A STUDY OF THE RELATION OF CALCIUM, PHOSPHORUS, AND NITROGEN IN KANSAS SOILS TO THESE ELEMENTS IN SECOND-CUTTING ALFALFA

by

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INTRODUCTION

As early as 1869, Hellreigel, according to Hall, (1) discussed the amounts of potash in oats straw as related to the supply in the soil. It was natural that attempts should be made to use the plant composition as a guide to manurial practices (2). The object of the experiment reported in this paper has been to find any existing relationship between the calcium, phosphorus, nitrogen, and ash content of alfalfa plants grown under field conditions in various parts of Kansas, and these elements as found in the soils upon which the alfalfa was grown. It is common knowledge that plants of different species grown under identical conditions differ in their elemental composition, especially in regard to the proportionate amount of the various elements that compose them (3). Also that the amount of any element that is found in the plant is influenced by the abundance, availability, and location of that element in the soil (3).

So uncertain are the conclusions to be drawn from the chemical analysis of the soil that new methods are now being employed for the estimation of fertilizer requirements of a soil based upon the growth of a test plant in the soil. Two experimental methods have been worked out by Mitscherlich of Konigsberg, and Neubauer of Tharandt; in both methods the conclusions are drawn from plants grown in samples of soils under regulated conditions and not from plants growing in the field (4). It was thought that if a definite relationship could be established between the soil composition and the plant composition in this experiment, that certain predictions as to the fertilizer needs of a soil could be deduced from the analysis of the plant even though the plant was grown under varying field conditions.

In the following pages of this paper I shall show the data acquired and attempt to discuss and summarize this data and to compare my findings with those of previous investigators.

This problem was proposed by Professor W. L. Latshaw of the Department of Chemistry, Kansas State College, and he is responsible for collecting the samples of soil and alfalfa and for their preparation for analysis and for the data concerning the location and conditions under which the plants were grown. He is also responsible for the data showing the quantity and quality of the crop and the general description of the land on which the alfalfa was grown.

ALFALFA AND SOIL SAMPLES USED IN THIS STUDY

Soils and alfalfa from 14 Kansas counties were used in this study. Most of the samples were obtained from the northeastern part of the state, except three which are from Barton and Pawnee counties. Figure 1 shows the general

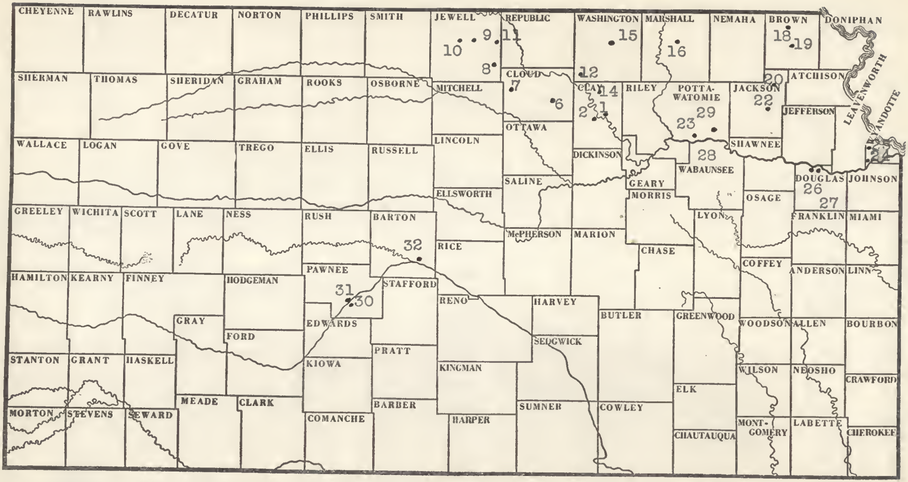

Figure I. Map showing locations from which samples were taken.

location from which the samples were taken. The numbers used in this illustration are the general sample numbers and correspond with the numbers used to designate the sample number of the surface soil. It was thought that by obtaining the samples from various parts of the state that it would eliminate the effect of soil type and show the effect of general environmental factors if they were evident.

Both surface and sub-surface soils were used in this study. The surface soil being the upper seven inches of the soil and being designated in the tables as 1, 6, etc. The sub-surface soil was taken from seven to twenty inches below the surface and is designated by 1s, 6s, etc. These samples were all taken by the soil tube method.

The alfalfa samples used represent a regular cutting of the crop, are all of the second cutting and were taken at the full bloom stage of growth. The alfalfa samples are numbered the same as the surface soils with which they correspond. However, no attempt was made to record the green weight of the alfalfa and, therefore, all the data are shown on the dry weight basis.

