THE EFFECT OF SOIL TYPE UPON THE CALCIUM AND MAGNESIUM CONTENT AND OTHER PHYSIOLOGICAL CHARACTERS OF SEVERAL IMPORTANT LEGUMES

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A CRITICAL STUDY OF THE INFLUENCE OF SOIL TYPE ON THE CALCIUM AND MAGNESIUM CONTENT AND OTHER PHYSIOLOGICAL CHARACTERS OF THE ALFALFA PLANT[1]

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Alfalfa is so important in the rations of all classes of farm animals, and its use in the maintenance and improvement of soil fertility has become so extensive that some knowledge, both of the degree to which its composition is variable and of the effect of soil differences upon its composition, is of unquestioned value.

Up to the present time considerable work has shown that a number of plants vary in composition when grown under different soil conditions and when given different fertilizer treatments. One of the important phases of this work has been in connection with the effect of different soil conditions upon the composition of the expressed juice of the plants.

It was to obtain information of the foregoing nature, in regard not only to the alfalfa plant but to several of the other important legumes, that this study was undertaken. This paper includes data showing the variations in the calcium and magnesium content of alfalfa stems and leaves, and likewise of their expressed juices, at different ages when grown on different soil types. In addition to these it contains data bearing on other relationships of the alfalfa plant and soil type.

HISTORICAL

McCool (14) has shown that the addition of fertilizers to soils under field conditions causes a measurable increase in the concentration of the expressed sap of corn plants, of sugar beets, of table beets, and of onions, and to a less extent of table carrots. These data also showed that there was nearly as much variation among the concentrations of the sap of young corn plants grown on different soil types, as there was among those grown on fertilized and unfertilized plots. The addition of fertilizers as noted by Austin (2) altered the composition of soybeans. The greatest effect was on Coloma sand and the least on Miami loam. But it was also observed that soil type was of greater

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influence in determining the composition of the soybean plants than was the application of fertilizers. McCool and Weldon (16) observed that the addition of fertilizers caused no evident increase in the amounts of calcium and magnesium present in the juice of wheat grown on Hillsdale sandy loam, but that the application of lime alone gave greater amounts of calcium present in the expressed juice. It was concluded by these authors that the application of the various nutrients to the soil generally resulted in an increase of these elements in the plant juice. Experiments carried out by Morse (19) seem to indicate less CaO in the plant tissue of clover, on a dry basis, grown on limed soils than on unlimed. On the other hand, Bryan (3) found that the calcium content of the tissue of alfalfa, alsike clover, and red clover grown in sand cultures was higher when the reaction of the nutrient solution was higher. McCool (15), states that the composition of the roots and tops of alfalfa varies according to soil fertility, stage of development, and varieties grown. It was concluded by Gilbert and Hardin (7) that the amounts of mineral elements in plant solutions were closely correlated with the amounts of these added in fertilizers.

Dinsmore (6) found, as alfalfa advanced in growth, a rather wide fluctuation in total ash content, although the tendency was to decrease as the plants became more mature. This was borne out by Widstoe (23), who showed also that there was a greater amount of water in the stems than in the leaves of alfalfai n the early stages of growth but that as the plants become older it was nearly the same in the stems and leaves or even greater in the leaves. The dry matter was greater in the leaves in the beginning but toward maturity became much less than in the stems. In second cutting alfalfa, the ash content was found by Widstoe (23) to be lower than that of the first cutting. Austin (2) found the calcium and magnesium content of soybeans to decrease as the plants became older and that the magnesium content was not so uniform as the calcium content. Burd (4) showed that in barley there were probably three periods of growth: one, a preliminary period of about six weeks in which the greatest gain in weight occurred; then a period of about six weeks in which the rate of gain in total weight became negligible; and a third period, continuing until maturity, in which there was an actual loss in weight, not only in the whole plant but in the various parts as well. However, it was observed further that the increase in dry matter followed a fairly straight line throughout the life of the plant and that the increase of calcium and magnesium parallel the formation of dry matter up to the eighth or ninth week, when the increase of these two elements lags behind. There was a decrease in calcium and magnesium in both the stems and the leaves at the time the heads were forming. This last result corroborated the findings of Hornberger (12). Russel (20) notes that magnesium, like phosphorus, finally moves to the seed, and is thus in contrast with calcium and potassium which remain behind in the leaf and straw. According to Hoagland (11) marked absorption of all the nutrient elements in sand and water cultures took place at all periods up to the final stage of growth. Whiting and Richmond (22) report that the calcium and magnesium content of the tops of the sweet clover plant changed but little during the first season's growth and that there was a ratio of about 3:1 for these elements. However, during the second season's growth the calcium and magnesium content decreased noticeably, there being one-third as much present at the end of the period of growth as at the beginning.

Widstoe (23) gave data to show the proportions of stem to leaves throughout the growing period of alfalfa. In the beginning there was a greater proportion of stems than of leaves—the amounts being 71.48 per cent stems and 28.52 per cent leaves. At maturity the proportion had changed to 35.83 per cent stems, 57.23 per cent leaves, and 6.94 per cent blooms. In the second cutting the proportions at the time buds were beginning to form was 51.03 per cent stems and 48.97 per cent leaves, and at maturity 30.51 per cent stems and 67.02 per cent leaves. Widstoe decided that alfalfa did not start to bloom until the leaves and stems were present in nearly like proportions, varying between 50 to 60 per cent of stalks and 40 to 50 per cent of leaves.

PLAN OF EXPERIMENT

The fundamental object of the work undertaken here was to determine what variations may occur in the composition of alfalfa plants grown on different soil types. The deep rooting habit of the alfalfa plant encourages the expectation that soil types do not greatly influence the composition of the plants. Millar (18) showed that the roots of alfalfa are able to obtain food from the substrata if the materials there are available. If alfalfa plants are able to obtain the mineral elements from any portion of the soil profile where the supply is abundant, there should be little variation in the composition of plants grown on different soil types because of the feeding range.

The results here reported are based on studies which were conducted during the growing season of 1928, beginning as soon as alfalfa had attained sufficient size for sampling. The first samples were taken on May 8 and thereafter at two-week intervals until June 7. After this date samples were collected when the plants had reached fall bloom, the date of which varied considerably on the different soil types. The samples taken on June 7 were just beginning to show buds. Three samples were obtained from the second growth of alfalfa, the first being taken on July 24 and the last at the full bloom stage. Thus the data obtained would not only show variations due to soil type, but would also give the variations at different stages of growth. Separate analyses were made of the leaves and stems and of the expressed juice of leaves and stems.

Alfalfa growing on the following soil types was used: Coloma loamy sand, Plainfield loamy sand, Hillsdale sandy loam, Fox sandy loam, Conover loam, Brookston loam (heavy), and Miami silt loam.

The alfalfa used in this study was of the Grimm variety, all the fields being located in Ingham County, five of them within 12 miles of East Lansing and the remaining two, on Brookston and Fox soil, at distances of 17 and 25 miles respectively.

EXPERIMENTAL PROCEDURE

All alfalfa samples were gathered between 8 and 10 a.m. on clear days, as McCool and Millar (17) had found that the freezing point lowerings indicated variations in the plant material at different hours of the day. The samples were placed immediately in a saturated atmosphere and brought to the laboratory in this condition.

As soon as possible after getting the samples to the laboratory, the leaves and stems were separated and 10-gm. samples of each were weighed out for total analysis and moisture determination. The remaining material was pressed to furnish the juice for analysis.

The juice was expressed from all samples at seven tons pressure per square inch, a constant pressure being necessary, as previous workers (8, 10, 13, 17) have shown that the concentration of the expressed juice varies according to the pressure applied and the previous treatment of the plant material. The specific gravity of the juice was determined and portions of about 10 gm. were then weighed out into porcelain crucibles for ashing. The juice thus obtained, along with the plant material weighed out as stated before, was ashed in a muffle furnace at dull red heat, taken up in five normal hydrochloric acid, and made up to 100 cc. The calcium determinations were made by the usual official volumetric method, 25-cc. aliquots being used for each determination. Twentieth normal $KMnO_4$ was used to permit greater accuracy, and all results reported are averages of closely agreeing duplicates. The magnesium determinations were made by the volumetric method of Handy (9); the filtrates from the calcium determinations being carefully obtained for this purpose. Twentieth normal KOH was used as the alkali and the averages of closely agreeing duplicates only are reported in this paper. No difficulties were experienced in these determinations as long as the described methods were adhered to and great care was observed in washing and drying filtrates.

EXPERIMENTAL RESULTS

Calcium content of first growth alfalfa stems and leaves

Calcium is such an important element in animal metabolism and its deficiency in a ration is followed by such objectionable effects that some knowledge of the variations which may occur in the calcium content of alfalfa is desirable, especially in the compounding of rations for poultry and swine.

The calcium content of alfalfa stems grown on different soil types and analyzed at different growth stages is given in table 1. According to these data there was a noticeable and consistent variation in the calcium content of the alfalfa grown on the different soil types throughout the growth period. More calcium was found in the stems of plants taken from the heavy soil types than from the lighter types at each stage of growth except that of full bloom, July 2, where the calcium content dropped on Brookston and Miami soils. The loam soils, Hillsdale and Fox, gave stems with the highest calcium content throughout the period of growth.

Generally a higher percentage of calcium was present in the stems at maturity than at the early stage of growth and the increase was quite uniform on all the types. With the exception of the stems of the plants grown on Coloma loamy sand, a decrease in the calcium content occurred after the plants reached the budding stage, or on June 7, and this decrease was greater in the stems obtained from the very heavy soils.

The calcium content of alfalfa leaves as percentage of dry material is also given in table 1. Much greater variation was evident in the amounts of calcium

TABLE 1

Calcium content of first growth alfalfa stems and leaves at different stages of growth when grown on different soil types*

SOIL TYPE	STAGES OF GROWTH							
	Very young May 8		May 22		June 7		July 2	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.770	1.103	0.777	0.826	0.782	2.140	0.767	2.522
Coloma	0.897	1.211	0.842	1.683	0.885	1.695	0.913	2.930
Hillsdale	0.850	1.182	1.051	2.120	1.025	2.339	0.911	4.060
Fox	0.956	1.571	0.993	1.737	1.172	3.108	1.167	4.020
Conover	0.949	1.353	.....	1.710	1.404	3.830	Not obtained	
Brookston	0.946	1.161	1.283	1.748	1.183	2.568	0.864	2.250
Miami	0.915	1.468	1.070	1.917	1.561	2.148	0.972	2.610

* Dry basis.

present in the leaves of alfalfa grown on different soil types than was found for alfalfa stems.

Throughout the period of growth, the calcium content was highest in the leaves grown on the soils of medium texture as compared with the very light or the very heavy soils.

The calcium content of alfalfa leaves increased uniformly as the plants became older and the percentage of calcium at full bloom was from two to nearly four times as great as in the very young leaves. The leaves grown on Brookston loam soil were the only ones to show a decrease in calcium after the budding stage, and the increase in the leaves obtained from Miami soil was small. These facts, and those noted in the case of the stems where the decrease after the budding stage was greater on these two heavy soils, may be explained by the fact that in these plants there was an adjustment made between the calcium present and some other cation as potassium, which did not occur in the plants obtained from the lighter soils.

The calcium content of alfalfa leaves was greater than that found for stems of the same plants. In the very young plants, this difference in calcium content of the leaves and stems was slight, but at maturity it was much greater, there being nearly four times as much calcium in the leaves as in the stems.

The data on the percentage of calcium present in the expressed juice of alfalfa stems grown on different soil types are given in table 2. It is apparent that there were differences in the calcium content of the juice obtained from stems of plants grown on the different soil types, although they are not consistent throughout the growing period. Generally the calcium content was low in the juice of stems grown on the very sandy soils and high on the sandy loams and the loams.

TABLE 2

Calcium content of expressed juice of first growth alfalfa stems and leaves at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH							
	May 8		May 22		June 7		July 2	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.133	0.175	0.060	0.185	.....	0.332	0.074	0.389
Coloma	0.133	0.275	0.068	0.227	0.095	0.262	0.145	0.618
Hillsdale	0.086	0.247	0.088	0.287	0.106	0.415	0.177	0.754
Fox	0.111	0.219	0.092	0.316	0.144	0.564	0.154	0.903
Conover	0.123	0.237	0.082	0.240	0.193	0.623	Not obtained	
Brookston	0.147	0.244	0.133	0.297	0.167	0.439	0.125	0.408
Miami	0.092	0.210	0.104	0.255	0.165	0.502	0.196	0.713

Although no uniform increase occurred in the percentage of calcium in the juice of alfalfa stems, there was a general tendency for the concentration to be higher in the juice of the mature stems than in that of the young stems. The plants obtained from Plainfield and Brookston soils were the only exceptions. The plants obtained from Brookston soil likewise were the only ones which showed a depression of calcium in the expressed juice of the stems after the budding stage, due again perhaps to the balance between the cations noted before. The period of greatest depression occurred on all of the soil types, with the exception of Hillsdale and Miami soils, at the time the second sampling was made (May 22). Although these exceptions cannot be explained, this depression at this time was probably due to a greater moisture content in the stems, a fact which will be brought out in subsequent data.

The calcium content of the expressed juice of alfalfa leaves grown on different soil types is given in table 2, along with the similar data relative to the juice of the stems. Large differences existed in the concentration of calcium in the juice obtained from leaves grown on different soil types, although the differences were not especially great in the juice of the young leaves.

The greatest concentrations of calcium appear to have been present in the juice of leaves grown on the heavy soil types, although that of the juice of leaves grown on Brookston loam was quite low. As usual, greater percentages of calcium were present in the juice of the leaves grown on Fox and Conover sandy loams than on either the very light or the very heavy soils.

A rather uniform increase in calcium content occurred in the juice of leaves as the plants became older and there does not appear to have been any stage of growth where a general depression occurred. However, the increase in concentration was small on May 22 on nearly all of the soil types and on some there was a depression of calcium in the juice of the leaves at this time. These

TABLE 3

Magnesium content of first growth alfalfa stems and leaves at different stages of growth on different soil types*

SOIL TYPE	STAGE OF GROWTH							
	May 8		May 22		June 27		July 2	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.247	0.256	0.313	0.285	0.184	0.258	0.156	0.337
Coloma	0.268	0.224	0.256	0.309	0.228	0.199	0.220	0.321
Hillsdale	0.231	0.226	0.400	0.244	0.240	0.241	0.238	0.330
Fox	0.396	0.268	0.366	0.297	0.369	0.397	0.325	0.587
Conover	0.414	0.313	0.495	0.250	0.484	0.444	Not obtained	
Brookston	0.319	0.241	0.388	0.203	0.325	0.263	0.174	0.263
Miami	0.336	0.265	0.346	0.284	0.432	0.262	0.211	0.298

* Dry basis.

conditions were probably due to the greater moisture content of the leaves at this stage of growth. Without exception, the concentration of calcium was greater in the juice of mature leaves than in that of the young leaves.

