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Studies of methods for determination of magnesium deficiency in soils

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STUDIES OF METHODS FOR DETERMINATION OF MAGNESIUM DEFICIENCY IN SOILS

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by

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Introduction

It has been known for more than seventy-five years that nitrogen, phosphorus, and potassium are necessary for plant growth. The list of elements essential for plant growth has been gradually extended. For some years the number stood at ten, but in recent years, with improved chemical methods and physiological technique, it has been found that at least sixteen chemical elements are essential under some conditions.

Soon after the discovery of the element magnesium in 1808 by Davy, he stated (6) that certain magnesian limestones may produce both beneficial and injurious effects on plant growth. Later, it was proved by Knop, Sachs, and others (20) that magnesium was one of the elements essential to plant growth.

The antagonistic action between calcium and magnesium in plant nutrition was brought out and emphasized by the extensive investigations of Oscar Loew (24). He and other workers attempted to establish rather definite ratio limits for calcium and magnesium necessary for optimum plant development. Although these limits may be pretty well defined for water cultures under some conditions, as brought out by Eisenmenger (8) and Gile (14) they are ill defined in the soil. MacIntire and Young (27) and others have shown that large amounts of magnesian limestone may be applied to the soil without injurious effects.

The beneficial effects on plant growth of certain magnesium salts, have been observed by a number of workers. Meyer (29) in 1904 obtained striking results in the growth of mustard from the use of magnesium citrate and magnesium carbonate. Wheeler and Hartwell (43) secured increased yields of barley from magnesium sulfate. Brioux and Jouis (3) obtained good results from both magnesium sulfate and magnesium oxide.

Garner and co-workers (12) determined that a deficiency of magnesium in certain Coastal Plain soils was responsible for a physiological disturbance in the tobacco plant known as "sand drown". Later it was observed that this deficiency disease occurred on tobacco grown on magnesium deficient soils in the Connecticut Valley. "Sand drown" of tobacco is characterized by a peculiar inter-vein chlorosis of the lower leaves.

Jones (21) proved that a chlorosis of the leaves of corn grown on one of the experiment fields of the Massachusetts Station was due to a deficiency of magnesium, and Chucka (5) has reported that magnesium deficiency exists in certain potato soils of Maine.

Scope of Thesis

The objective of the studies here reported has been the development of a rapid, dependable method of diagnosing magnesium deficiency of soils. The Neubauer method, to be described later, appeared promising, so it was studied first. Also certain chemical methods were investigated.

The writer has been very fortunate in having at his disposal soil from one of the experimental fields of the Massachusetts State College Experiment Station, known as North Corn Acre. This field has shown varying degrees of magnesium deficiency and has been used for fertilizer tests since 1891. It therefore offers exceptional opportunities for study.

Soils were obtained from various other states and from farms in the Connecticut River Valley where magnesium trouble had been manifested. From this variety of soils it was hoped that somewhat uniform values might be obtained by which magnesium deficient soils could be recognized.

Review of Literature Bearing on the Problem

1. Chemical Methods

It has long been the ambition and dream of soil chemists to develop chemical methods for diagnosing nutrient deficiencies of soils. Few of the attempts made in this field have been crowned with notable success, but progress has been made surely if slowly.

Chemical analyses, as applied to soils, may be grouped under three heads--total analyses, availability analyses, and biological analyses.

According to Emerson (9) a total analysis may be for one or more elements, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and sometimes barium, titanium, boron, chlorine, etc. Since this method only gives the total of any constituent and gives no information as to its availability to plants, it is of little concern to this problem. A total analysis is obtained by fusing 1 gram of soil with 5 grams of sodium carbonate or potassium carbonate and determining the constituents.

Chemists later realized that the important need was for a plan by which they could measure the "available" nutrients rather than the total constituents. Bear (2) points out that large numbers of "strong-acid-digestion" analyses were reported for the period 1890-1910. This method involves the use of hydrochloric acid (specific gravity 1.115) and is described in detail by Wiley (44). Lyon and Buckman (25) state that it has been used to such an extent that it may be considered the standard solvent. They point out further that this method of analysis is supposed to show the proportion of nutrient materials in the soil that is in a condition to be used ultimately by plants. The difficulty with this method as with the total analysis is that the nutrients extracted bear little or no relationship to the nutrients immediately available to plants.

Various extractive methods have been tried in an attempt to obtain the soil solution for study. Mention and brief description of various methods employed to study the soil solution are given by Lyon and Buckman (25) and Emerson (9).

Burd (4) worked with water extracts of soil but found quite different results on cropped and uncropped soil. He argues that data from a soil under crop cannot indicate its latent power, and data from uncropped soil taken alone do not take into account the fact that the solutes in the cropped soils cannot be reduced below a certain minimum. He does not show that this holds true with other methods.

Robinson (35) studied the relation between the total composition of the soil and the water extract. He referred to the fact that quite different water extracts may be obtained from the same soil according to conditions of rainfall and drought immediately preceding the taking of a sample. He showed that there was no relation between the total and water-soluble soil constituents.

Peter and Averitt (32) tried to determine the strength of acid best suited for determining the available plant food in soils. They concluded that neither water nor $\frac{N}{200}$ hydrochloric acid possess sufficient solvent power to give any idea of the amount of available phosphorus in the soils tested.

Extractions of soil with various weak acids have been made to imitate the solvent action of plant roots, the object being to determine the available plant foods of the soil. These extractions involve the use of, carbonated water, 1% nitric acid, 1% acetic acid, 1% citric acid, 0.2% nitric acid, 0.2N nitric acid, and 0.2N hydrochloric acid.

At the present time there is no universally accepted method for measuring the availability of the more important soil constituents.

From studies on the Neubauer method Salter and Ames (38) conclude that the Neubauer method offers no advantage over chemical methods since the latter are less complex and subject to less experimental error. Presumably they refer to Lemmerman's (23) 0.5% citric acid and Schollenberger's (39) $\frac{N}{100}$ nitric acid extraction.

Probably the most popular chemical method of soil analysis in Europe at present is the 1% citric acid method proposed by Dyer (7). This strength of acid seems to compare very favorably with results obtained by field tests.

Comparatively little work has been done in this country with 1% citric acid. Investigators have preferred using 0.2% hydrochloric acid or 0.2N nitric acid (32) (11). The results reported are about the same with either method but from an analytical standpoint the mineral acids seem to be easier to work with. Analytical data is very meager with any of these methods.

Frap's (11) discussion of chemical methods as a means of determining available soil nutrients, gives a fair picture of the value and limitations of the various methods being used. He states, "For the interpretation of a chemical analysis, the relation must be traced between the results of the analysis and the production in the field which the sample is supposed to represent, and the conclusion expressed in terms of soil fertility, or soil deficiency." He points out that analyses for total potash, acid-soluble potash, water-soluble potash, and replaceable potash, bring out a close relationship between the ability of the soil to supply potash as measured by these methods of chemical analysis and the results of pot experiments. Reference is made to the work of other investigators who found an agreement of 70% or more between the Neubauer method and acid extraction (1% citric acid and 0.2N nitric acid.) He concludes that the relation of available plant food to that determined by these methods, is sufficiently close to justify the extensive use of chemical analyses of soils.

Much more interest is being shown in the "base-exchange" properties of the soil than in acid extraction, especially in the United States. Base exchange takes place when a soil is treated with a neutral salt solution, usually normal. The salts that have been used for this work are, NH_4Cl, $NaCl$, KCl, $CaCl_2$, $BaCl_2$, and the one gaining favor at present $CH_3COO\ (NH_4)$.

Merkle (28) states that there is little fundamental difference between the action of acids and neutral salts as a means of extracting exchangeable cations. He also suggests that the results obtained by electrodialysis are in agreement with those obtained by neutral salt extraction.

Kelley (22) points out that base exchange material is definitely crystalline and the ultra microscopic crystals contain replaceable bases on their interior as well as on their exterior. Truog and Chucka (41) isolated base exchange material and found it to have a ratio of Al_2O_3 to

SiO_2 of 1:4.

