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THE

RELATION OF LIME AND MAGNESIUM

TO

PLANT GROWTH

IN

MISSOURI SOILS.

A

THESIS PRESENTED FOR THE DEGREE

OF

MASTER OF SCIENCE

IN

AGRICULTURE

BY.

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THE RELATION OF LIME AND MAGNESIUM TO PLANT GROWTH IN MISSOURI SOILS.

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PART I.

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INTRODUCTION.

The relation of lime and magnesium to each other in plant growth is a problem over which the Agronomist and Plant Physiologist have stumbled for some time, and before its solution is finally reached, will likely involve the consideration of several other mineral elements which are not now generally believed to function with them.

It has been known ever since the time of Aristotle that lime is beneficial to most soils, and since then it has been used in all its forms as a condiment; sometimes with success; sometimes with medium results and sometimes with apparent failure. SIR JOHN BENNET LAWS and SIR JOSEPH HENRY GILBERT were the first to make accurate observations upon the practice of liming. They found that the white or "fat lime" would produce better yields than the gray or "poor lime" which was sometimes injurious. From observations of this kind there has grown up the practice of applying lime to soils stiff and poor in texture. Magnesium on the other hand is never applied since it has no such benefi-

cial action,and is supposed to exist in sufficient quantities for all necessary needs of plant growth. This in general is true,as most soils in America and Foreign Countries,contain more lime than magnesium. However, there are instances where the magnesium content of some soils is below that of lime,and applications of magnesium to these soils would be found beneficial.

It will be the purpose of the following pages of this paper to discuss the Physical,Chemical,Bacteriological and Physiological relations of Calcium and Magnesium to soils and their effects upon plant growth. And while some of these theories are somewhat obsolete the majority are new and apparently true.

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THE PHYSICAL EFFECTS OF LIMING.

The necessity of lime to plant growth is a fact that has long been recognized. Its presence in a soil serves many purposes. The first and most beneficial is the physical effect exerted by its presence in improving the soil's tilth and texture. Sad and sour soils become porous while stiff,mucky soils loose their stickiness due to the coagulating power of the colloidal constituent of the clay. By liming,the individual soil particles are collected together forming compound particles,the so called crumb structure,which is so necessary to good drainage and areation. And areation means a great deal;by it carbon dioxide and

other poisonous gases are allowed to escape, while oxogen, which is necessary for nitrifying bacteria and other beneficial processes of decay, is not only admitted, but actually forced into and out of the soil by daily changes in temperature and the continual variation of barometric pressure. Under such conditions soluable plant food is formed more rapidly; the zone of root action is deepened and the action of food making bacteria intensified.

Soil temperature is also very largely influenced by liberal dressings of lime, which tends to lighten and increase the porosity of sticky clay soils. Aside from the heavy soils mentionedthe light sandy types are benefited to a certain degree by th e addition of lime, which, although not always necessary for areation, is sometimes beneficial in order to increase the moisture holding power. The addition of lime to a soil hastens the decay of humus and thereby encourages the activity of the various kinds of soil bacteria whose beneficial action ultimately results in more humus. And because of the limited quantity of humus in sandy soils there is much liability of over liming them and reducing the already small supply of humus tooseverely.

The act of nitrification is made possible by conditions which are largely indebted to the lime content of the soil. And in connection with nitrification there comes another use of lime which is fully as important, and this is its ability to

check or completely destroy bacterial and fungus diseases which hinders to a more or less extent the progress of root growth and development.

We may conclude therefore, that conditions of good tilth, good texture, and good drainage together with good areation are largely responsible to the activity of soil lime. And these conditions may be considered as most conducive to the succeeding activities which are Chemical, Bacteriological and Physiological in their nature.

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THE CHEMICAL EFFECTS OF LIMING.

The addition of calcium to a soil supplies of itself no needed plant food. Of course calcium functions as a food in the formation of plant tissues, but it would be a poor soil indeed which was too deficient in calcium to supply the actual needs of that element in the growing plant. Its action, therefore, when applied to the soil, is that of an indirect agent, acting upon the dormant soil residues and chemically reducing them to elements of fertility. In the chemistry of the soil calcium functions as a base, neutralizing soil acids and displacing the weaker bases as, Potassium, Sodium, Magnesium, Iron, Aluminium, and even Phosphorus where this element exists in the presence of iron and aluminium. It is the double hydrated silicates of these minerals which result from the breaking down

of feldspars,that are decomposed in the presence of calcium and humic acids. The resultant reaction is after this formula: "$Al_2O_3,K_2O,6SiO_2$ $Ca(HCO_3)_2$ $Al_2O_3,CaO,6SiO_3$ $2KHCO_3$" and this liberation of potassium in soils which is supplied with sufficient phosphorus is noted by a much increased plant growth above. Calcium is,therefore,a very powerful agent in bringing Potassium into solution. And its operation is considered to be that of a mass action in which one base displaces another in solution.