Table 1 presents a brief description of the soil as to presence of lime, the age of the crop, and the quantity and quality of the stand of alfalfa. However, the description of neither the soils nor alfalfa from Barton and Pawnee counties was obtained. No attempt will be made to classify

Table 1. Description of the soil and alfalfa samples

Sample	County	Classification	Quantity of growth	Quality of growth	Age of crop on field	Description of soil as to liming and natural lime present
1	Clay	Bottom	Good	12" to 14"	3 yrs.	
2	Clay	Bottom	Good	8" 10"	1 yr.	
6	Cloud	Upland	Good	12"		
7	Cloud	Upland	Good	12" 14"	3 yrs.	
8	Jewell	Upland	Good	10" 12"	1 yr.	
9	Jewell	Upland	Good	12" 14"	1 yr.	Limestone at 22 to 24"
10	Jewell	Upland	Good	10" 12"		Limestone at 30"
11	Jewell	Upland	Good	12" 14"		Limestone at 30 to 38"
12	Washington	Upland	Good	10" 12"	2 yrs.	Limestone at 30"
14	Clay	Upland	Good			
15	Washington	Upland	Good	small	1 yr.	
16	Marshall	Upland	Fair	10"		
18	Brown	Upland	Good	14" 20"	1 yr.	
19	Brown	Upland	Fair	10" 12"	3 yrs.	
20	Jackson	Upland	Fair	10" 12"	1 yr.	
22	Jackson	Upland	Good	10" 12"	1 yr.	
23	Pottawatomie	Upland	Good	10" 12"	1 yr.	
24	Wyandotte	Upland	Fair		5 yrs.	
25	Wyandotte	Upland	Fair		2 yrs.	
26	Douglas	Bottom	Good		3 yrs.	Limed soil
27	Douglas	Bottom	Fair		3 yrs.	Same as 26 but unlimed
28	Wabaunsee	Upland	Fair		4 yrs.	
29	Pottawatomie	Upland	Good	short	3 yrs.	
30	Pawnee					
31	Pawnee					
32	Barton					

any of the soils used as to type.

METHODS OF ANALYSIS

After the soil samples and the alfalfa samples were collected they were brought into the laboratory where they were dried to constant weight and prepared for analysis.

The more common methods will not be outlined in this paper but the less commonly used ones will be described in detail. The chemical composition of the soils was determined as follows: the amount of nitrogen was determined by the method of Kjeldahl (5), the total phosphorus by the magnesium nitrate method (5), the acid soluble calcium by a method outlined by Swanson, Gainey, and Latshaw (6), the ammonium chloride soluble or base exchangeable calcium by a method described by Gedroiz (7), and the available phosphorus by the method of Fraps and Fudge (8).

In the plant material, the total nitrogen was determined by the method of Kjeldahl (5), the total phosphorus by the magnesium nitrate method (5), the calcium by the McCrudden method (5), and the ash by the official method for plant material (5).

The acid soluble calcium in the soil was determined by the following method: ten grams of soil were placed in a 250 cc. Earlenmeyer flask and 100 cc. of normal hydrochloric acid added and the flask stoppered with a rubber stopper.

The flask was then heated to 60°C. in a water bath and then shaken on a shaking machine for one hour. After settling, the contents of the flask were filtered and aliquot portions of the filtrate were measured into 250 cc. beakers to which a few drops of dilute bromine water were added and the solution boiled for a few minutes to oxidize all the iron to the ferric condition and to remove the excess bromine. The solutions were then made alkaline with ammonium hydroxide to precipitate all of the iron. They were then filtered while hot and the precipitate washed with hot water until all the soluble chlorides were washed out. The calcium content of the filtrate was then determined by the official method (5).

The base exchangeable or ammonium chloride soluble calcium was determined in the following manner: a 10-gram sample of each soil was placed in a 500 cc. rubber stoppered bottle and 200 cc. of normal ammonium chloride was added, after which the bottles were well shaken on the shaking machine for 15 minutes. The content of each bottle was then filtered with the aid of a Buchner funnel and the residue returned to the original bottle and the volume increased to 200 cc. with ammonium chloride. This procedure was repeated until four extractions were made, as it was found that four extractions would remove about 97 per cent of the calcium removable by normal ammonium chloride.

This varies from the method of Gedroiz in that he repeated the extraction until all the calcium that could be removed with this solvent was removed. The extracted filtrate was then evaporated to a volume of about 200 cc. made slightly acid with 1 : 1 hydrochloric acid and heated to boiling and then made alkaline with ammonium hydroxide. The calcium content of the filtrate was then determined by the official method (5).

The available phosphorus was determined by the method of Fraps and Fudge (8) which they presented at the New Orleans meeting of the American Chemical Society in 1932. The authors of this method call it the "Rapid Chemical Methods for the Estimation of the Capacity of Soils to Supply Phosphoric Acid to Plants", and claim that the results correlate more exactly with the green house method of Neubauer than any of the nine methods which they tested. Their method of extraction which has never been published is as follows: ten grams of soil are placed in a 150 cc. Earlenmeyer flask and 100 cc. of fifth normal nitric acid is added and the flask stoppered with a rubber stopper. The contents of the flask are then shaken vigorously and let stand for five minutes and then shaken again; this procedure is followed until three shakings are complete. The contents are then filtered and the filtrate preserved and the available inorganic phosphorus determined by one of the common color methods.

THE CHEMICAL ANALYSIS OF THE SOILS

The chemical analysis of a soil aims at ascertaining the amount of the various elements necessary to the nutrition of the plant, with a view of either making good the general deficiencies of the soil or of adjusting the supply of plant food to such special requirements of a particular crop as may have been indicated by previous experiment, (4). Though much may doubtless be learned by a comparison of the analysis of a given soil with the analyses of others whose fertility has been proved by experiemce or by actual manurial experiments, there are yet many considerations which may prevent much weight being attached to the results thus obtained.

