ash and nitrogen contents of the plants on Miami loam (table 5, B), a decrease in the ash content of the plants on Fox sandy loam (table 6), and a decrease in the water and ash contents of the plants on Brookston* clay loam. The nitrogen content of the plants on Fox sandy loam was increased from 2.72% in the plants on the check plot to 3.96% in the plants on the plot receiving the complete fertilizer.

The effects of the fertilizer treatments on the plants 73 days after seeding were quite irregular as was true in the case of the younger plants. Though definite conclusions are not possible yet there are some marked evidences of definite effects. The lime applications did not have the same depressing effect upon the calcium content of these plants as was noted in the younger plants. Also the lime applications did not show any effects upon the composition of plants on Miami loam. The phosphorus, sulfur, and potassium contents of the plants were not affected by the fertilizer treatments, which was also true in the younger plants. Each fertilizer treatment on Fox sandy loam caused an increase in nitrogen content of the plants. This increase is notable because the only other increases were for the magnesic lime and complete fertilizer treatments on Kewanee loam.

ONE HUNDRED TEN DAYS AFTER SEEDING

The only appreciable effect of calcic lime alone upon the composition of the soybean plants approaching maturity was an increased nitrogen and a decreased water content of the plants on Miami loam (table 5, C), and a decreased ash content of the plants on Coloma sand (table 3, C).

The treatment of magnesic lime had no more effect on the composition of the soybean plants than the calcic lime treatment. The nitrogen content of the plants on Miami loam and the magnesium and nitrogen contents of the plants on Coloma sand were the only constituents of the plants that were increased by the magnesic lime treatment. The depressing effects of the magnesic lime were noted in the ash and nitrogen contents of the plants on Kewanee loam (table 4, C), the water and calcium contents of the plants on Miami loam (table 5, C), and the ash and calcium contents of the plants on Coloma sand (table 3, C). The calcium content

* No lime was applied on Brookston clay loam.
** Supplied in the acid phosphate.

of the plants on Coloma sand was depressed from 2.11% on the check plot to 1.17% on the magnesic limed plot. The calcium content of the plants on the calcic limed plot on Coloma sand was 2.08%, which was higher than for the magnesic limed plot by a difference of 0.91%. A higher calcium content of the plants on Miami loam and a higher ash and nitrogen content of the plants on Kewanee loam resulted from the treatment of calcic lime than from the magnesic lime treatment. On the other hand, there was a higher content of magnesium and nitrogen in the plants on Coloma sand, a higher content of calcium in the plants on Kewanee loam, and a higher ash content in the plants on Miami loam from the application of magnesic lime than there was from the application of calcic lime.

A higher content of magnesium in the plants grown on Brookston* clay loam was the only increase from the application of phosphorus either with or without lime. Several depressing effects occurred which were as follows: the water and nitrogen contents of the plants on Miami loam, (table 5, C), the ash and nitrogen contents of the plants on Kewanee loam (table 4, C), the calcium and ash contents of the plants on Coloma sand (table 3, C), and the ash and nitrogen contents of the plants on Brookston* clay loam (table 2, C). The effect of the addition of phosphorus to the fertilizer application was an increased calcium and a decreased magnesium content of the plants on Coloma sand and Miami loam. The nitrogen, water, and ash contents on Miami loam were also decreased by the addition of the phosphorus to the fertilizer treatment.

The phosphorus and sulfur treatments on the Brookston* clay loam caused increases in the ash, calcium and magnesium, and decreases in the nitrogen contents of the soybean plants. The ash and calcium contents of the plants were greater than where phosphorus alone was applied on Brookston* clay loam. The treatment of magnesic lime, phosphorus, and sulfur on the other soil types caused no increases in the composition of the plants. Decreasing effects, however, occurred in the nitrogen content of the plants grown on Coloma sand (table 3, C) and Kewanee loam (table 4, C), the calcium content of the plants on Coloma sand, and the ash content of the plants on Coloma sand, Kewanee loam and Miami loam. An increased ash content of the plants on Kewanee loam, an increased nitrogen content of the plants on Miami loam, and a decreased ash content of the plants on Coloma sand and Miami loam were attributed to the addition of sulfur in this fertilizer treatment.