To a considerable extent calcium acts as a liberator of which phosphorus in the acid form is seemingly able to act on the insoluable phosphates of iron and aluminium,converting them into the phosphates of calcium. However,there are many cases where an application of lime has apparently decreased the quantity of available phosphoric acid in the soil. This in all probability is due to cases of excessive liming in soils whose phosphoric acid is not only limited but already exists as phosphates of calcium,and when portions of this very slightly soluable di-basic phosphate does come into solution it is immediatly taken up by the awaiting atoms of calcium and converted into the insoluable tri-calcic form. On the other hand when lime is beneficial in liberating phosphoric acid it is assumed that the phosphates of iron and aluminium are replaced by calcium,forming the more soluable mono and di-calcic phosphates, which the plant uses as food. It is seen therefore that calcium does not only function as a neutralizer of acids but as a

liberator of plant foods as well,and under such conditions the best results are obtained by moderate applications made often.

The process of decay which results in the oxidation of humus is promoted by the presence of a base to combine with the organic acids produced by such decay. And the act of nitrification itself is dependent upon the presence of an easily attacted base. As a net result the oxidation of humus and the formation of nitrates are increased by an application of lime.

"When land begins to need lime it is a waste of time and energy to continue to cultivate it until that need is supplied. For the economical use of every other fertilizing material, including manure itself,is dependent upon the lime supply,and if this is deficient everything else will fall short of possible attainments." (Thorne Cir. 79)

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THE BACTERIOLOGICAL EFFECTS OF LIMING.

Many of the chemical changes brought about by liming a soil are directly responsible to the increased activity of bacteria. Soil bacteria are extremely sensitive to the alka - linity or the acidity of the soil in which they live,and the basic properties of calcium plays a significant part in the retarding or stimulating of their growth and activity. As the decay process of the humus and organic bodies proceeds acids are formed and poisonous by-products are created and thrown off by

the developing bacteria,which after a time accumulate until the growth and life of the nitrifying groups are impared. At this time the presence of a needed base,lime or something similar in reaction,neutralizes this organic poisoning and sets aright this adverse condition. Only a small balance either way from the neutral point will determine the character of the soil's bacterial flora. Those of the denitrifying groups require a sour,acid,stagnant condition while those of the opposite or nitrifying group require a medium slightly alkaline and a soil well areated. The bases of Sodium,Potassium or Magnesium do not seem to be strong enough to hold out of solution the acid radicles which act so injuriously against the development of the Azobacter groups. Hence, the need of calcium.

"The nitrogen forming bacteria of the Azobacter group may readily be isolated from soils abundantly supplied with calcium carbonate,whereas soils deficient in it,or in soils over charged with magnesium they can be found only with difficulty if at all" (Lipman, Bul.,New Jersey Station No.210.)

The dependence of the nodule forming bacteria of the legume families is largely upon the quantity and character of calcium in the soil. In eastern Ohio clover cannot be grown successfully owing to the deficiency of calcium, hence the scarcity of nodule forming bacteria. (Thorn Cir.79). The presence of calcium carbonate not only effects the gain of nitrogen in a soil but also the economy of its transformation.

This is a point upon which too much stress can scarcely be laid, since a difference of ten percent of available nitrogen in the humus or manure in the soil will materially effect the yield on that soil. But aside from the soil nitrogen the bacteriological effects of liming extends to the liberation of all the other elements of fertility. The evolution of carbon dioxide is a good index of organic decay, and in the presence of calcium carbonate, it will also serve as an index to the formation of the other elements of fertility. Hence, its bacteriological as well as its chemical effect. "If the liming of a limestone soil tends to decrease the available supply of phosphoric acid, the presence of bacteria in that soil will will tend to increase the supply. (Vorhees. Bul.210, New Jersey.).

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THE PHYSIOLOGICAL ROLE OF CALCIUM.

Ithas been known for a long time that calcium and magnesium cannot replace each other in their physiological functions, and the exact performance of these respective elements has been a matter of conjecture until quite recently. All that is known is due to the investigations of such able men as Boehm(75), Kellerman(80), Loew(92), Duggar(95), Reed(07), and Osterhout(07). These men in their investegations upon the functions of mineral nutrients have lifted the veil until sufficient evidence is now ascertained to partially affix their respective duties. It will

not be our purpose to discuss the uses of the other mineral nutrients only in so far as they bear upon the action of the two elements in question.

When making observations upon mineral nutrients in solution Heiden observed that maize and peas growing in solutions lacking calcium lived only four weeks, and reached the height of I8.9 and 27 centimeters respectively. But when cultivated in a solution lacking magnesium the maize lived ten weeks and reached a height of 44 centimeters, while the peas lived twelve weeks and grew 30 centimeters high.

This is the first authentic indication that there existed a relation between calcium and magnesium in plant development. Undoubtedly the reason for the plants living longest in the magnesium free solution was because of the preponderance of that element over calcium in the seed. The result of like experiments of my own recorded in this paper conform to these observations.

Results like these led other investigators to seek the real physiological reasons for this difference. A summary of their results and theories follows.