Of all the soil constituents, calcium shows the widest fluctuations: it may constitute 20 to 25 per cent of the soils resting on limestone or it may be present in very small amounts in sandy or clay soils. The soils analyzed and reported here (see table 2) show that the amount of the calcium ranged from 0.2 to 4.5 per cent. Soil calcium varies in its solubility in different solvents according to the elements with which it is in combination. The calcium present in the form of carbonate is exceedingly soluble in dilute acids while that present in other forms

Table 2. Data showing the composition of the soil

Soil sample	Percentage of: Acid soluble calcium	Ammonium chloride Soluble calcium	Total phosphorus	Available phosphorus	Total nitrogen
1	.2012	.2285	.0489	.022600	.1165
1s	.3276	.3736	.0540	.010200	.0680
2	.2909	.3604	.0615	.003760	.1460
2s	.3936	.4417	.0355	.006505	.0940
6	.3476	.4307	.0607	.008690	.1310
6s	.4062	.4725	.0615	.011200	.0860
7	.2769	.3406	.0440	.009920	.1600
7s	.2888	.3934	.0588	.008800	.1165
8	.3559	.4615	.0445	.009650	.1210
8s	.4732	.5164	.0769	.016500	.0760
9	.3613	.3670	.0573	.007400	.1240
9s	.4563	.4571	.0439	.016900	.0805
10	3.1620	2.1970	.0459	.010950	.1245
10s	4.5250	2.0580	.0471	.003940	.0930
11	.2785	.3010	.0376	.004640	.1400
11s	.4083	.4043	.0483	.009060	.0880
12	.2302	.2571	.0412	.002550	.1350
12s	.3559	.3626	.0420	.004310	.0960
14	.5675	.5494	.0392	.010400	.0895
14s	.6344	.6087	.0372	.010680	.0560
15	.2260	.2637	.0376	.003750	.1235
15s	.4732	.4989	.0357	.003940	.1180
16	.2785	.3032	.0348	.000977	.1605
16s	.3789	.4329	.0263	.000347	.0970

Table 2 continued

Soil sample	Percentage of Acid soluble calcium	Ammonium chloride Soluble calcium	Total phosphorus	Available phosphorus	Total nitrogen
18	.3308	.3626	.0584	.0021050	.1980
18s	.4062	.4087	.0384	.0035300	.1500
19	.3852	.4109	.0481	.0008250	.1980
19s	.4104	.4703	.0576	.0002450	.1165
20	.2680	.3076	.0503	.0003220	.1990
20s	.3810	.4285	.0461	.0002370	.1070
22	.3308	.3692	.0423	.0001190	.1225
22s	.3182	.3472	.0418	.0000980	.0730
23	.3033	.2659	.0393	.0002810	.1390
23s	.2951	.3296	.0307	.0000592	.1030
24	.3119	.2791	.0591	.0315000	.0870
24s	.3266	.3120	.0581	.0303000	.0795
25	.3042	.3032	.0388	.0001290	.1125
25s	.3600	.3538	.0512	.0001880	.1305
26	.3161	.3428	.0461	.0001210	.1800
26s	.2512	.2835	.0457	.0001420	.1710
27	.1968	.2461	.0473	.0001070	.1710
27s	.2096	.2417	.0467	.0000602	.1490
28	.4753	.4791	.0656	.0093100	.2310
28s	.5179	.5604	.0498	.0064500	.1725
29	.3789	.3714	.0389	.0002760	.1370
29s	.3505	.3516	.0391	.0002070	.1140
30	.4501	.4769	.0581	.0165000	.2025
30s	.4293	.4483	.0418	.0001100	.0905
31	.2575	.2527	.0546	.0187000	.1380
31s	.3831	.3692	.0530	.0203000	.0910
32	.6952	.7120	.0716	.0246000	.2100
32s	.8040	.8241	.0545	.0247000	.1160

is more readily soluble in ammonium chloride. The calcium in the samples used was determined from the extractions by two different methods, namely those with normal hydrochloric acid and normal ammonium chloride.

In 18 of the 26 soils analyzed, it was found that (see table 2) the calcium was more soluble in normal ammonium chloride than in normal hydrochloric acid.

The importance of free calcium carbonate in the soil lies not in the calcium that it supplies for the nutrition of plants, but in its use as a base to maintain the neutrality of the soil. The general opinion is that there is more calcium found in the sub-soil than in the surface soil because of its nearness to the source of supply, which is the limestone stratum underlying the soil, and the fact that it has not been leached away or used up by the plants.

In 21 of the 26 soils analyzed, there was a higher percentage of calcium soluble in normal hydrochloric acid in the sub-surface soil than in the surface soil. This shows that regardless of the solvent used, there is more soluble calcium in the sub-surface layer than in the surface layer.