In relation to the characteristics of base exchange Robinson (35) mentions some interesting facts. He states that the colloidal materials in soils of humid regions yield surprisingly constant proportions of calcium, magnesium, potassium, and sodium to a neutral salt solution. He even states that the exchanged solution contains on the average 65 equivalents of calcium, 25 of magnesium, and 5 each of potassium and sodium. He asserts further, that the reaction of base exchange is rapid, the greater part of it being practically instantaneous.

Joffe (19) in speaking of the "complex capable of base-exchange" states that it is within this division of the soil make-up that most of the reactions in relation to release and retention of plant food take place. He also states that the capacity for base exchange is an inherent property of every soil and is practically constant. Gedroiz (13) shows that although soils as a rule contain comparatively little exchangeable magnesium there is always a very definite quantity and that no soil has yet been found which has no exchangeable magnesium.

Salgado (37) found a very close agreement between the amounts of bases extracted by electrodialysis and those extracted by displacement with normal ammonium acetate. Mattson (26) found good agreement between the quantities of bases removed by electrodialysis and by extraction with normal ammonium chloride and 0.05N hydrochloric acid. Harris (16) concluded that for the conditions under which he studied, KCl treatment gave more complete replacement of calcium and magnesium than NH_4Cl.

2. Field Tests

The field method, for testing fertilizer needs, originated by

Boussingault and Lawes and Gilbert has been used to a considerable extent, but is considered too laborious, expensive, and difficult to control. However, the field must be the final testing ground for all other methods of testing soil requirements. The pot culture tests are open to the same objections but to much less extent. They are objected to also on the ground that they are carried out under artificial conditions.

3. Vegetative Tests

To answer the above objections and at the same time those against chemical or acid extraction methods (that the degree of solubility of soil constituents in acid solutions may not correspond with the ability of the plant to obtain these nutrients) Neubauer devised a rapid means of determining soil deficiencies by using rye seedlings. This method, to be described in detail later, involves the principle of removal from the soil of available nutrients by rye seedlings, and the determination by chemical methods of amount of nutrients removed.

Thornton (40) reports that nearly 200 articles have been published on the Neubauer method in the last few years and that although there is much criticism of the accuracy of the method there is even more commendation of its practical value.

Ames and Gerdel (1) objected to the Neubauer method on the ground that no one plant such as rye, can serve as an indicator of the availability of any given nutrient for all plants. Furthermore, they objected that the small absolute values for potash assimilation obtained, and relatively large errors involved due to variations between duplicates in a series render the value of the method doubtful.

Haley and Holben (15) used a modified Neubauer method and obtained a close correlation between the quantities of potassium absorbed by buckwheat plants above the roots and that obtained by the use of 0.2N hydrochloric acid extraction. However, Ames and Gerdel (1) claim buckwheat to be of no value for such a test because of low germination and a variable seed content. Salter and Ames (38) cite Lemmermann's 0.5% citric acid method and Schollenberger's $\frac{N}{100}$ nitric acid method as being in general agreement with that of Neubauer.

A comparison of the Illinois phosphate test, the Hoffer corn stalk test, the 0.2N nitric acid extraction, and the Neubauer method carried out by Thornton (40) revealed that the Neubauer method was in closest agreement with results of pot tests.

The Mitscherlich (30) method has not gained sufficient prominence in this country to warrant a review of literature here. It may be said, however, that in restricted areas in Europe it has become very popular. It is essentially a pot test, by means of which the needs of the soil for nitrogen, phosphoric acid, and potash are determined simultaneously. Whether this method can be used for determining magnesium deficiency or not is problematical, but the writer sees no reason why it could not be used. Both Mitscherlich and Neubauer have suggested rates of fertilizer application based upon results obtained from their methods.

4. Biological Methods

The Azotobacter method perfected by Sackett (36) is one of the simplest methods being used at present to determine soil deficiencies of lime, phosphate, and potash. It is based upon the discovery of Winogradsky and Ziemiecka of the Pasteur Institute, that such plant foods as phosphate, potash, and lime, which are essential to the growth of crops, are essential also to the development of Azotobacter. Its present application is rather limited. Waksman (42) refers to the mineral content of the ash of Azotobacter chroococcum and gives the magnesium oxide content as 0.82 per cent. Whether this method can be used for determining magnesium deficiency is doubtful.

A method of determining soil fertility that has proved very popular of late in certain parts of Europe is the Aspergillus niger method. Niklas, Poschenrieder and Frey (31) describe a method of determining magnesium deficiency by this method. They found a closer relationship between the weight of mycelium produced and exchangeable magnesia than between the weight of mycelium and the "absolute" content of magnesia.

5. Conclusions to be drawn from Literature Studies

1. Total analysis is of little concern in this investigation since it only gives information as to the total amount of any plant food but no information as to its availability to plants.

2. Although the strong acid extraction method has an important agricultural value, in that it shows the proportion of plant nutrients ultimately available, it is of little or no value in determining immediately available plant food.

3. The soil solution would give us the most valuable information concerning available plant nutrients but as yet no satisfactory means have been devised for extraction of it from the soil.

4. Water extracts bear some relationship to available soil constituents but water does not possess sufficient solvent power to furnish any idea of the amount of available nutrients.

5. The best weak acid extraction methods for available magnesium involve the use of 0.2N nitric acid, 0.2N hydrochloric acid, or 1% citric acid. Good correlations have been obtained with these methods and pot and field tests.

6. Normal ammonium chloride, potassium chloride, and ammonium acetate are the salts most widely used in base-exchange determinations. These salt extractions agree with results obtained by electrodialysis. This method seems to offer the best means of determining available sodium, potassium, calcium, and magnesium.

7. The Neubauer method of soil analysis is claimed to be a reliable method and has much practical value in spite of its many limitations.

8. The aspergillus method seems to indicate possibilities of being used for available magnesium determinations. The Azotobacter method appears to be less promising, because it is doubtful if Azotobacter require magnesium in the presence of sufficient calcium for their needs.

Methods Employed

Composite soil samples of the upper seven inches of soil were obtained from the fields under consideration. The soil obtained from 10 to 12 borings with a one and one-half inch soil auger was thoroughly mixed, dried, and passed through a 2 m.m. sieve.

The hydrogen-ion concentration of the soils studied was determined by the quinhydrone method. Calcium was measured volumetrically as described by Popoff (33) and Fales (10). Magnesium was determined by the 8-hydroxyquinoline method developed by Redmond and Bright (34). These methods or modifications of them will be described later.

Preliminary tests were conducted using the standard magnesium ammonium phosphate method for determining magnesium. The amount of magnesium was quite small, both in the soil and plant extract. The results obtained by this method were quite inconsistent. Attention was, therefore, directed toward volumetric and colorimetric methods, since generally they are more accurate for minute quantities of material. Such a method involving the use of 8-hydroxyquinoline and potassium permanganate is described by Hough and Ficklen (17). This method appeared to offer the accuracy and simplicity desired. Considerable work was done in an attempt to make use of the method as given and to perfect it so that it might be used but it was finally necessary to abandon it.

A similar method, involving the use of 8-hydroxyquinoline, developed by Redmond and Bright (34) was investigated. Preliminary tests with this method soon revealed that, with a few modifications, it could be used for magnesium determinations of plant extract and soil extract.

It was deemed advisable to determine the calcium content of all samples since some investigators (24) (14) have shown a fairly close relationship of calcium to magnesium.

1. The Neubauer Method

100 grams of carefully prepared soil are placed in a glass dish having a diameter of 11.5 centimeters and a depth of 7 centimeters. This soil is well mixed with 50 gm. of sand and moistened with 20 c.c. of distilled water. After the above mixture has been spread evenly over the bottom of the dish, 100 grams of sand moistened with 30 c.c. of distilled water are spread uniformly over the sand-soil mixture. With the aid of a smoothing board, which will fit inside the glass dish, a smooth, firm surface can be obtained. By means of a stamping board 100 small depressions are made, into which 100 weighed rye seeds are placed. (Best results are obtained by using 100 seeds weighing 3.75 gm.) A small glass tube reaching to the bottom to assist in supplying water and air, is placed in the center of the dish. The seeds are covered with 100 gm. of sand which has been moistened with 30 c.c. of distilled water. The dish is next weighed, covered with a glass plate, and placed in a dark, cool room. Three samples of each soil are thus prepared. Three blank tests are prepared in a similar manner using 100 gm. sand in place of the 100 gm. soil.