In a series of experiments of this nature, Boehm observed irregularities in starch transformation when calcium was lacking in the solution. He was working on the bean (Phaseolus Multi - florens) and found that the plant rapidly recovered when a few drops of calcium nitrate solution were added, but the addition of

magnesium nitrate on the other hand hastened death. The accu - mulation of starch was found to be in the pith and bark of the lower stem. He also observed that death began in the upper leaves and proceeded downward. By further observations he at - tributes to the use of calcium a function in the formation of the cell wall,and says "In order to form the cell wall from starch and sugar,calcium is just as important as in the formation of bone". In this position this investigator maintains is that calcium assists in forming the skeletin of the cell wall. (See Bul.45, B.P.I.).

In this connection Reed while working with Spyrogyra in calcium free solutions,found after a growth of six weeks that nuclear division had been complete,or nearly so,in most cases, but in the case of cellular mitosis the transverse cell walls were NOT OFTEN COMPLETE and in many cases they had not FORMED at ALL. A still more striking need of calcium in cellular form - ation was shown in a case,by the same author,where Spyrogyra in the initial stages of conjugation were placed in calcium free solutions. In the proper time normal conjugation tubes were formed and gametes produced,BUT WHEN THE CONJUGATING NUCLEI HAD FUSED TO FORM THE RESTING SPORE? NO CELLULAR WALL WAS EVER FORM-ED TO PROTECT THE RESULTING PLASMATIC MASS. The process of this of this conjugation had in all respects been normal,but the lack of a cellular covering for the resulting spores is the best kind of evidence that calcium is needed in cellular formation.

Calcium however, is not a constiuent of cellulose but seems only to function in its formation. (See Annals of Botany, Vol. XXI, - No. LXXXIV, Oct. '07).

Schimper, Groom and others consider calcium to function in the precipitation of oxalates, which bodies prevent the action of diastase in the transformation of starch into sugar. This would be in accord with Boehm's results on the accumulation of starch in the absence of calcium, and it is very probable that calcium does function in such precipitation since much of the calcium found in the leaves of plants exists in this form.

Loew strongly propounds the theory that in the synthesis of the internal cellular structures calcium functions in the formations of proteids. This is a very ingenious theory. Loew supposes that in the formation of proteids magnesium functions up to a certain stage, and then should it continue beyond that stage an over abundance of the element would result in a clogging or a congested condition which would impare proteid development. But in the presence of calcium, it being the stronger base, would replace magnesium and permit constructive metabolism to proceed. This theory holds up very well in the chlorophyll bearing plants but in the fungi, which are able to manufacture proteids in the absence of calcium, it fails altogether. The accumulation of lecithin and oily substances in calcium free solutions rather indicates that calcium does not function as a proteid builder, leaving that office more likely to magnesium. It is very likely

that the radicles or by-products produced inthe evolution of lecithin bodies are either neutralized or eliminated by the presence of calcium,or it may be that calcium functions in the translocation of lecithin bodies,much as potassium functions in the translocation of starch.

From what has been said it appears that calcium unlike potassium and phosphorus does not function directly in the living parts of the cell,but is rather a catalytic agent or scavenger which removes injurious residues from synthesizing protoplasm.

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PHYSICAL EFFECTS OF MAGNESIUM.

The physical effects of magnesium are as much pronounced as are those of calcium,only this element effects the soil oppositly Like calcium it increases the moisture holding power of the soil and especially the osmotic strength of soil solutions. These salts do not precipitate as strongly as calcium salts do. In fact they make the soil sticky,rendering it stagnant and sour. Under this condition it does not promote nitrifying bacteria,but hinders instead. Vegetation usually grows sparingly on magnesian soils,and root development is also limited owing both to the poisonous effects of the element and to the sour condition of the soil. Magnesium seems to have no function in the soil other than a plant food.

PHYSIOLOGICAL USES OF MAGNESIUM.

Magnesium is needed for the complete development of all plants. It occurs more abundantly in fruits and seeds than it does in leaves and stems. A part of the functions of magnesium appear to be accomplished directly and a part indirectly as in the case of calcium.

Loew (03) and Reed(07) observed that phosphorus was assimilated in the presence of magnesium. Loew reasoned that since magnesium was always found to be more abundant in rapidly growing regions of the plant it necessarily followed that it and phosphorus worked in conjunction with each other. After working upon the problem for some time he concluded that as all magnesium salts were easily hydrolized the secondary magnesium phosphate while in the constructive process of metabolism became decomposed into the tertiary phosphate,,thereby leaving a molecule of free phosphoric acid to proceed with the process of assimilation. He maintained also that nitrates and sulphates would be hydrolized by the same reaction and that the result of such metabolism would be a MAGNESIUM-PROTEID compound. And he further maintains that without the presence of calcium this magnesium- proteid compound would accumulate until the activities of the plant were either ruined or seriously impared. In this connection it might be well to remember Boehm and Reed's observations on the accumulation of vegetable oils and lecithin in

plants grown in calcium free solutions. In the presence of calcium a small amount of magnesium can do a great deal of work as it may be used over and over again.