The percentage of calcium in the expressed juice of alfalfa leaves was higher than that of the juice of alfalfa stems. In the young plants, the concentration of calcium in the juice of leaves was about twice as great as in the juice of stems, but as the plants became older the difference became greater until at maturity the concentration of calcium in the juice of the leaves was five or six times that in the juice of the stems.

About one-fifth as great a percentage of calcium was present throughout the period of growth in the juice of alfalfa leaves as in the tissue of leaves. The increase in concentration of calcium in the juice was accompanied by a similar increase of calcium in the tissue of the leaves.

Magnesium content of first growth alfalfa stems and leaves

Although probably of less importance than calcium from the nutritional standpoint, magnesium is an important constituent of all plant materials and a knowledge of variations in the amounts present in plants at different times in the growth period and as affected by soil type is undoubtedly valuable.

The magnesium content in percentage of dry material present in the stems of first growth alfalfa on different soil types is given in table 3. It is evident that throughout the growth period there was considerable difference in the amount of magnesium present in the stems grown on the various types of soil. During the entire growth period the heavier soil types gave stems containing noticeably greater amounts of magnesium than did the light soils, although as the plants became older this influence of soil texture became less marked. Higher magnesium content was always evident in the stems grown on the sandy loam soils, Fox and Conover, than in the stems grown on either the very heavy or the very light soils.

A depression of greater or less magnitude occurred in the magnesium content of stems grown on all of the soil types after the budding stage. On some of the soil types, as Coloma, Plainfield, and Brookston, the decrease of magnesium in the stems may be almost uniform from the early stage of growth to maturity. With but one exception the percentage of magnesium was lower in the mature stems than in the very young stems samples on May 8.

The magnesium content of alfalfa stems was much lower than the calcium content throughout the period of growth. Although the amount of magnesium varied very uniformly with that of calcium, it did not parallel the amount of the calcium, at times rising and falling independently of it.

Table 3 likewise contains data showing the magnesium content of first crop alfalfa leaves at several stages of growth on different soil types. Variations appeared in the percentages of magnesium in the leaves grown on the different soil types, but until the plants approached maturity the differences were not great. At no time during the period of growth could the influence of soil texture be discerned except insofar as the leaves from plants grown on Fox and Conover sandy loams were generally somewhat higher than those produced on the other soil types. Usually the magnesium content was as high in the leaves grown on sandy soils as that of the leaves obtained from heavy soils.

The amount of magnesium increased in the leaves of alfalfa on all the types as the period of growth advanced. This increase was more evident in the leaves grown on loamy sands and sandy loams than in those grown on the heavier loam soils, and on only one type was this increase uniform from first to last. Thus periods of depression were noted on all soil types except Fox sandy loam at one or another of the periods of sampling.

The magnesium content of alfalfa leaves was about equal to that of alfalfa stems at each stage of growth on all the soil types. A deviation from this occurred at the mature stage when the percentage of magnesium in the leaves became greater than that in the stems, partly by because of the increase in the leaves after the budding stage and partly because of the decrease or depression noted in the stems at the same time.

The magnesium content of alfalfa leaves was always much lower than the calcium content. The proportion of magnesium to calcium was about 1:5 in the very young plants and increased to about 1:8 at maturity. This increase in the magnesium-calcium ratio was not noted for stems; the ratio remaining about 1:4 throughout the entire growth period.

Table 4 shows the percentages of magnesium present in the expressed juice of first growth alfalfa stems grown on different soil types. The influence of soil type was evident throughout the growing period of the plant, but at no stage of growth was there any evidence that the texture of the soil was related

TABLE 4

Magnesium content of expressed juice of first growth alfalfa stems and leaves at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH							
	May 8		May 22		June 7		July 2	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield............	0.084	0.075	0.038	0.038	0.026	0.052	0.045	0.076
Coloma..............	0.053	0.079	0.038	0.043	0.036	.....	0.068	0.096
Hillsdale.............	0.038	0.056	0.045	0.052	0.050	.....	0.067	0.088
Fox.................	0.047	0.060	0.052	0.064	0.048	0.072	0.081	0.115
Conover.............	0.034	0.053	0.055	0.064	0.076	0.076	.....	.....
Brookston............	0.064	0.078	0.060	0.052	0.060	0.062	0.052	0.067
Miami...............	0.041	0.051	0.052	0.050	0.062	0.062	0.084	0.088

to the concentration of magnesium in the juice of the stems except the fact that at the two intermediate growth stages the concentration was least in the stems grown on Plainfield and Coloma loamy sands.

Except on Plainfield loamy sand and Brookston loam, the concentration of magnesium in the juice of alfalfa stems was greater at maturity than at the early part of the growth period. On some of the types, as Hillsdale sandy loam, Conover sandy loam, and Miami silt loam, the increase in the concentration of the juice of stems was uniform from first to last; on the other types there was a depression in the amount of magnesium present in the juice of the stems at one of the stages of growth succeeding the first.

There was a smaller amount of magnesium in the juice of alfalfa stems than there was calcium and the ratio remained about 1:2 or 1:3 throughout the period of growth. The soil type which gave a high calcium content in the juice of stems likewise gave a high magnesium content, and the fluctuations during the growing period occurred somewhat nearly at the same time for both calcium and magnesium.

The magnesium content of the juice of alfalfa leaves grown on the different soils is also given in table 4. That variations in the concentration of the juice of leaves grown on different soil types occurred, is quite evident and they continued throughout the growth of the plant. In the very young plants there appeared to be no influence of soil texture but as the plants became older those grown on the heavy soils, and especially those grown on the sandy loams, showed a higher magnesium content in the juice of their leaves than did those grown on the light sandy soils. At the stage of full bloom little effect of soil texture on the magnesium content of the juice was evident. At this time Fox sandy loam gave leaves with a considerably greater amount of magnesium in their juice than did any others, and the sandy soils were about equal to the heavy soils in this respect.

TABLE 5

Calcium content of second growth alfalfa stems and leaves at different stage of growth on different soil types*

SOIL TYPE	STAGE OF GROWTH					
	July 24		August 7		Full bloom	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	1.198	1.289	1.261	1.598	.....	.....
Coloma	1.170	.....	1.044	1.895	1.092	3.690
Hillsdale	1.125	1.618	1.038	2.080	1.060	2.19†
Fox	2.047	1.787	1.047	2.065	0.932	2.550
Conover	1.410	2.020	1.249	2.388	0.900	3.955
Brookston	1.337	1.874	1.158	3.432	0.991	2.680
Miami	1.347	1.792	.....	.....	0.864	2.950

* Dry basis.

† Half bloom.

Greater amounts of magnesium were present in the juice of mature alfalfa leaves than in immature ones, though the difference was very small. On all of the soil types studied, except the sandy loams, there was a depression in the concentration of magnesium in the juice of alfalfa leaves on May 22. This depression, which corresponds to the depression noted for the calcium content at this stage of growth, was most noticeable on the sandy soils.

The magnesium content of the juice of alfalfa leaves was but slightly higher at any time than that of the stem juice. The relative concentrations remained about the same during the growing period so that at no time was the concentration of the juice of one much different from that of the other.

Much smaller amounts of magnesium than of calcium were present in the juice of first growth alfalfa leaves. The proportion of magnesium to calcium was less in the young plants, about 1:4, but increased as the plants become older until it was about 1:7, or even wider.

Calcium and magnesium content of second growth alfalfa stems and leaves and in their expressed juices

The analysis of second growth alfalfa showed that the calcium and magnesium contents of the tissue and of the juice of both stems and leaves corresponded quite closely to those found in the first crop. Some disagreements were found, however, which are worthy of note.

More calcium was present throughout the growth period, and a more rapid and more general decrease occurred in the percentage of calcium, as the period of growth advanced, in the second crop stems (table 5) than in the first crop stems.

TABLE 6

Calcium content of expressed juice of second growth alfalfa stems and leaves at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH					
	July 24		August 7		Full bloom	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.104	0.204	0.075	0.198	.....	.....
Coloma	0.122	0.174	0.084	0.243	0.202	0.892
Hillsdale	0.106	0.200	0.094	0.280	0.108	0.364*
Fox	0.106	0.247	0.112	0.345	0.168	0.668
Conover	0.134	0.295	0.127	0.403	.....	.....
Brookston	0.128	0.290	0.130	0.430	0.170	0.678
Miami	0.115	0.245	.....	.....	0.157	0.708

* Half bloom.

Greater amounts of calcium appeared in the leaves of the second crop (table 5) when the plants were young than occurred in those of the first crop, but the increase of calcium from early growth to maturity was slower in the second growth leaves, resulting in a lower content at full bloom than was observed in the first crop leaves. The least increase of calcium with advancing age occurred in the leaves of plants obtained from the soil types which had given up the greatest amounts of calcium to the first crop.

From table 6 it is evident that similar amounts of calcium were present in the expressed juice of both stems and leaves of the two crops throughout the growing period.

Soil type produced variations in the calcium content of the second crop which were similar in magnitude to those produced in the first crop but the influence of soil texture was much less evident and became practically negligible toward the close of the growth period, perhaps because of an equalizing of the supply of calcium in the nutrient medium.

Tables 7 and 8 show that only the following differences occurred in the magnesium content of the second crop in comparison with that of the first crop of alfalfa.

TABLE 7

Magnesium content of second growth alfalfa stems and leaves at different stages of growth on different soil types*

SOIL TYPES (INCREASING TEXTURES)	DATE OF SAMPLING					
	July 24		August 7		Full bloom	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	.....	0.446	0.300	0.374	.....	.....
Coloma	0.690	.....	0.322	0.311	0.408	0.489
Hillsdale	0.578	0.583	0.292	0.490	0.348	0.393†
Fox	0.648	0.535	0.184	0.310	0.310	0.366
Conover	0.760	0.539	0.537	0.502	0.501	0.741
Brookston	0.537	0.523	0.351	0.381	0.246	0.381
Miami	0.798	0.470	.....	.....	0.360	0.489

* Dry basis.
† Half bloom.

TABLE 8

Magnesium content of expressed juice of second growth alfalfa stems and leaves at different stages of growth on different soil types

SOIL TYPES (INCREASING TEXTURES)	DATE OF SAMPLING					
	July 24		August 7		Full bloom	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.093	0.088	0.048	0.072	.....	.....
Coloma	0.079	0.081	0.045	0.064	0.129	0.134
Hillsdale	0.088	0.088	0.069	0.088	0.076	0.086*
Fox	0.084	0.096	0.048	0.074	0.084	0.122
Conover	0.112	0.105	0.105	0.093	.....	.....
Brookston	0.096	0.091	0.086	0.098	0.103	0.110
Miami	0.100	0.084	.....	.....	.....	0.144

* Half bloom.

Greater amounts of magnesium were present in the tissue and in the juice of both stems and leaves of the second growth than occurred in the first growth.

A more rapid decrease took place in the magnesium content of the tissue of second growth stems than in that of the first growth stems as the period of growth advanced. In the juice of the stems of the second crop a smaller increase of concentration of magnesium occurred than was found in the juice of the first growth stems.

A tendency was apparent for the magnesium content of the tissue of second crop leaves to decrease with advancing age in contrast to the general tendency for it to increase in the tissue of first growth leaves.

Soil texture was less marked in its influence upon the magnesium content of the second crop of alfalfa than upon that of the first crop. In the second growth the Fox soil appeared to have lost its ability to produce alfalfa containing the large amounts of calcium and magnesium which were observed in the plants obtained from that soil during the first growth period.

Calcium and magnesium content of the plant tissue of alfalfa stems and leaves free of all sap

The quantity of any substance found in moisture-free plant tissue consists of the amount of this substance present in the woody tissue plus the amount originally present in the juice of the plant and left in the tissue upon drying. In order to determine the amount of any substance which makes up a part of the structural tissue of the plant it is necessary to separate from this the amount contained in the juice of the green plant material.

Attempts have been made by some workers (5, 20) to extract separately material of the vacuole portion of plant cells and the material contained in the protoplasm. The methods used were chemical, as the application of extreme mechanical methods was considered to break open the cell wall and allow the escape of some of the protoplasmic material.

In the work presented here the woody plant tissue is considered to consist of cell walls only. Any material in solution or suspension in the vacuole or protoplasmic material is not considered as incorporated in the structural tissue of the plant. Because of this, the total material expressed under rather high pressure, as seven tons per square inch, is assumed to represent the plant substance other than that of the woody tissue, although there is considerable controversy on this point among a number of workers (8, 9, 12).

If the amount of a substance present in the green material of the plant and the amount in the liquid portion of the plant material (represented here by the content in the expressed juice of the plant) are known, the amount of the substance in the woody tissue can be found as the difference of these two. This procedure is represented by the following equation for the determination of a substance A:

$$A \text{ in woody tissue} = \text{per cent } A \text{ in green plant material} - \text{per cent } A \text{ in juice} \times \text{grams juice per grams green material.}$$

The data necessary in the use of this equation consist of the percentage of the substance sought in the green tissue of the plant, the percentage of the substance in the expressed juice of the green material, and the exact moisture content of the green material. The moisture content of the plant equals, with but slight error, the total amount of plant juice which could be extracted if it were possible to press the material so greatly that it would be moisture free.

Results obtained from the use of the above formula are incorporated in tables 9 to 12 inclusive. The moisture content of the materials is presented subsequently in table 13.

The amounts of calcium in the woody tissue of first growth alfalfa stems and leaves when the plants were very young and also when they were at full bloom are given in table 9. A much smaller amount of calcium was present in the woody tissue of young alfalfa stems than in that of old ones. This indicates that during the period of growth a certain amount of calcium was being added to the tissue. The amounts of calcium deposited in the tissue of the stems after the plants were sampled on May 8 until they were in full

TABLE 9

Relative amounts of calcium present in the woody tissue of first growth alfalfa stems and leaves in early growth and at maturity

When grown on different soil types

SOIL TYPE	EARLY STAGE, MAY 8				MATURE STAGE					
	Mgm. Ca per gm. green material		Mgm. Ca in tissue of 1 gm. green material		Mgm. in gm. green material		Mgm. Ca in tissue of 1 gm. green material		Amount added after May 8, mgm. per gm.	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
Plainfield	1.14	2.06	0.003	0.634	2.00	5.78	1.50	0.297	1.497	−0.337
Coloma	1.60	2.75	0.500	0.619	2.40	6.97	1.33	0.150	0.830	−0.469
Hillsdale	1.38	2.50	0.664	0.551	2.38	9.11	1.31	0.327	0.646	−0.224
Fox	1.56	3.47	0.627	0.177	2.56	9.76	1.21	0.294	0.583	0.117
Brookston	1.84	2.64	0.655	0.075	2.00	6.00	1.03	0.300	0.375	0.225
Miami	1.565	3.24	0.796	0.161	2.64	7.08	1.21	0.190	0.414	0.030

bloom varies from 0.375 mgm. per gram of green material to 1.49 mgm. per gram.

