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A study of the percentage and total intake of certain elements by calciphilic and calciphobic plants grown on soils varying in pH.

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A STUDY OF THE PERCENTAGE AND TOTAL INTAKE OF CERTAIN ELEMENTS BY CALCIPHILIC AND CALCIPHOBIC PLANTS GROWN ON SOILS VARYING IN pH

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A Study of the Percentage and Total Intake of Certain Elements by Calciphilic and Calciphobic Plants Grown on Soils Varying in pH

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Introduction

Ever since man began to till the soil, he has observed differences in it. As knowledge of the soil increased, many different properties were noticed. Some of these were ill-defined and many not defined at all, but they were brought to the attention of the student interested in soils and a remedy or partial remedy was found. One of the first characteristics to be observed, was referred to as "sourness" of the soil. The remedy for this condition has been the application of some form of calcium, either the carbonate or hydroxide form.

At the present time, "sourness" of the soil is referred to as acidity, while "sweetness" is spoken of as basicity, or alkalinity. Each is measured in terms of pH. Although the former soil condition has been known and a means for measuring the relative degree of acidity has been found, there is still a great deal of work to be accomplished before a satisfactory solution is obtained.

As previously stated, a partial remedy has been found in the use of lime, but a satisfactory answer for the differences in plant growth upon an acid soil and a basic soil, has not been given. Consequently, optimum returns are not to be had as yet, from soils having a comparatively high acidity.

It is essential that optimum returns, both quantitatively and qualitatively be obtained, inasmuch as man's existence depends upon plant and animal life. Further, animal life depends upon plant life, which makes the plant all important to the human race. It is a foregone conclusion that the quantity and quality of plant life is the foundation upon which it will decline or flourish in the future.

With these facts in mind, the following problem was undertaken in an attempt to learn more about the relative action of an acid and a basic soil upon plant growth.

The chemical composition of the plant was given especial attention inasmuch as it is essential from the nutritional standpoint, and as a comparative measure of the available plant food under the given conditions.

It was also the purpose of this investigation to determine the relative behavior of two groups of plants, namely, calciphilic, those producing optimum growth on high-calcium soils, and calciphobic, those producing optimum growth on soils relatively low in calcium.

Review of Literature

Contejean (4), 1881, classified over 1700 species of plants on the basis of their reaction to lime in soils under the three general heads, calciphile, calciphobe, and indifferent. Hilgard (16) later indicated that the broad distinction between lime-loving or calciphilic, and lime-repelled or calciphobic plants had been generally recognized and discussed, but the cause of this reaction by plants was more or less a subject of controversy. Wherry (39) pointed out that some plants may require a definite acidity or alkalinity, either for themselves or symbiotic organisms, while others may be favorably affected by some physical or chemical property of the soil, which, in turn, accompanies the development of that particular reaction. It is a well established fact that the reaction of the soil may affect the growth and yield of crops, either favorably or adversely. It has been demonstrated that individual species of plants may be successfully grown in soils exhibiting a range of pH variation as great as 3.5 pH units, yet the range of optimum growth is usually much smaller.

Truog (36), in working with cultivated plants in natural and artificial cultures, found that corn, the grains, and cowpeas grow relatively better at a more acid reaction than alfalfa, sweet clover, and Kentucky blue grass. However, results with the artificial cultures confirm the observations made when plants are grown in soil cultures, and leave not a doubt that so far as the reaction of soils is concerned, the most favorable range for the common agricultural plants is pH 6.0 to 8.0.

Hartwell and Damon (14) in long time experiments, have determined the effect of liming on different kinds of plants. Their results confirm those of Truog (35), Wherry (39), and other workers. Barley, alfalfa, sweet clover, and Kentucky blue grass are among the plants deriving the most benefit from liming. Oats, rye, redtop, and peanuts derive less benefit from liming.

Crist (5) found that heavy applications of lime greatly reduced the intake of calcium in certain plants. Hardenburg (13) also reported that there was some indication that the calcium content in lettuce tissue decreased with increasing pH values.

Naftel (29) made a study of the influence of lime on the growth and composition of Austrian peas, rape, sorghum, and vetch. He found that in the soils low in bases, crop yields were increased by liming, the per cent of calcium in the plant increased, and the percentage of magnesium, potassium, manganese, and iron decreased.

Horner (20) reported that, in the growth of soybeans as related to the total quantity of calcium at a constant hydrogen ion concentration, a good correlation existed between the calcium content and the total exchangeable calcium in the soil. There was a constant increase in the amount of calcium in the plants as the saturation by calcium increased, regardless of whether hydrogen, magnesium, barium, or potassium was used as the ion supplementary to the varying calcium saturation. The results also indicated that the two soil conditions which largely control the amount of calcium absorbed from the soil by the plant are, first, the actual quantity of calcium present in the available form, and second, the degree of saturation of the clay absorptive complex by this element. As the total amount of available calcium becomes greater at a constant degree of saturation, the rate of absorption by the plant becomes greater. Under the conditions of this investigation, an increase in the available calcium from a value of 0.05 milligram equivalents per plant to six times that value, was accompanied by an increase of over 250 per cent in the amount of calcium in the plants. The better growth and nodulation was directly related to this increase in the calcium absorption by the plants. On the other hand, if the total available supply remains constant and the degree of saturation of the colloidal complex by calcium is increased, there is an accompanied stimulation in calcium absorption and other accompanying plant activities.

Truog (35) in his studies on the effect of acid soil on plant growth pointed out that, in the majority of cases it appeared that the main specific harmful influence of soil acidity on certain plants is due to its influence in preventing those plants from getting, at a sufficiently rapid rate, the calcium as the carbonate or bicarbonate which is needed to neutralize and precipitate certain acids in the plants themselves, which are probably largely by-products produced as a result of certain vital reactions in the growth of plants. If calcium in these forms is not furnished at a sufficiently rapid rate, then the rate of those reactions is lowered accordingly as is also the rate of plant growth. The basis for this conclusion was the total calcium content of plants grown at various reactions which gave an increase in calcium content with an increase in pH. Hester and Shelton (15), Shive, Wadleigh, and Travis (34), Holtz (19), Iljin (22), and Zimmerly (40) found the same relationship to exist between the pH of the soil or culture medium and calcium content of the plant.

Hutchings (21) showed that calcium not only decreased soil acidity but also aided the soybean plant in making more tissue and tissue of a higher per cent content of nutrients. His idea as to the mechanism of this action was that the absorbed calcium affects the availability of the other elements because of its influence upon solubility. He is also of the opinion that the calcium may affect the plant directly by acting upon the cell membrane or cell contents in such a way as to make possible better entrance, retention, and utilization of the available nutrients.

Iljin (22) presented a very logical explanation for the high calcium content of plants usually encountered on limestone soils. He found a higher content of dissolved oxalic acid in plants grown on soil poor in calcium than in those grown on limestone soils. The latter specimens contained considerably more of the precipitated oxalate as well as higher total amounts of the acid. The reason for this may lie in the excessive rate of calcium intake on limestone soils and the eventual precipitation of the oxalate, which effected a continuous regeneration of the substance in the plant. Oxalic acid in its dissolved state is found only in a limited number of plants, which, as a rule, are found on soils low in calcium. High rates of calcium absorption stimulate precipitation and reduce proportionally the content of dissolved acids.

According to Miller (28) and others, magnesium is found in much smaller quantities in the plant, than is calcium. Exception to this can be taken only when the calcium content of the soil is extremely small and magnesium is added in comparatively large quantities (Albrecht and McCalla (1)). Naftel (29), in studying the influence of lime on the chemical composition of certain plants found that the percentage of magnesium was decreased by the application of lime to the soil. Hester and Shelton (15), working with three sandy coastal plain soils with reactions ranging from pH 3.9 to 7.6, found that the absorption of magnesium was quite uniform. Shive, Wadleigh and Travis (34) found that in corn plants grown in culture solutions ranging in pH from 3.0 to 8.0, the absorption of magnesium was highest at pH 8.0.

Nitrogen was found, by Emmert (8), to increase slightly in the tomato plant when grown on alkaline soils. He noted especially that a large total nitrogen content favored foliage growth. Naftel (29) found the same relationship to be true regarding foliage production with a slight decrease in total nitrogen on limed soils. He explained this by pointing out that the nitrogen level of the high pH soils was probably insufficient for the large increase in growth. Horner (20) was able to get a very good correlation between the quantities of total nitrogen and total calcium in the plant, each of which increased with an increasing calcium level. According to Dutcher and Haley (7), the differences in total nitrogen content of plants grown on soils varying in pH is evidently due to an increase in conditions favorable for the growth of nitrifying organisms.

Pierre and Robinson (30) have found no significant increase or decrease in the absorption of phosphorus by various plants when grown on soils varying in pH. Crist (5) found that heavy applications of lime greatly reduced the intake of phosphorus, whereas Emmert (8) showed that the phosphorus content in tomato fruit and leaves, was not consistent. In some cases lime applied to the soil decreased the phosphorus content of the plant. Naftel (29) reported that in working with light textured soils, the phosphorus content of the plant was lowered on limed soils but on the heavier textured soils, there was very little decrease due to liming. Hester and Shelton (15) found the absorption of phosphorus to be quite uniform on soil ranging in pH from 3.9 to 7.6.