The seedlings reach their optimum development in 17 days. These seedlings with their rootlets are separated from the soil and sand and ashed in a Muffle furnace at 550°C. The ash is dissolved in 5 c.c. of 10% hydrochloric acid. By means of a rubber policeman and two or three 10 c.c. portions of hot water the ash is washed and filtered through a 9-cm. filter paper. The filter paper is washed with hot water until the filtrate is free from chlorine. The washing is made up to 100 c.c. volume after the solution has attained room temperature, and is then ready to be used in aliquot portions for analysis.

2. Determination of Calcium

To 25 c.c. of the above solution add 25 c.c. of distilled water and one drop of phenol red (0.1%). Then add concentrated ammonium hydroxide drop by drop until the color changes to pink. Place a small piece of filter paper in each sample and heat to boiling on the hot plate. Allow the precipitate to settle slightly and filter while hot, washing five or six times with a hot 2 per cent solution of ammonium chloride. Add concentrated ammonium hydroxide drop by drop until the solution is pink, then make just acid (yellow) with sulphuric acid (one volume concentrated sulphuric acid to ten volumes of water). Add 5 c.c. of $\frac{N}{5}$ sulphuric acid and 10 c.c. of 2.5% oxalic acid and heat to boiling. Add 25 c.c. of 4% ammonium oxalate solution, and again bring to a boil. Allow the mixture to remain on the hot plate below boiling for one-half hour, stirring occasionally.

The mixture may be filtered as soon as it is cool or, preferably, allowed to stand overnight. The supernatant liquid is decanted through a 11 centimeter filter paper (Whatman 5) and the precipitate washed several times with a 0.5% solution of ammonium oxalate. The precipitate is then transferred to the filter paper and washed five times with 0.5% ammonium oxalate and five times with distilled water. (Use smallest amount of water possible each time but wash entire filter paper, taking care not to allow the precipitate to crawl over the edge.)

The stem of the funnel is washed with distilled water. (ammonium oxalate crawls up on the outside of the stem). Place a clean beaker beneath the funnel, pierce the apex of the filter cone with a pointed, thin glass rod and wash the rod and paper with 20 c.c. of hot 3N sulphuric acid. (This is best accomplished by using a pipette). Now wash the filter paper with two portions of hot water, 50 c.c. each.

Heat the solution to 90°C and titrate with $\frac{N}{50}$ permanganate solution. (1 c.c. is equivalent to 0.0004 grams of calcium).

3. Determination of Magnesium

Heat the filtrate, obtained from the calcium precipitation, to nearly boiling and add 1 c.c. of concentrated ammonium hydroxide. Next add 20 c.c. of 8-hydroxyquinoline solution (1.25%) and then 4 c.c. of ammonium hydroxide (conc.) per 100 c.c. of solution. Stir continuously for at least 15 minutes before setting aside. (Two samples can be stirred at a time if the work is to be carried out by hand. A mechanical stirring machine simplifies this process.)

Allow the precipitate (magnesium oxyquinolate) to settle for at least two hours, preferably over night. Filter and wash with hot dilute ammonium hydroxide (1:40). The precipitate should be washed at least six times. The same size and quality of filter paper may be used in filtering magnesium oxyquinolate as was used in filtering calcium oxalate.

Dissolve the precipitate by pouring over the filter paper two 50 c.c. portions of hot dilute hydrochloric acid (1:9). Add 15 c.c. of concentrated hydrochloric acid and about 100 c.c. distilled water. The solution should be at room temperature or nearly so before the titration is carried out.

Add from a pipette (preferably automatic) 25 c.c. of the standard potassium bromate-bromide solution. (10 g. potassium bromide and

2.785 g. potassium bromate per liter). Immediately add 10 c.c. of potassium iodide solution (12.5 g. of potassium iodide per 100 c.c water) and titrate with standard sodium thiosulphate solution, using 2 to 3 c.c. of starch solution (5 g. soluble starch and 2.5 g. salicylic acid in one liter of water) as an indicator.

Reference should be made to the original method by Redmond and Bright (34) for a study of the accuracy of the method, for the means of standardizing solutions, and for certain details not mentioned here.

In determining the calcium and magnesium contained in the N-Salt extraction it is not necessary to remove iron and aluminum. The procedure is the same as that described above after the iron and aluminum are removed.

Description of Soils Used

Soil samples were obtained from experiment stations at Oxford, North Carolina; Upper Marlboro, Maryland; Orono, Maine; and Amherst, Massachusetts. Samples were also obtained from several farms in the Connecticut Valley. These samples were obtained from experimental plots which had shown varying degrees of magnesium deficiency as indicated by chlorosis of corn and tobacco.

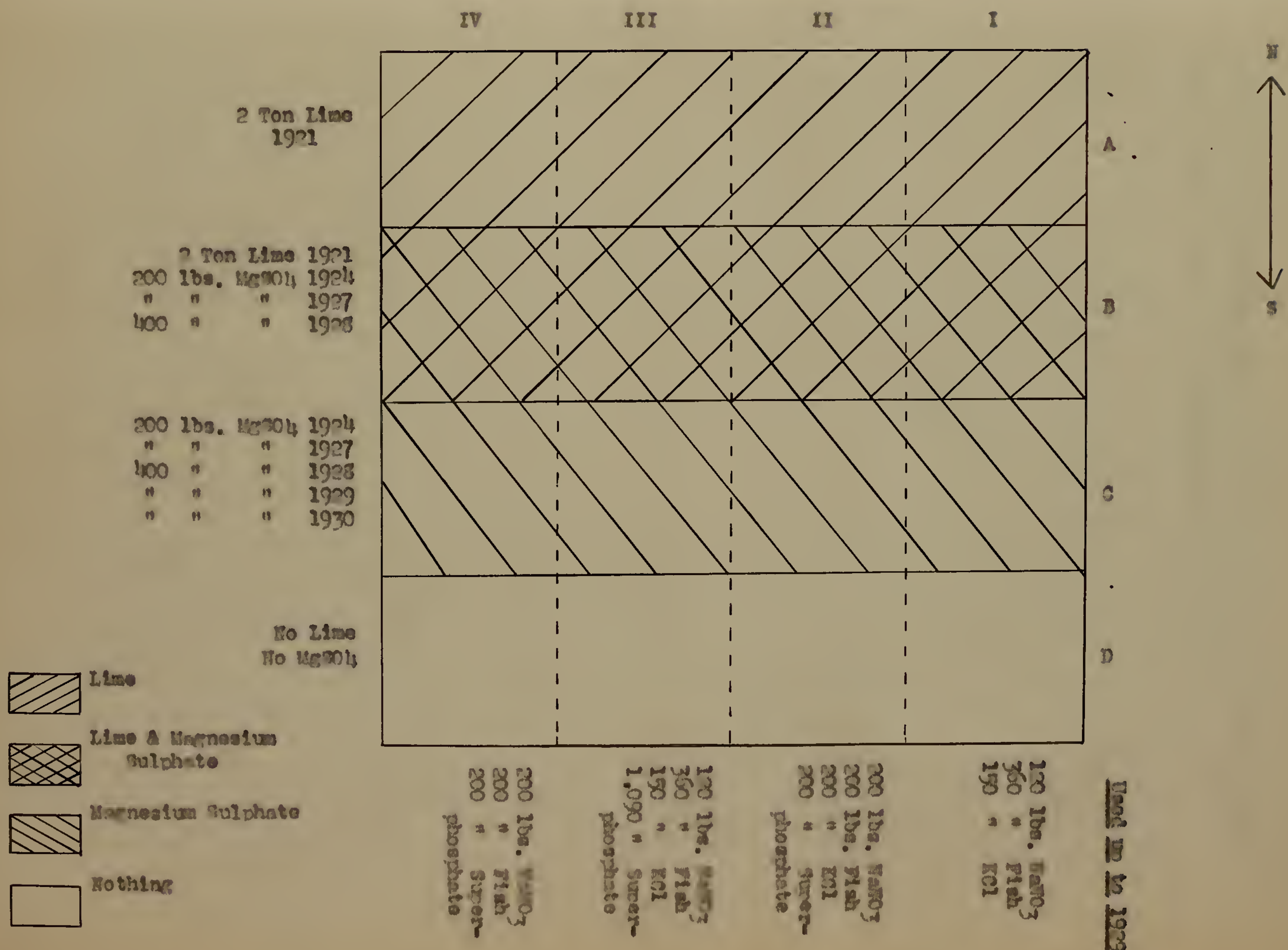
The soils from the corn and tobacco plots under consideration are very similar in character. The soils showing magnesium deficiency at this station are classed as Merrimac fine sandy loam. Magnesium deficiency occurs also in the Connecticut Valley on a heavier type known as Agawam fine sandy loam. The two soils from Maine, one of which indicates magnesium deficiency as shown by response of potato plants, are classified as Caribou loam. The five soil samples from Upper Marlboro, Maryland belong to the Collington series and range in type from fine sandy loam to loamy sand.