Loew goes still another step farther and maintains that oils are synthesized only in the presence of phosphorus and magnesium;with this Reed also concurres. It is a fact that phosphorus and magnesium,in oily seeds,greatly exceed that found in starchy seeds.. The ratio being as 5 : 2. The phosphorus found in this instance is in the organic form,LECITHIN.. In this connection Reed observed that Vaucharia when placed in cultural solutions lacking magnesium did not produce any oil globules and that in a similar solution lacking calcium oil globules were plentiful. The inability of this plant to form oils without the presence of magnesium seems to prove that the foregoing hypothesis is a correct one. Thus far it seems that this function of magnesium is its most important one.

It is also known that the spores of fungi store most of their reserve food in the form of oils. And as shown by Duggar (05) the spores of Agaricus Campestris will germinate best(when they germinate at all)in solutions containing phosphates. It seems that there is no way of getting away from the fact that magnesium and phosphorus are always found together,and the presence of relatively large amounts of magnesium in oilyseeds ans spores confirm what has been said regarding the necessity of magnesium to assist in the assimilation of phosphorus. This

necessity is the more evident when we remember that the formation of fat is usually preceeded or accompanied by the formation of lecithin.

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PART II.

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POT CULTURE STUDIES ON THE LIME MAGNESIUM RATIO.

On account of the intimate relation between calcium and magnesium, and because of their variation in Missouri soils it seems expedient to ascertain their exact relations to plant growth, and then compare this relation in pot culture with several types of Missouri soils. It so happens that a survey is being made of Missouri soils, and already several types have been analyzed and chosen for practical field tests. The chemical analyses of several types under field tests, have shown some of these to be deficient incalcium, while in some magnesium has greatly predominated. On soils of this type it becomes all the more desirable to fimd the exact relation of the two elements.

When planning these experiments it was thought best to deter-

mine the calcium magnesium ratio in sand cultures before taking up the types of soil to be tested. While these tests were going on it was thought best to run several tests in water culture in order to be exactly certain about the exact ratio. Time would not permit the completion of the water culture tests before taking up those of the soil,and so the soil and sand cultures were taken up first.

For the sand cultures it was thought best to use the wire basket method of the bureau of soils,while for the soil tests the method of Hopkins and Voorhees was employed. A description of the method and a record of the results follow.

The baskets were made from strips of quarter inch wire cloth calculated so that when rivited together they would just hold one quart. After the baskets were made they were coated with paraffin,by dipping them,-filled with damp sand,-into a bucket of melted paraffin. The sand used was a medium grade obtained from a Missouri river sand bar. Being the best to be had. It contained but little clay and comparatively little organic matter was present. However,it was thought best to wash it free of all soluable matter before proceeding with the test. This was done by placing the sand into a large three gallon funnel and attaching a hose to the bottom at full force,the clay,organic matter and lighter substances were thus carried over. This method was very ineficient but the bulk,-two bushels,-was so large that the expense of washing with acids was prohibitive.

The cultural baskets were made up in duplicate and desig - nated la,lb,etc. up to the six cultures which compose one set. In the following cultures there were seven sets. One killogram of air dried sand was placed into each basket and made up with the cultural solution to a moisture content of 20%. This required 200 c.c. of solution for each basket or 16800 c.c.for all.

These solutions were somewhat difficult to prepare,since it was necessary to maintain,as a constant,,all the nutrients except calcium and magnesium,which were manipulated in such a way that one would increase from la,to6a,while the other decreased from la, to 6a. In order to reach this result three solutions,designated A. B. C. were made up. Solution A. contained all the nutrients except calcium and magnesium,and was compounded according to Knop's solution formula. In subsequent trials this formula was varied for reasons to be stated. SolutionsB. and C.were calcium and magnesium respectively,while distilled water was used to fill up the shortage of the other solutions.

Molecular solutions were employed throughout,and where it became necessary they were diluted to suit the best plant growth A careful study of the formulae in Table 1,will show how the solutions were made up,and Table 11,will show how they were compounded.

TABLE No.1 FORMULA 1.

Sol.	Chemicals used.	Molecular weight.	Strength of Sol.	Grams in liter	No.of grams	No.of liters	Times diluted	Total grams.
	KNO3	101	M/100	1.01	10.1	10	2	20.2
A	NaSO4 10H2O	322	M/400	.805	8.05	10	2	16.1
	K2HPO4	174	M/200	.87	8.7	10	2	17.4
B	CaCl2	111	M/200	.555	2.22	4	4	8.88
C	MgCl2	95	M/200	.475	1.94	4	4	7.76
D	Dist. H2O					20		

TABLE No. 11 HOW THE SOLUTIONS WERE COMPOUNDED.