Nitrogen may exist in the soil in several different forms: as nitrates, nitrites, ammonia, urea, protein, amides, amino acids, and many other nitrogenous compounds excreted by animals and formed by bacterial decomposition of plant and animal residue. The nitrogen of soils upon which legumes are grown is replenished by atmospheric nitrogen fixed by symbiotic bacteria, but it also must be remembered that legumes in general use more nitrogen in their metabolism than do any other crop plants. The nitrogen content of pasture soils ranges from 0.5 per cent to 0.1 per cent depending upon reaction and other factors of the soil (4).

The nitrogen content of these soils ranged from 0.23 per cent to 0.056 per cent (see table 2). In all cases the nitrogen content of the surface soil was higher than that of the sub-surface soil, except in the case of sample No.25. Location of the land from which the sample was taken was probably the cause of the fluctuation in the latter case. This might be caused by leaching or by the original surface layer being covered with wash dirt or dirt being blown onto the land. The nitrogen content of the soils containing high phosphorus or high calcium showed no variation from those of low phosphorus or calcium content.

Phosphorus exists in the soil in many distince compounds: in combination with carbon, it is found in nuclein and lecithin, which in a more or less humified condition are found among the plant and animal residues; it also occurs as phosphates of iron and aluminum and as di-basic and tri-basic phosphates of lime. Of these compounds the di-basic phosphate of lime is undoubtedly the most soluble in either pure water or the carbonic-acid-charged water of the soil. Almost invariably phosphoric acid is less abundant in sub-soil than in the surface, where it has accumulated as a residue from the decay of previous vegetation (4).

Sixteen of the 26 soils analyzed have a higher total phosphorus content in the surface soil than in the sub-surface layer, although in some cases this is but a small amount (see table 2). There is considerable fluctuation in the percentage of total phosphorus in the various soils, the maximum being 0.0769 per cent and the minimum being 0.0263 per cent. Apparently there is no relationship between the calcium content of the soil and the total phosphorus content of the soil.

Of all the constituents of the soil, the one most widely studied has been the available phosphorus. One might think that all of the phosphorus in the soil would be readily available to the plant but it is generally known that such is not the case. The work of the soil chemist, then, must be extended to include some investigation of the availability of the plant food in the soil, as well as the absolute quantity. It is not enough to determine what constituents are present with the view of making good the deficiencies, because there is always more than enough for many crops. Inquiry must, therefore, be directed towards finding how much is likely to reach the crop. The attempt to discriminate between the total and what may be termed the available plant food in the soil has been in two ways: by using the plant as an analytical agent, and by attacking the soil with very dilute acids, whose action is thought to be similar to the natural solvent agencies at work when the plant is growing (4).

Whatever theories have been advanced as to the manner in which the phosphorus of the soil passes into solution, it is improbable that the conditions can be reproduced in the laboratory. Therefore, for practical purposes of analysis, various solvents have been suggested and used, and have been checked against the various plant analytical methods. Solutions of acetic, citric, hydrochloric, and carbonic acids have been used for the extraction as well as water free from carbonic acid. The phosphorus in these extracts is usually determined colorometrically. In the report of Fraps and Fudge (8) we find a method which the authors claim correlates with the plant analytical methods more nearly than any other methods devised up to this time. The principle of this method is the extraction with one-fifth normal nitric acid and the determination of the phosphorus from this extract by a color method. The latter method was used in determination of the available phosphorus in this experiment and will be found under that heading in table 2.

The idea that the phosphorus of acid soils is in an unavailable condition, and that through liming, it will be made more available, has long been held, although no entirely satisfactory explanation or proof that this is generally the case has been offered. Ames and Schollenberger (9) claim that in general the availability of phosphorus is not increased by the addition of lime, while Breazeale and Burgess (10) say that in a slightly acid soil, or in a soil containing carbon dioxide but no calcium carbonate, the plants will have difficulty in absorbing the phosphorus before it enters into combination with the iron and aluminum of the soil.

Thirteen of the 26 soils analyzed (see table 2) showed more available phosphorus in the surface soils than in subsurface soils. This difference varied from two to one hundred sixty-five times as much in the surface as in the sub-surface soil. While the other 13 showed as marked a contrast in the opposite direction.

There was no indication of any correlation between the total phosphorus in the soil and the available phosphorus in the same sample. In some samples the total phosphorus was five-hundred times that which was available while in others it was less than twice the available amount. There seemed to be no correlation between the calcium and nitrogen content of the soil and the available phosphorus.

Although this subject has been studied extensively, there apparently still remains a large field of study in the work on available phosphorus and its relationship to the other mineral constituents of the soil. Before anything can be definitely decided as to the effect of the minerals of the soil on the availability of the phosphorus, a great deal more data must be collected on this subject.

In conclusion it may be said, no correlation was found between any of the mineral constituents of the soil. Thus before much information can be extracted from the analysis of a soil, we must begin by studying and establishing the soil types, by a suil survey in fact, in which the collected data are correlated with the observed behavior of the soils in the fields and under experiment.