It is pointed out by those investigators (12) (21) who discovered that certain types of chlorosis are related to an insufficient supply of available magnesium in the soil, that chlorosis appears on corn and tobacco grown on the lighter soil types.

The soils and their treatment, which are given special consideration in this investigation, are described in some detail by Jones (21). However, the following diagram and explanations may help to show the correlation of soil treatment, chlorosis, and soil analysis.

Part of the soil samples were taken in the summer of 1931 while the crops were growing and part were taken in the fall of 1931, after

DIAGRAM OF THE NORTH CORN ACRE



the crops had been harvested. Soil samples from the pot tests were taken several weeks after the plants were harvested.

Original Investigations

1. Preliminary

There is no standard method of determining available plant nutrients. An attempt was made to compare the effect of various weak solvents and salt solutions, upon the availability of magnesium.

The following procedure was followed in making the soil extractions. Thirty grams of soil are shaken for one hour with 75 c.c. of N-Kcl solution (or any other solution to be used.) The mixture is then shaken well and immediately filtered through any medium grade filter paper. A 50 c.c. aliquot is taken for the calcium and magnesium test. It is not necessary to remove aluminum and iron if near neutral salt solutions are used.

Table 1 shows the results of the investigation. These results indicate that each of the solvents correlates fairly well with the available magnesium, as determined by the growth of corn. The use of the salt solutions appears to give as good or better results than distilled water or carbon-dioxide saturated water.

A close examination will show that the best correlation is obtained from the use of 0.15N K_2SO_4. However, in every case the amount of calcium and magnesium extracted with N-Kcl is greater than it is when 0.15 N K_2SO_4 is used. Good correlation is obtained by using 0.15N $CaSO_4$ but the determination of available calcium is made somewhat difficult by its use. Apparently there is little difference in the effect of various salt solutions of the same strength upon the amount of calcium and magnesium extracted. The results show however, that solutions of normal concentration or possibly greater strength remove more calcium and

Table 1.

CALCIUM AND MAGNESIUM EXTRACTED FROM SOILS WITH DIFFERENT SOLVENTS

No.	Treatment	Soil pH	Chlorosis	Distilled Water		CO_2-Saturated Water		0.15 N $CaSO_4$		0.15 N K_2SO_4		0.15 N KCl		N KCl	
				Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
1	1-4 (1) No Ca: No Mg	4.8	Extreme	35.5	0.6	35.0	1.14	-	1.32	65	0.66	80	0.63	81.1	3.10
2	3-8 600 lbs. $MgSO_4$	5.05	No	33.5	0.45	36.5	1.9	-	3.90	65	4.2	-	-	79.9	4.8
3	65-68 2 Ton pure CaO	5.75	Medium	30.0	0.00	46.4	1.57	-	1.70	75	1.86	-	-	115.0	1.81
4	69-72 2T. $MgCO_3$ MgO 10-20%	5.5	No	19.5	2.7	29.0	4.5	-	8.1	60	7.5	-	-	89.2	9.3
5	73-76 2T.Ag.Hyd.Lime 25-30% MgO	6.15	No	20.8	7.2	36.5	10.4	-	16.5	65	20.5	77.5	15.65	97.0	22.6
6	77-80 600 lbs. $MgCO_3$	5.25	No	15.0	2.41	25.0	2.2	-	4.9	65	6.63	-	-	75.6	6.7
7	No Ca: No Mg.	5.20	Medium	8.6	0.24	12.5	2.95	-	2.0	40	0.85	50	1.23	51.1	1.52
8	Mg alone	5.10	Slight	7.2	1.95	11.0	2.25	-	4.5	44.5	3.9	50	4.7	49.7	6.16
9	Ca + Mg.	5.70	Slight	4.75	0.12	16.0	0.55	-	3.6	55.	2.6	55	2.1	66.1	3.68
10	Ca alone	5.50	Medium	5.05	0.06	14.0	1.8	-	0.78	60	1.02	55	0.33	72.1	2.36

Results expressed in milligrams per 100 grams soil

(1) Soils 1-6 from pot experiment, 7-10 from field experiment of Massachusetts Experiment Station.

magnesium from the soil and give results more indicative of the available magnesium present.

It was decided to compare further the effects of various extracting agents upon a soil deficient in magnesium. Table 2 gives the results of these tests. Again, carbon dioxide-free water, and carbon dioxide-saturated water proved inadequate. The use of 0.15N Kcl did not displace all the exchangeable calcium and magnesium. The maximum displacement occurred somewhere between concentration of 0.75N and 1.13N Kcl solution. The amount of calcium and magnesium obtained from the use of 0.2N hydrochloric and 0.2N nitric acid was much greater than that obtained from the neutral salt extraction, showing that more than the exchangeable calcium and magnesium was extracted by these solvents. Several investigators (11) (32) have indicated that 0.2N hydrochloric acid and 0.2N nitric acid have the same ability to extract available plant foods as does 1% citric acid. This is certainly not true in regard to calcium. It was so difficult to rid the citric acid solution of iron and aluminum that an attempt was made to precipitate the magnesium in their presence but without success. The figures given for magnesium probably bear no relation to the amount of magnesium in the extract. The 1% citric acid extract gave a closer relation to the neutral salt extraction than did the nitric or hydrochloric acid extraction, in respect to calcium.

Table 3 shows the effect of dilution and leaching upon the amount of calcium and magnesium extracted from soils deficient in magnesium and soils having a magnesium reserve. These results seem to agree with Humfeld (15) who refers to the fact that base exchange reactions are

Table 2.

EFFECT OF SOLVENT AND TIME OF SHAKING ON EXTRACTION OF

CALCIUM AND MAGNESIUM *

No.	Treatment	pH	Shaken for 1 hour and filtered immediately		Shaken 1 hour every eight hrs. for 24 hrs.	
			Ca.	Mg.	Ca.	Mg.
1	Distilled water	6.07	5.0	0.12	21.8	0.25
2	CO_2-Saturated water	4.00	12.40	0.12	25.8	0.60
3	0.15 N KCl	5.75	-	-	59.0	0.90
4	0.75 N KCl	5.5	-	-	79.2	0.93
5	1.13 N KCl	5.85	72.20	1.53	78.95	0.93
6	1.5 N KCl	5.9	-	-	78.05	0.82
7	1% citric acid	2.3	76.10	36.7 +	96.5	35.25+
8	0.2 N hydrochloric acid	0.75	122.7	9.90	125.1	20.75
9	0.2 N nitric acid	0.75	131.45	8.05	124.5	21.45

* Magnesium deficient soil. 30 g. soil and 75 c.c. of solution used except where noted.

\+ This figure does not represent the magnesium content. It was impossible to precipitate the iron and aluminum without evaporating the solution to dryness. This figure is probably magnesium, aluminum and possibly iron.

Results expressed in milligrams per 100 grams soil.

Table 3.

EFFECT OF DILUTION AND LEACHING UPON THE AMOUNT OF CALCIUM AND MAGNESIUM EXTRACTED.