Loehwing (23), in an extensive study of the effect of the calcium, potassium, and iron balance in the soil, on the growth and composition of wheat, corn, and clover, found that applications of lime diminished the potash content to a point of starvation. Dean (6) also found a similar trend in the relation of liming to the availability of potassium, but the results were not as severe. McCalla and Woodford (25) showed that by limiting calcium, the absorption of potassium by wheat seedlings in culture solutions was increased. Naftel (29) has presented results showing that lime applied to the soil reduced the potassium content in the plant.

Upon studying the data concerning the iron content of plants grown on soils circumneutral in reaction, it is evident that iron may be deficient as found by Gile (10), Gile and Carrero (12) and Bennett and Oserkowsky (2), or that it may be plentiful and comparatively superabundant, as found by Hoffer (17) and Mann (24). Carr and Brewer (3) have shown that ferric iron is precipitated as the hydroxide at pH 5.5, whereas ferrous iron begins to precipitate at pH 6.6 and precipitation is not complete until pH 7.9 is reached. It is evident, as Wallis (38) pointed out, that in order for iron to be rendered unavailable at circumneutral reactions, the potential of the soil must be such as to keep the iron in the ferric condition. Shive and Rogers (33) have found that in plants having tissue fluid of high pH, in general show low soluble iron content and low total iron content. They also indicated that the range of pH values over which iron precipitates in different plants, is wider than the corresponding range for inorganic systems.

Experimental

1. The Soil

The soil used in this experiment was a Chenango loam obtained along the Tuscarawas River in the State of Ohio. It was a second terrace soil derived from residual sandstone and shale. The profile consisted of a brown mellow topsoil, a yellow-brown friable subsoil, and a gravelly substrate below 20 to 30 inches. It was medium in fertility, low in reaction and extremely responsive to soil treatment.

Eight pounds of the air-dry soil were put into each of sixty one-gallon crocks. A base fertilizer consisting of 1.27 grams of urea, 2.45 grams of potassium phosphate, and 0.658 grams of potassium chloride, was added to each crock.

The sixty crocks were divided into two equal groups. For convenience these groups will be referred to as groups A and B. To each crock in group B was added 12.5 grams of calcium hydroxide.

The Veitch lime requirement method was used to determine the amount of calcium hydroxide necessary to raise the pH of the soil to 7.5. At this point, the two groups had received the same treatment except for the addition of calcium hydroxide to group B. The pH of group A was 4.4 and the pH of group B was 7.5. The soil was kept in a moist condition for two weeks prior to planting.

The crocks were then packed in sawdust and placed in small cars. The cars were on a track running in and out of the greenhouse so that the plants to be grown could be kept in the open when the weather permitted.

2. The Plants

The plants were selected on the basis of their sensitivity to acid soil. On this basis they may be classified as follows: calciphilic, those needing an abundance of calcium; calciphobic, those needing a comparatively small amount of calcium; and intermediate, those midway between the other two groups in their need for calcium. These plants are listed in Table 1.

Seed of the ten plants in Table 1 was planted in the crocks of group A and also of group B. By using thirty crocks in each group, three crocks of each plant were grown. After the seed had germinated, the seedlings were thinned, so that in the crocks of like plants there were an equal number of seedlings.

Table 1

1.	Barley*	Hardeum vulgare	calciphile
2.	Wheat*	Triticum vulgare	intermediate
3.	Oats*	Avena byzantina	calciphobe
4.	Sweet clover (annual)	Melilotus alba annua	calciphile
5.	Cowpeas	Vigna sinensis	intermediate
6.	Peanuts	Arachis hypogaea	calciphobe
7.	Kentucky blue	Poa pratensis	calciphile
8.	Timothy	Phleum pratense	intermediate
9.	Redtop	Agrostis alba	calciphobe
10.	Tomato	Lycopersicum esculentum	intermediate

Note: Although barley, wheat, and oats are of the grass family, they will be referred to as small grains, in order to differentiate between them and Kentucky blue, timothy, and redtop.

The plants were harvested, except for the grasses, at a comparable stage of maturity; the small grains at the early milk stage, sweet clover and peanuts past full bloom, cowpeas after the pod was fully formed but not filled out, and tomatoes when the first fruit began to develop. The grasses were clipped upon reaching a height of six inches. Three clippings were made in order that the length of the growing period would be comparable to that of the other plants.

Immediately after harvest, the plant material was weighed and dried in a steam oven until crisp. After securing the dry weight, the material was ground and put into tightly stoppered bottles.

3. Methods of Analysis

Analytical methods were selected for the determination of total ash, insoluble ash, calcium, magnesium, phosphorus, potassium, iron, and nitrogen in plant tissue.

The ashing procedure followed was the dry ashing method described in A.O.A.C. (27). Duplicate five-gram samples of plant material were ignited and the ash weighed as total ash. It was then extracted with hydrochloric acid, the silica rendered insoluble by heating on a steam bath, and the extract filtered into a 250 milliliter volumetric flask. After making to volume, aliquot quantities were taken out for the determination of calcium, magnesium, phosphorus, potassium, and iron. The insoluble material remaining on the filter paper after filtering was ignited and weighed as insoluble ash.

Determination of Calcium

The calcium procedure was essentially that of McCrudden (26). The principle of this method involves the precipitation of calcium as calcium oxalate. The oxalate is then titrated with standard potassium permanganate.

Determination of Magnesium

Magnesium was determined by the use of 8-hydroxyquinoline exactly as described by Redmond and Bright (31). In this procedure, magnesium is precipitated by 8-hydroxyquinoline as magnesium oxyquinolate. The precipitate is then dissolved in hydrochloric acid. To this solution is added a standard solution of potassium bromate-bromide which reacts with the hydrochloric acid liberating free bromine. The free bromine reacts with the 8-hydroxyquinoline in solution forming di-bromo hydroxy quinolate. Upon addition of a potassium iodide solution, the excess free bromine is replaced with free iodine which is titrated with a standard solution of sodium thiosulfate.

Determination of Potassium

The method used in the determination of potassium was the colorimetric method of Emmert (9), in which cobaltinitrite is employed as the precipitating agent of potassium. The principle of the determination consists in measuring colorimetrically the change in strength of the precipitating agent, sodium cobaltinitrite.

Determination of Phosphorus

Phosphorus was determined colorimetrically by a modification of Denige's method as proposed by Truog and Meyer (37). The principle of this method consists in reducing the molybdenum combined in ammonium phosphomolybdate to molybdenum blue by the action of stannous chloride. The resulting blue color is compared in a colorimeter with the color developed by a standard containing a known amount of phosphorus.

Determination of Nitrogen

The Kjeldahl-Gunning-Arnold method modified to include nitrogen of nitrates was used to determine total nitrogen. The method as outlined in A.O.A.C. (27) consists in digesting a sample of plant material in a sulfuric-salicylic acid mixture, using copper sulfate as a catalytic agent. This completely oxidizes the carbon and hydrogen, and converts the nitrogen into ammonia which is held by the sulfuric acid as ammonium sulfate. The acid solution is diluted with water, an excess of sodium hydroxide added, and the resultant ammonia distilled into a measured quantity of standard acid. The excess acid is determined by titrating with standard sodium hydroxide.

Determination of Iron

Iron was determined as proposed by Holland (18). In this procedure, an aliquot quantity of the plant material in solution is oxidized to the ferric salt. A colored iron salt, $Fe(CNS)_3$, is produced with potassium sulphocyanate which is compared with a standard iron solution in which the color has been developed in the same manner.

Plate 1

Barley		Wheat		Oats	
Acid Soil	Basic Soil	Acid Soil	Basic Soil	Acid Soil	Basic Soil

Date of Seeding

June 15, 1938
Acid soil pH-(B) 4.4, (W) 4.6, (O) 4.4.
Basic soil pH-(B) 7.6, (W) 7.2, (O) 7.3.

Date of Harvest

August 1, 1938
Acid soil pH-(B) 4.3, (W) 4.5, (O) 4.4.
Basic soil pH-(B) 7.2, (W) 7.0, (O) 7.2.

Barley: The plants on the basic soil were slightly taller and larger in diameter than those on the acid soil. However, these differences tended to disappear during the two weeks previous to harvest.

Wheat: The growth on the two soils was equal in height until head formation began. The plants on the acid soil produced more lateral growth than those on the basic soil, as shown above.

Oats: The plant growth was the same on both soils, however, the leaves of the plants on the acid soil were more numerous at base of plant than at top.

Plate 2

Sweet Clover
Acid Soil   Basic Soil

Date of Seeding	Date of Harvest
June 15, 1938	August 20, 1938
Acid soil pH-4.5	Acid soil pH-4.1
Basic soil pH-7.2	Basic soil pH-6.8

The plant growth was uniform and equal among the plants on the two soils for the first four weeks. After that time, the plants on the acid soil grew rather slowly and at blossom time, were smaller and much less hardy than the plants on the basic soil.

Plate 3

Cowpeas

Acid Soil   Basic Soil

Date of Seeding	Date of Harvest
June 15, 1938	August 20, 1938
Acid soil pH-4.3	Acid soil pH-4.2
Basic soil pH-7.5	Basic soil pH-7.1

The plants on the acid soil grew faster, were larger and more vigorous throughout the growing season. Two weeks previous to harvest, they appeared to stop growing and their characteristic dark color began to fade. The growth of the plants on the basic soil continued normally until harvest so that they approached the plants on the acid soil in size and vigor. The foliage remained a dark green throughout the growing period.