CHEMICAL ANALYSIS OF PLANT MATERIAL

It is generally known that a plant will vary in its elemental composition depending upon the species of plant and upon the soil in which it is grown. In the following discussion I have attempted to show the existing relationship between the different constituents of the plant as found by analysis. It has been stated by Salter and Ames (2) that aside from the question of nutrient supply, there is a host of environmental factors that are known to affect the intake of nutrients by the plant. As examples may be mentioned temperature, reaction of growth medium, supply of oxygen and moisture, and the degree of competition. However, in this paper no attempt will be made to differentiate between plants grown under one condition and those grown under another. These plants have been analyzed for nitrogen, calcium, phosphorus, and ash, (see table 3) and various ratios of these constituents have been calculated and are shown in table 4.

Calcium is essential to the growth and development of all green plants with the exception of some lower algae. As a rule, the legumes, lettuce, cabbage, and tobacco have a high percentage of calcium on the dry basis, while the members of the grass family have a relatively small amount (3). In this experiment, a marked fluctuation was found in the amount of calcium in the different samples, the range being from 1.41 to 2.48 per cent. The general variation, however, was from 1.57 per cent to 2.23 per cent.

The effect of calcium on the other elements of the plant is not known, but from the data obtained (see table 3) it might be said that as the calcium increases, there is a general tendency for the phosphorus to decrease. This is shown when the percentage of calcium is plotted against the calcium phosphorus ratios. (See figure 2). There was a

Table 3. Composition of the alfalfa plants

Alfalfa	Percentage of Calcium	Phosphorus	Nitrogen	Ash
1	1.725	0.284	3.110	9.31
2	2.201	.212	2.990	9.65
6	2.140	.229	3.135	9.37
7	1.570	.310	3.460	9.28
8	2.180	.232	3.110	10.91
9	2.180	.269	3.260	9.26
10	2.480	.241	3.160	10.33
11	2.230	.261	3.050	9.38
12	1.790	.298	3.410	10.97
14	1.630	.275	3.297	10,14
15	1.670	.271	3.380	10.93
16	1.940	.204	3.165	9.72
18	1.650	.253	3.220	10.64
19	1.810	.248	2.970	8.87
20	1.620	.314	3.600	10.57
22	1.630	.246	3.470	9.95
23	1.990	.200	2.880	9.60
24	1.410	.312	2.595	10.82
25	1.620	.273	2.990	12.23
26	2.170	.198	3.120	11.13
27	2.040	.225	3.010	10.50
28	1.840	.277	2.790	12.82
29	2.080	.249	2.910	11.60
30	1.465	.230	2.760	8.37
31	1.700	.270	2.730	9.09
32	2.130	.261	3.510	11.06

Table 4. Ratios of the various elements of the alfalfa plant

Alfalfa	Calcium phosphorus ratio	Calcium nitrogen ratio	Nitrogen phosphorus ratio
1	6.06	0.555	10.92
2	10.38	.735	14.12
6	9.35	.684	13.68
7	5.08	.458	11.50
8	9.40	.703	13.40
9	8.12	.670	12.10
10	10.29	.786	13.12
11	8.54	.732	11.69
12	6.02	.527	11.49
14	5.94	.496	11.93
15	6.15	.494	12.45
16	9.52	.614	15.50
18	6.52	.529	12.72
19	7.29	.609	11.98
20	5.15	.450	11.49
22	6.64	.470	14.10
23	9.95	.690	14.40
24	4.52	.545	8.30
25	5.94	.541	10.92
26	10.95	.695	15.75
27	9.08	.678	16.42
28	6.64	.660	10.08
29	8.35	.714	11.69
30	6.37	.530	12.00
31	6.30	.623	10.10
32	8.17	.605	13.45

tendency for the calcium phosphorus ratio to increase as the calcium increases. When the percentage of calcium is plotted against the nitrogen phosphorus ratio, there is a constant increase of the ratio until the calcium reaches about 2.30 per cent and then the nitrogen phosphorus rstio becomes constant at about 13.5 as is shown in figure 3. The effect of the calcium on the calcium nitrogen ratio is shown in figure 4, and indicates that there was a gradual increase in the calcium nitrogen ratio with each increase in calcium. This shows that the nitrogen was almost constant or decreased with the increase of calcium. However, it was found that the nitrogen was almost a constant factor and did not seem to be affected by changes in the calcium content of the plant material.

Parker and Truog (11) observed that there is a close relationship between the calcium and the nitrogen in plants. The first group has a calcium nitrogen ratio of about 0.3 and contains almost entirely members of the grass family which have a low calcium requirement. The second group has an average calcium nitrogen ratio of about 0.55 and includes the legumes and those plants which require a large amount of calcium and are sensitive to soil acidity. The data in this experiment tends to substantiate the above statements as the calcium nitrogen ratio in the plants examined was from 0.450 to 0.786 (see table 4).