Widely different amounts of calcium were present in the woody tissue of first growth alfalfa stems grown on the different soil types. Stems grown on Plainfield soil contained in their woody tissue when very young, only 0.003 mgm. of calcium per gram, whereas those grown on Miami soil contained in their woody tissue 0.796 mgm. per gram. At maturity the stems grown on Plainfield soil contained 1.50 mgm. calcium per gram in their woody tissue and those grown on Brookston soil contained only 1.03 mgm. per gram. Consequently it appears that the texture of the soil influenced the amount of calcium deposited in the woody tissue, that of stems grown on heavy soil types containing more calcium when very young than that of stems grown on light soils, and the woody tissue of stems grown on heavy soils containing less at full bloom than that of stems grown on light soils.

There was a much greater amount of calcium deposited in the woody tissue of stems grown on the sandy soils during the period of growth following the first sampling. These data indicate that at no time during the period of growth was calcium actually removed from the woody tissue of the stems, as may have been interpreted from the analysis of the dry material (table 1).

The data in table 9 show that noticeable differences existed in the amounts of calcium deposited in the woody tissue of the first growth leaves from the different soil types both in the early stage of growth and at full bloom. Greater amounts of calcium were present in the woody tissue of the leaves grown on heavy soils when the leaves were young. As the period of growth advanced, however, calcium was removed from the woody tissue of leaves grown on the ligher soils whereas calcium was deposited in the tissue of leaves grown on heavier soils, with the result that the amount of calcium in the woody tissue of

TABLE 10

The relative amounts of magnesium in the woody tissue of first growth alfalfa stems and leaves at early growth and at maturity

When grown on different soil types

SOIL TYPE	EARLY STAGE, MAY 8				MATURE STAGE					
	Mgm. Mg per gm. green material		Mgm. in tissue of 1 gm. green material		Mgm. Mg per gm. green material		Mgm. Mg. in tissue of 1 gm. green material		Amount Mg added after May 8	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
Plainfield	.....	0.48	.....	....	.....	0.77	.....	0.16	.....	....
Coloma	0.480	0.50	0.040	....	0.476	0.77	0.073	0.04	0.033	....
Hillsdale	0.384	0.48	0.066	0.03	0.624	0.74	0.128	0.06	0.062	0.03
Fox	0.648	0.60	0.249	0.13	0.720	1.44	0.085	0.58	0.164	0.45
Brookston	0.624	0.55	0.106	....	0.408	0.69	0.003	0.18	0.103	....
Miami	0.576	0.60	0.236	0.21	0.576	0.81	0.117	0.17	0.119	−0.04

leaves grown on ligher soils was less at full bloom than in that of leaves grown on the heavier soils, except in the case of Miami soil.

Smaller amounts of calcium were present in the woody tissue of alfalfa leaves of the first crop at both stages of growth studied than was the case with the stems. Also less calcium was deposited in the woody tissue of the leaves than of the stems during the period of growth. Apparently there was a translocation of calcium from the leaves of alfalfa grown on the light sandy soils.

In table 10 are given the relative amounts of magnesium in the woody tissue of the stems and of the leaves of first growth alfalfa at early growth and at full bloom. Much smaller amounts of magnesium than of calcium were present in the woody tissue of stems at any time, and it appears that at least in stems grown on heavy soil types there was a removal of a portion of the magnesium as the plants advanced in age.

The amount of magnesium in the woody tissue of the alfalfa leaves was usually about equal to the amount of calcium present, and in some cases the amount was even greater. Although the data are incomplete it appears that only small amounts of magnesium were deposited in the woody tissue of leaves in the latter portion of the growth period and some may even have been

TABLE 11

Relative amounts of calcium in the woody tissue of second growth alfalfa stems and leaves in early growth and in full bloom

When grown on different soil types

SOIL TYPES	EARLY STAGE				FULL BLOOM					
	Mgm. Ca in gm. green material		Mgm. Ca in actual tissue		Mgm. Ca in gm. green material		Mgm. Ca in actual tissue		Amount Ca added after July 24	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
Plainfield	1.90	3.03	1.03	1.49	....	....	....	....	....	....
Coloma	1.38	....	0.21	....	3.34	7.38	1.94	1.06	1.73	....
Hillsdale	1.58	2.95	0.66	1.32	....	....	....	....	....	....
Fox	1.83	3.52	0.92	1.54	3.02	7.94	1.88	3.35	0.96	....
Conover	1.95	4.10	0.80	1.76	....	....	....	....	....	....
Brookston	2.26	4.08	1.21	1.82	3.18	7.58	2.02	2.73	0.82	0.92
Miami	1.88	3.60	0.89	1.65	2.79	8.26	1.67	3.17	0.78	1.52

TABLE 12

Relative amounts of magnesium in the woody tissue of second growth alfalfa stems and leaves in early growth and in full bloom

When grown on different soil types

SOIL TYPE	EARLY GROWTH				FULL BLOOM					
	Mgm. Mg in gm. green material		Mgm. Mg in tissue of 1 gm. green material		Mgm. Mg. in 1 gm. green material		Mgm. Mg in tissue of 1 gm. green material		Mgm. Mg added after July 24	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
Plainfield	....	1.05	....	0.38	....	....	....	....	....	....
Coloma	0.81	....	0.04	....	1.83	1.68	0.94	0.72	0.90	....
Hillsdale	0.81	1.01	0.05	0.29	....	....	....	....	....	....
Fox	0.91	1.05	0.19	0.28	1.94	1.86	1.37	1.92	1.18	1.64
Conover	1.05	1.08	0.08	0.25	....	....	....	....	....	....
Brookston	0.91	1.03	0.13	0.32	1.92	1.69	1.23	0.90	1.10	0.58
Miami	1.15	0.96	0.29	0.30	1.89	1.37	1.05	0.34	0.76	0.04

removed. Apparently soil texture influenced the amount of magnesium deposited in the tissue at the early stage of growth, when there was more in the stems and leaves grown on heavy soil types.

Data showing the amounts of calcium in the woody tissue of second growth alfalfa stems and leaves are given in table 11. In the case of stems, soil texture did not appear to influence the amount of calcium in the woody tissue but it did influence the amounts that were added during the final stages of growth, greater amounts being added to the stems grown on light soil types.

About equal amounts of calcium were present in the stems of first and second growth alfalfa when very young, but in the more mature plants the amount became greater in the second crop stems, and greater amounts were added during the growth period. Noticeably greater amounts of calcium were present in the woody tissue of second crop leaves during the entire growth period, and greater amounts were deposited in the tissue during the life of the plant.

TABLE 13

Moisture content of first and second growth alfalfa stems at different stages of growth and on different soil types

Per cent on dry basis

DATE OF SAMPLINGS	SOIL TYPE						
	Coloma	Plainfield	Hillsdale	Fox	Conover	Brookston	Miami
First growth							
May 8	82.10	85.35	83.85	83.73	83.75	80.55	82.90
May 22	86.95	97.75	86.35	86.70	85.95	83.95	86.15
June 7	83.20	81.85	84.00	81.80	79.85	79.70	82.25
July 2	73.90	73.85	73.85	77.90	.....	76.85	72.80
Second growth							
July 24	88.20	84.15	86.90	86.05	86.10	82.05	86.05
August 7	82.90	84.80	77.85	75.25	77.25	74.75	.....
Full bloom	69.40	.....	.....	67.60	.....	67.90	68.37

Greater amounts of calcium were present in the woody tissue of second growth alfalfa leaves than in that of the stems. This is the reverse of what was found for alfalfa of the first crop.

Table 12 includes data showing the amounts of magnesium in the woody tissue of second growth alfalfa stems and leaves. Greater amounts of magnesium were present in the leaves of the young plants, but more was deposited in the tissue of the stems as the plants became older, resulting in a greater quantity in the woody tissue of the stems at full bloom. Magnesium was added to the woody tissue of both stems and leaves in every instance.

More magnesium was found in the woody tissue of the stems of the second crop at full bloom than in that of the first crop stems. In the young plants, however, there was little difference in the amounts present in the two crops and a remarkable agreement is evident in the data of tables 10 and 12 relative to this early growth.

Greater amounts of magnesium were present in the woody tissue of second growth leaves than in that of first growth leaves throughout the growth period, and more magnesium was deposited in second crop leaves as the plants became older.

Smaller amounts of magnesium and of calcium were always present in the woody tissue of both stems and leaves of the second crop of alfalfa than in that of the stems and leaves of the first crop.

Relationship of soil type to additional characteristics of the alfalfa plant

Great uniformity is shown in the moisture contents of alfalfa stems and leaves grown on the different soil types by the data presented in table 13.

TABLE 14

Moisture content of first and second growth alfalfa leaves at different stages of growth and on different soil types

Per cent on dry basis

DATE OF SAMPLINGS	SOIL TYPE						
	Coloma	Plainfield	Hillsdale	Fox	Conover	Brookston	Miami
First growth							
May 8	77.03	81.26	78.75	77.62	78.57	77.15	77.75
May 22	79.73	82.30	79.05	79.10	79.60	76.95	76.40
June 7	78.40	81.40	78.15	77.65	77.35	76.25	77.10
July 2	75.95	76.85	77.45	75.45	.....	73.60	72.70
Second growth							
July 24	82.20	76.35	81.70	80.30	79.85	78.20	79.55
August 7	80.75	79.45	78.45	74.95	78.05	75.45	.....
Full bloom	72.00	.....	.....	68.85	.....	71.65	72.05

Although the moisture content of stems and leaves grown on Plainfield soil was usually the greatest and that of stems and leaves grown on Brookston soil was usually lowest, the differences between the two were not great at any stage of growth. Although it is recognized that there were not large differences in the moisture contents of the stems and leaves grown on the several soil types, yet some interesting variations which appear to be related to soil type differences, will be pointed out in the following discussion.

Greater percentages of moisture were present in the stems than in the leaves of alfalfa when the plants were young. The moisture content of both stems and leaves decreased as the plants became older, it being noticeably less at full bloom than in the very young materials. An increase in moisture was noted on almost every soil type for both stems and leaves at the sampling made on May 22. After this date the decrease in moisture content was quite uniform on all of the soil types.

The moisture content of the stems grown on the different soil types was about equal when the plants were very young; but there was a greater decrease in the amount of moisture in the stems grown on the light soils as the season advanced, resulting in a generally lower moisture content at full bloom in these as compared with the stems grown on the heavy soils.

Contrary to what was found for the stems of alfalfa, the decrease of moisture in the leaves as the growth period advanced was slower on the sandy soils than on the heavy soils. This resulted not only in the fact that the moisture content was higher in the leaves on sandy soils at the full bloom stage but also in the fact that the leaves on sandy soils decreased slowly enough in moisture that they contained more than did the stems at the full bloom stage. This

TABLE 15

Specific gravity of expressed juice of first growth alfalfa stems and leaves at different stages of growth

Specific gravity of distilled water = 1.000

SOIL TYPE	STAGE OF GROWTH					
	May 22*		June 6		July 2	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
Plainfield	1.023	1.035	1.026	1.041	1.031	1.046
Coloma	1.023	1.037	1.029	1.044	1.028	1.054
Hillsdale	1.020	1.041	1.030	1.046	1.032	1.056
Conover	1.026	1.046	1.034	1.054	.....	.....
Fox	1.031	1.046	1.034	1.052	1.032	1.060
Brookston	1.032	1.048	1.040	1.052	1.034	1.054
Miami	1.030	1.047	1.034	1.052	1.038	1.058

* Data not obtained for first sampling.

was not true of leaves grown on the heavy soil types, whose moisture contents were always lower than those of the stems.

Noticeably greater amounts of moisture were present in the second growth alfalfa plants (table 14) than were present in those of the first growth when the plants were very young. But at the full bloom stage the amount of moisture was greater in the first growth alfalfa plants. There appeared to be no relationship between soil type and the moisture content in the second growth alfalfa. Although Brookston stems were still lowest in moisture, Plainfield stems and leaves were no longer highest.

Much greater amounts of moisture were present in the stems of young second growth alfalfa than were present in the leaves. A much greater decrease took place, however, in the moisture content of the stems during the growth period than occurred with the leaves and, as a result, the moisture content at full bloom was greatest in the leaves on all the types studied.

The specific gravity of the expressed juice of first growth alfalfa stems and leaves at different stages of growth, and its relationship to soil types

The specific gravities of the expressed juice of first growth alfalfa stems and leaves at different stages of growth are shown in table 15. Here it is evident that the specific gravity was much greater for the juice of alfalfa leaves than it was for that of stems at all stages of growth.

As the alfalfa plants became older, the specific gravity of the expressed juice of the leaves increased in an almost arithmetical progression on all of the soil types studied. This increase is rapid throughout the period of growth, and agrees rather closely with the increase noted in the calcium and magnesium content of the juice of the leaves.

An increase at early growth was observed in the specific gravity of the juice of alfalfa stems almost identical to that observed for the leaves, but on only

TABLE 16

Specific gravity of expressed juice of second growth alfalfa stems and leaves at different stages of growth and on different soil types

Specific gravity of distilled water = 1.000

SOIL TYPE	STEMS		LEAVES	
	Stage of growth			
	August 7	Maturity	August 7	Maturity
Plainfield	1.026	.....	1.040	.....
Coloma	1.021	1.040	1.036	1.072
Hillsdale	1.028	.....	1.042	.....
Fox	1.028	1.048	1.048	1.082
Conover	1.028	.....	1.045	.....
Brookston	1.030	1.044	1.050	1.068

two soil types was the increase uniform throughout the growth period. On the remaining soil types the specific gravity either increased very slowly to full bloom or decreased more or less rapidly until it was but slightly higher than that observed in the young plants. Any increase or decrease in the specific gravity of the juice of alfalfa stems did not correspond uniformly to similar increases or decreases in the calcium and magnesium content of the juice of stems as given previously, although on three of the soil types, Plainfield, Miami and Brookston, there was an agreement.

Marked differences were found in the specific gravities of the juice from stems and leaves of plants grown on the soils of different texture. Table 15 shows that the specific gravity of the juice of both stems and leaves of plants grown on heavy soils was much higher than that of stems and leaves grown on the light soils. This is in general agreement with the data obtained in regard to the calcium and magnesium content of the juice of the stems and leaves, and it would appear, therefore, that these elements were largely responsible for the specific gravity of the juice. Deviations from this were no doubt due to the presence of other cations which probably varied in amount in the plants grown on the different soil types.