Culture	Determinants showing strength and ratio.	Sol. A	Sol.B	Sol.C	Sol.D	Total.
1a&1b	CaCl2,M/200:MgCl2,M/200	100	50	50		200
2a&2b	CaCl2,M/200:MgCl2,M/400	100	50	25	25	200
3a&3b	CaCl2,M/200:MgCl2,M/600	100	50	16.6	33.4	200
4a&4b	CaCl2,M/200:MgCl2,M/800	100	50	12.5	37.5	200
5a&5b	CaCl2,M/400:MgCl2,M/200	100	25	50	25	200
6a&6b	CaCl2,M/600:MgCl2,M/200	100	16.6	50	33.4	200

Three culture solutions were made up in quantity ; eighty four baskets were supplied with 1,000 grams each of air dried sand and a quantity of seven varieties of seeds were set to germinate. The seeds used were Corn, Oats, Wheat, Cowpeas, Clover, Alfalfa andMustard. As fast as the seeds became germinated sufficiently, the cultural solutions were compounded as shown in Table 11. and poured over the sand, the seeds were then uniformly planted. A great deal of pains were taken in selecting seeds the same in size, and degree of germination. Immediately after planting the baskets were weighed and covered to prevent evapor - ation.

As soon as the plants were sufficiently up,-one inch high,- the baskets were reweighed and the loss of moisture made up.with distilled water. The baskets were then sealed, that is a piece of paraffined paper cut to fit the top of the basket, and permit- ting the plantlets to protrude through, was sealed close to the surface of the sand. The baskets were then weighed again and all future weighings were compared to this one. The water used in these experiments was obtained by condensing the steam from the heating plant by means of a block tin condenser.

The first four series of cultures ran through to a success- ful conclusion, the last three failed. Clover and Alfalfa will not grow in sand and an accident happened to the Mustard. The results in the tables are not as uniform as they should be, but the general results point in the direction which later trials follow. An anylitical digest of the table follows.

TABLE No. 111 CORN. FORMULA 1.

Culture	Ratio	Am't. Transp.	Average Transp'on.	Compar. Transp.	Green Weight	Average Weight	Compar. Growth	Grand Average	Final Injury
1a&1b	Cal : Mg1	134.5 131.0	132.7	100	7.2 8.0	7.6	100	100	0
2a&2b	Cal : Mg/2	131.0 112.0	121.5	91.6	6.5 3.9	5.2	68.3		Do to Lime
3a&3b	Cal : Mg/3	139.0 129.0	134.0	101.0	5.4 5.2	5.3	68.4	65.7	34.3%
4a&4b	Cal : Mg/4	122.0 128.0	125.0	94.2	4.8 4.4	4.6	60.4		Do to Magne-
5a&5b	Ca/2: Mg/1	118.0 128.0	123.0	92.7	4.5 5.7	5.1	68.1		sium
6a&6b	Ca/3: Mg1	122.0 130.0	126.0	94.9	8.7 7.0	7.8	102.4	85.2	14.8%

INJURY ofLIME OVER MAGNESIUM 19.5 %

Tabulated results of CORN grown in sand culture to show the exact relation of lime to magnesium. Transpiration method.

TABLE No. IV OATS. FORMULA 1.

Culture	Ratio	Am't. Transp.	Average Transp'on	Compar. Transp.	Green Weight	Average Weight	Compar. Growth	Grand Average	Final Injury
1a&1b	Ca1 : Mg1	567 568	567.5	100	4.25 4.6	4.42	100	100	0
2a&2b	Ca1 : Mg/2	566 567	571.5	100.6	4.7 4.5	4.6	104.2	95.0	Do to Lime 5 %
3a&3b	Ca1 : Mg/3	541 427	484.0	85.1	4.6 3.7	4.15	94.0		
4a&4b	Ca1 : Mg/4	533 540	536.5	94.4	4.2 3.5	3.85	86.8		
5a&5b	Ca/2: Mg1	583 598	590.5	104.0	5.0 4.4	4.7	106.2	98.3	Do to Magne-
6a&6b	Ca/3: Mg1	538 608	103.5	103.5	3.8 3.7	3.75	90.4		sium 1.7 %

INJURY OF LIME OVER MAGNESIUM 3.3 %

Tabulated results of OATS grown in sand culture to show the exact relation of lime to magnesium. Transpiration method.

TABLE No.V. WHEAT. FORMULA 1.

Culture	Ratio	Am't Transp.	Average Transp'on	Compar. Transp.	Green Wt.	Average weight	Compar. Growth	Grand Average	Final Injury
1a&1b	Ca1 : Mg1	492.5 491.0	491.2	100	2.2 1.8	2.0	100	100	0
2a&2b	Ca1 : Mg/2	443.0 490.0	466.5	95.0	1.05 1.15	1.6	80.0		Do to Lime 20.9
3a&3b	CaL : Mg/3	480.0 540.0	510.0	103.0	1.7 1.8	1.75	87.5	79.1	
4a&4b	Ca1 : Mg/4	548.0 518.0	533.0	108.0	1.6 1.2	1.4	70.0		
5a&5b	Ca/2: Mg1	484.0 589.0	519.5	109.1	2.0 1.4	1.7	85.0	85.0	Do to Magne-sium 15.0
6a&6b	Ca/3: Mg1	506.0 523.0	519.5	104.5	1.9 1.5	1.7	85.0		

INJURY OF LIME OVER MAGNESIUM 5.9 %

Tabulated results of WHEAT grown in sand cultures to show the exact relation of lime to magnesium. Transpiration method.