No.	Treatment	Dilution	Soil showing slight chlorosis		Soil showing no chlorosis		Soil showing medium chlorosis		pH of solution before extraction	pH of soil extract
			Ca	Mg.	Ca	Mg.	Ca	Mg.		
1	100 gram soil + 500 cc N-NH_4 Cl	1:5	121.5	4.30	104.0	21.7	-	-		
2	30 gram soil + 75 cc N-NH_4 Cl	1:2.5	119.5	3.93	103.4	20.0	51.5	2.82		
3	100 gram soil + 500 cc N-KCl	1:5	117.5	4.45	104.0	20.65				
4	30 gram soil + 75 cc N-KCl	1:2.5	115.0	4.22	97.0	22.55	52.6	2.03		
5	30 gram soil + 75 cc N-CH_3 COO NH_4	1:2.5	133.0	3.05	117.15	25.27				
6	25 gram soil + 75 cc N-KCl Leached to 500 cc	1:3 (Leached)	159.7	2.00	152.2	24.5			5.9	6.4
7	25 gram soil + 75 cc N-CH_3 COO NH_4 Leached to 500 cc	1:3 (Leached)	152.8	7.0	146.4	27.7			5.25	5.3

Results expressed in milligrams per 100 gram soil.

Note: All soils shaken one hour and filtered immediately.

instantaneous. There is very little difference in results whether the soil is diluted five times or only two but there appears to be some advantage in leaching the soil with 500 c.c. volume of salt solution. The time required to leach a soil to 500 c.c. is somewhat of a disadvantage.

2. Discussion of Data

Soil was obtained from the magnesium deficient area of the North Corn Acre and put in earthen pots, twenty-five pounds of soil in each pot. The soil was uniformly fertilized with a 5-8-7 mixture at the rate of 1200 pounds per acre. In addition the pots were treated as indicated in table 4, rates per acre being given. Four pots of each treatment were used.

a. Soil Extraction Studies

The degree of chlorosis corresponds very well with the amount of exchangeable magnesium in the soil. It may appear strange that soil 3 in table 4 should have given only 1.81 milligrams of magnesium while soil 1 gave 3.1 milligrams, especially since the former showed less chlorosis and removed more magnesium from the soil. It appears reasonable to assume that where large amounts of lime were used, much of the exchangeable magnesium was released from the base exchange portion of the soil. This freed magnesium may have served to lessen chlorosis.

The ratio of exchangeable calcium to exchangeable magnesium appears to be an important factor in relation to magnesium deficient soils.

In some respects the magnesium content of the corn stover seems to have been a better indication of a magnesium deficient soil than was the growth of the crop, especially was this true where a large amount of lime was used on the soil. It is interesting to note that the best growth of corn was obtained under conditions which supply enough magnesium to give a narrow ratio, about 1:1, of calcium to magnesium in the stover. The ratio which gives optimum growth is not known nor is it certain at what point the plant begins to suffer. It is known, however,

Table 4.

THE EFFECT OF SOIL TREATMENT UPON PLANT GROWTH, CHLOROSIS, AND AVAILABLE CALCIUM AND MAGNESIUM IN THE SOIL. GREENHOUSE STUDIES.

No.	Treatment	pH	Grams Fodder oven-dry basis	Height of stalks in inches	Total Grams of Mg. removed by plants	Chlorosis	Content of Corn fodder per cent		Milligrams per 100 grams soil KCl extraction	
							Ca	Mg.	Ca	Mg.
1-4	No Ca; No Mg.	* 4.8	** 19.5	** 31	.0117	Severe	* 0.20	* 0.06	* 81.1	* 3.10
5-8	600 lbs. $MgSO_4$	5.05	38.5	50	.0385	No	0.21	0.10	79.9	4.8
65-68	2T. Pure CaO	5.75	45.0	55	.0317	Medium	0.22	0.07	115.0	1.81
69-72	2T. $MgCO_3$ MgO 10-20%	5.5	52.1	54	.0677	No	0.15	0.13	89.2	9.3
73-76	2T. $MgCO_3$ MgO 28-30%	6.15	53.4	58	.0641	No	0.15	0.12	97.0	22.55
77-80	600 lbs. $MgCO_3$	5.25	45.1	56	.0677	No	0.19	0.15	78.6	6.7

* Analysis of composite sample from 4 pots.

** Mean of 4 pots.

that magnesium deficiency in corn and tobacco is manifested by chlorosis, at least that is true in one stage of deficiency. Wherever magnesium deficiency is referred to in this discussion the degree of deficiency which causes chlorosis is indicated, unless otherwise stated.

Soil acidity may have had some influence in causing a decreased growth of corn stover on soil 1 but apparently had little or no influence upon chlorosis.

Under the conditions of this experiment the amount of exchangeable magnesium necessary to prevent chlorosis in corn appears to be somewhere between 3.10 and 4.8 milligrams per 100 gram soil. This varies, of course, with the soil treatment. Although 4.8 milligrams is sufficient to prevent chlorosis the best growth resulted where the exchangeable magnesium content reached 10 to 20 milligrams per 100 gram soil.

Table 5 shows the results obtained from field tests on the North Corn Acre. Table 6 summarizes these results. They are for the year 1931, but do not show the marked differences in yield that have been obtained on the same plots in other years. There was only a slight advantage in yield of shelled corn in favor of the magnesium treated plots while the yield of stover was less with magnesium than without. There is a marked difference in the total amount of magnesium removed by these plants. The extent of chlorosis does not agree with the soil treatment in every detail. The most striking difference is found in the magnesium content of the corn stover, which agrees fairly well with the exchangeable magnesium of the soil and both of these agree in some measure with the degree of chlorosis.

The amount of exchangeable magnesium necessary to prevent chlorosis

Table 5.

THE EFFECT OF EXCHANGEABLE CALCIUM AND MAGNESIUM IN THE SOIL UPON THE YIELD OF CROPS, CHLOROSIS AND CALCIUM AND MAGNESIUM CONTENT OF THE CROP.

No.	Treatment	pH	Lbs. of Stover Per A.	Lbs. of Shelled Corn Per A.	Lbs. of Mg. Removed by Corn Fodder Per A.	Chlorosis	Content of Corn Stover Per cent		KCl extraction Surface Soil *		KCl extraction Sub soil *	
							Ca	Mg.	Ca	Mg.	Ca	Mg.
1A	Ca alone	5.5	2078	2987	2.08	Medium	0.56	0.10	77.5	1.79	-	-
2A	"	5.52	1625	2094	1.63	Extreme	0.41	0.10	49.5	1.42	25.0	1.23
3A	"	5.85	1738	2872	1.74	"	0.45	0.10	67.75	2.46	30.95	2.05
4A	"	5.7	2082	3257	3.33	Very slight	0.53	0.16	67.5	1.93	-	-
1B	Ca + Mg.	5.5	1754	3262	2.98	Very slight	0.36	0.17	65.0	2.74	-	-
2B	"	5.75	1760	3097	2.29	"	0.34	0.13	64.65	3.05	29.3	2.08
3B	"	5.80	1407	2359	2.11	Slight	0.41	0.15	67.90	3.17	25.40	2.07
4B	"	5.05	1590	3008	2.54	No	0.46	0.16	69.0	2.47	-	-
1C	Mg. alone	5.05	1489	3269	2.98	No	0.43	0.20	48.5	4.94	-	-
2C	"	5.15	1875	3479	2.63	No	0.26	0.14	49.5	5.45	28.8	2.56
3C	"	5.35	1164	2078	1.86	Slight	0.33	0.16	42.5	2.80	22.90	2.61
4C	"	5.55	1636	3102	3.27	No	0.42	0.20	49.25	4.04	-	-
1D	No Ca; No Mg.	5.25	1524	2555	1.22	Extreme	0.42	0.08	52.6	2.03	-	-
2D	" "	5.05	1644	3184	1.15	"	0.31	0.07	45.6	0.87	22.2	1.05
3D	" "	5.5	2150	3222	1.72	"	0.47	0.08	66.5	1.74	29.3	1.16
4D	" "	5.55	1295	2273	1.17	"	0.44	0.09	51.6	1.84	-	-

* Results expressed in milligrams per 100 gram soil.