In table 16 is given the specific gravity of the juice of second growth stems and leaves, which was much higher in the full bloom stage than in the case of first crop alfalfa. There was little difference in the values of the two crops when the plants were young, and therefore the increase in specific gravity of the juice as the growth period advanced was much more rapid in second cutting plants. Here, as was found in the first crop, it appears that there was rather a close agreement between the specific gravity of the juice and its calcium and magnesium content, and that these elements were important in determining the specific gravity. This does not lose sight of the fact that other cations were also present, and these may account for the irregularities which were noted.

TABLE 17

Proportion of leaves and stems of alfalfa at budding stage on different soil types

Per cent green material

PART OF PLANT	SOIL TYPE						
	Plainfield	Coloma	Hillsdale	Fox	Conover	Brookston	Miami
Leaves	62.0	59.0	65.4	61.1	59.1	58.0	61.1
Stems	38.0	41.0	34.6	38.9	40.9	42.0	38.9

There appeared to be no relationship between soil texture and the specific gravity of the juice of leaves and stems of second cutting alfalfa.

Proportions of stems and leaves in the alfalfa plant as affected by soil type

Some variations occurred in the proportion of stems and leaves of the alfalfa plants grown on different soil types at the time buds were appearing. Widstoe (23) found that as the period of growth advanced, the percentage of leaves increased. It is noticeable in table 17 that the percentage of leaves was greater on the plants grown on Plainfield, Hillsdale, Fox, and Miami soils, but it is entirely possible that this was due to a more advanced stage of growth on these types; throughout this work, a more luxuriant growth was observed on these soil types and it may be that the budding stage was a few days more advanced than on the other types. Strength is added to this supposition by the fact that the growth was always slowest on Brookston, and here the proportion of leaves was lowest.

Considering these facts, it is probable that there was little difference in the percentages of leaves and stems grown on the different soil types and it is also evident that soil texture did not influence it.

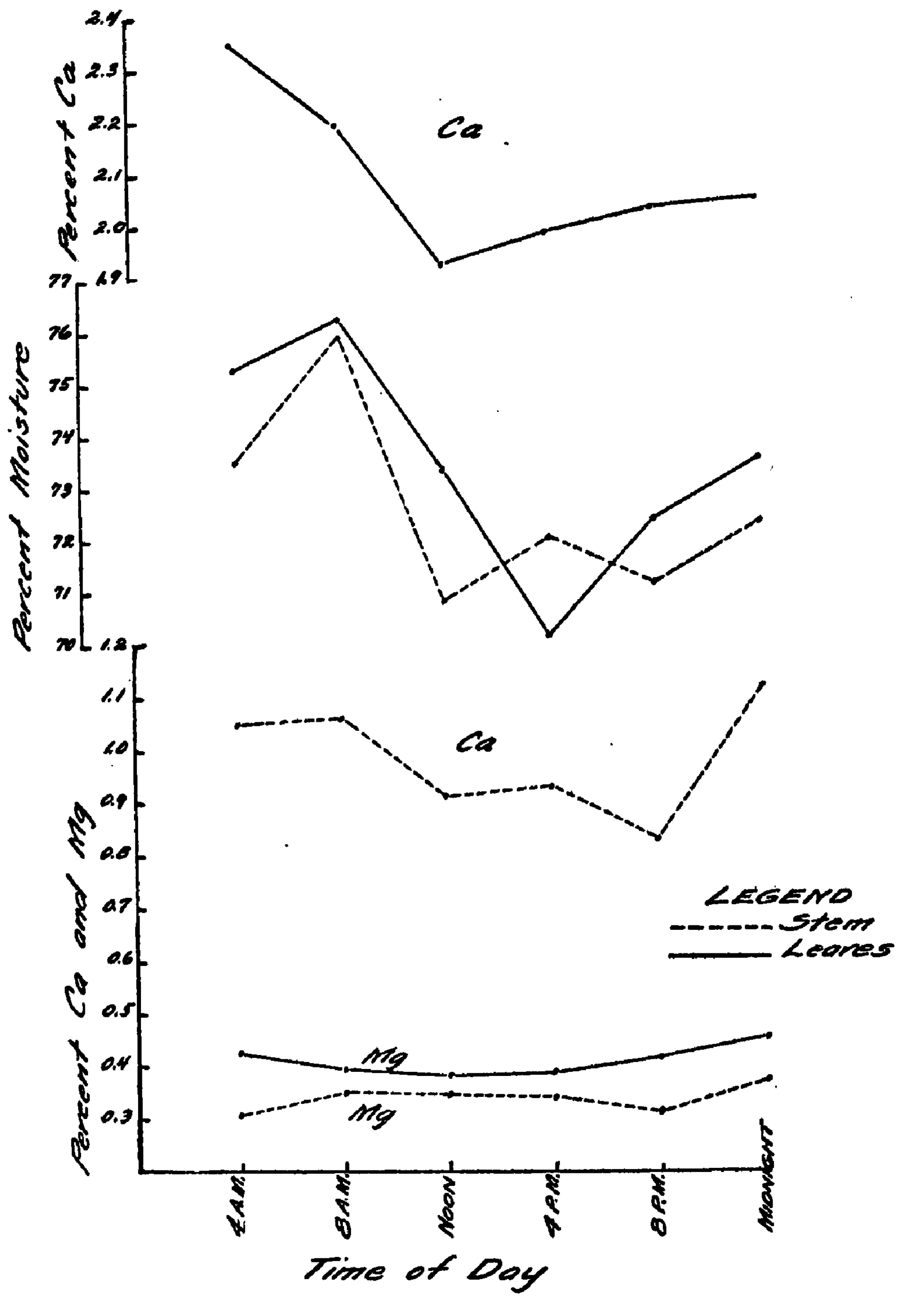

FIG. 1. THE RELATION OF TIME OF DAY TO THE CALCIUM, MAGNESIUM, AND MOISTURE CONTENTS OF ALFALFA STEMS AND LEAVES

Variations in the composition of the alfalfa plant at different hours of the day

Differences in the rate of transpiration and in the physiological activity of the plant occur at different hours of the 24-hour cycle. In order to determine what variations occur in the factors studied in this work, samples of alfalfa grown on Hillsdale sandy loam were taken at 4-hour intervals during the 24-hour day.

That considerable variation occurred in the calcium and magnesium content and in the moisture content of alfalfa stems and leaves at different times of the day is shown by figure 1. These three substances showed a remarkable correlation, a rise or a fall in one being accompanied by almost a proportionate rise or fall in the other two.

In the case of the stems a rather sharp rise in the calcium, magnesium, and moisture content took place in the period of time from 4 until 8 a.m. After 8 o'clock a marked depression occurred and continued until 4 p.m. or even until 8 p.m. During the 4-hour period between 8 p.m. and midnight, there was a sharp rise in the amounts of moisture, calcium, and magnesium present.

The moisture content of the leaves nearly paralleled that of the stems during the 24-hour period, but its relationship to the calcium and magnesium content of the leaves was not so exact as was noted for stems. During the 4-hour period from 4 until 8 a.m. there was an increase in the moisture content but a decrease in the amount of calcium and magnesium. Also during the 4-hour period between noon and 4 p.m. there was a decrease in the moisture content but an increase in the calcium and magnesium content.

At 4 p.m. the lowest moisture content was reached for the leaves and at noon the lowest content of calcium and magnesium was reached. Greater variation in the composition of the leaves took place between 4 a.m. and noon, and the least between noon and 8 p.m.

Variations occurring in the specific gravity and in the calcium and magnesium content of the expressed juice of alfalfa stems and leaves are given in figure 2. For the juice of the stems, the lowest specific gravity occurred at 8 a.m., after which there was a rise until noon and then a constant value maintained until midnight. A decrease in the calcium and magnesium content of the juice also occurred at 8 a.m., followed by a rise lasting until 4 p.m.

Greater variations took place in the specific gravity, the calcium content, and the magnesium content between 8 a.m. and noon than during any other 4-hour period.

Figure 2 also shows variations taking place in the specific gravity and in the calcium and magnesium content of the expressed juice of alfalfa leaves during the 24-hour cycle. Somewhat the same trend was taken by the varying values for the leaves as was observed for the stems, the low points occurring at 8 a.m., followed by increases during the middle of the day.

The greatest variation in specific gravity and in the calcium content occurred from 8 a.m. until noon, followed by a uniform period from noon to

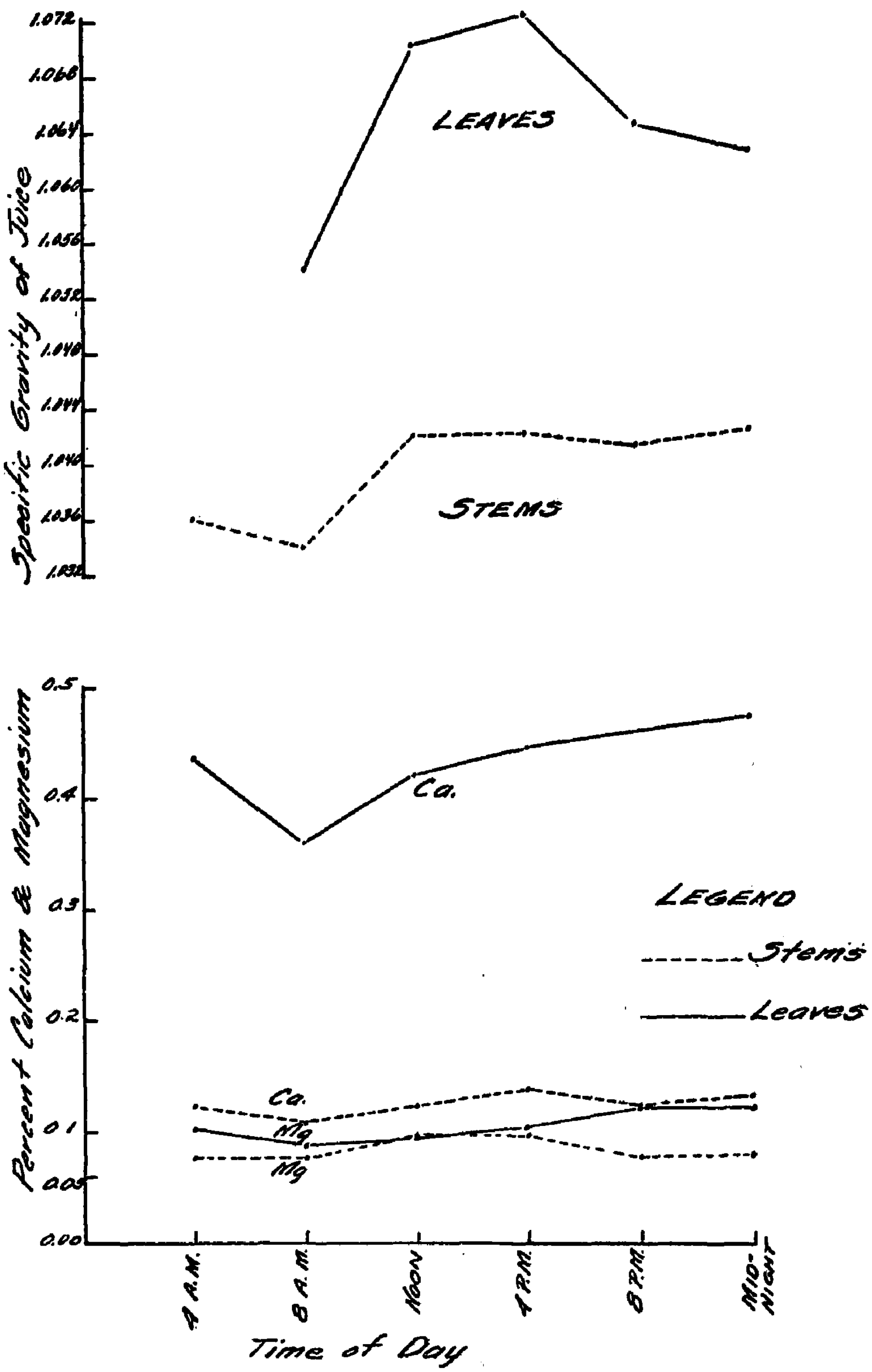

FIG. 2. THE RELATION OF TIME OF DAY TO THE SPECIFIC GRAVITY AND THE CALCIUM AND MAGNESIUM CONTENTS OF THE EXPRESSED JUICE OF ALFALFA STEMS AND LEAVES

4 p.m. The magnesium content was singularly uniform during the entire day in the expressed juice of alfalfa leaves.

The concentration of calcium and magnesium in the juice of stems and leaves varied inversely as the amounts of these present in the tissue at different times of the day. However, the variations in concentration of the juice were accompanied by like changes in the specific gravity and by unlike changes in the amounts of moisture present in the green material. Since it has been established that a large part of the calcium and magnesium present in the tissue is due to that contained in the juice, a reduction in the juice, even though accompanied by an increased concentration, would bring about a decrease of these elements in the tissue. Evidently this is what occurred to cause a decrease of the two elements in the tissue simultaneously with the decrease in moisture.

SUMMARY AND CONCLUSIONS

Alfalfa stems and leaves and the expressed juice of alfalfa stems and leaves grown on seven soil types were analyzed for calcium and magnesium at different stages of growth. The moisture content and the specific gravity of the expressed juice were determined. The proportion of stems and leaves and the effect of time of day on the composition of the alfalfa plant were determined. In addition, the amounts of calcium and magnesium present in the woody tissue of the leaves and stems free of the amounts in the liquid portion of the plants were determined in very young and in mature plants.

There were marked differences in the calcium and magnesium contents of alfalfa stems and leaves, and of their expressed juice in the plants grown on the different soil types. Likewise marked differences were found in the specific gravity of the juice of stems and leaves and slight differences in the amounts of moisture present in them when obtained from the different soil types.

Generally the calcium content was higher in the dry tissue and in the expressed juice of alfalfa stems and leaves grown on the heavy soil types studied. Sandy loams, however, gave a higher calcium content in these than did the heavier loams.

Soil type had less influence on the second crop than on the first and the effect of soil texture became practically negligible in the second crop. It would appear that with the continued growth of the plants, changes which equalized the facilities with which the plants were able to obtain their supply of calcium and magnesium, had occurred in the soils, resulting in a uniformity of composition (in respect to these elements) of the plants from the different soil types.

No consistent relationship appeared to exist at any time between the texture of the soil and the magnesium content of the alfalfa plant.

More calcium was present in the tissue and in the juice of the alfalfa leaves than in the tissue and in the juice of the stems.

About equal amounts of magnesium were present in the tissue of leaves and stems and also in their juice.

More calcium than magnesium was always present in the tissue and the juice of both the stems and the leaves.