TABLE No. VI. COWPEAS. FORMULA 1.

Culture	Ratio	Am't. Transp.	Average Transp'on	Compar. Transp.	Green Weight	Average weight	Compar. Growth	Grand Average	Final Injury
1a&1b	Ca1 : Mg1	537 575	556.0	100	9.4 10.8	10.1	100	100	0
2a&2b	Ca1 : Mg/2	548 633	590.5	106.2	9.0 10.6	9.8	97.0		Do to Lime 10 %
3a&3b	Ca1 : Mg/3	576 535	555.5	99.9	7.7 8.5	8.1	90.1	90.0	
4a&4b	Ca1 : Mg/4	575 568	571.5	102.8	8.2 8.6	8.4	83.1		
5a&5b	Ca/2: Mg1	572 547	554.5	99.7	9.9 9.9	9.9	98.0	96.0	Do to Magnesium 4 %
6a&6b	Ca/3: Mg1	559 512	535.5	105.5	9.5 9.5	9.5	94.0		

INJURY OF LIME OVER MAGNESIUM 6.0 %

Tabulated results of COWPEAS grown in sand cultures to show the exact relation of lime to magnesium. Transpiration Method.

These four series,(See tables 111,1V,V,V1), were sown on Jan.17 and were allowed a growing period of 48 days. Their growth was very satisfactory notwithstanding the variable temperature due to a very unusually warm February. More differences were shown during the first two weeks of growth than were apparent at any time later,and these differences usually favored the heavier addition of lime,which later seemed to be the cause of reducing the growth. In this trial corn was most effected and oats least effected. Contrary to all expectations,and previous notions,the growing leaves in the pots where magnesium predominated did not become brown and fall off to any greater,and possibly to a lesser extent,than did those of the pots treated heaviest with lime. In fact they had a better green,and as growth advanced became more stocky than did those in the limed pots. The corn and cowpeas although grown"leggy"were stiff enough to stand,but the wheat and oats soon fell over.

PLATE 1.

COWPEAS IN SAND CULTURE. SEE TABLE V1.

The transpiration data of these experiments,as shown by the tables,did not prove to be very accurate. This was due to the large size of the pots and to the tendency of the paraffin to melt loose from the sides of the pots,thus admitting an error. This data was therefore,thrown away and that of the green weights substituted as the basis of our calculations. Considering these, some surprising results were obtained. By examining the column marked "Comparative growth" in tables 111 to V1 it is ascertained that the percent of growth increases as the quantity of magnesium in the culture increases,or to state it differently, if calcium in the ratio of one to the decreasing quantity of magnesium in the culture IS COMPARED to magnesium in the ratio of one to the decreasing quantity of calcium in the culture the RESULT varies from 3.3 % to 19.5 % in favor of magnesium. This is directly opposed to all the consepts we ever had of the relation of lime and magnesium to plant growth. Some relief was had when it was shown by chemical analysis that the sand contained but 462 pounds of magnesium as against 5206 pounds of calcium,calculated on the acre basis. This low condition of magnesium was undoubtedly brought about by the washing of the sand which dissolved away the soluble magnesium and left the more insoluble calcium behind. Then too,in the matter of plant feeding,the calcium would have a tendency to precipitate out of solution or revert the phosphates and weaker bases while magnesium on the other hand does not do this but instead increases the osmotic activity of the solutions.

Hence there appears a double reason for the superiority of the magnesium pots.

This test although preliminary was sufficient to show several things.

1st. Sand is an absolutely unfit substance in which to test so delicate a broblem as the calcium magnesium ratio, because it is entirely impossible to eliminate these elements. See the eratic growth of cowpeas in this sand. Plate 1.

2nd. Paraffined pots with 1000 cc. capacity, or holding one killogram of sand are too unwieldy for such delicate tests.

3rd. Some medium absolutely free of lime and magnesium must be used for these determinations, if results are to be depended upon.

4th. Constant attention is necessary at all times to avoid errors in the nature of leaks, breaks, and extremes of temperature.

Before writing up the results of the water culture tests those of the greenhouse pot cultures will be considered, and illustrated as well as possible with photographs.

GREEN HOUSE EXPERIMENTS.

There were planned in connection with the soil survey a series of coordinate greenhouse, pot culture, experiments, which were to be duplicate treatments of those in the out laying fields. And in order to make a comparatively easy observation of the effect of the lime magnesium treatment, some extra pots treated with the

two elements were added on to the other series. When doing this it was thought best to select soils which varied in the total quantity of lime and magnesium present. Some should be as nearly equal as possible, while others should vary to opposing extremes. By consulting Table VIII the ratios of the two elements will be seen to be nearly equal in the soils from Adrian, and Lamar, while calcium predominated in the soil from Poplar Bluff, Eldorado Springs, and Victoria and in that from Cuba, Salem, and Harrisonville the magnesium predominated.