The treatment consisting of magnesic lime, phosphorus, sulfur, and potassium increased the ash and magnesium contents of the plants on Coloma sand (table 3, C) and the water, ash, and nitrogen contents of the plants on Miami loam (table 5, C). This treatment also decreased the ash content of the plants on Kewanee loam (table 4, C) and the calcium and nitrogen contents of the plants on Coloma sand. On the Brookston* clay loam the only appreciable effect was a reduction in the nitrogen content of the plants. The effects attributed to the addition of potassium to the fertilizer treatment were an increased ash content of the plants on Coloma sand (table 3, C) and Miami loam (table 5, C), an increased water content of the plants on Miami loam, and an increased nitrogen content of the plants on Brookston* clay loam (table 2, C), Kewanee loam (table 4, C) and Miami loam. This treatment also caused a decreased calcium content of the

* No lime was applied on the Brookston clay loam.

plants on Brookston* clay loam and a decreased ash content of the plants on Brookston* clay loam and Kewanee loam.

The complete fertilizer increased the magnesium content of the plants on Brookston* clay loam and the ash and nitrogen contents of the plants on Miami loam (table 5, C). The treatment also decreased the ash content of the plants on Brookston* clay loam (table 2, C), Coloma sand (table 3, C) and Kewanee loam (table 4, C), the nitrogen content on Brookston* clay loam and Coloma sand, and the calcium content on Coloma sand. No increases resulted from the addition of the nitrogen to this fertilizer application. The addition of nitrogen, however, did cause a decreased ash and nitrogen content of the plants on Brookston* clay loam and a decreased ash, magnesium and nitrogen content of the plants on Coloma sand.

The foregoing data and notations of the effects of the treatments upon the composition of the plants are quite irregular. However, there are some regularities. The phosphorus, sulfur and potassium contents were not appreciably changed by the treatments. There were few increased ash contents but many decreased ash contents. These resulted more from the treatments carrying two or more elements. In fact, there were very few increases in the content of any element, but many decreases. A decrease in the mineral elements resulting in an increased growth, certainly resulted in an increased content of the other constituents, as carbohydrates, etc. Though no yields were obtained, increased growth did result from all treatments on each soil, except possibly some of the lime treatments. It is the opinion of the writer that these soils do not suffer from a deficiency of phosphorus in comparison to other elements though one or two of the soils may be low in total phosphorus content. A shortage in phosphorus available to plants, when the other elements are available in sufficient amounts for normal growth, constitutes a true and detrimental shortage from which the composition of the plant will doubtless suffer. This condition surely has not existed in these soils under experimentation. Doubtless, phosphorus was not abundantly available in Coloma sand and Kewanee loam, but it was also as probable that nitrogen, potassium, and other factors were not up to optimum for production, for there was plainly visible response to fertilization. The effects upon the growth of the plants was less, the growth on all treatments was also greater, and the effect upon the composition of the plant was less on Miami loam than on either Kewanee loam or Coloma sand. A shortage of an element necessitates, to a certain extent, an unbalanced proportion of the elements available to the plants. Effects from soil treatments upon the composition of the plant certainly can be expected where there is a deficiency of some one or two of the added elements, but where there is a condition approximating a balanced condition any moderate fertilizer treatment does not give regular and appreciable effects upon the composition of the plant. A lack of control of the many contributing factors accounts in part for the irregularity in the results which have been reported upon the subject.

EFFECT OF SOIL TYPE UPON THE COMPOSITION OF THE SOYBEAN

A study of the effect of the soil type upon the composition of the soybean plant was made upon the untreated soils used in these experiments at the three periods

* No lime was applied on the Brookston clay loam.

during the growth of the plants. The comparisons are drawn for the periods separately.