There was either an increase or a decrease in the calcium content of the tissue and of the juice of first growth alfalfa stems as the plants became older, but there was only a decrease in the calcium content of the tissue and juice of second growth stems as the plants advanced in age.

The magnesium content of the tissue of first and second growth alfalfa stems decreased as the plants became more mature.

The calcium content increased in the tissue and in the juice of leaves of the first and second crops of alfalfa as the plants grew older.

With the advance of the growth period, the magnesium content increased in the tissue of first growth alfalfa leaves but decreased in the tissue of the leaves of the second growth.

Greater concentrations of magnesium were usually present in the juice of more mature leaves and stems than in that of the young leaves and stems of both the first and second crops.

The calcium content was higher in the stems and in the young leaves of second growth alfalfa than in the first growth. The content of calcium was higher in mature leaves of first crop alfalfa than in the mature leaves of the second growth.

About equal percentages of magnesium were present in the stems and leaves of first and second growth alfalfa and likewise the concentrations of calcium and magnesium were about equal in the juice of stems and leaves of both cuttings of alfalfa.

Large amounts of calcium were deposited in the woody tissue of alfalfa stems as the plants advanced in age, and greater amounts were added to the stem tissue of the second growth than to that of the first growth.

In the first crop of alfalfa, calcium was added to the woody tissue of the leaves on some of the soil types as the growth period advanced, whereas on other soil types it was removed from the woody tissue. In the second crop calcium was always added to the woody tissue of the leaves.

Greater amounts of calcium were usually present in woody tissue of alfalfa stems than in that of the leaves, and more was deposited in the woody tissue of the stems than in that of the leaves as the period of growth advanced.

Soil type influenced the amount of calcium in the woody tissue of alfalfa stems and leaves. In the early stage of growth the calcium content was low in the woody tissue of stems grown on light soil and low in the tissue of the leaves grown on heavy soils, whereas at maturity the calcium content of the woody tissue of stems was low on the heavy soils and in that of leaves it was low on the light soils.

Much smaller amounts of magnesium than of calcium were present in the woody tissue of first growth alfalfa stems, whereas the amounts of calcium and magnesium were about equal in the woody tissue of leaves.

In second growth alfalfa, greater amounts of calcium than of magnesium were present in the woody tissue of both stems and leaves.

In first growth alfalfa, the amount of magnesium in the woody tissue of stems and leaves was either decreased or increased as the plants became older. In the second crop it always increased in both stems and leaves.

The amount of magnesium in the woody tissue of stems and leaves of both the first and the second crops of alfalfa varied on the different soil types but it did not appear to depend on soil texture.

Greater amounts of magnesium were present in the woody tissue of stems and leaves of second growth alfalfa than in that of the first crop. It appears that the calcium and magnesium present in the plant material were largely due to that contained in the juice of the plant and not incorporated in the tissue itself.

The moisture content of alfalfa stems and leaves decreased as the plants became more mature.

More moisture was present in the stems than in the leaves of alfalfa when the plants were young but it became about equal, or slightly greater in the leaves, as the plants advanced in age, especially in the second crop.

Greater moisture content occurred in the stems and leaves of the second crop than of the first crop of alfalfa when the plants were young, but when the plants became older there was more present in first growth stems and leaves.

Soil type apparently was related to some changes which occurred in the moisture content of alfalfa as the growth period advanced.

Greater specific gravity was possessed by the expressed juice of alfalfa leaves than of stems.

The specific gravity of the juice of alfalfa stems increased for a period and then usually decreased to maturity. That of the juice of alfalfa leaves increased in an arithmetical progression during the growth period.

The specific gravity of the juice of both stems and leaves was noticeably greater in plants on heavy soil types.

The specific gravity of the juice of second growth alfalfa stems and leaves was much greater than that of the juice of first growth stems and leaves.

The specific gravity of the juice of the stems and leaves of both crops appeared to conform very closely to the calcium and magnesium content, showing that these cations were important in determining it.

The ratio of stems to leaves was about equal on the different soil types at the budding stage.

The calcium, magnesium, and moisture content of alfalfa stems and leaves varied at different hours during the day. This was also true of the calcium and magnesium contents and the specific gravity of the expressed juice of stems and leaves.

The percentages of calcium and magnesium in the tissue of stems and leaves varied almost inversely as the concentration of these in the juice of the stems and leaves at different hours of the day, probably because of differences in the amounts of juice present in the tissue as a result of changes in the moisture content.

The most satisfactory time to obtain alfalfa samples in order to eliminate variations due to time of day lies between noon and 4 p.m. The least satisfactory time lies between 8 a.m. and noon.

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THE RELATIONSHIP OF SOIL TYPE TO THE CALCIUM AND MAGNESIUM CONTENT OF GREEN BEAN STEMS AND LEAVES AND OF THEIR EXPRESSED JUICE[1]

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In a previous paper (9) the influence of soil type upon the calcium and magnesium content of alfalfa was discussed. Data on the relationship of soil type to the calcium and magnesium content of the bean plant are set forth in this paper.

Since beans grow readily under greenhouse conditions, thus permitting of carefully controlled experiments, it was possible not only to determine variations in the composition of the plants with respect to calcium and magnesium but also to study the relationships between certain characteristics of the soils and the calcium and magnesium content of the plants. These data are made a major part of the discussion included herein.

REVIEW OF LITERATURE

Burd (4) showed that the correlation between the amounts of plant-food in uncropped soil and the crop-producing power of the soil is sufficiently great to justify the belief that the amounts are a measure of the soil's crop-producing power. Duley (7) found no very definite correlation between the calcium in the soil solution and the soil's ability to produce crops under field condition. According to Russell (22), Brazeale's work shows that small variations in the concentration of the soil solution are without effect on the growth of plants, but Rothamsted's experiments have shown the growth of crops to vary directly with the concentration of the soil solution.

Since the addition of some fertilizers enriches the soil solution, as explained by Kelley (15), and since several workers (1, 10, 16, 17, 19) have found that the addition of fertilizers influences the composition of plants, it is possible that there is a relationship between the composition of the soil solution and the composition of plants.

Burd (4) asserts that good, uncropped soils may contain considerably more solutes than poor, uncropped soils, but both good and poor soils are reduced to the same low level by growing plants. Hoagland (13) states that from

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neither the water extract nor the freezing point method is there any indication that the soil solution has a constant composition; on the other hand, the soil solution may vary greatly under different conditions and a growing crop markedly diminishes its concentration. The soil solution under conditions favorable to crop growth was found by Hoagland (13) to be very dilute, especially during the height of the growing season. Duley (7) found the calcium content of Colby silt loam to be reduced from 22 to 54 per cent by a crop of clover. Stewart (23) showed that soils under crop always contain smaller amounts of calcium and magnesium than their uncropped duplicates. According to Burd (5), the water extracts of soils on which barley was growing showed variations in the calcium and magnesium content which were related to the content of these in the plants; as there was an increase in the plants, there was a decrease in the water extract. McCool and Millar (18) found that the freezing point lowering of the tops of plants was not very sensitive to changes in the concentration of the soil solution.

Duley (7) concluded there was a closer correlation between the amount of calcium in a soil soluble in 0.04 normal carbonated water and the soil's response to liming than there was between the pH value of the soil and this response.

Fleetwood (8) determined that the amount of calcium soluble in 0.04 normal carbonated water in the 0-7 inch layer of soil was closely related to the returns from application of lime to the soil. Swanson, et al, (24) showed a close correlation between the calcium content of the soil soluble in cold normal hydrochloric acid and the pH value of the soil, provided the soils were all of the same texture. Duley (7) ascertained that in nearly all cases the addition of lime increased the amount of calcium in the soil solution.

Russell (23) states that soils kept in dry conditions increase the amounts of their available plant-foods. Duley (7) found that very acid Kolby silt loam increased the concentration of the calcium in its soil solution when kept in the greenhouse for a number of months.

PLAN OF THE EXPERIMENT

Although primarily intended to show variations which may occur in the calcium and magnesium contents of green bean stems and leaves and in their expressed juice at different stages of growth, when the bean plants are grown on different soil types, the work presented here was planned also to show the effect of crop growth upon the concentration of calcium and magnesium in the soil solution and upon the pH value of the soil and the relationship of these to the composition of the plants. The textures of the soils in relation to the calcium and magnesium contents of the plants were also observed.

The experimental work consisted of growing Robust field beans in 2-gallon crocks containing surface soils of seven different types. Five pots of each soil type were planted with beans. One pot of each soil type was planted to grow 20 bean plants for the first sampling and the remaining four pots to carry 7 plants for the subsequent samplings.

The soil types used in this experiment included Roselawn loamy sand, Plainfield loamy sand, Kewanee sandy loam, Onaway sandy loam (heavy phase), Hillsdale sandy loam, Brookston loam (heavy), and Miami silt loam. The Roselawn was much more alkaline than is typical and the Plainfield had been limed. The Miami was very heavy and appeared to include at least some subsoil material. From the textural standpoint, the soils fell into two distinct groups, the one very light and including the sandy soils, and the other very heavy, consisting of the Brookston and Miami soils.

The analysis was planned to show the amounts of calcium and magnesium present in both the leaves and the stems and likewise in the expressed juice of each of these. The green weights of the stems and leaves were also obtained. The hydrogen-ion concentration of the soils and the amounts of calcium and magnesium present in the soil solutions were determined at each sampling. The soil solution consisted of the displaced liquid portion of the soil.

EXPERIMENTAL PROCEDURE

The experiments were begun in the greenhouse on February 2, 1928, when 35 two-gallon pots were planted to Robust field beans.

The first samples were taken on February 21, as soon as the plants were large enough to furnish enough material for analysis and the second when the plants were 6 weeks old. The third samples were obtained when flower buds had appeared, regardless of the age of the plants; the fourth, when the fruit was setting; and the fifth, when the pods were well filled out but the plant material had not started to wilt. All samples were taken between 8 and 10 a.m. and only on clear days, in order to reduce to the minimum variations due to shading and intensity of transpiration. As the plants were cut from each pot, the leaves and stems were separated, weighed immediately, and placed in a saturated atmosphere to prevent loss of moisture.

In the laboratory the plant parts were cut into very small pieces to allow a more representative sample to be taken. In most of the work, two or three grams of the green material was weighed out for total analysis and the juice extracted from the remainder.

The juice of the green material was obtained by the pressure method described by McCool and Weldon, (19) and at seven tons pressure per square inch. This great pressure was necessary because of the small amount of material available. The expressed juice thus obtained was not centrifuged but was weighed directly into crucibles and ashed along with the green material in a muffle furnace at dull red heat. Especially in the early stages of growth and with the expressed juice, the amount of each sample was so small that some method was required which would give the maximum amount of material for each determination. Therefore, the ashed material was taken up in 5 normal hydrochloric acid and made up to 110 cc. Of this solution, 50-cc. aliquots were used for each determination, allowing that five-elevenths of all the material be done in duplication.

The calcium determinations were made by the official volumetric method and the magnesium by the volumetric method of Handy (11). Twentieth normal $KMmO_4$ and KOH standard solutions respectively were used in each determination and the averages of only closely agreeing duplicates are reported here.

Immediately following the removal of the plants from the pots in the greenhouse, the soil was carefully sieved and portions were taken for the determination of the moisture content, the hydrogen-ion concentration, and the soil solution respectively.

The moisture content of the soil was based upon the weight of the absolutely dry soil obtained by heating in an electric oven at 105°C. for 15 hours.

The hydrogen-ion concentration was determined by the quinhydrone method of Briilman as described by Baver (2).

The suggestions as to technique made by Briilman and Tovborg-Jenson (3) and by Baver (2) were observed.

The soil solutions were obtained by the modified Lipman's direct water pressure method described by Burd and Martin (6) and supported by a number of workers, including Parker (2), Parker and Tidmore (21), and Hubbard (12). One thousand grams of soil was packed into the tubes, covered with 200 cc. of water and the soil solution displaced under pressure, which ranged from 40 to 50 pounds per square inch. The first 10 cc. of soil solution were discarded and the next 30 cc. caught and analyzed by the same method as was used for the first material. The distilled water used for watering the plants and for analytical purposes was obtained by distilling tap water through block tin pipes.

EXPERIMENTAL RESULTS

The data obtained from this experiment consist of those bearing upon the variations in the calcium and magnesium content of the bean plants at different growth stages when grown on different soil types, which show also the relationship of these variations to certain properties of the soils, and also of those related to the influence of the growth of the plants upon certain properties of the soils. Since a knowledge of the latter data is necessary to an understanding of the former, the latter are considered first in the following discussion.

Effect of the growth of beans upon certain characteristics of the soil, and the variations of different soil types in this regard

The marked influence of the growth of beans on the soil solution is shown in tables 1 and 2, where the calcium and magnesium contents, respectively, are given for the growing period of the plants.

Great differences were found to exist in the amounts of calcium present in the various soil solutions before plant growth started. The solutions of Roselawn loamy sand contained more than six times as much calcium as did the solution of Plainfield loamy sand, with the other soils solutions varying in between.

During the growth of the plant the calcium content of the soil solutions was reduced to a low level in which there was little variation. Usually the solutions of the soils which were highest in the beginning remained highest during the growth period.

Smaller amounts of magnesium than of calcium were present in the soil solutions. Although the range of difference in the soil types was small, it is evident that the soil solutions varied in the amounts of magnesium they contained; the soil solutions which were high in calcium generally were likewise high in magnesium.

TABLE 1

Variations in the calcium content of soil solutions growing beans

Parts per million of water-free soil

SOIL TYPE	INITIAL Ca CONTENT	STAGES OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
Plainfield	10.60	12.50	2.68	2.16	5.05	4.00
Kewanee	44.70	24.60	30.40	......	16.10	....
Onaway	24.55	9.71	12.85	.....	.....	3.33
Roselawn	66.80	36.00	37.00	27.80	.....	8.95
Hillsdale	14.62	16.65	31.30	23.00	17.80	3.18
Brookston	19.10	.....	13.05	6.90	.....	3.33
Miami	30.06	26.90	26.62	.....	.....	6.89

TABLE 2

Variations in the magnesium content of soil solutions growing beans

(Parts per million of water-free soil)

SOIL TYPE	INITIAL CONTENT	STAGES OF GROWTH OF BEANS			
		3 weeks	6 weeks	Budding	Fruiting
Plainfield	4.44	3.089	Trace	Trace	0.7488
Kewanee	8.88	3.390	4.086	....	2.784
Onaway	7.45	2.056	1.938	....	Trace
Roselawn	9.84	3.900	3.354	....	1.114
Hillsdale	4.08	2.394	6.384	....	5.548
Brookston	3.48	0.926	1.566	....	1.600
Miami	10.20	5.810	5.352	....	....