Note: The light color of the plants on the basic soil, as shown in the picture, is due to imperfect photography.

Plate 4

Peanuts
Acid Soil   Basic Soil

Date of Seeding	Date of Harvest
June 15, 1938	August 20, 1938
Acid soil pH-4.4	Acid soil pH-4.2
Basic soil pH-7.2	Basic soil pH-6.7

The plants on both soils grew at the same rate for the first three weeks. After that time, the plants on the acid soil grew faster than did the plants on the basic soil. The plants on both soils maintained a dark green color.

Plate 5

Tomato
Acid Soil   Basic Soil

Date of Seeding	Date of Harvest
June 15, 1938	August 20, 1938
Acid soil pH-4.4	Acid soil pH-4.3
Basic soil pH-7.1	Basic soil pH-6.9

The plant growth on the acid soil was not so uniform as the growth on the basic soil. The plants on the basic soil were uniform and healthy throughout their period of growth. Although the plants on the acid soil started faster, several grew rather poorly, were a lighter green, and tended to send out roots from the stalk.

The Grasses

Kentucky Blue-Redtop-Timothy

Date of Seeding		Date of Harvest
June 15, 1938		July 15, 1938 August 1, 1938 August 25, 1938
Acid Soil		Acid Soil
pH-4.4	Kentucky Blue	pH-4.3
pH-4.5	Timothy	pH-4.4
pH-4.5	Redtop	pH-4.4
Basic Soil		Basic Soil
pH-7.4	Kentucky Blue	pH-7.3
pH-7.3	Timothy	pH-7.2
pH-7.2	Redtop	pH-6.9

The plants on both the acid and the basic soil appeared to grow equally well. The growth on the basic soil was slightly faster after the grass was clipped.

Experimental Results and Discussion

Table 2

The Green and Dry Weights, and Percentage of Moisture of the Plants Grown on Acid and Basic Soils

Plants		Green Weight In Grams	Dry Weight In Grams	Moisture In Per cent
Barley	A	219	39	82.19
	B	346	45	86.99
Wheat	A	189	34	82.01
	B	210	34	83.80
Oats	A	313	43	86.26
	B	358	44	87.70
Sweet clover	A	89	15	83.15
	B	165	34	79.39
Cowpeas	A	599	109	81.80
	B	601	92	84.69
Peanuts	A	281	52	81.49
	B	121	21	82.64
Kentucky blue	A	119	21	82.35
	B	108	18	83.33
Timothy	A	126	16	87.30
	B	121	17	85.95
Redtop	A	147	20	86.39
	B	133	34	74.44
Tomato	A	504	72	85.71
	B	670	102	84.78

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

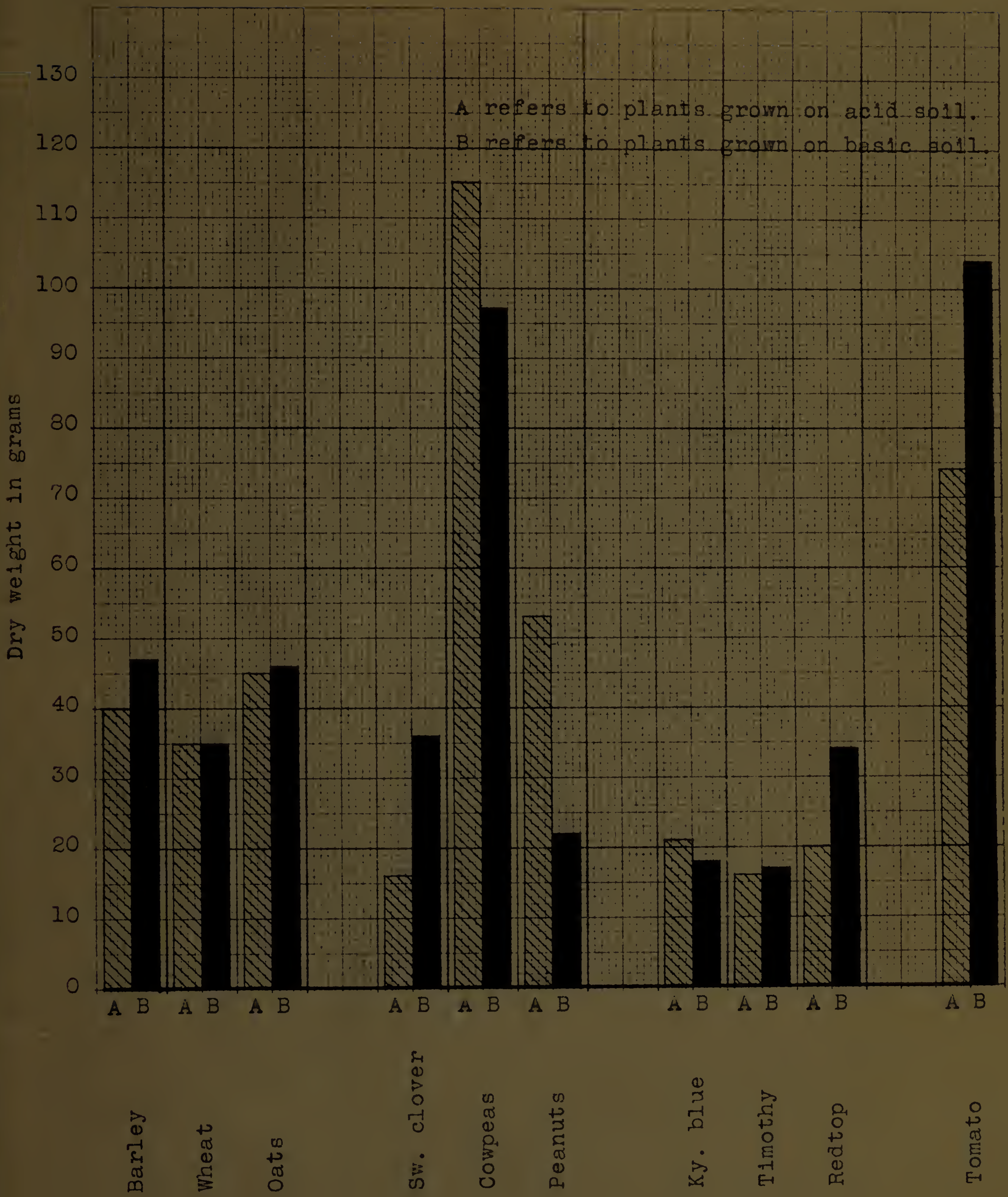

Figure 1

The dry weight in grams of certain plant species grown on acid and basic soils on dry matter basis.

Table 3

Percentage Composition of the Total Ash in Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Per Cent Ash	Per Cent Insoluble Ash	Per Cent Ca	Per Cent Mg	Per Cent N	Per Cent P	Per Cent K	PPM Fe
Barley	A	12.06	1.57	.23	.12	2.88	.48	2.18	168
	B	13.51	.82	.82	.17	3.16	.45	2.04	120
Wheat	A	13.18	1.93	.27	.15	2.83	.44	2.50	282
	B	13.93	2.41	.50	.18	3.34	.48	1.96	346
Oats	A	12.92	1.52	.21	.16	2.72	.53	2.66	124
	B	12.85	.76	.78	.20	2.86	.45	1.56	146
Sweet clover	A	11.64	.36	1.27	.41	2.92	.18	2.81	136
	B	11.32	.27	1.97	.25	2.86	.25	2.49	155
Cowpeas	A	6.64	1.04	.66	.24	.93	.22	3.36	130
	B	8.97	.55	1.88	.38	1.49	.16	3.32	158
Peanuts	A	10.22	.95	.77	.40	2.91	.26	2.48	157
	B	13.39	1.32	2.51	.42	3.20	.24	2.74	196
Kentucky blue	A	9.33	1.89	.36	.20	3.23	.35	2.56	143
	B	11.17	2.02	1.00	.22	3.30	.33	2.64	183
Timothy	A	11.37	1.60	.25	.13	4.36	.54	2.02	147
	B	14.77	3.29	.96	.21	4.94	.47	2.44	427
Redtop	A	13.03	1.93	.28	.27	4.88	.61	1.79	157
	B	14.40	2.90	1.09	.23	4.96	.50	2.43	383
Tomato	A	8.50	1.38	.43	.15	1.96	.16	3.03	199
	B	12.34	1.18	1.98	.22	2.01	.19	3.27	182

A refers to the plant material grown on acid soil.
B refers to the plant material grown on basic soil.