Table 6.

THE EFFECT OF EXCHANGEABLE CALCIUM AND MAGNESIUM UPON CROP GROWTH,

CHLOROSIS AND THE CALCIUM AND MAGNESIUM CONTENT OF CORN STOVER.

No.	Treatment	pH	Lbs. of Stover Per A.	Lbs. of Shelled Corn Per A.	Lbs. of Mg. Removed by Corn Fodder Per A.	Chlorosis	Content of Corn Stover Per cent		Milligrams per 100 g. soil KCl Extract	
							Ca	Mg	Ca	Mg
		*	**	**	**		**	**	*	*
I	Ca. alone	5.50	1580	2810	2.19	Medium	0.49	0.12	72.05	2.36
II	Ca. + Mg.	5.7	1628	2931	2.48	Slight	0.39	0.15	66.1	3.68
III	Mg. alone	5.10	1541	2952	2.69	No	0.38	0.18	49.70	6.18
IV	No Ca; No Mg.	5.2	1653	2806	1.31	Extreme	0.41	0.08	51.10	1.51

* Determination on composite sample.
** Mean of 4 determinations.

More than 85% of plants normal = No chlorosis
75 - 85% " " " = Very slight chlorosis
50 - 75% " " " = Slight chlorosis
25 - 50% " " " = Medium chlorosis
Less than 25% " " " = Extreme chlorosis

on corn in the field was somewhat less than that found in the greenhouse pot tests. Studies were therefore conducted upon the sub-soil of eight plots to determine if it had a greater exchangeable magnesium content than the surface soil. Only one case was found in which the sub-soil showed a larger magnesium content. The greater feeding zone of the sub-soil probably had some influence upon the amount of magnesium obtained.

In this experiment the amount of exchangeable magnesium necessary to prevent chlorosis in the field seems to be between 2.5 and 3.0 milligrams of magnesium per 100 gram soil. This standard does not strictly apply, for the application of lime or fertilizer will influence this to some extent. The application of fertilizer causes a more rapid development of the plant and a more rapid intake of nutrients, and hence calls for a more liberal supply of magnesium to take part not only in the transfer of phosphorus but also in the making of chlorophyll. It has been noted that soils that produce small, slow-developing plants because of low fertility may supply sufficient magnesium to prevent chlorosis even though the available magnesium content is very low. It would seem, therefore, that chlorosis is not an infallible guide to magnesium deficient soils. A better guide appears to be the ratio of calcium to magnesium in the plant itself. But since this ratio agrees very well with the exchangeable calcium and magnesium of the soil, the writer sees no reason why the exchangeable calcium and magnesium cannot be used as an index of available magnesium.

Table 7 shows the results of soil tests from random plots in the vicinity of Amherst. The treatments of these soils are not known

Table 7.

OBSERVATIONS ON CORN AND TOBACCO SOILS ON COLLEGE FARM AND OTHER FARMS IN THE CONNECTICUT VALLEY.

No.	Crop & Location	pH	Observation	Milligrams per 100 g. soil KCl extraction	
				Ca	Mg.
1	E. Funk Leaming N.	5.8	Normal corn	82.0	5.26
2	E. Rustler's White Dent	5.6	Corn matured early	81.0	4.36
3	E. Funk Leaming	5.8	Normal corn	73.7	6.15
4	Canada Leaming (Hill)	6.3	Normal corn	78.9	5.86
5	Canada Leaming (Hollow)	6.3	Normal corn	83.35	7.99
6	Rustler's White Dent	6.55	Corn matured early	88.9	8.14
7	Rustler's White Dent	7.05	Corn matured early	135.55	6.84
8	Buckeye tobacco farm	6.45	Chlorosis on tobacco	31.55	1.84
9	Near Buckeye farm	5.55	Normal tobacco	24.95	3.66
10	N. Hadley tobacco home lot	5.55	Normal tobacco	48.50	5.1
11	N. Hadley corn plot	5.7	Severe chlorosis on corn	12.25	1.75

in all cases but the appearance of the plants growing on them is noted. The object of these tests was to determine the exchangeable magnesium content of soil other than North Corn Acre which was growing corn and tobacco. The two plots showing chlorosis have about the same exchangeable magnesium content as magnesium deficient soils on the North Corn Acre. As a rule the cultivated plots growing good healthy corn have a good supply of magnesium but that does not mean that there is sufficient magnesium for the best growth.

The results found in table 8 were obtained from a study of soils from three different states. The pH range is about the same as that of the soils to which reference has already been made. Although soil No. 2 has not been in tobacco it has not shown magnesium deficiency for some other crops. It is not known whether or not corn has been grown on this plot. It is very difficult to understand why chlorosis has appeared on soil No. 10 and why it has not shown on soil No. 12 unless it is that the high calcium content of soil No. 12 has resulted in more available magnesium. Other than this striking exception the results are very similar for the North Carolina, Maryland, and North Corn Acre soils.

The minimum amount of exchangeable magnesium necessary to prevent sand drown of tobacco in the North Carolina and Maryland soils is very near 3.0 milligrams per 100 gram soil. These soils are similar in texture to those of North Corn Acre and it would be expected that the same exchangeable magnesium content would cause chlorosis in corn and tobacco.

Soils number 13 and 14 are rather interesting in that the soil

Table 8.

SHOWING THE RELATION OF CHLOROSIS ON SAND DROWN OF TOBACCO TO THE EXCHANGEABLE MAGNESIUM OF THE SOIL.

No.	Treatment or designation	pH	Chlorosis	Milligram per 100 gram soil KCl Extraction	
				Ca	Mg.
1	Special Potash (No lime)	5.45	Shows chlorosis clearly	10.5	0.81
2	Control sample	5.45	Has not been in tob. but does not show on other crops	14.95	1.99
3	Calcite end plot	5.9	Very bad	26.50	1.36
4	No lime end	5.15	Very bad	5.25	1.92
5	Dolomite end	6.1	No sand drown since 1921	14.55	5.6
6	No lime end (Legume)	5.03	Shows Deficiency	10.15	2.24
7	1 Ton dolomitic limestone 1918--Limed end (Legume)	5.08	No	13.00	2.85
8	Sample I	5.4	Pronounced	42.45	0.90
9	Sample II	5.5	No	22.00	6.94
10	Sample III	5.15	Severe Moderately	32.0	5.65
11	Sample IV	4.95	No	13.0	8.00
12	Sample V	5.85	No	63.9	3.05
13	Not Mg. deficient	5.15	No	81.25	5.30
14	Mg. deficient	4.9	Has indicated deficiency for potatoes	42.5	23.06

Soil samples No. 1 to 12 furnished through the courtesy of Dr. W. W. Garner, U. S. D. A. Soils No. 1 to 7 were sent from Oxford, North Carolina, and soils No. 8 to 12 were shipped from Upper Marlboro, Maryland. Samples No. 13 and 14 were furnished by Dr. Jos. A. Chucka from Aroostook potato section, Maine.

reported as being deficient in magnesium has more than four times as much magnesium in exchangeable form as has the normal soil. It will be seen, however, that soil No. 13 has twice as much calcium as has soil No. 14. The pH of No. 14 is also quite low. It is not difficult to believe that rather than being deficient in magnesium the soil has an improper relation of calcium to magnesium. Potatoes have failed to show any striking effects while growing on magnesium deficient soil on North Corn Acre. More detailed investigation will be necessary before an explanation can be given for the response of potatoes on this soil but it seems quite certain that it is not magnesium deficiency.

From the above discussion it may be tentatively suggested that a soil be considered deficient in magnesium if there are less than three milligrams of exchangeable magnesium per 100 gram soil. This value may be increased to five milligrams of exchangeable magnesium in cases where the exchangeable calcium falls much below 50 milligrams per 100 gram soil.

b. Work with Neubauer's Method

The Neubauer method of soil analysis is gaining favor as a means of analysing the soil for readily available phosphorus and potassium. After both the phosphorus and potassium tests are made there remains 30 c.c. of solution obtained from the plant ash filtrate. It was thought advisable to test this filtrate, or 25 c.c. of it, for magnesium and determine the possibility of using this excess solution for magnesium deficiency determinations where needed.