No relationship appeared to exist between soil texture and the calcium or magnesium content of the soil solutions. The very sandy soils had either very high or very low calcium and magnesium contents in their solutions and the same was true of the fine textured soils.

The hydrogen-ion concentrations of the soils used are given in table 3, where it may be seen that a wide range of reaction existed, Miami soil being the most acid, with a pH value of 5.0 and Roselawn the most alkaline, with a pH value of 7.8. No appreciable change occurred in the pH value of the soils during the growth period of the plants. The fluctuations appear to have been within the range of the influence of moisture and temperature changes and of biological activities.

Apparently there was no relationship between the pH values of the soils and the amounts of calcium and magnesium in the soil solutions.

Since it developed that the solutions of the soil types used varied in calcium and magnesium, in the order of Roselawn loamy sand, Kewanee sandy loam, Onaway sandy loam, Hillsdale sandy loam, and Plainfield loamy sand for the coarse-textured soils, and of Miami silt loam and Brookston loam for the fine-textured soils, and since the soil types fell into about this same order in respect to the extent that the calcium and magnesium contents of their solutions were maintained during the growth period, throughout the following work the soils will be considered as of decreasing strengths in this same sequence.

TABLE 3

Changes in pH values of soils growing beans

SOIL TYPE	INITIAL VALUE	STAGES OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	pH	*pH*	*pH*	*pH*	*pH*	*pH*
Plainfield	7.35	7.40	7.30	7.17	7.30	7.25
Kewanee	5.10	5.18	5.20	....	5.12	....
Onaway	7.40	7.27	7.36	....	7.37	7.42
Roselawn	7.85	7.87	7.87	7.72	8.00	7.80
Hillsdale	6.25	6.39	6.20	6.37	6.10	6.72
Brookston	7.05	6.94	7.08	6.66	6.75	....
Miami	5.00	5.10	4.60	....	....	5.64

Calcium content of green bean stems and leaves at different growth stages

The calcium content of green bean stems varied on the different soil types throughout the growth period, as is shown in table 4, where the soils are separated into light and heavy groups and then arranged according to decreasing amounts of calcium in their solutions at the beginning of the growth period. It is evident that the higher calcium contents occurred in green bean stems grown on soils with the greater amounts of calcium in their solutions. Some deviations from this appeared but the general tendency was very marked in this regard.

Considering that the calcium content of green bean stems was highest on Roselawn loamy sand and lowest on Plainfield loamy sand during the entire growth period, and that the stems grown on the very heavy soils contained about the same amount of calcium as stems grown on some of the very light soils, it appears that there was no relationship between soil texture and the amount of calcium in the green bean stems.

Similarly, the hydrogen-ion concentration appears to have borne no direct relationship to the amount of calcium in the green bean stems. Although the pH value of the Roselawn soil was highest and the calcium content of stems grown upon it was likewise highest, the pH value of the Plainfield soil was nearly as high, and yet the calcium content of stems grown upon this soil was lowest; Miami silt loam and Kewanee sandy loam had very low pH values and stems grown upon them had calcium contents about equal to the stems grown on soils with higher pH values, as Onaway sandy loam and Hillsdale sandy loam.

Larger percentages of calcium were present in the mature green bean stems than when the stems were young. The increase from early growth to maturity was not uniform and there generally appeared on each type an intermediate period during which little calcium was added to the stems, or during which calcium was actually removed. A large increase of calcium occurred in the stems grown on all soil types for which data were obtained except Brookston clay loam after the fruit had set.

TABLE 4

The effect of soil type on the calcium content of green bean stems at different stages of growth

SOIL TYPE	INITIAL Ca CONTENT OF SOIL SOLUTION	STAGES OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	66.8	0.253	0.4060	0.337	0.380	0.482
Kewanee	44.7	0.187	0 255	.....	0.351	.....
Onaway	24.5	0.202	0.230	.....	0.293	0.399
Hillsdale	14.6	0.243	0.225	0.267	0.263	0.422
Plainfield	10.6	0.162	0.220	0.216	0.234	0.336
Heavy soils						
Miami	30.0	0.207	0.200	.....	.....	0.434
Brookston	19.1	0.197	0.300	0.305	0.344	0.319

In table 5 are given the amounts of calcium present in the green material of bean leaves grown on different soil types. In this table the soils are arranged as in table 4.

The calcium content was much greater in green bean leaves grown on some soil types than in those grown on others. Here again, Roselawn soil generally gave leaves with the highest calcium content and Plainfield soil gave leaves with the lowest, and throughout the period of growth, a marked relationship was evident between the calcium content of the soil solution and that of the plant material. At each stage of growth, the calcium content of the green leaves grown on the different soil types, with few exceptions, varied directly as the decreasing amounts of calcium present in the initial soil solutions.

The calcium content of bean leaves was usually high on the soil types which gave stems with a high calcium content. Because of this, it is evident that there was no correlation between the texture or the pH values of the soils and the calcium content of bean leaves grown upon them.

A marked increase occurred in the calcium content of green bean leaves as the growth period advanced. The greatest increase in calcium occurred when the leaves were between three and six weeks old and between the time the fruit set and maturity. During the intermediate period, the increase in calcium was very slow or the calcium was even depressed. Much greater amounts of calcium were present in the green material of bean leaves than in that of bean stems throughout the growth period. A more rapid increase took place in the calcium content of the leaves than occurred in the stems, resulting in a wider difference between the calcium contents of the two plant parts at maturity.

TABLE 5

Effect of soil type upon calcium content of green bean leaves at different stages of growth

SOIL TYPE	INITIAL Ca CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	66.80	0.316	0.620	0.620	0.586	0.706
Kewanee	44.70	0.361	0.530	.....	0.566	.....
Onaway	24.55	0.360	0.538	.....	0.586	0.731
Hillsdale	14.62	0.266	0.503	0.483	0.421	0.722
Plainfield	10.60	0.249	0.434	0.403	0.411	0.564
Heavy soils						
Miami	30.06	0.448	0.658	0.400	.....	0.686
Brookston	19.10	0.301	0.476	0.450	0.556	0.601

Calcium content of the expressed juice of bean stems and leaves

Variations in the calcium content of the expressed juice of bean stems grown on different soil types are shown in table 6. Very similar differences can be seen in the calcium content of the expressed juice of bean stems as was evident in that of the green material. Generally the concentration of calcium in the juice was high in the stems which contained large amounts of calcium in their green tissue. Thus it follows that a high calcium content in the expressed juice of the bean stems was associated with a high calcium content in the soil solution. Deviations from this appeared on some of the soils at various times during the period of plant growth but still the correlation between the concentration of the calcium in the soil solution and the concentration of calcium in the expressed juice of the stems was plainly very high.

No closer relationship was evident between the texture nor the pH value of the soil and the calcium content of the expressed juice of bean stems than was evident between these and the calcium content of the green material.

In table 7 is given the calcium content of the expressed juice of bean leaves at different stages of growth and on different soil types. Wide variations occurred in the calcium content of the juice of leaves grown on the different

TABLE 6

Effect of soil type upon the calcium content of the expressed juice of bean stems at different stages of growth

SOIL TYPE	INITIAL Ca CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	66.80	0.213	0.217	0232	0.240	0.288
Kewanee	44.70	0.200	0.205	.....	0.217	.....
Onaway	24.55	0.205	0.191	0.235	0.238	.....
Hillsdale	14.62	0.138	0.172	0.191	0.178	0.206
Plainfield	10.60	0.199	0.155	0.138	0.229	0.137
Heavy soils						
Miami	30.06	0.181	0.157	.....	.....	.....
Brookston	19.10	0.127	.....	0.170	.....	0.276

TABLE 7

Effect of soil type upon the calcium content of the expressed juice of bean leaves at different stages of growth

SOIL TYPE	INITIAL Ca CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OE BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per ccnt*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	66.8	0.365	0.529	0.583	0.595	0.635
Kewanee	44.70	0.334	.....	.....	0.599	.....
Onaway	24.55	0.271	0.595	.....	0.598	0.690
Hillsdale	14.62	0.220	0.451	0.433	0.409	0.537
Plainfield	10.60	0.167	0.326	0.313	0.338	0.515
Heavy soils						
Miami	30.60	0.368	0.555	.....	.....	0.558
Brookston	19.10	0.189	0.348	0.413	.....	0.531

soil types throughout the period of growth. The relationship of the concentration of calcium in the soil solution to that of the expressed juice was less evident here than in the cases heretofore observed, although it still appears that the concentration of calcium in the plant juice was high where the concentration of calcium in the soil solution was high. The calcium contents of the expressed juice of the leaves grown on Roselawn, Kewanee, and Onaway soils were very nearly equal regardless of marked differences in the amounts of calcium in the soil solutions.

Since there were marked similarities in the calcium contents of the juice of leaves grown on several of the soil types differing widely in texture and in hydrogen-ion concentration, it appears that there was no relationship between either the pH value or the texture of the soils and the calcium content of the juice of the bean leaves grown upon them.

In the juice of both stems and leaves there was an increase in the calcium content as the plants became more mature. The increase was more uniform in the juice of leaves than in that of the stems and it was much more rapid, so that in the mature stage there was a wide difference in the concentration of calcium in the juice of the two plant parts, there being more than twice as much in the juice of the leaves as in that of the stems.

TABLE 8

Effect of soil type upon the magnesium content of green bean stems at different stages of growth

SOIL TYPE	INITIAL Mg CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	9.84	0.044	0.029	0.052	0.083	0.0700
Kewanee	8.88	0.054	0.016	.....	0.026	......
Onaway	7.45	0.037	0.072	.....	0.079	0.0570
Plainfield	4.44	0.034	0.056	0.066	0.048	0.0792
Hillsdale	4.08	0.042	0.016	0.061	0.052	0.0570
Heavy soils						
Miami	10.20	0.058	0.064	.....	.....	0.0260
Brookston	3.48	0.062	0.061	0.100	0.086	0.0260

Magnesium content of green bean stems and leaves

The influence of soil types on the magnesium contents of green bean stems at different growth stages, is given in table 8, where the soil types are divided into light and heavy soils and then grouped according to decreasing amounts of magnesium in their solutions.

The magnesium content of green bean stems fluctuated greatly during the growing period on each of the soil types. Although noticeable differences occurred in the amounts of magnesium present in the green material at each stage of growth on the different soil types, there evidently was no relationship between the magnesium content and either the amount of magnesium present in the soil solution or the pH value of the soils as described earlier. However, it does appear that the magnesium content was higher in the stems of plants grown on the two heavy soil types than in those of the plants grown on the light soil types. This last relationship did not hold when the plants had reached maturity.

On the light soil types there was more magnesium present in the green bean stems when the plants had reached maturity than when they were young, but during the intermediate growth stages a high point was always reached in which the magnesium content was greater than in the mature stage. On the heavy soil types the magnesium content of the stems was always lower at maturity then in the early stages of growth.

Much less magnesium than calcium was present in the green material of bean stems throughout the period of growth and the amount present fluctuated much more than the calcium.

A somewhat more uniform amount of magnesium was present in the green material of bean leaves than in that of the stems, as is evident in table 9.

TABLE 9

Effect of soil type upon the magnesium content of green bean leaves at different stages of growth

SOIL TYPE	INITIAL Mg CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	9.84	0.058	0.077	0.096	0.193	0.114
Kewanee	8.88	0.060	0.066	.....	0.075	.....
Onaway	7.45	0.068	0.077	.....	0.083	0.140
Plainfield	4.44	0.079	0.118	0.096	0.079	0.083
Hillsdale	4.08	0.055	0.105	0.083	0.075	0.105
Heavy soils						
Miami	10.02	0.082	0.099	.....	.....	0.079
Brookston	3.48	0.060	0.105	0.123	0.092	0.123

Greater amounts of magnesium were present at each stage of growth in the green material of leaves grown on some soil types than on others. Generally, in the early growth stages at least, there was more magnesium present in the leaves grown on soils with lower magnesium contents in their solutions. This was especially noticeable on the two heavy soils though this difference here might have been due to the low pH value of the Miami soil, a possibility which is supported by the fact that the plants grown on Kewanee soil also gave leaves with a low magnesium content. Further than this, no relationship appeared to exist between the characteristics of the soils and the magnesium content of the bean leaves.

Greater amounts of magnesium were present in the green bean leaves at maturity than when they were 3 weeks old in all plants except those grown on Miami soil. The increase of magnesium from early growth to maturity was generally not uniform. More magnesium was present in the leaves than in the stems at all stages of growth and the rate of increase was somewhat faster. Much less magnesium than calcium was present in the leaves of beans throughout the growth period.

Magnesium content of the expressed juice of bean stems and leaves

In tables 10 and 11 are given the percentages of magnesium present in the expressed juice of bean stems and leaves at different stages of growth and on different soil types. Great fluctuation in the magnesium content was characteristic of the juice of both the stems and leaves of plants grown on different soil types and it appears that soil texture, the pH value of the soil, and the concentration of magnesium in the soil solution had no controlling influence on the concentration of magnesium in the plant juice.

TABLE 10

Effect of soil type upon the magnesium content of the expressed juice of bean stems at different stages of growth

SOIL TYPE	INITIAL Mg CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	9.84	0.041	0.031	0.067	.....	0.105
Kewanee	8.88	0.053	0.036	.....	0.048	.....
Onaway	7.45	0.043	0.035	.....	.....	0.115
Plainfield	4.44	0.037	0.055	0.050	0.099	0.155
Hillsdale	4.08	0.045	0.050	0.064	0.040	0.076
Heavy soils						
Miami	10.20	0.046	0.066	.....	.....	.....
Brookston	3.48	.....	.....	0.087	.....	0.060

Greater concentrations of magnesium were usually present in the juice of both stems and leaves as the plants advanced in age. On many of the soil types this increase of concentration of magnesium in the juice was quite uniform and it also was of considerable magnitude.

Magnesium was about equally concentrated in the juice of the stems and leaves throughout the growth period. This is in contrast with the concentration of calcium in the two plant parts, which was greater in the juice of the leaves than in that of the stems and which also increased much more rapidly in the juice of the leaves.

Total green plant material produced on the different soil types

The green plant material produced on each soil type at the various periods of growth is given in grams in table 12 and the corresponding proportion of stems and leaves in per cent is given in table 13.