THIRTY-FIVE DAYS AFTER SEEDING

The moisture content of the young soybean plants grown on the soils used in these experiments was uniform within very small variations. It was higher in the plants on Brookston clay loam and lower in the plants on Coloma sand than in the plants on Hillsdale sandy loam, Miami loam, or Kewanee loam (table 7, A). The plants grown on Hillsdale sandy loam and Coloma sand had the highest ash (10.70% and 10.12%) and calcium (2.70% and 2.79%), and the lowest magnesium (0.58% and 0.69%) and nitrogen (4.41% and 4.17%) contents. The calcium content was the lowest in the plants grown on Kewanee loam (2.08%). The soybean plants grown on Brookston clay loam had the highest magnesium (1.08%) content, one of the highest nitrogen contents (4.81%), and one of the lowest calcium (2.16%) and ash (9.72%) contents. The Kewanee loam produced plants were the highest, and the Miami loam produced plants were second highest in the nitrogen content (5.06% and 4.97%). The phosphorus, sulfur, and potassium contents did not vary to any great extent on the soil types used in this experiment. A small difference in the sulfur content existed between the plants grown on Coloma sand and Hillsdale sandy loam (0.31% and 0.23%). The variation in the phosphorus content was from 0.46% in the plants grown on Brookston clay loam and 0.41% in the plants grown on Coloma sand to 0.23% in the plants grown on Hillsdale sandy loam. The Kewanee loam grown plants had the highest potassium content (0.81%). The potassium content ranged in the other plants from 0.69% in the plants on Hillsdale sandy loam to 0.50% in the plants on Coloma sand.

A general correlation exists between the ash content and the size of the young plants. Those grown on Coloma sand, Kewanee loam, and Hillsdale sandy loam were smaller and possessed a higher ash content than those on Brookston clay loam, and Miami loam, which were the largest in size. For a finer comparison, this correlation will not hold true, because the plants on Coloma sand and Kewanee loam were the smallest in size and the highest ash content occurred in the plants on Hillsdale, which ranked third in size, and second highest in the plants on Coloma sand. An apparent correlation exists between the size of the plant and magnesium content in that those grown on Brookston clay loam and Miami loam were larger and had a higher magnesium content than those on the other three soils.

SEVENTY-THREE DAYS AFTER SEEDING

The variations in the water content of the soybean plants 73 days after seeding (table 7, B), though small, were greater than in the younger plants (table 7, A). Appreciable differences occurred in the ash content of the plants grown on the several soils. The highest ash content was in the plants grown on Coloma sand (11.36%), and Brookston clay loam (10.61%) and Fox sandy loam (10.57%), and the lowest ash content was in the plants grown on Miami loam (8.58%). Only a small difference existed between the ash contents of the plants on Kewanee loam (9.41%) and Hillsdale sandy loam (9.23%). Less variation occurred in the calcium contents of the soybean plants 73 days after seeding (table 7, B) than in the plants 35 days after seeding (table 7, A). The calcium content was

TABLE 7

Soybeans. Unfertilized plants.

A. 35 Days After Seeding (July 13). Analysis based on dry weight

Sample No.	Soil type	Water per gm. dry wt. gms.	Ash %	Ca %	Mg %	N %	S %	P %	K %
011	Hillsdale	4.03	10.70	2.702	0.586	4.414	0.232	0.234	0.695
111	Brookston	4.29	9.72	2.162	1.083	4.815	0.289	0.469	0.635
211	Coloma	3.76	10.12	2.799	0.694	4.173	0.318	0.411	0.504
311	Kewanee	4.10	9.87	2.081	0.663	5.063	0.275	0.345	0.812
511	Miami	4.09	9.46	2.370	0.832	4.977	0.258	0.312	0.663
B. 73 Days After Seeding (Aug. 19).									
051	Hillsdale	4.32	9.23	2.050	0.846	3.833	0.283	0.287	0.722
151	Brookston	4.88	10.61	1.792	1.086	3.463	0.291	0.374	0.627
251	Coloma	3.34	11.36	1.760	0.644	2.163	0.321	0.403	0.729
351	Kewanee	3.58	9.41	1.813	0.643	3.556	0.236	0.383	0.623
551	Miami	4.32	8.58	1.834	0.773	4.023	0.260	0.242	0.774
651	Fox	......	10.57	1.894	0.665	2.725	0.347	0.377	0.511
C. 110 Days After Seeding (Sept. 26).									
081	Hillsdale	......	8.13	1.865	0.719	3.167	0.249	0.329	0.576
181	Brookston	......	8.56	1.681	0.795	2.291	0.326	0.390	0.713
281	Coloma	......	8.37	2.115	0.607	2.441	0.286	0.462	0.591
381	Kewanee	......	6.92	1.294	0.536	3.528	0.277	0.423	0.738
581	Miami	5.03	6.29	1.291	0.637	3.277	0.229	0.280	0.532