Table 4

Weight of the Total Ash Constituents in Plant Material
Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Grams Ash	Grams Insoluble Ash	Grams Ca	Grams Mg	Grams N	Grams P	Grams K	PPM Fe
Barley	A	4.7034	.6123	.0897	.0468	1.1232	.1872	.8502	6552
	B	6.0795	.3690	.3690	.0765	1.4220	.2025	.9180	5400
Wheat	A	4.4812	.6562	.0918	.0510	.9622	.1496	.8500	9588
	B	4.7362	.8194	.1700	.0612	1.1356	.1612	.6664	11764
Oats	A	5.5556	.6536	.0903	.0688	1.1696	.2279	1.1438	5332
	B	5.6540	.3344	.3432	.0980	1.2584	.1980	.6864	6424
Sweet clover	A	1.7460	.0540	.1905	.0615	.4380	.0270	.4215	2040
	B	3.8488	.0918	.6698	.0850	.9724	.0850	.8466	5270
Cowpeas	A	7.2576	1.1336	.7194	.2616	1.0137	.2398	3.6624	14170
	B	8.2024	.5060	1.7296	.3496	1.3708	.1472	3.0544	14536
Peanuts	A	5.3144	.4940	.4004	.2080	1.5132	.1352	1.2896	8164
	B	2.8119	.2772	.5271	.0882	.6720	.0504	.5754	4116
Kentucky blue	A	1.9593	.3969	.0756	.0420	.6783	.0735	.5376	3003
	B	2.0106	.3636	.1800	.0396	.5940	.0594	.4752	3294
Timothy	A	1.8192	.2560	.0400	.0208	.6976	.0864	.3232	2352
	B	2.5109	.5593	.1632	.0358	.8398	.0799	.4148	7259
Redtop	A	2.6060	.3860	.0560	.0540	.9760	.1220	.2580	3140
	B	4.8960	.9860	.3706	.0782	1.6864	.1700	.8262	13022
Tomato	A	6.1200	.9936	.3096	.1080	1.4112	.1296	2.1816	14328
	B	12.5868	1.2036	2.0196	.2244	2.0502	.1938	3.3354	18564

A refers to the plant material grown on acid soil.
B refers to the plant material grown on basic soil.

Table 5

The Percentage and Weight of Total Ash and Acid Insoluble Ash in Plants Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Per Cent Total Ash	Grams Total Ash	Per Cent Insoluble Ash	Grams Insoluble Ash
Barley	A	12.06	4.7034	1.57	.6123
	B	13.57	6.0795	.82	.3690
Wheat	A	13.18	4.4812	1.93	.6562
	B	13.93	4.7362	2.41	.8194
Oats	A	12.92	5.5556	1.52	.6536
	B	12.85	5.6540	.76	.3344
Sweet clover	A	11.64	1.7460	.36	.0540
	B	11.32	3.8488	.27	.0918
Cowpeas	A	6.64	7.2576	1.04	1.1336
	B	8.97	8.2524	.55	.5060
Peanuts	A	10.22	5.3144	.95	.4940
	B	13.39	2.8119	1.32	.2772
Kentucky blue	A	9.33	1.9593	1.89	.3969
	B	11.17	2.0106	2.02	.3636
Timothy	A	11.37	1.8192	1.60	.2560
	B	14.77	2.5109	3.29	.5593
Redtop	A	13.03	2.6060	1.93	.3860
	B	14.40	4.8960	2.90	.9860
Tomato	A	8.50	6.1200	1.38	.9936
	B	12.34	12.5868	1.18	1.2036

A refers to the plants grown on acid soil.
B refers to the plants grown on basic soil.

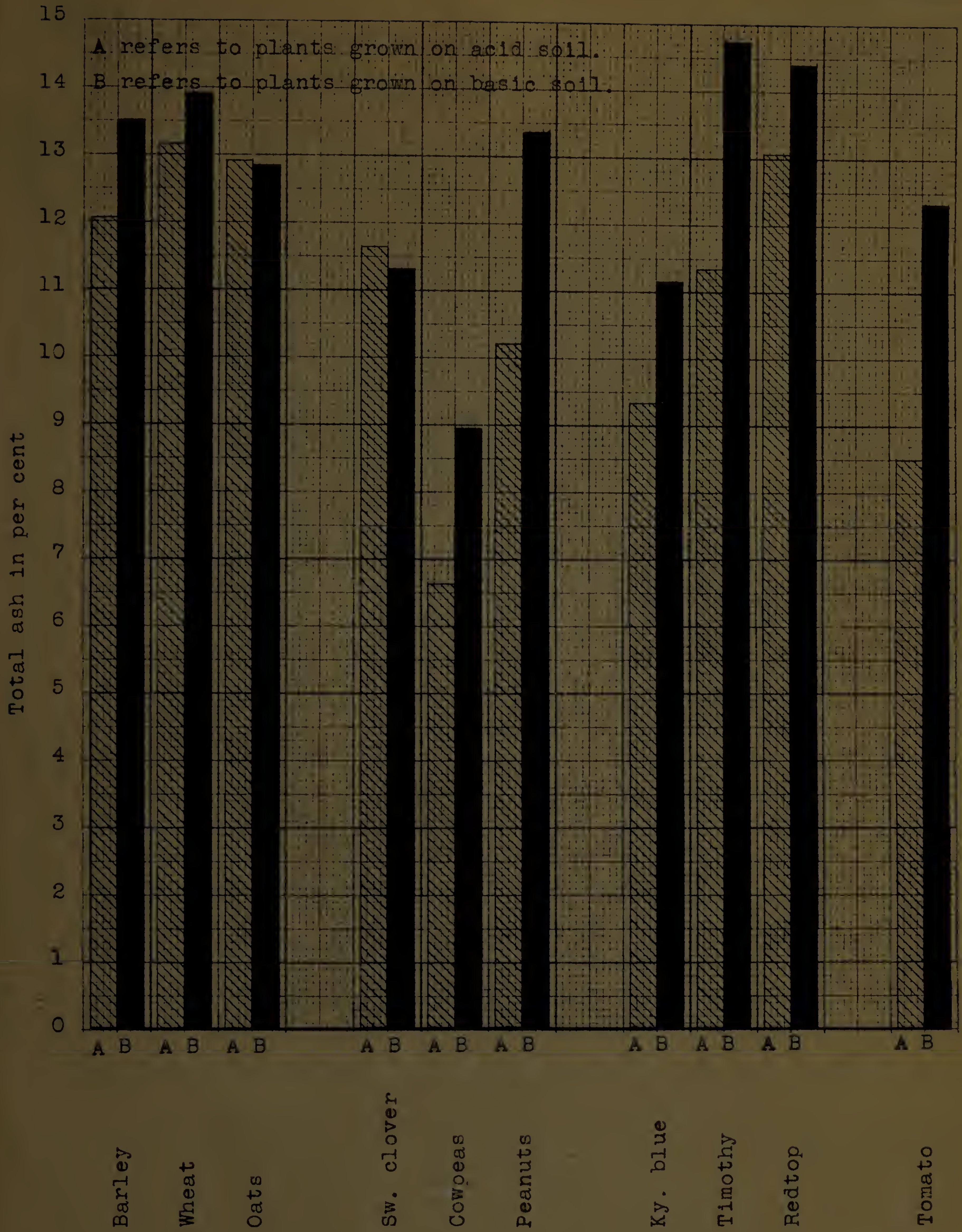

Figure 2

The percentage of total ash in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

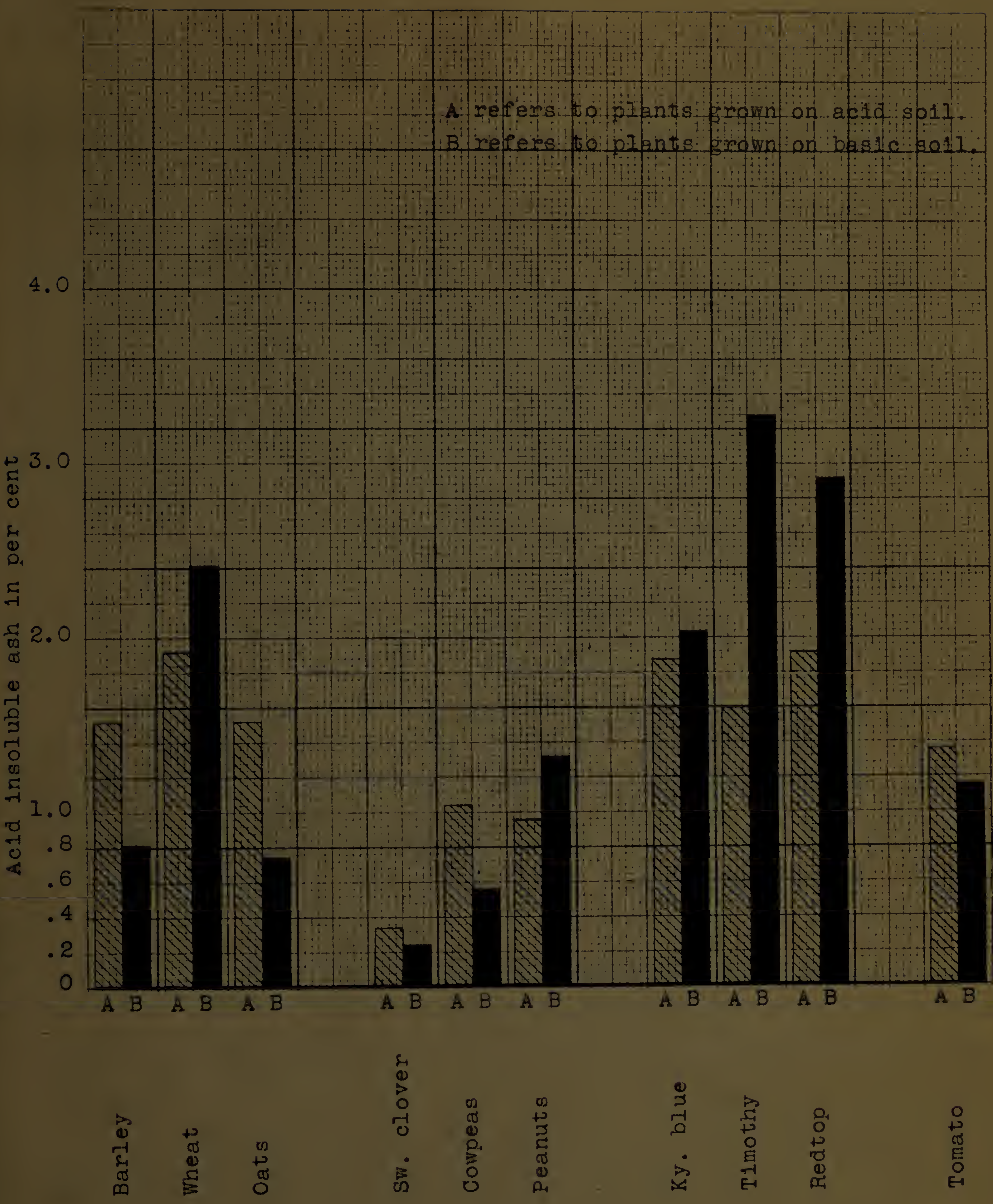

Figure 3

The percentage of acid insoluble ash in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