These soils were collected in the vicinities of the towns named, and were shipped in considerable quantities to the green house at Columbia. They were sampled at a depth of eight inches, and were gathered in places where an average of the field would be had when the samples were composited. At the green house they were dried, pulverized, and sifted through an ordinary screen wire sive. This removed all clods, gravel, small stones,and roots besides putting the soil in excellent physical condition.

To get these soils moistened, fertilized and into the pots in a uniform condition was no small task; it was accomplished in this manner. Enough soil for the entire series was heaped upon a zinc covered table and wetted down in layers with distilled water, and, as it was necessary to pot the soil with all the moisture possible it required considerable skill in wetting to prevent puddling. In order to permit moisture distribution the soil was let stand for some hours after wetting. Then the mass was turned, sifted

and turned again and again to insure a uniform sample. When it was ready a portion sufficient to fill a three gallon stone jar to with in one inch of the top was weighed out, and placed in pot number one as a check. All other weighings and compactings were the sames as this one. By compactings is meant the method of filling the pot pots so the soil in each one would have approximately the same degree of texture and firmness. The pots were prepared by inverting them over a quantity of loose sand or soil and driving a drainage hole the size of one's thumb into the bottom. This and the bottom of the pot were covered with a layer of pottery and sand which served for drainage purposes, the later pots, however, were provided with a false bottom of eighth inch mesh wire cloth which rested upon several pieces of broken pottery. This addition of the fertilizer was the most particular and tedious of all the processes. The area of each pot was reduced to the fractional part of an acre, and the quantity of fertilizer computed accordingly.

WORKING FORMULAS TABLE V11.

Size Pots	Surface Area	100#	300#	500#	600#	1000#	2000#	4000#
2	0.3712	.386	1.160	1.85	2.22	3.712	7.736	14.848
3	0.4921	.512	1.538	2.56	3.07	5.128	10.25	20.512
4	00.63029	.656	1.970	3.28	3.94	6.568	13.13	26.275

Size of pots used in these experiments, together with representative amounts of fertilizer per fractional acre, expressed in grams.

The proper amounts of the various kinds of fertilizer, as expressed in table VII,was weighed out into separate packages and compounded as the several soil series were set up. All the series of pots were prepared and weighed before any planting was begun,and all seeds were germinated before being planted.

When work of this character is going on there is always great difficulty in keeping large cracks from forming in the surface soil and especially around the edges of the pots. This permits toorapid evaporation and possible injury to the roots. To over come this three methods were employed; the first was by applying a shallow layer of sand on top of the soil. This prevented cracking in the center but had little effect on the edges,and besides permitted the sand to mix with the soil which interfered with the texture,and ofcourse gave different results from those to which the soil was entitled. The second method was that of sealing the pots with paraffin or paraffined paper through which holes hsd been punched to admit the plantlets. This method was also deficient as it does not admit of sufficient air circulation although solving the problem of surface cracking. (The appearance of this method may be seen by observing the pots in the foreground in PLATE 28. The last method was the only feasible one it consisted in cultivating the surface one and one half inches after the soil had become sufficiently dry from watering.

By consulting the following table the ratios of lime and magnesium and a description of the soils studied can be ascertained. Succeeding tables will give the final results of the various treatments.

CHEMICAL ANALYSES OF THE SOILS UNDER TEST. TABLE VIII.

Location	N	P	K	Ca	Mg	Description of Soil.
Adrian	2840	698	5120	6880	6560	Black prairie, fine texture, loamy, flat, poorly drained, puddled.
Lamar	2480	445	4620	4960	4240	Shallow brown clay loam, poor in texture, low in humus, sour.
Victoria	1460	454	5520	6240	2500	Brown clay loam, poor in texture, low in humus, sticky.
Poplar Bluff	?	low	?	6346	4135	White, silty, good texture, caustic swamp soil, low in humus.
Eldorado Springs	?	low	?	7112	4162	Red sandy loam, fine, good texture, friable, leachy, timber soil.
Harrisonville	?	good	?	12351	13808	Black limestone, crumy texture, deep, well drained, prairie.
Cuba	3720	1020	4760	5460	8000	Dark loamy streak in Post Oak flats poor texture,
Salem	1140	288	3120	2600	3540	Yellow, sandy clay, shallow, poor texture, low in humus.

GREEN HOUSE POT CULTURE, COWPEAS, WHEAT, CORN. TABLE IX.