Table 9 gives the results of some of these tests on the Neubauer method as a means of determining magnesium deficient soils. A comparison is also made with the amount of replaceable magnesium and the amount of strong acid soluble magnesium. These results indicate that with the Neubauer method negative values are obtained for magnesium in most cases where the soil is lacking in this element. The explanation for this phenomenon probably lies in the fact that the soil tested has greater absorptive powers than does the sand check and has a tendency to absorb or absorb the soluble magnesium from the germinated seeds. A soil having insufficient magnesium to prevent chlorosis in corn and tobacco, is unable to supply enough magnesium to the rye plants, in the seventeen days allowed for growth, to off-set the amount of magnesium absorbed from the germinated seeds. These results are not in strict agreement with the amount of exchangeable magnesium or the degree of chlorosis but are in fair agreement.

The strong hydrochloric acid extraction bears no relation to the degree of chlorosis in soils 1 to 4.

Table 10 is very similar in results to table 9. In most cases

Table 9.

COMPARISON OF NEUBAUER METHOD, N-KCl EXTRACTION AND STRONG HYDROCHLORIC ACID EXTRACTION WITH OBSERVED CHLOROSIS ON CORN

No.	Treatment	pH	Neubauer Method Mgs. available		N-KCl Extraction		Strong HCl Extraction		Chlorosis
			Ca.	Mg.	Ca.	Mg.	Ca.	Mg.	
1	1-4 No Ca; No Mg.	4.8	3.9	-0.62	81.1	3.10	451	796.	Extreme
2	5-8 600 lbs. $MgSO_4$	5.05	4.1	0.54	79.9	4.8	455	561.	No
3	65-68 2 Ton pure CaO	5.75	3.9	-0.70	115.0	1.81	510	652.	Medium
4	69-72 2 Ton $MgCO_3$ 10-20% MgO	5.5	-0.4	1.64	89.2	9.3	444	464.	No
5	72-76 2 Ton Agr. Hyd. Lime 25-30% MgO	6.15	0.80	1.45	97.0	22.55	-	-	No
6	77-80 600 lbs. $MgCO_3$	5.25	2.95	1.19	78.6	6.7	-	-	No
7	No Ca; No Mg.	5.2	6.05	0.11	51.10	1.51	-	-	Extreme
8	Mg. alone	5.1	6.10	1.01	49.70	6.18	-	-	No
9	Ca. + Mg.	5.7	5.25	0.23	66.1	3.68	-	-	Slight
10	Ca. alone	5.5	6.20	-0.07	72.05	2.36	-	-	Medium

Results expressed in milligrams per 100 gram soil.

Table 10

COMPARING THE NEUBAUER METHOD WITH N-KCl EXTRACTION AS A MEANS OF DETERMINING MAGNESIUM DEFICIENCY

No.	Treatment	pH	Neubauer Method Mgs. available		N-KCl Extraction		Chlorosis
			Ca.	Mg.	Ca.	Mg.	
1	I A Calcium alone	5.5	8.65	-0.22	77.5	1.79	Medium
2	IV A Calcium alone	5.7	7.85	-1.40	67.5	1.93	Very Slight
3	I B Ca. + Mg.	5.5	11.50	-0.03	65.0	2.74	Very Slight
4	IV B Ca. + Mg.	5.05	7.90	0.57	69.0	2.47	No
5	I C Mg. alone	5.05	10.75	1.22	48.5	4.94	No
6	II C Mg. alone	5.15	12.75	0.86	49.5	5.45	No
7	III C Mg. alone	5.35	8.65	1.36	42.5	2.80	Slight
8	IV C Mg. alone	5.55	2.80	1.46	49.25	4.04	No
9	I D No Ca: No Mg.	5.25	10.4	-0.70	52.6	2.03	Extreme
10	II D No Ca: No Mg.	5.05	10.5	-0.24	45.6	0.87	Extreme
11	III D No Ca: No Mg.	5.50	11.80	-1.07	66.5	1.74	Extreme
12	IV D No Ca: No Mg.	5.55	3.25	-0.72	51.6	1.84	Extreme
13	Maine Soil (N) Not Mg. defic.	5.15	5.69	0.88	81.25	5.30	-
14	Maine Soil (D) Mg. Deficient	4.8	2.81	1.56	42.5	23.05	-
15	I Special potash	5.45	1.53	0.64	10.5	0.81	Shows Clearly
16	II Control Sample	5.45	0.77	2.20	14.95	1.99	Has not been in Tobacco
17	III Calcite and plt.	5.9	3.37	0.96	26.50	1.36	Very bad
18	IV No lime and	5.15	1.77	0.48	5.25	1.92	Very bad
19	V Dolomite end	6.1	1.77	4.24	14.55	5.6	No sand drawn since 1927
20	VI No lime end (Legume)	5.03	1.93	2.44	10.15	2.24	Shows deficiency
21	VII Limed end (Legume)	5.08	3.21	1.20	13.0	2.85	Did not show on Tob.1931

Results expressed in milligrams per 100 gram soil.

the magnesium deficient soils are indicated by negative values, while those soils having sufficient available magnesium to prevent chlorosis give positive values. Soils numbered 15 to 21 do not correspond with the above classification in that there are no negative values. However, all soils deficient in magnesium as judged by chlorosis of tobacco are very near the negative value. The only striking exception is soil No. 20. The writer cannot give an explanation for this exception since the soils are of about the same texture.

The Neubauer method of soil analysis may be employed for magnesium deficiency determinations where the method is already being used for phosphorus and potassium tests. More work with this method will be necessary before definite recommendations can be made as regards the values for absorbed magnesium. The results obtained thus far suggest that a soil is deficient in magnesium if negative values are obtained, and that it is well supplied with available magnesium if 1.50 milligrams or more of magnesium are taken up by the rye seedlings per 100 grams soil.

The Neubauer method is much more difficult to manipulate and less accurate than the N-Kcl extraction method. Furthermore it only gives a very general idea of the available magnesium present in the soil tested.

A fair agreement exists between the results of the Neubauer method and those of the N-Kcl extraction.

3. Summary and Conclusions

1. Considerable interest has been manifested in magnesium deficient soils in the past few years. The great loss in crop yields and quality suggested the possibility of developing a method that would be valuable in detecting soils lacking in available magnesium.

2. Various methods of soil analysis have been suggested as possibilities and the more promising have been used in an effort to find some means of diagnosing a soil for magnesium deficiency.

3. Two of the methods have been used with more or less success. The writer does not claim that these are the best methods that can be devised for available magnesium determinations. They do show, however, a fair agreement with greenhouse pot tests and field studies. Further work must be done along this line before a definite statement can be made as to the worth of these methods as compared to other procedures.

4. Chlorosis of corn and tobacco is a good indication of magnesium deficient soil but soils may be very deficient in magnesium without causing chlorosis on corn or tobacco, depending upon the rate of plant growth.

5. The Neubauer method may be used for detecting magnesium deficiency, but only in a very general way. It gives very little information as to the amount of available magnesium in a soil. Negative values are obtained for soils sufficiently depleted of magnesium to cause chlorosis of corn and tobacco.

6. The amount of magnesium obtained from soil extraction with carbon dioxide-free water, carbon dioxide-saturated water, or strong

hydrochloric acid (Sp. Gr. 1.115) is not a good measure of the magnesium immediately available to plants.

7. It will be necessary to conduct investigations with 0.2N nitric acid, 0.2N hydrochloric acid, and normal ammonium acetate extractions before conclusions can be drawn as to the best method for determining magnesium deficiency. It is known that the weak acid extractions relieve the soil of more than the exchangeable magnesium and calcium but it is not certain that these soil extractions correlate with the available magnesium present in the soil.

8. One per cent citric acid appears to extract about the same amount of calcium and magnesium from the soil as does N-Kcl solution but presents difficulties in the magnesium determinations that are objectionable.