The percentage of ash was significantly higher in barley, wheat, cowpeas, peanuts, Kentucky blue, timothy, redtop, and tomato on the basic soil. Oats and sweet clover contained a slightly higher ash content on the acid soil, but the difference was not considered significant. In general, the grasses presented the most consistent increase in ash content on the basic soil, and the legumes, with the exception of sweet clover, the greater percentage and total increase. The plants classed as intermediates-wheat, cowpeas, timothy, and tomato were the most consistent in their increase of total ash of the basic soil. There was no significant difference between the calciphilic and calciphobic plants in this respect.

It is quite evident from these results that the ash content of the various plants was increased by the addition of calcium. This is substantiated by the results of Gile and Ageton (11) who found that the total carbon-free ash was increased in bush beans, soybeans, radishes, and sunflowers grown on soils that had been treated with calcium carbonate.

There was no correlation in per cent or total insoluble ash of the plants grown on the acid or basic soil. However, there was an indication that the per cent insoluble ash was highest in the grasses-Kentucky blue, timothy, and redtop, and the small grains-barley, wheat, and oats contained a higher percentage than did the legumes-sweet clover, cowpeas, and peanuts. In relation to the other two groups the small grains contained the highest total amount of insoluble ash. The grasses contained a higher total amount than did the legumes.

Table 6

Plant Weight, Percentage of Calcium, and Total Calcium Content of Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Weight In Grams	Per Cent Calcium	Grams Calcium
Barley	A	39	.23	.0897
	B	45	.82	.3690
Wheat	A	34	.27	.0918
	B	34	.50	.1700
Oats	A	43	.21	.0903
	B	44	.78	.3432
Sweet clover	A	15	1.27	.1905
	B	34	1.97	.6698
Cowpeas	A	109	.66	.7194
	B	92	1.88	1.7296
Peanuts	A	52	.77	.4004
	B	21	2.51	.5271
Kentucky blue	A	21	.36	.0756
	B	18	1.00	.1800
Timothy	A	16	.25	.0400
	B	17	.96	.1632
Redtop	A	20	.28	.0560
	B	34	1.09	.3706
Tomato	A	72	.43	.3096
	B	102	1.98	2.0196

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

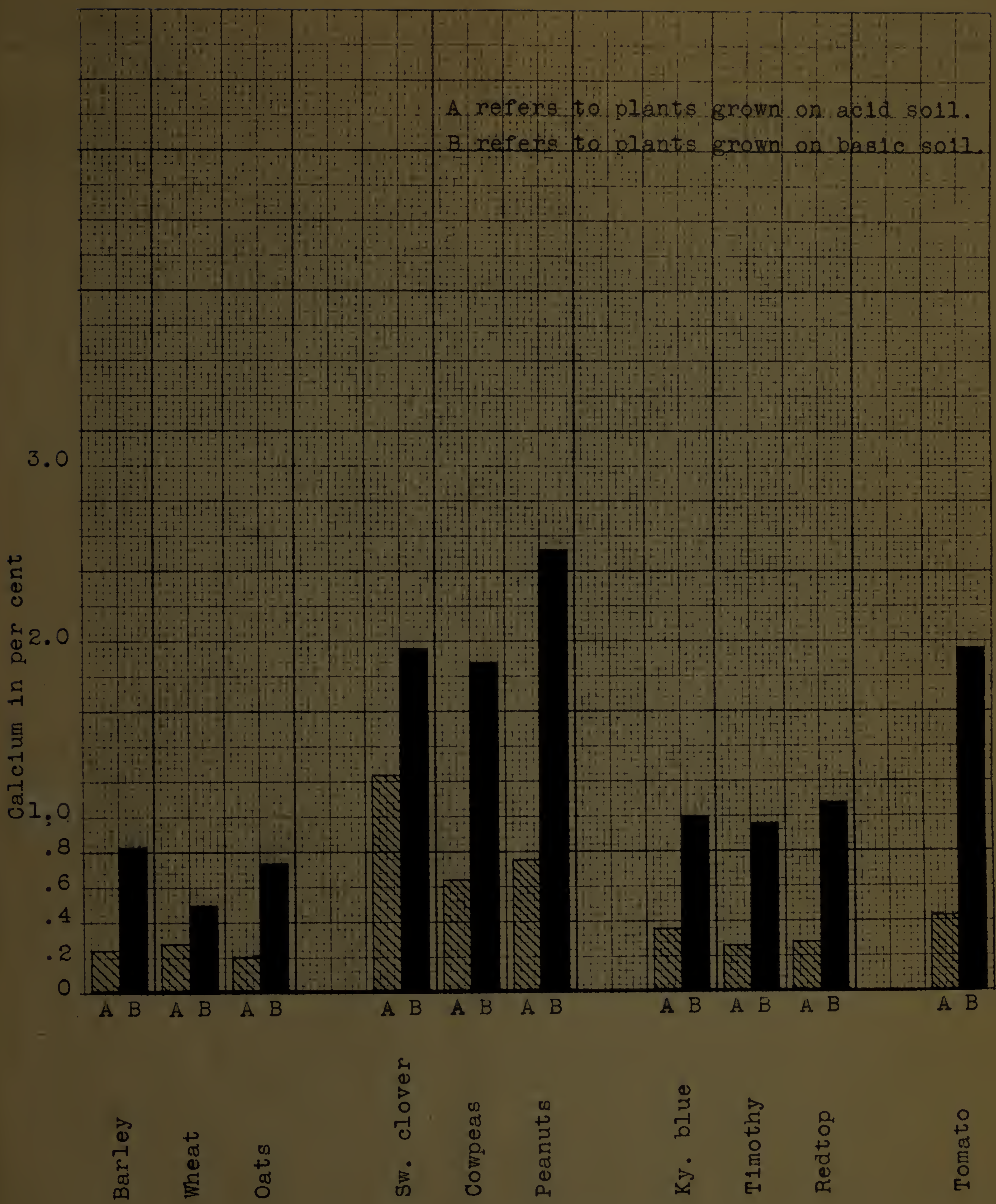

Figure 4

The percentage of calcium in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

The percentage of calcium increased in all plants grown on the basic soil. The highest percentage total calcium was found in the legumes on both the acid and basic soil. The grasses contained the next highest percentage and total calcium, and the small grains contained the lowest amounts of the three groups. The intake of calcium by tomato corresponded closely to the intake by the legumes. On the percentage basis, calcium increased from one to four times in the plants grown on the basic soil. The total amount of calcium in the plant material harvested, increased from one to six times in the plants on the basic soil. Iljin (22) reported an increase from one to seven times among plants grown on calcareous soils. In comparing the percentage of calcium and the total calcium in the various plants, it is evident that there is a tendency toward a luxury consumption of calcium, especially in the peanut plants.

In general, these data support those of Hutchings (21) in that calcium added to the soil not only decreases soil acidity, but also aids the plant in producing more tissue, and tissue of a higher percentage content of calcium.