a little higher in the plants grown on Hillsdale sandy loam (2.05%) and was lowest in the plants grown on Coloma sand (1.76%) and Brookston clay loam (1.79%) than in the plants grown on the other soils. The Brookston clay loam grown plants had the highest magnesium content (1.08%) and the plants grown on Hillsdale sandy loam had the second highest magnesium content (0.84%). Very little difference existed between the magnesium contents of the plants grown on the other three soils of which the Coloma sand and Kewanee loam grown plants were the lowest (0.64%). The nitrogen content of the plants was greatest on Miami loam (4.02%), Hillsdale sandy loam (3.83%), Kewanee loam (3.55%) and Brookston clay loam (3.46), and was lowest on Coloma sand (2.16%) and Fox sandy loam (2.72%). The difference in the sulfur contents of the plants grown on Kewanee loam (0.23%—the lowest) and on Fox sandy loam (0.34%) was not large. Variations in the phosphorus content of the plants grown on the soil types used in this experiment were appreciable. The highest phosphorus content of the soybean plants was on Coloma sand (0.40%), Kewanee loam (0.38%), Brookston clay loam (0.37%) and Fox sandy loam (0.37%). Miami loam and Hillsdale sandy loam grown plants were the lowest in phosphorus content (0.24% and 0.28%). The effect of the soil type upon the potassium content of the soybean plants was not pronounced. Fox sandy loam grown plants were the lowest and Miami loam grown plants were the highest in their content of potassium (0.51% and 0.77%). Practically no difference existed between the potassium content of the plants grown on Coloma sand and the plants grown on Hillsdale sandy loam (0.72%), and between the plants grown on Brookston clay loam and the plants grown on Kewanee loam (0.62%).

The larger more thrifty plants, which were those grown on Miami loam, and Brookston clay loam had higher nitrogen and magnesium contents and lower phosphorus and ash contents than the smallest plants, which were those grown on Coloma sand. These data lend themselves less to correlations to the size of the plant than did the data for the younger plants.

ONE HUNDRED TEN DAYS AFTER SEEDING

The influence of the soil type upon the composition of the soybean plants at the stage or growth for hay is shown by the data in table 7, C. The total ash content was the highest in the plants grown on Brookston clay loam (8.56%), Coloma sand (8.37%) and Hillsdale sandy loam (8.13%), and was lowest in the plants grown on Miami loam (6.29%) and Kewanee loam (6.92%). The magnesium (0.79%) and sulfur (0.32%) contents were the highest in the plants grown on Brookston clay loam, and the calcium (2.11%) and phosphorus (0.46%) contents were the highest in the plants on Coloma sand. The Brookston clay loam and Kewanee loam grown plants contained the highest per cent of potassium (0.71% and 0.73%), and the Miami loam grown plants contained the lowest per cent of potassium (0.53%). The highest per cent of nitrogen was in the plants grown on Kewanee loam (3.52%), Miami loam (3.27%), and Hillsdale sandy loam (3.16%), and the lowest per cent of nitrogen was in the plants grown on Brookston clay loam (2.29%) and Coloma sand (2.44%). Miami loam produced the plants containing the lowest per cent of ash (6.29%), calcium (1.29%), sulfur (0.22%), phosphorus (0.28%) and potassium (0.53%), and one of the highest per cents of nitrogen (3.27%).