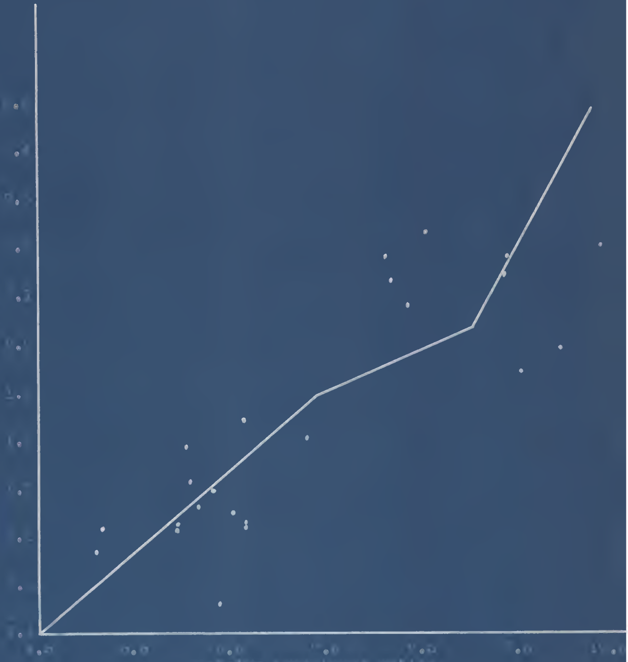

Figure [illegible]. Graph showing the relationship between the percent of [illegible] and the calcium phosphorus ratio.

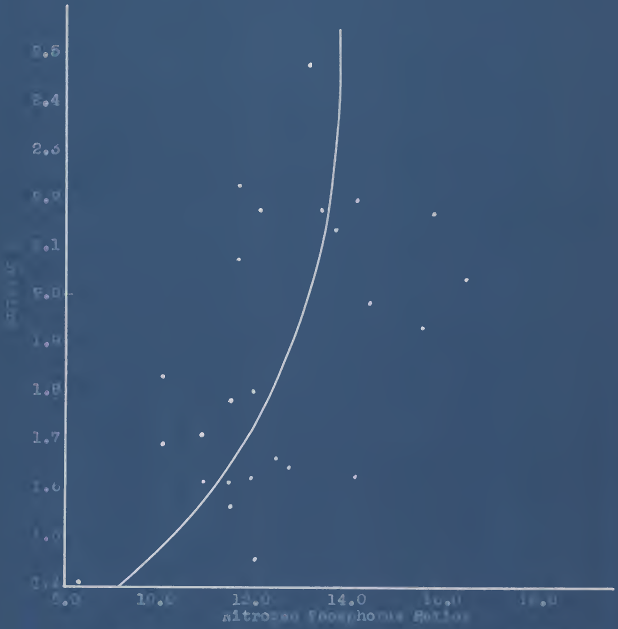

Figure [illegible]. Graph showing the relation between the percentage of calcium and the nitrogen phosphorus ratio

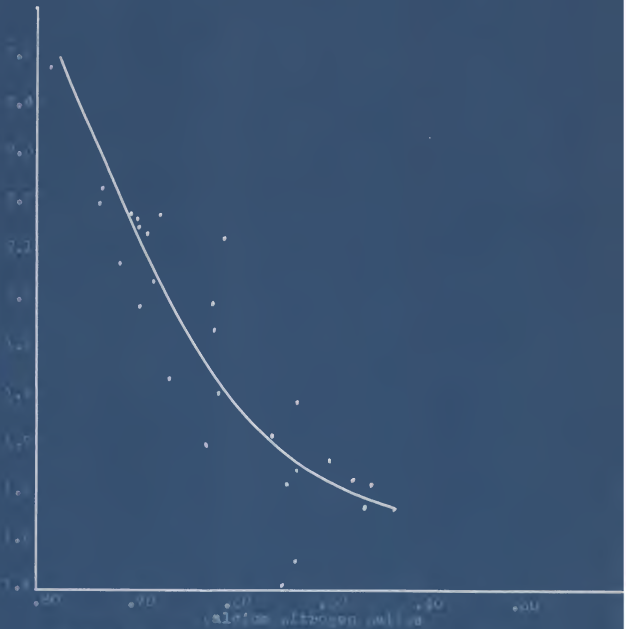

Figure 4. Graph showing the relationship between the percent of calcium and the calcium nitrogen ratio

The second mineral constituent to be considered is phosphorus. It is known that no plant can exist without a supply of available phosphorus. Truog (12) states that plants having a high content of calcium oxide have a relatively high feeding power for phosphorus and are called high-phosphorus-response crops. In general, the phosphorus in plants ranges from 0.2 to 0.8 per cent on the dry weight basis. In contrast with the findings of Truog, the results of this experiment tend to indicate that there was a gradual decrease in the calcium with every increase in phosphorus (see table 3).

With each decrease in phosphorus there is a gradual increase in the calcium phosphorus ratio (figure 2). We must now consider the effect of phosphorus on the nitrogen phosphorus ratio. It will be noticed in figure 5 that there was a gradual increase in the nitrogen phosphorus ratio, although this decrease was small. It is quite evident then that the percentage of nitrogen was not affected by the phosphorus, as it remained almost constant while the phosphorus decreased.