Table 7

Plant Weight, Percentage of Magnesium, and Total Magnesium Content of Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Weight In Grams	Per Cent Magnesium	Grams Magnesium
Barley	A	39	.12	.0468
	B	45	.17	.0765
Wheat	A	34	.15	.0510
	B	34	.18	.0612
Oats	A	43	.16	.0688
	B	44	.20	.0880
Sweet clover	A	15	.41	.0615
	B	34	.25	.0850
Cowpeas	A	109	.24	.2616
	B	92	.38	.3496
Peanuts	A	52	.40	.2080
	B	21	.42	.0882
Kentucky blue	A	21	.20	.0420
	B	18	.22	.0396
Timothy	A	16	.13	.0208
	B	17	.21	.0358
Redtop	A	20	.27	.0540
	B	34	.23	.0782
Tomato	A	72	.15	.1080
	B	102	.22	.2244

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

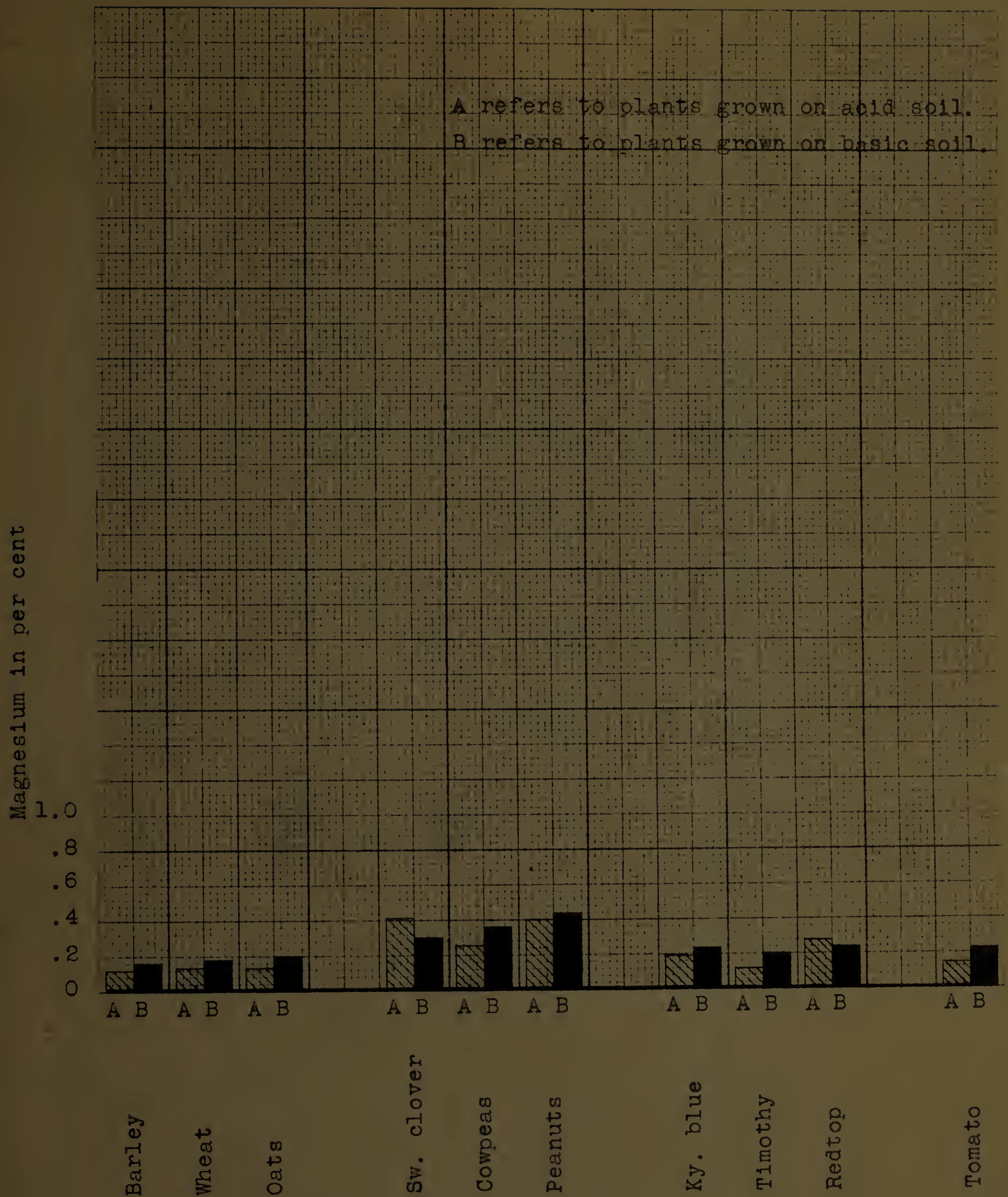

Figure 5

The percentage of magnesium in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

In general, the plants grown on the basic soil contained a higher percentage content of magnesium than did the plants grown on the acid soil. Only sweet clover and redtop contained a higher percentage of the acid soil. In the absorption of magnesium, the three groups of plants show the same general trend as was shown in the absorption of calcium, namely, the legumes absorbed the highest percentages of magnesium from the soil and the small grains the lowest. The tomatoes contained approximately the same percentage of magnesium as did the grasses.

In terms of the total amount of magnesium in the plant tissue, the legumes, in general, contained the highest amounts and the grasses the lowest. The content in tomatoes was analogous to that of the legumes. Peanuts and Kentucky blue grass contained a higher total content on the acid soil.

On both the percentage and total weight basis, the calciphilic, intermediate, and calciphobic plants contained a higher content of magnesium on the basic soil. The intermediate plants-wheat, cowpeas, timothy, and tomato were most outstanding in this respect.

Table 8

Plant Weight, Percentage of Nitrogen, and Total Nitrogen Content of Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Weight In Grams	Per Cent Nitrogen	Grams Nitrogen
Barley	A	39	2.88	1.1232
	B	45	3.16	1.4220
Wheat	A	34	2.83	.9622
	B	34	3.34	1.1356
Oats	A	43	2.72	1.1696
	B	44	2.86	1.2584
Sweet clover	A	15	2.92	.4380
	B	34	2.86	.9724
Cowpeas	A	109	.93	1.0137
	B	92	1.49	1.3708
Peanuts	A	52	2.91	1.5132
	B	21	3.20	.6720
Kentucky blue	A	21	3.23	.6783
	B	18	3.30	.5940
Timothy	A	16	4.36	.6976
	B	17	4.94	.8398
Redtop	A	20	4.88	.9760
	B	34	4.96	1.6864
Tomato	A	72	1.96	1.4112
	B	102	2.01	2.0502

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

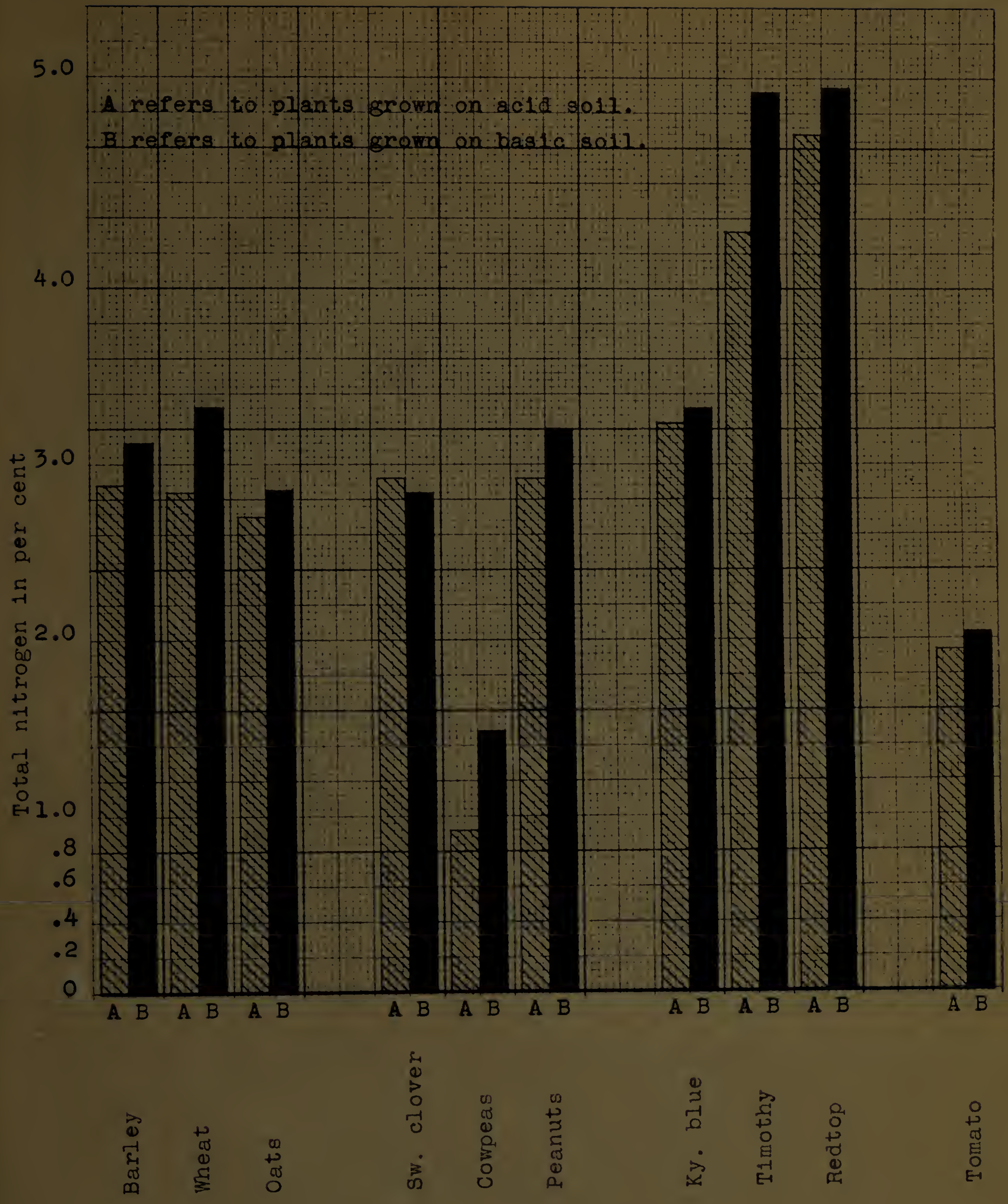

Figure 6

The percentage of total nitrogen in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

The total nitrogen on the percentage basis was higher in the plants grown on the basic soil except for sweet clover. Among the different groups the grasses contained the highest percentage of total nitrogen. Timothy and redtop were especially high. No significant differences were found in the content of the small grains and legumes except for cowpeas. No explanation can be given at present for the relatively low content. The tomatoes also contained comparatively low total nitrogen content. However, in the case of cowpeas and tomatoes, growth did not appear to be abnormal in any way.