TABLE 11

Effect of soil type upon the magnesium content of the expressed juice of bean leaves at different stages of growth

SOIL TYPE	INITIAL Mg CONTENT OF SOIL SOLUTION	STAGE OF GROWTH OF BEANS				
		3 weeks	6 weeks	Budding	Fruiting	Maturity
	p.p.m.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Roselawn	9.84	0.037	0.070	0.073	.....	0.098
Kewanee	8.88	0.024	.....	.....	0.031	.....
Onaway	7.45	0.057	0.088	.....	.....	0.109
Plainfield	4.44	0.052	0.061	0.091	0.076	0.042
Hillsdale	4.08	0.052	0.084	0.086	.....	0.088
Heavy soils						
Miami	10.20	0.057	0.122	.....	.....	0.075
Brookston	3.48	0.023	0.071	0.103	.....	0.105

TABLE 12

Green weight of beans at different stages of growth on different soil types

(Weight of 7 plants in grams)

SOIL TYPE	STAGE OF GROWTH OF BEANS				
	3 weeks	6 weeks	Budding	Fruiting	Maturity
Plainfield	9.94	32.5	33.25	42.0	40.0
Kewanee	10.20	16.0	.....	38.0	....
Onaway	10.50	19.8	.....	38.0	38.0
Roselawn	9.80	16.1	41.00	43.0	56.0
Hillsdale	12.88	26.0	45.50	46.5	55.0
Brookston	11.20	19.5	29.00	31.0	22.5
Miami	10.29	16.5	.....	....	23.5

TABLE 13

Proportions of leaves and stems of beans at different stages of growth on different soil types

SOIL TYPE	STATE OF GROWTH OF BEANS									
	3 weeks		6 weeks		Budding		Fruiting		Maturity	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	47.3	52.7	38.4	61.6	39.8	60.2	30.8	69.2	32.1	67.9
Kewanee	....	....	34.4	65.6	....	....	34.2	65.7	....	....
Onaway	45.0	55.0	35.8	64.2	....	....	36.0	64.0	31.6	68.4
Roselawn	43.0	57.0	33.0	67.0	35.3	64.7	36.0	64.0	28.5	71.5
Hillsdale	43.8	56.2	55.4	44.6	38.5	61.5	37.9	62.1	31.8	68.2
Brookston	47.7	52.3	35.8	64.2	34.5	65.5	32.2	67.9	35.5	64.5
Miami	47.4	52.6	39.3	60.7	....	....	....	....	36.1	63.9

Considerably better growth was made on some of the soil types than on others. The growth was usually light on the very heavy soils and also on the very acid soils and apparently was independent of the amount of calcium and magnesium present in the soil solutions. There is no evidence that there was any relationship between the rate of growth and the calcium or magnesium content of the plant material.

Proportion of stems and leaves of the bean plant

Some variance occurred in the proportions of stems and leaves produced on the different soil types at each stage of growth but it was small and does not appear to depend on the rate of growth nor upon the characteristics of the soil which are considered here. The proportion of stems is less than that of leaves during the entire period of growth. At the beginning of growth, the difference in the proportions was small, averaging 45.7 per cent stems and 54.3 per cent leaves. The proportion of leaves increased as the growth period advanced, with the result that at maturity the proportions were 32.6 per cent of stems and 67.4 per cent of leaves.

A comparison of calcium and magnesium contents of cropped and uncropped soils

Depressions in the amount of calcium and magnesium in the soil solutions, as was observed in this work, may not have been entirely due to the growth of the crop. To check this point, two series of pots containing Plainfield and Hillsdale soils were left fallow and sampled at the same time that two other series, containing the same soils, but growing beans, were analyzed. The results obtained are given in table 14. Here it will be seen that there were fluctuations in the amounts of calcium and magnesium present in the soil solutions of both the cropped and uncropped soils, but the general tendency was for the concentration of the elements in the solutions to decrease on the cropped soils and to hold about constant on the uncropped soils.

Power of soils to rebuild their solutions when air-dry

The noticeable reduction in the concentration of the soil solution due to the growth of plants (9, 23) indicates that during a period of rest soils must be able to rebuild their solutions in order for plant growth to be possible year after year. In the work presented here, two soils previously depleted in the greenhouse, were allowed to rest for 82 days and their solutions obtained and analyzed. The data obtained are given in table 15 where it will be seen that in the case of calcium, both Plainfield and Hillsdale soils were able to rebuild their solutions above what they were before crop growth started. These soils were held as air-dry under greenhouse conditions.

The magnesium content of the soil solutions was likewise rebuilt during the period of rest and attained a level higher than that possessed before the beginning of plant growth. Since the calcium content is reduced on Hillsdale to a lower level that on Plainfield, by the growing crop and yet after the rest period has rebuilt its solution to contain more than three times as much calcium, it would appear that Hillsdale has more ability to rebuild its solution than has Plainfield.

Although this result is in agreement with that of Duley (7), this increase of solutes in the soil solution might perhaps be attributed to the wetting and drying of the soil. It is a question as to whether a soil maintained in the dry condition can actually increase the amount of solutes available for solution. Unfortunately this question did not present itself until too late to obtain data bearing upon it.

TABLE 14

Calcium and magnesium content of cropped and uncropped soils

Parts per million of moisture-free soil

SOIL TYPE	CALCIUM				MAGNESIUM			
	Initial content	Stage of growth			Initial content	Stage of growth		
		10 days	24 days	35 days		10 days	24 days	35 days
Plainfield cropped	17.87	8.51	1.44	1.74	6.67	2.12	9.16	1.46
Plainfield uncropped	17.81	11.91	16.30	11.15	6.67	4.99	1.57	8.73
Hillsdale cropped	38.15	32.80	12.86	4.04	12.02	11.50	1.22	0.80
Hillsdale uncropped	38.15	45.80	39.90	50.30	12.02	11.34	9.57	9.62

TABLE 15

Power of soils to rebuild their solution when dry

SOIL TYPE	CALCIUM			MAGNESIUM		
	At start of growth period	At end of growth period	After resting 82 days	At start of growth period	At end of growth period	After resting 82 days
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Plainfield	10.60	4.00	11.58	4.44	0.7488	6.783
Hillsdale	14.62	3.18	35.48	4.08	1.7100	10.996

SUMMARY AND CONCLUSIONS

In this work the effect of crop growth upon the calcium and magnesium content of the soil solutions and upon the pH value of the soils was observed, as were also the relationships between these characteristics of the soils and the calcium and magnesium content of the plants. Variations occurring in the calcium and magnesium contents of green bean stems and leaves and in their expressed juice when obtained from plants of different ages grown on a number of soil types were studied. The relationship of soil texture to the foregoing characteristics of the plants was noted.

Widely different amounts of calcium and magnesium were found present in the various soil solutions before plant growth began but they were greatly reduced by the growing plants and were almost equal at the end of the growth period. The soil solutions with the highest concentrations of calcium and magnesium at the beginning of the growth period generally maintained a higher concentration during the growing period.

Insignificant variations appeared in the pH values of the different soils as the growth period advanced but they did not appear to result from the growth of the plants.

No relationship appeared to exist between the calcium and magnesium content of the soil solutions and either the pH value or the texture of the soils.

Marked variations were found in the amounts of calcium and magnesium present in the green tissue and in the juice of both stems and leaves of bean plants grown on the different soil types.

An increase generally occurred in the calcium and magnesium contents of the tissue and of the juice of stems and leaves as the growth period advanced. Some minor exceptions occurred.

The calcium content was always greater than the magnesium content. The calcium and magnesium contents of the leaf tissue were always greater than those of the stem tissue. The calcium content of the juice of leaves was always greater than that of the juice of stems but the magnesium content of the juice was sometimes greater in the stems and sometimes greater in the leaves.

Greater increases in the calcium and magnesium contents of the tissue and juice of stems and leaves generally occurred in early growth and near maturity than during the intermediate stages of growth.

A very decided correlation appeared to exist between the calcium content of the tissue and juice of both stems and leaves and that of the soil solution. A high calcium content in the soil solution was associated with a high calcium content in the plants when the soils were of similar texture.

No correlation appeared to exist between the calcium content of the plants as studied and either the texture or the pH value of the soil.

The variations in the magnesium content of the plants were so inconsistent that no correlations could be drawn between them and the magnesium content of the soil solutions, the textures of the soils, or their pH values.

There appeared to be no relationship between the rate of growth and either the calcium or the magnesium content of the plants.

There were slight variations in the proportions of stems and leaves on different soil types and they did not appear to depend on any of the properties of the soils studied. The proportion of leaves was always greater than that of stems and the ratio became wider as the period of growth advanced.

The calcium and magnesium in the soil solutions were greatly reduced in the soils growing plants, as compared with the solutions of the uncropped duplicate soils.

Plainfield and Hillsdale soils were able greatly to rebuild the calcium and magnesium contents of their solutions when kept air-dry in the greenhouse for 82 days. The Hillsdale soil surpassed the Plainfield in this respect.

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VARIATIONS IN THE CALCIUM AND MAGNESIUM CONTENTS OF PEA PLANTS ON DIFFERENT SOIL TYPES[1]

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Two previous papers (2, 3) contained data showing variations in the calcium and magnesium contents of alfalfa and bean plants when grown on different soil types, and also showing the relationship of these to some properties of the soils. The material presented here is of the same nature in regard to the pea plant and completes the material dealing with the effect of soil type upon certain of the characteristics of three important legumes.

Because of their wide range of adaptability, field peas constitute one of the leading sources of legume forage, and likewise one of the important leguminous crops used widely in farm rotations looking to the maintenance of soil fertility. Because of these facts any information related to variations in the composition of field peas, and causes inducing them, has a practical significance.

A rather comprehensive review of the work which has been done relative to the discussion taken up here was given in the aforesaid papers on alfalfa and beans, obviating any need for such review in this paper. Likewise the plan of the experiment was the same as that followed for beans (3) and the experimental methods were the same as reported in the other two papers. These exceptions should be noted however, that Roselawn soil was not included in the work with peas, reducing the number of soils to six, and also that the period of growth of the peas was prolonged so greatly, probably because of abnormal photoperiodism, that three stages of growth were obtained before budding and no samples were taken at the stage when the fruit was setting on. The variety of peas used was Scotch green field peas.

As in the case of the work reported on beans, a knowledge of the effect of plant growth on the soil characteristics studied here is necessary to an understanding of the other material. For this reason a discussion of these data will be given first.

EFFECT OF GROWTH OF PEAS UPON CALCIUM AND MAGNESIUM CONTENTS OF SOIL SOLUTIONS AND UPON pH VALUES OF SOILS

Very much the same effect upon the calcium and magnesium contents of the soil solution was produced by the growing pea plants, shown in tables 1 and 2,

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[2] The writer wishes to express his appreciation to Dr. M. M. McCool for his kindly interest and suggestions in the execution of this work.

as was found in the case of growing bean plants (3). Although it is evident that before growth started the amounts of calcium and magnesium present in the several soil solutions varied greatly, by the time the pea plants had reached the mature stage the amounts had been reduced until there was but little difference among the soil types. However, the reduction in the concentration of the two elements in the solutions was not rapid and was very uniform, the soil types maintaining the same order with respect to each other during most

TABLE 1

Variations in calcium content of soil solutions growing peas

Parts per million of water-free soil

SOIL TYPE	INITIAL CONTENT	STAGES OF GROWTH		
		Content at 3 weeks	Content at 6 weeks	Content at maturity
Plainfield	10.60	2.99	4.85	3.02
Kewanee	44.70	38.80	21.00	1.60
Onaway	24.55	20.95	.....	1.93
Hillsdale	14.62	12.81	7.00	1.92
Brookston	19.10	8.22	10.12	5.10
Miami	30.06	23.35	18.50	3.13

TABLE 2

Variations in magnesium content of soil solutions growing peas

Parts per million of water-free soil

SOIL TYPE	INITIAL CONTENT	STAGES OF GROWTH			
		Content at 3 weeks	Content at 6 weeks	Content at 8 weeks	Content at maturity
Plainfield	4.44	3.18	Trace	0.66	1.90
Kewanee	8.88	4.55	4.99	1.87	Trace
Onaway	7.45	5.11	....	1.33	1.55
Hillsdale	4.08	2.39	0.98	2.52	1.71
Brookston	3.48	0.92	Trace	Trace	Trace
Miami	10.2	5.81	1.11	2.05	1.61

of the growth period. It appears that pea plants reduced the calcium content of the soil solution less rapidly, but to a greater degree, than had been found for bean plants, although the effect of the two crops on the magnesium content of the soil solutions was found to be about the same. It thus appears from tables 1 and 2 that in point of concentration of calcium and magnesium in their solution the soils may be considered as decreasing in the order of Kewanee, Onaway, Hillsdale, and Plainfield for the light soils, and of Miami and Brookston for the heavy soils.

CHANGES INDUCED IN THE HYDROGEN-ION CONCENTRATION OF THE SOILS BY THE GROWTH OF PEA PLANTS

The hydrogen-ion concentration of the soils, represented by the pH values in table 3, appears to have fluctuated considerably during the growth period of the plants. Rather larger variations appeared than can be attributed to other contributory causes, and it is evident that the pH values of the strongly acid soils were raised whereas those of the alkaline or neutral soils were decreased by the growing plants. This was not found true for beans (3) but appears to be in order with the work reported by Arrhenius (1). However, throughout the growth period the soils maintained their relative positions in respect to their hydrogen-ion concentrations and can be considered as in the order given in table 3, where they are grouped into light and heavy soils.

TABLE 3

Effect of growth of peas on the pH value of the soil

SOIL TYPE	INITIAL VALUE	STAGES OF GROWTH				
		Value at 3 weeks	Value at 6 weeks	Value at 8 weeks	Value at budding	Value at maturity
	pH	*pH*	*pH*	*pH*	*pH*	*pH*
Onaway	7.40	7.15	....	7.50	7.14	7.17
Plainfield	7.35	7.69	7.40	7.37	6.99	6.95
Hillsdale	6.25	6.12	6.18	6.64	6.50	5.96
Kewanee	5.10	5.11	5.00	5.80	....	5.85
Heavy soils						
Brookston	7.05	7.33	7.01	7.15	....	6.83
Miami	5.00	5.18	4.80	5.05	....	5.38

CALCIUM CONTENT OF GREEN PEA STEMS AND LEAVES AT DIFFERENT STAGES OF GROWTH WHEN GROWN ON DIFFERENT SOIL TYPES

Stems

Noticeable differences were found in the calcium content of the stems of green pea plants grown on the different soil types, as is shown in table 4. Generally the stems of plants grown on any one soil were quite uniformly either high or low in calcium in relation to the stems of plants grown on the other soils. But it is readily apparent that the calcium content of the stems did not depend entirely upon the concentration of this element in the soil solution, nor upon either the pH value of the soils or their textures. It does appear however, that all three of these factors may have played a part in controlling the amounts of calcium contained in the stems. Thus, the calcium content was generally high in the stems of plants grown on the heaviest soil types, but always one of the lighter soils produced plants the stems of which were likewise high in calcium. Also, if only the light textured soils are considered, and if Onaway and Plainfield are recognized as alkaline, and Kewanee and Hillsdale as acid, it becomes apparent that the soils of similar hydrogen-ion concentrations produced pea plants whose stems usually contained calcium in proportion to the amounts present in the soil solutions. This relationship cannot be applied to the Miami and Brookston soils studied.