The influence of the soil type upon the composition of the plants is shown in the above notations from table 7. To draw definite correlations of the growth of the plants to the content of an element is difficult because of the irregularities, but there are some general correlations apparent. Those plants grown on Miami loam had the lowest contents of ash, sulfur, calcium, phosphorus, and potassium, and were among the largest, being exceeded in size only by those grown on Brookston clay loam. The magnesium content of the plants at each period of growth was associated with the larger growth of plants. The calcium content tended to a limited extent to be inversely proportional to that of the magnesium. The calcium and phosphorus contents of these plants were not low to the extent that it would be detrimental to the nutrition of the livestock consuming the hay therefrom (6, 12). These soils are therefore not deficient in available phosphorus to the extent of an unbalanced proportion to the other elements, which in all probability, is the condition existing in those localities suffering from the deficiency of lime and phosphorus in the hay and pasture grass produced (6, 12, 39).

CELL SAP STUDIES

That the concentration and phosphorus content of the sap of several crops was affected by fertilizer treatments and soil type, has been shown by McCool (24). In this paper are presented the results of similar studies of the effect of additions of phosphorus and potassium and also the effect of the soil type upon the phosphorus, potassium, and calcium contents of the cell sap of the soybean plant. These studies were confined to the greenhouse grown plants except for a few samples from field plots on Miami loam.

TABLE 8

Cell Sap of Soybean Plants Grown in Greenhouse.
Phosphorus Content.

Soil Type	16 Days After Seeding			33 Days After Seeding			51 Days After Seeding		
	Treatment of pots			Treatment of pots			Treatment of pots		
	none	P 0.2* K 0.1*	P 2* K 1	none	P 0.2 K 0.1	P 2 K 1	none	P 0.2 K 0.1	P 2 K 1
	%	%	%	%	%	%	%	%	%
Kalamazoo muck	....	....	....	0.006	0.016	0.075	0.025	0.044	0.074
Miami loam	....	....	....	0.011	0.015	0.036	0.055	0.055	0.092
Nappanee loam	....	....	....	0.018	0.019	0.033	0.061	0.062	0.073
Kewanee loam	....	....	....	0.029	0.031	0.040	0.050	....	....
Coloma sand	0.029	0.026	0.026	0.033	0.037	0.062	0.057	....	....
Fox sandy loam	....	....	....	0.024	0.011	0.026	0.056	0.048	0.056
Plainfield sand	0.027	0.030	0.028	0.033	....	0.050	0.064	....	....
Berrien sandy loam	....	....	....	....	....	....	0.047	....	....

Potassium Content

Soil Type	16 Days none	16 Days P 0.2 K 0.1	16 Days P 2 K 1	33 Days none	33 Days P 0.2 K 0.1	33 Days P 2 K 1	51 Days none	51 Days P 0.2 K 0.1	51 Days P 2 K 1
Kalamazoo muck	....	....	....	0.191	0.192	0.308	0.178	0.188	0.326
Miami loam	....	....	....	0.089	0.133	0.209	0.212	0.233	0.307
Nappanee loam	....	....	....	0.212	0.216	0.269	0.240	0.241	0.322
Kewanee loam	....	....	....	0.171	0.169	0.380	0.246	....	....
Coloma sand	0.228	0.210	0.135	0.173	0.281	0.299	0.219	....	....
Fox sandy loam	....	....	....	0.147	0.169	0.477	0.181	0.213	0.282
Plainfield sand	0.171	0.169	0.207	0.319	....	0.402	0.209	....	....
Berrien sandy loam	....	....	....	....	....	....	0.263	....	....

* Grams of mono-calcium phosphate per pot.
** Grams of potassium chloride per pot.