In the oven-dry plant tissue, the small grains-barley, wheat, and oats contained the highest total amount of nitrogen. The grasses-Kentucky blue, timothy, and redtop, contained the lowest total amounts. The content in tomato tissue was comparable to that in the small grains.

The plants classed as intermediates-wheat, cowpeas, timothy, and tomato, gave the most consistent increase in total nitrogen content on the basic soil.

Table 9

Plant Weight, Percentage of Phosphorus, and Total Phosphorus Content of Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Weight In Grams	Per Cent Phosphorus	Grams Phosphorus
Barley	A	39	.48	.1872
	B	45	.45	.2025
Wheat	A	34	.44	.1496
	B	34	.48	.1612
Oats	A	43	.53	.2278
	B	44	.45	.1980
Sweet clover	A	15	.18	.0270
	B	34	.25	.0850
Cowpeas	A	109	.22	.2398
	B	92	.16	.1472
Peanuts	A	52	.26	.1352
	B	21	.24	.0504
Kentucky blue	A	21	.35	.0735
	B	18	.33	.0594
Timothy	A	16	.54	.0864
	B	17	.47	.0799
Redtop	A	20	.61	.1220
	B	34	.50	.1700
Tomato	A	72	.18	.1296
	B	102	.19	.1938

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

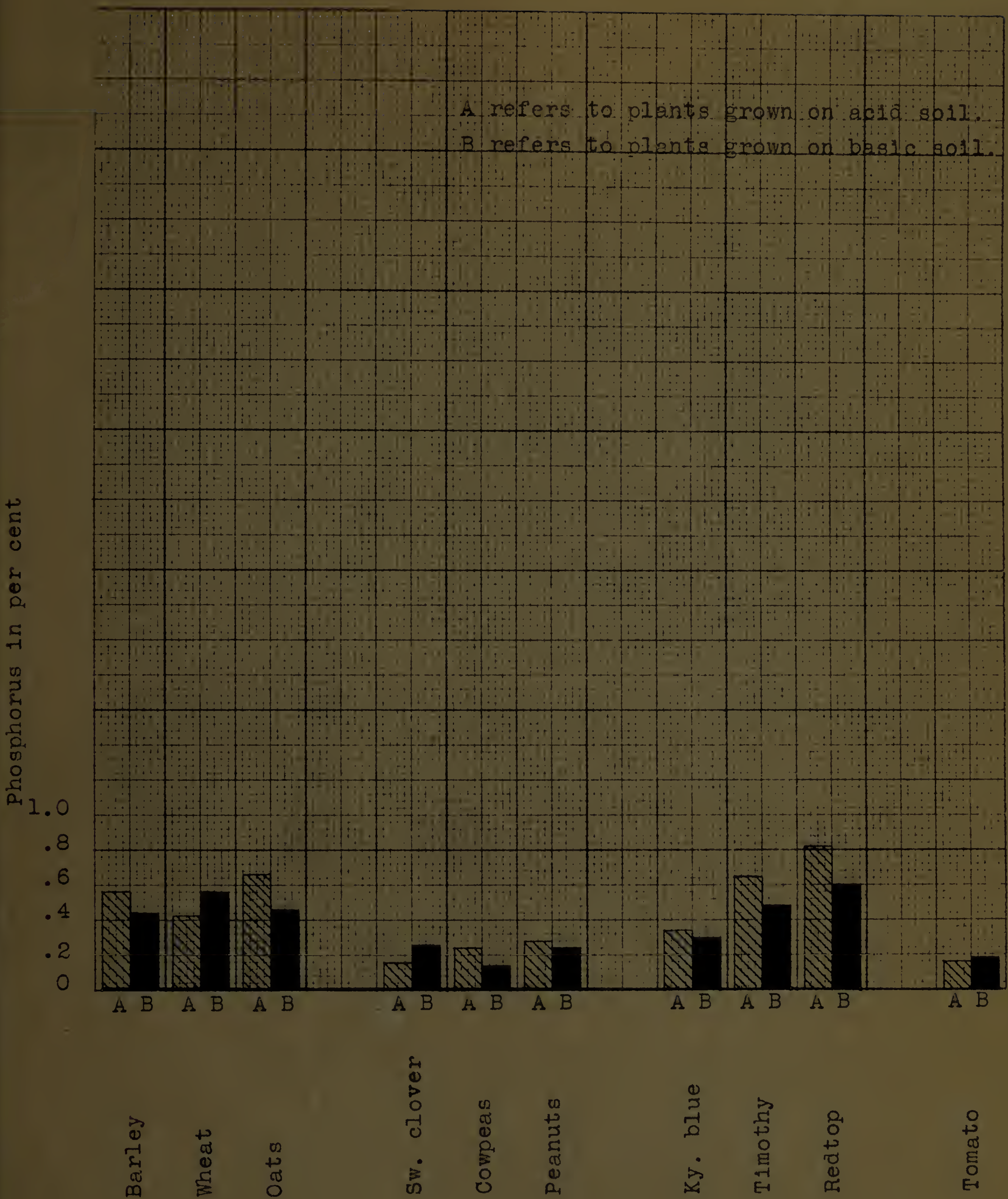

Figure 7

The percentage of phosphorus in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

The percentage increase in phosphorus was greater in barley, oats, cowpeas, peanuts, Kentucky blue, timothy, and redtop when grown on the acid soil than when grown on the basic soil. The difference in the content of tomatoes on the two soils was not significant. Wheat and sweet clover gave a greater percentage increase on the basic soil. The phosphorus content of the small grains-barley, wheat, and oats, was of the same relative magnitude as that of the grasses-Kentucky blue, timothy, and redtop, whereas the content of the legumes was much lower.

On the basis of the total phosphorus content of the different plant tissues, there was no correlation between the tissue content on either soil. The phosphorus content of the plants was, in general, inconsistent.

A correlation of any significance could not be found to exist between the calciphilic, intermediate or calciphobic plants.

Table 10

Plant Weight, Percentage of Potassium, and Total Potassium Content of Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Weight In Grams	Per Cent Potassium	Grams Potassium
Barley	A	39	2.18	.8502
	B	45	2.04	.9180
Wheat	A	34	2.50	.8500
	B	34	1.96	.6664
Oats	A	43	2.66	1.1438
	B	44	1.56	.6864
Sweet clover	A	15	2.81	.4215
	B	34	2.49	.8466
Cowpeas	A	109	3.36	3.6624
	B	92	3.32	3.0544
Peanuts	A	52	2.48	1.2896
	B	21	2.74	.5754
Kentucky blue	A	21	2.56	.5376
	B	18	2.64	.4752
Timothy	A	16	2.02	.3232
	B	17	2.44	.4148
Redtop	A	20	1.79	.2580
	B	34	2.43	.8262
Tomato	A	72	3.03	2.1816
	B	102	3.27	3.3354