The nitrogen content of legumes as a rule is much higher than that of any other crop plant (24). Although nitrogen is taken into the plants mostly as nitrates and ammonia, it is seldom found in those forms in the plant, but usually as protein or amino-acids. The fluctuation of

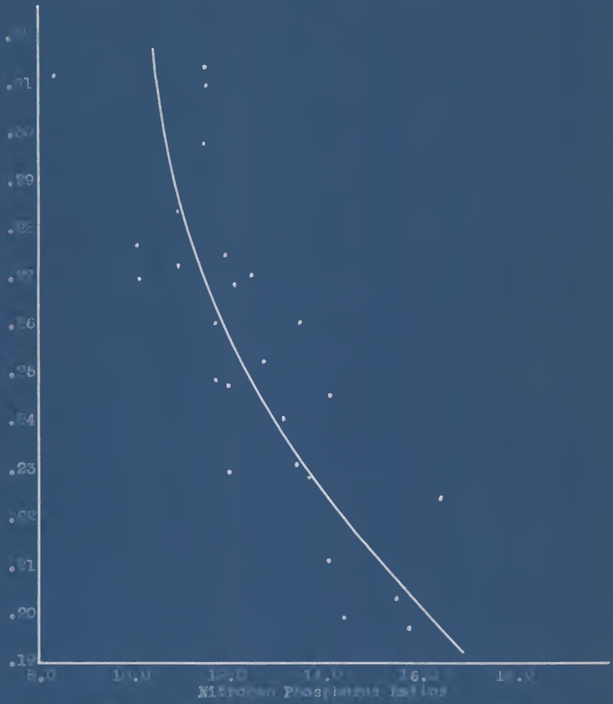

Figure 5 Graph showing the relation between the percentage of phosphorus and the nitrogen phosphorus ratio

the nitrogen content of the plants examined was from 2.59 per cent to 3.60 per cent.

The effect produced by the nitrogen on the calcium phosphorus ratio, if any, was very small. The constancy of the nitrogen content has an effect on the nitrogen phosphorus ratio as is explained under the discussion of phosphorus. The explanation of the effect of nitrogen on the calcium nitrogen ratio is also given above, but it might be of interest to note that as the nitrogen increases, the calcium nitrogen ratio will increase until the nitrogen is about 3.00 per cent and then the calcium nitrogen ratio decreases at about the same rate when the nitrogen increases above three per cent. (see figure 6).

Apparently the ash content bears no relation to the elements of the plant that were determined, as no correlation existed between them or the ash and any of the ratios set up in this experiment. Since other elements make up a portion of the total ash, it is likely that their effect on the ash was greater than the effect of either the calcium or the phosphorus.

EFFECT OF THE MINERAL CONSTITUENTS OF THE SOIL ON THE COMPOSITION OF THE PLANT

The use of the plant as a guide to the composition of the soil and the availability of the constituents in the soil has been affirmed and denied. Hall (1) states that the

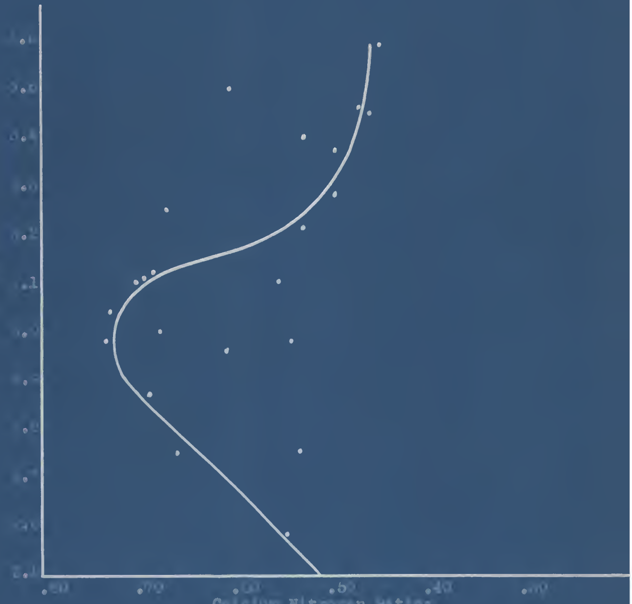

Figure [illegible]. Graph showing the relationship between the percentage of nitrogen and the calcium nitrogen ratio composition of the ash of mangels grown without manure on a particular soil gives a valuable indication of the requirements of the soil for potash manuring. Similarly the phosphoric acid requirements are well indicated by the composition of the ash of unmanured swedes, though in this case determination of the citric acid soluble phosphoric acid in the soil gives even more definite information (1). And pending the determination of phosphoric acid and potash constants for some test plant occurring naturally on unmanured land, the interpretation of soil conditions from analysis of plant ashes is not a practicable method by which to determine the chemical analysis of the soil. Also, Jordan (13) secured results that tend to indicate that what a given crop contains of certain elements is not necessarily to be regarded as a measure of what must be supplied in order to meet the needs for maximum growth. Teakle (26) could find no relation between the amount of material absorbed by the plant with that present in the cultural solution or in the soil in the case of phosphates. Parker and Pierre (25) state that there is no correlation between the phosphorus in the soil and its absorption by the plant.

In contrast to the above, Ames (14) found that a comparison of the composition of the wheat grown on the same soil under different conditions of fertilization, gives a better indication of the available supply of nitrogen, phosphorus and potassium in the soil than can be obtained from the analysis of the soil. Ames and Boltz (15) found in the case of alfalfa that the composition of the plant reflects with considerable exactness the supply of available phosphorus. Salter and Ames (2) observed that there exists a general relation between the intake of a given element and its supply under field conditions. A more exact relation might be expected to exist when plants are grown under controlled conditions, especially when an attempt is made to hold all other growth factors at the optimum point (2). It was finally concluded that it is impossible to estimate the supply of a given element in the soil from its content in the plant, unless it is assured that other growth factors are supplied in abundance, a condition which is by no means easy of attainment, especially under field conditions (2). Gilbert and Hardin (16) suggested that the current mineral nutrient content of plant solution be used as an index of fertilizer needs, and tentative critical concentrations be chosen for each nutrient.