EFFECT OF FERTILIZER TREATMENT UPON THE COMPOSITION OF THE CELL SAP

Greenhouse Studies. The phosphorus content of the cell sap of the soybean plants 16 days after seeding was not affected by the treatment of mono-calcium phosphate and potassium chloride in either the light or the heavy application on Coloma sand and Plainfield sand. The application of the phosphorus and potassium did cause an increase in the phosphorus content of the cell sap of the plants 33 days after seeding on six of the seven soil types used in this experiment. The effects of the light application were very small, but relatively large increases resulted from the heavy application of phosphorus and potassium. The phosphorus content of the cell sap of the plants on Fox sandy loam 51 days after seeding (table 8) was reduced a very small amount by the light application, and was not affected by the heavy application. A somewhat similar condition occurred in these plants 33 days after seeding. A marked increase in the phosphorus content of the cell sap of the plants on Kalamazoo muck resulted from both the light and the heavy application of phosphorus and potassium. The light application had no effect but the heavy application increased the phosphorus content of the cell sap of the plants on Miami loam and Nappanee loam.

The potassium content of the cell sap of soybean plants 16 days after seeding showed a tendency for the potassium content to be higher in the plants on Plainfield sand and to be lower in the plants on Coloma sand, (table 8). The effect of the light application of phosphorus and potassium was negligible in the plants

TABLE 9

Cell Sap of Soybean Plant Grown on Miami Loam, near Mason, Michigan.

Date Days After Seeding:		July 27. 49	Aug. 20 74	July 27. 49	Aug. 20 74	July 27. 49	Aug. 20 74
Plot No.	Treatment	Phosphorus %		Potassium %		Calcium %	
1	none	0.022	0.038	0.195	0.123	0.342	0.600
2	Ca-lime	0.022	0.034	0.210	0.091	....	0.586
3	Mg-lime	0.036	0.035	0.228	0.251	....	....
4	*Mg P	0.040	0.033	0.104	0.107	....	....
5	Mg P S	0.044	0.040	0.108	0.179	....	....
6	Mg P S K	0.040	0.036	0.300	0.177	....	....
7	Mg P S K N	0.036	0.041	0.310	0.175	....	0.475

* Magnesic lime.

on these soils. The study of the potassium content of the cell sap of the plants 33 and 51 days after seeding reveals a general tendency for it to be increased by the treatment. However, the effects of the light application were practically nil in the plants 33 days after seeding on Kalamazoo muck, Nappanee loam, Kewanee loam and Fox sandy loam, and also in plants 51 days after seeding on Kalamazoo muck, Miami loam, Nappanee loam and Fox sandy loam. Very marked increases were observed in the potassium content of the cell sap of the plants 33 days after seeding from the heavy application of phosphorus and potassium on Kalamazoo muck, Kewanee loam and Fox sandy loam. The plants on the other soils showed smaller increases in the potassium content of the cell sap of the plants 33 days after seeding from the heavy application. The light application had relatively little effect on the potassium content of the cell sap of the plants 51 days after seeding, but the heavy application caused appreciable increases in the potassium content of the cell sap of the plants. This effect was most pronounced in the plants grown on Kalamazoo muck.

Field Studies. The phosphorus content of the cell sap of the soybean plants on the field plots on Miami loam 49 days after seeding was increased by each of the fertilizer treatments with the exception of the calcic lime treatment which had no effect (table 9). The treatment of magnesic lime, phosphorus, and sulfur on plot number 5 produced the greatest increase in the phosphorus content of the cell sap of the plants. Seventy-four days after seeding, the only indication of an increased effect was also from the treatment on plot number 5 and from the complete fertilizer treatment on plot number 7 (table 9). Calcic lime alone, magnesic lime alone, magnesic lime and phosphorus, and magnestic lime, phosphorus, and sulfur caused decreases in the phosphorus content of the cell sap of the soybean plants 74 days after seeding. The phosphorus content of the cell sap of the plants on the check plot was higher in the older plants than in the younger plants. The calcic lime alone and the complete fertilizer were the only treatments which produced an increased phosphorus content of the cell sap with the growth of the soybean plant.