9. Exchangeable magnesium as obtained by soil extraction with N-Kcl solution gives close agreement with magnesium deficient soils as shown by chlorosis of corn and tobacco. The method is simple, rapid, and accurate.

10. Magnesium deficiency appears to depend, to a certain extent, upon the ratio of exchangeable calcium to exchangeable magnesium. In these studies it has been found that chlorosis is likely to appear on corn and tobacco grown on soil having less than 3 milligrams of exchangeable magnesium per 100 gram soil. In soils having an exchangeable calcium content of less than 50 milligrams per 100 gram soil it may be necessary to have 5 milligrams of magnesium to prevent chlorosis.

Bibliography

1. Ames, J. W. and Gerdel, R. W.
The Seedling Plant Method of Determing Soil Nutrient Deficiency.
Soil Science 23:455-466 1927

2. Bear, Firman E.
Theory and Practice in the Use of Fertilizers.
pp. 128 1929

3. Brioux ch. et Jouis Edg.
Action Fertilisante de la Magnesie.
Annales Agronomiques
No. 2 Mars - Avril 1932

4. Burd, John S.
Water Extracts of Soils as Critera of Their Crop-producing Power.
Jour. Agr. Res. 12:297-309 1918

5. Chucka, J. A.
Paper presented at: The Calcium and Magnesium Symposium of the American Society of Agronomy.
Chicago, Nov. 19-20 1931

6. Davy, Sir Humphrey
Elements of Agricultural Chemistry.
pp. 281 1813

7. Dyer, B.
The Analytical Determination of Probable Available Mineral Plant Food in Soils.
Jour. Chem. Soc. 65:115 1894

8. Eisenmenger, W. S.
Toxicity, Additive Effects, and Antagonism of Salt Solutions as Indicated by Growth of Wheat Roots.
Bul. of The Torrey Botanical Club.
55:261-304 Aug. 1928

9. Emerson, Paul
Principles of Soil Technology.
pp. 169-181 1930

10. Fales, Harold A.
Inorganic Quantitative Analysis.
pp. 198 1925

11. Fraps, G. S.
How Reliable are Existing Chemical Methods for Determining Soil Deficiencies in Ash Constituents of Plants.
Jour. Am. Soc. Agron.
22:337-351 1931

12. Garner, W. W., McMurtrey, J. E., Bacon, C. W., and Moss, E. G.
Sand Drown, a Chlorosis of Tobacco Due to Magnesium Deficiency and the Relation of Sulphate and Chlorides of Potassium to the Disease.
Jour. of Agr. Res. 23:27-41 1923

13. Gedroiz, K. K.
Exchangeable Cations of the Soil and the Plant: I Relation of Plant to Certain Cations Fully Saturating the Soil Exchange Capacity.
Soil Science 32: 51-63 1931

14. Gile, P. L.
Lime-Magnesia Ratio as Influenced by Concentration.
Porto Rico Agr. Exp. Sta. Bul. 12:5-9 1912

15. Haley, D. E. and Holben, F. J.
A Biological Measurement of Available Soil Potassium.
Soil Science 24:345-350 1927

16. Harris, A. Evan
Effect of Replaceable Sodium on Soil Permeability.
Soil Science 32:435-446 1931

17. Hough, W. A. and Ficklen, J. B.
Determination of Magnesium with 8-Hydroxyquinoline---Gravimetrically, Volumetrically, and Colorimetrically.
Jour. Amer. Chem. Soc.
52:4752-4755 1930

18. Humfeld, Harry
Electrodialysis of Soils: III Effect of Different Fertilizer Treatments of Soils on the Bases and Acids Extracted by Electrodialysis.
Jour. Amer. Soc. Agron. 20:1141
1928

19. Joffe, J. S. and McLean, H. C.
Colloidal Behavior of Soils and Soil Fertility.
II Cation Replacement and Saturation of Soil with Calcium.
Soil Sci. 23:127-135 1927

20. Johnson, Samuel W.
How Crops Grow. pp. 172 1882

21. Jones, J. P.
Deficiency of Magnesium the Cause of a Chlorosis in Corn.
Jour. Agr. Res. Vol. 39
pp. 873-892 1929

22. Kelley, W. P.
The Agronomic Significance of Base Exchange.
Jour. Amer. Soc. Agron. 22:977-985 1930

23. Lemmermann, O.
Determination of the Phosphate Requirement of Soils by the Lemmermann-Fresenius Citric Acid Method.
Tras. 2nd Com. Intern. Soc. Soil Sci.,
A: 135-142 1929

24. Loew, Oscar and May, D. W.
Relation of Lime and Magnesia to Plant Growth.
U. S. Dept. of Agr.
Bureau of Plant Industry
Bul. No. 1 pp. 52 1901

25. Lyon, T. L. and Buckman, H. O.
The Nature and Properties of Soils.
pp. 314 1927

26. Mattson, S.
Electrodialysis of the Colloidal Material and the Exchangeable Bases.
Jour. Agr. Res. 22:553 1926

27. MacIntire, W. H. and Young, J. B.
The Transient Nature of Magnesium-Induced Toxicity and Its Bearing Upon Lime-Magnesia Ratio Studies.
Soil Sci. 15:427 1923

28. Merkle, F. G.
The Influence of Fertilizer Treatments on the Content of Exchangeable Cations in Hagerstown Silt Loam.
Soil Sci. 26:377-384 1928

29. Meyer, D.
Untersuchungen uber die Werkung Verschiedener Kalk und Magnesia-formen.
Landw. Jahrb. 33: 371-404 1904

30. Mitscherlich, E. A.
Die Bestimmung des Dungerbedurfnisses des Bodens.
Berlin: Paul Parey 1924

31. Niklas, Von Prof. Dr. H., Poschenrieder, Dr. H. and Frey, Dr. A.
Ubersuchungen zur Festsbellung der Magnesia Dungsbedurftgkeit Von Boden Mittels Aspergillus Niger.
Die Ernahrung der Pflanze Heft 22. S 465-470 1931

32. Peter, Alfred M. and Averitt, S. D.
On the Proper Strength of Acid to be Used for Determining Available Plant Food in Soils.
U.S.D.A. Bur. Chem. Bul. 99: 115-116 1905

33. Popoff, Stephen
Quantitative Analysis (Second edition) 1927

34. Redmond, J. C. and Bright, H. A.
Determination of Magnesium in Portland Cement and Similar Materials by the Use of 8-Hydroxyquinoline.
Bureau of Standards Journal of Research. 6: 113-120 1931

35. Robinson, W. O.
The Relation Between the Total Chemical Composition of the Soil and the Water Extract.
Jour. Amer. Soc. Agron. 20: 793-801 1928

36. Sackett, W. G.
Determining Soil Deficiencies.
Amer. Fert. 73 No. 3 P. 36 1930

37. Salgado, M. L. M. and Chapman, G. W.
A Simple Electrodialysis cell for the Routine Determination of Exchangeable Bases in Soils.
Soil Sci. 32: 199-213 1931

38. Salter, Robt. M. and Ames, J. W.
Plant Composition as a Guide to the Availability of Soil Nutrients.
Jour. Amer. Soc. Agron. 20: 808-836 1928

39. Schollenberger, C. J.
Exchangeable Hydrogen and Soil Reaction.
Science 65: 552-553 1927

40. Thornton, S. F.
Experiences with the Neubauer Method for Determining Mineral Nutrient Deficiencies in Soils.
Jour. Amer. Soc. Agron. 23: 195-208 1931

41. Truog, Emil and Chucka, J. A.
The Origin, Nature, and Isolation of the Inorganic Base Exchange Compound of Soils.
Jour. Amer. Soc. Agron.
22: 553-557 1930

42. Waksmann, Selman A.
Principles of Soil Microbiology.
pp. 381 1927

43. Wheeler, H. J. and Hartwell, B. L.
Magnesium as a Manure.
R. I. Agr. Exp. Sta. 17th Annual Report 1903-1904
pp. 221-260 1905

44. Wiley, Harvey W.
Principles and Practices of Agricultural Chemical Analysis.
Vol. 1, pp. 398-399 1906

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