Very little correlation between the mineral constituents or the nitrogen of the soil with these constituents in the plant was found (see tables 2 and 3). It will be noticed, however, that there is a correlation between the phosphorus in the plant and the available phosphorus in the soil. The plants containing the highest phosphorus content with few exceptions were shown to have been grown on the soils containing the highest average available phosphorus. Further, that the plants containing the lowest phosphorus were grown on the soils containing the least amount of available phosphorus. It is quite evident then, that there is a correlation between the phosphorus content of the plant and the available phosphorus in the soil. Another striking thing was that the plant containing the highest calcium percentage was grown on the soil containing the highest calcium content. This, however, only existed in one case, the other samples showing no correlation in this respect. No correlation was found to exist between any of the other elements.

Dickson (18) found in working with the oat plant that the plant as a whole responds quite markedly to environment by changes in its composition and that for no two cases are these responses the same. Doak (17) found that different weather conditions altered the composition of lucerne. Hall (1) found the variation of plant composition due to the amount of constituents present in the soil was due to seasons, and other environmental factors. Miller and Duley (19) reported that as an average of all cases, minimum moisture content gave a higher nitrogen and mineral content than when optimum moisture was applied, during any period of growth the percentages of both nitrogen and mineral elements usually decreased with the age of the plant. In most cases the decrease was more marked with optimum than with minimum moisture treatments.

Soil type is also another factor that helps to eliminate the chances of using the plant as a guide for the availability of soil constituents. It was noted by Ponder (20) that soil type has less effect on the calcium content of the expressed juice of alfalfa in the second cutting than in the other cuttings, in fact the effect of soil textures was negligible in the second cutting. Sassure (21) has shown that the composition of plant ash is not constant but varies with the nature of the soil and the plant. Newton (22) made the statement that the character of the soil and other factors the absorption of soil elements by the plant.

Another important factor is the effect of application of lime or fertilizers on the composition of alfalfa. Ames (14) found that the addition of lime to the soil increased the amount of phosphorus assimilated by the plant, and that phosphorus applied to the soil deficient in this element as measured by crop yield, increased the amount of phosphorus in the grain. Doak (17) found that the mineral content of lucerne was altered considerably by treatment with fertilizer. Larson (23) working with alfalfa found that the water soluble calcium content of the soils can be increased by the application of sulphur and calcium. Lipman and Blair (24) stated that the percentage of nitrogen in alfalfa increased gradually from the no lime plot to the plot receiving the most lime.

Considering the above authorities, it may be stated that the mineral content of the plants growing under field conditions in various localities is no way indicative of the mineral content of the soils upon which they are growing. And that in order to use the plant for such an indicator, it would be much better to grow it under controlled conditions. There is, however, some indication from the data in this experiment that there is a direct correlation between the amount of phosphorus in the plant and the available phosphorus in the soil.

In conclusion I might say that the proportion of the various elements that may be found in the plants depends thus upon numerous and varied factors, such as, the species of plant, type of soil, the distribution of roots, the rainfall, and general climatic conditions as well as the methods of fertilization and cultivation.

In the past the livestock feeders of Kansas and other states have been willing to pay a premium for alfalfa grown on soils with high mineral content, thinking that in this way they would obtain alfalfa with high mineral content. The data in this paper have definitely shown that the above is not true and that alfalfa hay obtained from a relatively poor soil may have a higher total mineral content than that obtained from a soil with a high mineral content.

SUMMARY

1. The calcium content of the sub-surface soil was found to be higher than that of the surface soils.

2. The nitrogen content of the surface soils was found to be higher than that of the sub-surface soils.

3. The majority of the soils showed a higher phosphorus content in the surface layer than in the sub-surface soils.

4. The so-called available phosphorus varied more than any other soil constituent.

5. There is no relationship between the total phosphorus of the soil and the available phosphorus.

6. There is no existing relationship between any of the constituents of the soil in this experiment.

7. The calcium and the phosphorus of the plant vary inversely, that is, as the calcium increases there is a decided decrease in the phosphorus.

8. The nitrogen content of the plant does not vary with changes in the calcium content. There is almost a constant calcium nitrogen ratio which varies from 0.450 to 0.786.

9. There is no apparent relationship between the phosphorus and nitrogen content of the plant.

10. There is no correlation between any of the constituents and the total ash content of the plant.

11. There is a direct correlation between the phosphorus in the plant and the available phosphorus in the soil.

12. The plant containing the greatest amount of calcium was grown on the soil containing the highest percentage of calcium, however, this correlation existed with no regularity in the other samples.

13. There is no indication from the data obtained, with the exception of available phosphorus, that any correlation existed between the mineral constituents of the soil and the composition of the plant.

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