The potassium content of the cell sap of the soybean plants 49 days after seeding was reduced by the application of magnesic lime and phosphorus, and magnesic lime, phosphorus, and sulfur. Lime alone did not affect the potassium content of the cell sap of the younger plants to any great extent, but in the older plants the calcic lime alone reduced the potassium content of the cell sap and the

TABLE 10

Cell Sap of Soybean Plants Grown in Greenhouse.
Calcium Content

Toil Type	16 Days After Seeding	33 Days After Seeding	51 Days After Seeding
	%	%	%
Kalamazoo muck	....	0.255	0.234
Miami loam	....	0.445	0.372
Nappanee loam	....	0.286	0.243
Kewanee loam	....	0.273	0.185
Coloma sand	....	0.228	0.240
Fox sandy loam	....	0.404	0.225
Plainfield sand	0.075	0.341	0.230
Berrien sandy loam	....	....	0.248

magnesic lime increased the potassium content of the cell sap of the soybean plants. The complete fertilizer treatment and the fertilizer treatment lacking nitrogen increased the potassium content of the cell sap in both the young and the older soybean plants.

EFFECT OF SOIL TYPE UPON THE COMPOSITION OF THE CELL SAP

That the composition of the cell sap is affected by the soil type is shown by the data of the phosphorus, potassium, and calcium contents presented in tables 8 and 10.

The phosphorus content of the cell sap of soybean plants 33 days after seeding was highest in the plants grown on Kewanee loam, Coloma sand, Fox sandy loam and Plainfield sand. Fifty-one days after seeding the phosphorus content of the cell sap of the plants on these soils was again high, and the phosphorus content of the cell sap of the plants on Nappanee loam, Miami loam and Berrien sandy loam was also high. The phosphorus content of the cell sap of the plants 33 and 51 days after seeding was lowest in the plants on Kalamazoo muck (table 8).

The potassium content of the cell sap of the plants 33 days after seeding was highest on Plainfield sand, Nappanee loam and Kalamazoo muck, and 51 days after seeding it was highest in the plants on Berrien sandy loam, Nappanee loam and Kewanee loam. The lowest potassium content of the cell sap of the soybean plants was in the plants on Miami loam, Fox sandy loam, Kewanee loam and Coloma sand for the period 33 days after seeding, and in the plants on Kalamazoo muck, Fox sandy loam, Plainfield sand, Miami loam and Coloma sand for the period 51 days after seeding (table 8).

The calcium content of the cell sap of the soybean plants 33 days after seeding was highest in the plants grown on Miami loam (0.44%) and on Fox sandy loam (0.40%). The lowest calcium content of the cell sap for this period was in the plants on Coloma sand (0.22%). The cell sap of the plants on Nappanee loam and Kewanee loam contained 0.28% and 0.27% of calcium respectively. Fifty-one days after seeding the calcium content of the cell sap of the soybean plants was lower than in the plants 33 days after seeding. The highest calcium content of the cell sap of the plants 51 days after seeding was 0.37% in the plants on Miami loam, and the lowest was 0.18% in the plants on Kewanee loam. The

TABLE 11

Freezing Point Depression of Green Soybean Plant
Miami loam, Mason, Michigan.

Mid-season sample. Aug. 19 (73 days after seeding)

Sample No.	Treatment	Degrees depression
551	none	0.874
552	Ca-lime	0.942
553	Mg-lime	1.009
554	*Mg P	0.902
555	Mg P S	0.952
556	Mg P S K	0.901
557	Mg P S K N	0.865

* Magnesic lime.

calcium content of the cell sap of the plants on Fox sandy loam was much lower (0.22%) than in the plants 33 days after seeding (0.40%), (table 10).

FREEZING POINT DEPRESSION

The Freezing Point Depression was determined on one set of samples of the soybean plants taken from the plots on Miami loam 24 days after seeding. The freezing point depression as a means of determining the concentration of the sap has been presented by Bouyoucos and McCool (5). That the concentration of the sap of the young corn plants, sugar beets, table beets, table carrots, and onions was increased by fertilizer applications, has been shown by McCool (24). These results (table 11) show that the fertilizer treatments increased the freezing point depression of the cell sap of the soybean plants. However, the depression was less in the plants receiving the complete fertilizer treatment than in the plants receiving no fertilizer treatment. There appears to be a general correlation between the freezing point depression and the phosphorus and potassium contents of the soybean plants.

SUMMARY

Fertilizer tests with soybeans were located on five soil types from which crop samples were taken periodically for the laboratory studies.