Considerable variation occured in the calcium content of the pea stems at different stages of growth, but there was no uniform increase or decrease as the growth period advanced. In the stems of plants grown on four of the soil types, less calcium was present in the green material at maturity than at the beginning of growth, but in the other two samples there was more present.

TABLE 4

Calcium content of green pea stems at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Light, alkaline soils					
Onaway	0.181	.....	0.124	0.140	0.208
Plainfield	0.167	0.139	0.157	0.110	0.121
Light, acid soils					
Kewanee	0.135	0.173	0.146	.....	0.191
Hillsdale	0.144	0.135	0.087	0.102	0.132
Heavy soils					
Miami	0.162	0.233	0.168	.....	0.108
Brookston	0.174	0.176	0.150	.....	0.128

Leaves

It is apparent from the data in table 5 that similar variations occurred in the calcium content of the green material of pea leaves as was found in that of the green material of pea stems. Differences of considerable magnitude appeared in the calcium content of the leaves obtained from the different soil types throughout the period of growth, and these became greater toward the close of the growth period.

Although it is evident that the calcium present in the pea leaves did not correspond entirely to the concentration of this element in the soil solutions, when the soils were of similar texture and hydrogen-ion concentration, the amount of calcium contained in the green leaves was higher when the amount contained in the soil solution was high, and vice versa. It is noticeable that the average percentage of calcium in the leaves grown on alkaline soils was greater than that of the leaves grown on the acid soils, where Brookston and Miami soils are not considered. In these cases the situation was reversed.

Much greater amounts of calcium were present in the mature green pea leaves than in the young leaves and, although not entirely uniform throughout the period of growth, the increase of calcium was generally quite rapid.

Larger amounts of calcium were present in the leaves of peas than in the stems during the entire period of growth and the ratio between the amounts in the two plant parts became much wider toward maturity.

TABLE 5

Calcium content of green pea leaves at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Light, alkaline soils					
Onaway	0.259	.....	0.260	0.462	0.536
Plainfield	0.193	0.286	0.285	0.379	0.384
Light, acid soils					
Kewanee	0.196	0.359	0.274	0.292	0.418
Hillsdale	0.185	0.332	0.254	0.292	0.282
Heavy soils					
Miami	0.197	0.384	0.278	.....	0.582
Brookston	0.193	0.293	0.336	.....	0.436

CALCIUM CONTENT OF THE EXPRESSED JUICE OF PEA LEAVES AND STEMS AT DIFFERENT STAGES OF GROWTH ON THE DIFFERENT SOIL TYPES

Juice of stems

Significant differences were found in the amounts of calcium in the expressed juice of pea stems of plants obtained from the different soil types, as is shown in table 6. These data are marked by considerable lack of uniformity among the different soil types, no one type giving stems with juice consistently higher or lower in calcium than any of the other soil types.

The same relationship between the calcium content of the juice and the properties of the soils studied is evident here as was noted in the case of the calcium content of the green tissue of stems, except that variations in texture had less influence than in the other case. But on soils of similar reaction the calcium content of the expressed juice usually varied directly as the concentration of calcium in the soil solution. Where soil texture and more particularly soil reaction, are disregarded there appears to have been no relationship between the amounts of calcium in the soil solutions and those in the juice of the plants.

In plants grown on four of the soil types the concentration of calcium was less in the juice of mature stems than in that of young stems, whereas in the plants from the other two types it was slightly higher. During the intermediate growth period the concentration of calcium varied greatly, but appeared to reach its highest point when the plants were 6 to 8 weeks old.

Juice of leaves

Although marked differences were found in the amounts of calcium present in the juice of pea leaves obtained from plants grown on the different soil types, as appears in table 7, there was so much fluctuation during the growth period that it appears to be impossible to associate the amounts present with any of the soil properties which were considered. Likewise it is only possible to say that in the plants obtained from all of the soil types the concentration of calcium was greater in the juice expressed from the mature leaves than in that expressed from the young leaves and that it varied greatly because of soil type during the intermediate period of growth.

TABLE 6

Calcium content of the expressed juice of pea stems at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Alkaline soils					
Onaway	0.164	.....	0.114	0.109	0.142
Brookston	0.125	0.143	0.114	.....	0.093
Plainfield	0.125	0.132	0.136	0.071	0.104
Acid soils					
Kewanee	0.128	0.173	0.105	.....	0.220
Miami	0.121	0.185	0.145	.....	0.142
Hillsdale	0.103	0.177	0.065	0.086	0.095

The concentration of calcium was greater in the expressed juice of the leaves at all times than in that of the stems and the difference became greater as the growth period advanced.

MAGNESIUM CONTENT OF GREEN PEA STEMS AND LEAVES AT DIFFERENT STAGES OF GROWTH ON DIFFERENT SOIL TYPES

The magnesium content of plants studied previously (2, 3) was found to fluctuate so much that any study of its relationship to modifying factors was difficult. A cursory examination of the data presented in the following pages indicates that such difficulty is to be encountered here.

Stems

In table 8 are given the data representing the magnesium contents of the stems of green pea plants at different stages of growth on the several soil types.

TABLE 7

Calcium content of the expressd juice of pea leaves at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Alkaline soils					
Onaway	0.206	.....	.....	0.372	0.126
Brookston	0.145	0.260	0.235	.....	0.358
Plainfield	0.206	0.236	0.170	0.260	0.272
Acid soils					
Kewanee	0.162	0.298	0.184	.....	0.382
Miami	0.147	0.315	0.185	.....	0.558
Hillsdale	0.098	0.296	0.223	0.205	0.199

Great differences existed in the amounts of magnesium present in the plant material obtained from the different soils and the greatest range of variation appeared during the intermediate stages of growth, the contents at the beginning and close of the growth period being more uniform.

Generally a larger percentage of magnesium was present in the stems obtained from the heavy soils during the early part of the growth period. There appears to have been a tendency for the amount of magnesium to increase in the stems of plants grown on the sandy soils as the growth period advanced, whereas a decrease occurred in the stems of plants obtained from the heavy soils. This resulted in about a uniform content at maturity as far as the effect of soil texture was concerned.

There is no evidence that the magnesium content of the pea stems was influenced by either the reaction of the soil or the concentration of magnesium in the soil solution. Likewise the date given here and those in table 1 indicate that there was no relationship between the amounts of magnesium and the amounts of calcium present in the pea stems.

Leaves

Apparently the magnesium content of the leaves of pea plants grown on the different soil types was more uniform than that of the stems of the same plants. This is brought out by the data in table 9, where differences of less magnitude are evident throughout the period of growth.

The amounts of magnesium present in the green pea leaves varied independently of any of the soil characteristics studied here, insofar as could be determined by the data of table 9.

TABLE 8

Magnesium content of green pea stems at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.039	0.017	0.043	0.046	0.052
Hillsdale	0.052	0.013	0.017	0.046	0.039
Kewanee	0.032	0.066	0.026	.....	0.053
Onaway	0.062	.....	0.037	0.052	.....
Brookston	0.066	0.077	0.043	.....	0.052
Miami	0.066	0.046	0.026	.....	0.039

TABLE 9

Magnesium content of green pea leaves at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.055	0.108	0.061	0.105	0.096
Hillsdale	0.063	0.099	0.052	0.079	0.083
Kewanee	.....	0.066	0.057	.....	0.070
Onaway	0.076	.....	0.053	0.108	0.109
Brookston	0.063	0.079	0.087	.....	0.118
Miami	0.071	0.082	0.052	.....	0.257

Greater amounts of magnesium were present in the green material of pea leaves than in that of pea stems at each stage of growth. Likewise there was an increased amount present in mature leaves as compared with that of young leaves on all of the soil types studied, resulting in a wider ratio in the two plant parts at maturity than in the early stages of growth.

MAGNESIUM CONTENT OF THE EXPRESSED JUICE OF PEA STEMS AND LEAVES

Stems

Aside from the fact that the magnesium content of the juice of pea stems varied greatly in the plants grown on the different soil types, there is only one significant feature brought out by the data of table 10. It is strikingly evident that the magnesium content of the juice of the stems obtained from plants grown on the two very acid soils was very low when the plants were 3 weeks old. However, on these soils a greater increase in concentration occurred in the magnesium content of the juice, resulting in a greater percentage of magnesium at maturity in the samples obtained from the very acid soils. Just what property of the soils or the plants induced this condition is not indicated.

TABLE 10

Magnesium content of the expressed juice of pea stems at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.058	0.037	0.037	0.028	0.043
Hillsdale	0.045	0.053	0.025	0.028	0.032
Kewanee	0.018	0.039	0.021	.....	0.064
Onaway	0.057	.....	0.027	0.036	0.048
Brookston	0.056	0.066	0.031	.....	0.041
Miami	0.011	0.067	0.043	.....	0.058

TABLE 11

Magnesium content of expressed juice of pea leaves at different stages of growth, on different soil types

SOIL TYPE	STAGE OF GROWTH				
	3 weeks	6 weeks	8 weeks	Budding	Maturity
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	0.049	0.071	0.056	0.053	0.059
Hillsdale	0.023	0.070	0.067	0.062	0.058
Kewanee	0.021	0.056	0.036	.....	0.059
Onaway	0.037	.....	0.062	0.088	0.039
Brookston	0.059	0.076	0.069	.....	0.092
Miami	0.059	0.078	0.051	.....	0.171

Evidently there was no relationship between the texture of the soil or the amounts of magnesium present in the soil solutions and the concentration of magnesium in the juice of the stems.

Leaves

In table 11 are given the data showing the magnesium content of the expressed juice of the pea leaves. Marked differences existed in the magnesium contents of the juice of the leaves obtained from the different soil types and it appears that these contents were greater in the plants grown upon the heavy soil types during the entire growth period than they were in the plants obtained from the light soils. However, there was no correlation between the magnesium present in the plant juice and that present in the soil solution, nor was there evident any influence of the reaction of the soil upon the amount of magnesium in the plant juice.

In the early stages of growth the concentration of magnesium was about equal in the juice of the stems and leaves but as the growth period advanced the concentration increased more rapidly in the juice of the leaves with the result that in the mature stage it was higher here.

All of the data obtained in this work showed that there was always more calcium than magnesium present in the green plant material and in the juice of the pea plant.

TABLE 12

Green weight of peas at different stages of growth on different soil types

Weight in grams of 7 plants

SOIL TYPE	STAGE OF GROWTH		
	3 weeks	6 weeks	8 weeks
	gm.	*gm.*	*gm.*
Plainfield	9.10	21.7	65.5
Kewanee	7.28	16.9	61.2
Onaway	7.25	....	54.6
Hillsdale	11.90	29.0	82.7
Brookston	8.26	21.0	46.5
Miami	7.14	9.1	27.7

GREEN WEIGHT OF PEAS ON DIFFERENT STAGES OF GROWTH ON DIFFERENT SOIL TYPES

The green weights of pea plants produced on the different soil types were obtained for only three stages of growth, because of the extent to which the leaves dropped as the plants approached maturity. These data appear in table 12.

When the plants were 3 weeks old, their green weight was nearly equal on all of the soil types, but as the growth period advanced, the rate of growth changed markedly. Plants grown on Hillsdale and Plainfield soils made the most rapid growth and those grown on Miami and Brookston soils made the least rapid growth. The data showing the calcium and magnesium contents of the plants indicate that the rapidly growing plants were usually low in these two elements, whereas the slowly growing plants were usually high in them. It thus appears that at least some of the differences noted in the calcium and magnesium contents of the plants may be attributed to differences in the rate at which the plants were making growth as well as to the differences in the characteristics of the soils.

PROPORTION OF LEAVES AND STEMS OF PEAS GROWN IN THE GREENHOUSE ON DIFFERENT SOIL TYPES

In table 13 are given the green weights of the stems and leaves of peas at several growth stages. At 3 weeks of age there was little variation in the proportion of leaves and stems on the different soil types, but as the plants became older, greater differences appeared.

There was an increase in the proportion of stems to leaves during the period of growth until it became about constant at the budding stages. In the beginning the average percentages were 40 for stems and 60 for leaves. When the plants were 8 weeks old, the average percentage of stems had become 58.2 and that of leaves 41.8; which about reversed the situation found at the age of 3 weeks. At the 3-week stage of growth the proportion of stems and leaves in peas was about the same as was found for beans, but in beans the proportion of stems decreased, while in peas it increased with the age of the plant.

TABLE 13

Proportion of leaves and stems of peas at different stages of growth on different soil types

SOIL TYPE	STAGE OF GROWTH							
	3 weeks		6 weeks		8 weeks		Budding	
	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Plainfield	36.1	63.9	40.5	59.5	64.1	35.9	55.6	44.4
Kewanee	40.9	59.1	45.5	54.5	60.4	39.6	....	....
Onaway	39.1	60.9	....	....	56.4	43.6	57.2	42.8
Hillsdale	42.6	57.4	45.0	55.0	55.6	44.4	53.8	46.2
Brookston	40.0	60.0	33.3	66.7	56.5	43.5	....	....
Miami	40.4	59.6	41.7	58.3	56.5	43.5	....	....

SUMMARY AND CONCLUSIONS

In this work the influence of the growth of field peas upon the calcium and magnesium content of the soil solution and upon the reaction of the soil was observed. Likewise, variations in the calcium and magnesium content of pea stems and leaves and in their juice when obtained from plants grown on different soil types were studied. The relationship of certain characteristics of the different soil types to the amounts of calcium and magnesium present in the pea plants was considered.

Growing pea plants greatly reduced the amounts of calcium and magnesium present in the different soil solutions. They also tended to decrease the acidity of strongly acid soils and to increase that of alkaline or nearly neutral soils.

The calcium and magnesium content varied greatly in the pea plants grown on the different soil types. On soils of similar texture and reaction, the amount of calcium present in the pea plant varied directly with the amount present in the soil solution. Soil texture and soil reaction influenced the calcium content of the peas to the extent of obscuring the effect of the concentration of the soil solution if not allowed for. The magnesium content of the plants was very irregular and appeared to be influenced more by soil texture than any other characteristic of the soils studied here.

There was more calcium and magnesium present in the tissue and in the juice of pea leaves than in the tissue and the juice of the stems. As the plants became older, the concentration of calcium and magnesium increased in the tissue and juice of pea leaves, whereas it sometimes increased and sometimes decreased in the tissue and juice of stems.

Greater amounts of calcium than of magnesium were always present in the tissue and in the juice of pea stems and leaves.

It appeared that the calcium and magnesium content was higher in slowly growing plants than in those making a rapid growth.

The proportion of stems was smaller than that of leaves in the young plants but became greater as the plants advanced in growth.

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