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

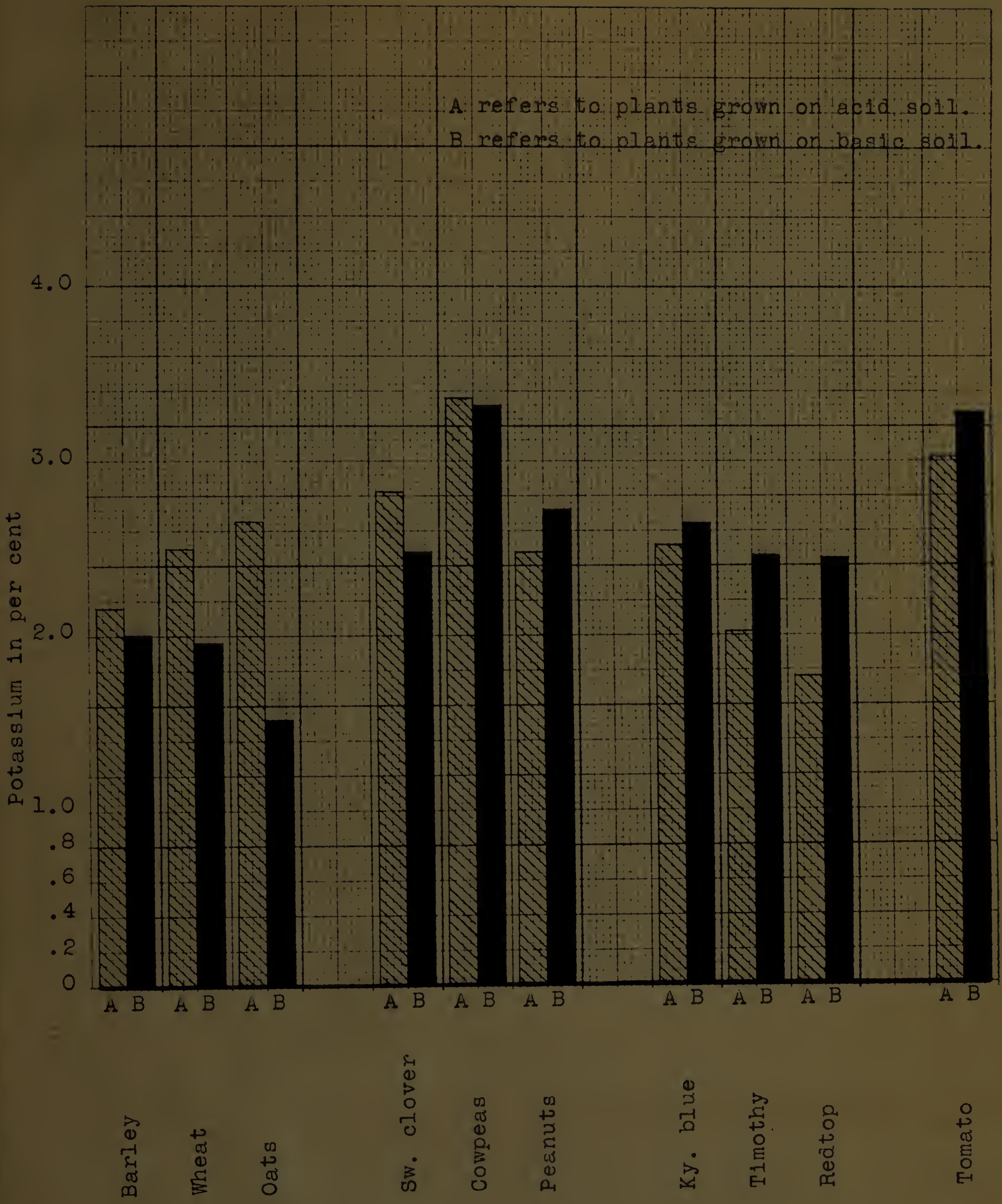

Figure 8

The percentage of potassium in the tissue of certain plant species grown on acid and basic soils on dry matter basis.

Potassium was the only element determined that did not show any general trend in the plants as a whole. Among the small grains-barley, wheat, and oats, the percentage of potassium was higher in the plants grown on the acid soil, whereas among the grasses-Kentucky blue, timothy, and redtop, the percentage of potassium was higher in the plants on the basic soil. The legumes were extremely inconsistent in their percentage intake of potassium, with the percentage being lower on the basic soil for sweet clover, and higher on the basic soil for peanuts. The difference between the percentage intake by cowpeas on the two soils was not significant. The intake of potassium by the tomato plants was high on both soils; the greater intake was by the plants on the basic soil.

The total amount of potassium found in the plant is of especial enterest. From a study of the total amounts in the plant tissues (Table 10), it is evident that several of the plants-oats, cowpeas, and tomatoes, absorbed a relatively great amount of potassium. These data indicate that the calcium hydroxide added to the soil did not greatly affect the availability of potassium.

There was no significant correlation found to exist between the calciphilic, intermediate and calciphobic plants.

Table 11

Iron Content in Parts Per Million (Gram and Total Weight Bases) and Weight of Plant Material Grown on Acid and Basic Soils, on Dry Matter Basis

Plants		Weight In Grams	P.P.M. Fe per Gram	P.P.M. Fe per Total Weight
Barley	A	39	168	6552
	B	45	120	5400
Wheat	A	34	282	9588
	B	34	346	11764
Oats	A	43	124	5332
	B	44	146	6424
Sweet clover	A	15	136	2040
	B	34	155	5270
Cowpeas	A	109	130	14170
	B	92	158	14536
Peanuts	A	52	157	8164
	B	21	196	4116
Kentucky blue	A	21	143	3003
	B	18	183	3294
Timothy	A	16	147	2352
	B	17	427	7259
Redtop	A	20	157	3140
	B	34	383	13022
Tomato	A	72	199	14328
	B	102	182	18564

A refers to plant material grown on acid soil.
B refers to plant material grown on basic soil.

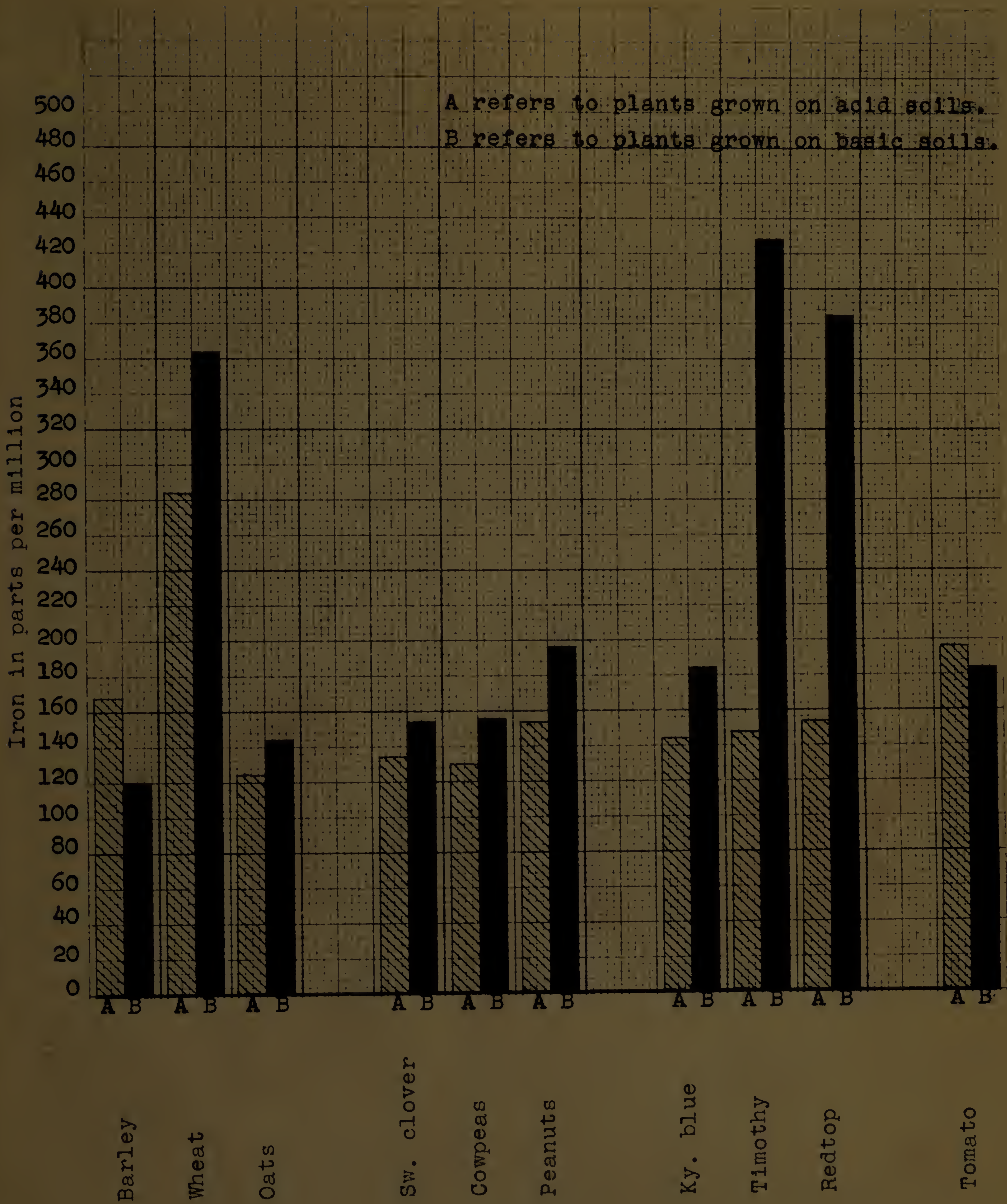

Figure 9

The parts per million of iron in one gram of plant tissue grown on acid and basic soils on dry matter basis.

The intake of iron in terms of parts per million, in general, was found to increase in the plants on the basic soil. The plants in which iron was lower on the basic soil were barley and tomatoes. With the exception of wheat, timothy, and redtop, the iron content was uniform throughout. No significant differences were found in the small grains, legumes, or grasses.

In general, the total amount of iron was greater in the tissue of plants grown on the basic soil. However, peanuts and barley, on the contrary, showed a greater total intake of iron on the acid soil. This may be explained on the basis of the weight of plant tissue produced on the acid and basic soil. Peanuts produced much more growth on the acid soil than on the basic.

Here again, as noted before, the calciphilic and calciphobic plants are relatively inconsistent in their intake of elements. The intermediate plants definitely have a greater intake on the basic soil. Both of these statements are true of the behavior of iron.

Summary

The object of this investigation was to determine the relative intake of elements by calciphilic, intermediate, and calciphobic plants when grown on soils varying in pH.

Nine important agronomic crop plants and one vegetable were grown in crocks of soil of pH 4.4 and 7.2. These plants were analyzed for total ash, insoluble ash, calcium, magnesium, nitrogen, phosphorus, potassium, and iron.

On the basis of the data obtained, it may be concluded that the total ash and the intake of calcium, magnesium, nitrogen, and iron increased in the plant when calcium hydroxide was added to the acid soil to raise the pH. In general, the intake of phosphorus decreased with the addition of calcium. Potassium increased or decreased depending largely upon the species of plant grown. The plants grouped as intermediates were consistent in their intake of elements. The calciphobic plants were comparatively consistent and the calciphiles indicated a great variance in their absorption of elements.

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