The samples of soybean plants were analyzed for total ash, calcium, magnesium, nitrogen, sulfur, phosphorus and potassium.

The freezing point depression was determined upon one set of samples of fresh plant material from Miami loam.

Tests were conducted in the greenhouse to study the effect of soil type and fertilization with phosphorus and potassium upon the phosphorus and potassium contents of the cell sap of the soybean plant.

SUMMARY OF RESULTS

1. The total ash content of the soybean plants was lowest 110 days after seeding and in many cases it was highest 73 days after seeding.

2. In the young plants the high ash content was associated with smaller growth.

3. The calcium, magnesium, and nitrogen contents of the soybean plants decreased with the age of the plants.

4. There was very little change in the sulfur content of the soybean plants during the growth of the plants or from the influence of fertilizers or soil type differences.

5. The results of these experiments suggest a tendency for the phosphorus content of the soybean plants to increase during the latter half of the growing period.

6. The potassium content of the plants was very irregular, but the variations were small.

7. The effects of the fertilizer treatments upon the composition of the soybean plants were small.

8. Fertilizer treatments were more effective in changing the composition of the soybean plants grown on Coloma sand than on the other soil types.

9. The composition of the soybean plants grown on Coloma sand was changed by the application of magnesic lime as follows:

(1) Thirty-five days after seeding there was an increase in the magnesium and a decrease in the ash, calcium, nitrogen and phosphorus contents of the plants.

(2) Seventy-three days after seeding there was an increase in the magnesium and a decrease in the nitrogen content of the plants.

(3) One hundred nine days after seeding there was an increase in the magnesium, nitrogen and sulfur, and a decrease in the ash and calcium contents of the plants.

10. Fertilizer treatments were less effective in changing the composition of the plants on Miami loam than on the other soil types.

11. The Brookston clay loam produced plants had the highest magnesium content (1.08%), one of the highest nitrogen contents (4.81%) and one of the lowest calcium (2.16%) and ash (9.72%) contents 35 days after seeding, among the plants without fertilizer treatment.

12. Hillsdale sandy loam and Coloma sand produced plants had the highest ash (10.70% and 10.12%) and calcium (2.70% and 2.79%) contents, and the lowest magnesium (0.58% and 0.69%) and nitrogen (4.41% and 4.17%) contents of the unfertilized plants 35 days after seeding.

13. The phosphorus content of the unfertilized soybean plants varied from 0.46% in the plants on Brookston clay loam to 0.23% in the plants on Hillsdale sandy loam.

14. The Brookston clay loam produced plants had the lowest calcium content (1.79%), the highest magnesium content (1.08%), and one of the highest ash (10.61%) and nitrogen (3.46%) contents of the unfertilized soybean plants 73 days after seeding.

15. The phosphorus content of the unfertilized soybean plants 73 days after seeding varied from 0.24% and 0.28% in the plants on Miami loam and Hillsdale sandy loam to 0.40% in the plants on Coloma sand.

16. For the unfertilized soybean plants 110 days after seeding the plants on Brookston clay loam had the highest ash (8.56%) and magnesium (0.79%) contents, the plants on Coloma sand had the highest calcium (2.11%) and phosphorus (0.46%) contents, and the plants on Kewanee loam had the highest nitrogen (3.52%) content.

17. The Miami loam produced plants contained the lowest per cent ash (6.29%), calcium (1.29%), sulfur (0.22%), phosphorus (0.28%) and potassium (0.53%), and one of the highest per cent nitrogen (3.27%) of the soybean plants on the unfertilized plots 110 days after seeding.

18. All treatments on Fox sandy loam increased the nitrogen content of the plants.

19. The phosphorus and potassium contents of the cell sap of the soybean plants were increased by the application of phosphorus and potassium.

20. The phosphorus, potassium and calcium contents of the cell sap of the soybean plants were affected by the type of soil upon which they grew.

21. The soil type upon which the soybeans grew was a greater factor in determining the composition of the soybean plants than was the application of moderate amounts of fertilizers.

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