Pot No.	Treatment.	ADRIAN. Cowpeas 1907 Dry Wt.	ADRIAN. Wheat 1908 No. of Stalks	Height	Wt. of Heads	Wt. 20 Heads	LAMAR. Cowpeas 1907 Dry wt.	LAMAR. Corn 1908 No. of Stalks	Wt. of Corn
1	Check	13.3	19	30	18.8	30.4	16.6	4	43.2
2	NaNo3 100#	14,5	20	32	33.8	33.8	11.2	4	85.8
3	CaCo3 2000# NaNo3 100	15.4	20	32	24.9	24.9	13.1	4	45.8
4	CaCo3 2000 N 100# P 300#	18.9	20	27	41.9	41.9	14.5	4	90.0
5	CaCo3 2000 N.100# P 300# K 100#	19.5	16	32	40.5	50.6	19.6	4	103.0
6	Manure	19.0	18	36	51.3	57.0	17.0	4	100.7
7	Manure & Rock Phos.	22.6	16	31	30.3	37.8	17.5	4	113.5
8	Ground Limestone 1000	12.7	17	30	17.9	21.0	17.3	4	53.8
9	" " 2000#	11.9	22	26	17.5	15.9	14.0	4	47.7
10	" " 4000#	15.2	17	33	31.0	35.9	15.5	4	56.6
11	Magnesium Carbonate 500#	14.2	20	23	18.9	18.9	13.5	4	39.7
12	" " 1000#	11.2	12	29	20.0	33.3	12.1	4	56.4
13	" Sulphate 500#	9.9	18	30	17.1	21.0			
14	" " 1000#	10.3	14	24	21.0	30.1			
15	CaCo3 500, MgCo3 500	12.	12	30	27.9	46.3			

POT CULTURE ON ADRIAN SOIL.

This is a fine grained, black, loamy soil located on a high flat prairie in Bates County. It is a part of the glacial drift that extended below the Missouri River, and while not very deep is fairly rich in native fertility. This particular field however, had been roughly handled for a number of years and was in very poor physical condition when sampled for these pot cultures. The analysis of this soil (Table VIII, Page 30) shows it to be low in nitrogen and especially so in phosphorus, while the lime magnesium content is nearly equal. The lime however, exceeding by a few pounds.

The first culture of wheat was sown in the winter of 1907 but it did not reach maturity because of unfavorable weather in its early period of growth. On the whole enough growth was made to give good indications as to the effect of the fertilizers added. By a little study of the growth in this series it is observed that the wheat in the limed pots is better tham that of the check pot, which is as we should expect it. If on the other hand a comparison between the limed and magnesium treated pots is made it is seen that those treated with magnesium outrank those treated with lime. This is something of a surprise and is directly opposed to all our expectations. In seeking the reason for this new departure it might be suggested that

there were more lime than magnesium in the original soil,

and that the addition of magnesium approximated a close balance of the two elements to which might be ascribed the cause for the enhanced growth. It is true that there were more pounds of native lime than magnesium in this soil, but when the chemical equivalents of the two elements are estimated the magnesium is found to be about 30 % in the ascendency. Then, in the light of this and the contention that the correct relation of lime and magnesium should be in the ratio of one to one, the limed pots should have given the best results. The following photograph illustrates the results.

WHEAT IN POT CULTURE. PLATE II.

Wheat on Adrian soil, winter of 1907. Showing treatment of lime and magnesium.

Without further treatment of this soil cowpeas were sown on the pots and harvested sometime in October. Their growth was much more satisfactory than the wheat and should give a fair index of the fertilizer needs of this soil. By observing the photograph of the peas on the following plate it is seen that magnesium very noticably retarded the growth, and when compared with the check it was found that lime did also. In connection with this plate a little study of the table of dry weights (Table VIII) it is seen that there are only two instances out of eight that growth exceeded the check, and the average growth is far below the check.

COWPEAS IN POT CULTURE. PLATE III.

COWPEAS ON ADRIAN SOIL. SUMMER OF 1907. SHOWING THE RESIDUAL EFFECTS OF THE LIME MAGNESIUM TREATMENT.

Whether these results are due to the chemical effects of these elements on the soil or whether these elements have this effect on cowpea growth is a question. That the injury is due to their effect on cowpeas is made plain by a study of the 1908 wheat crop (Table VIII). Here it is observed that twenty heads of the check plot weighed 30.4 grams, the nitrogen pot (#2) 33.8 grams and the lime nitrogen pot (#3) 24.9 grams. Lime in this

pot was certainly injurious and by dropping down to the lime treated pots Nos. 8,9,10 it is ascertained that they are much below the check yielding an average of but 26.4 grams,while the magnesium treated pots yielded an average of 29.9 or but .5 grams below the check.

The conclusions to be drawn from these experiments are as follows; in the case of the first plamting of wheat the lime did not act as a plant food but as a corrector of soil acidity. The magnesium either did this same thing or acted as a chemical stimulent or both. At any rate its presence in the soil benefitted the growth of the wheat. The cowpeas,on the other hand, presents a radically different problem. In this instance the soil acidity had been corrected,and if lime is a plant food it should show itself here as well as in the next culture,but it retarded the growth in both cases ,while magnesium retarded the growth of cowpeas but did not materially effect the wheat. The addition of lime to this soil seems to have resulted in the reversion of all the available phosphoric acid which the soil contained and figured as the direct cause of reduced plant growth,while magnesium on the other hand had no such injurious action on the other elements of fertility,or had very little if any. The injury coming from magnesium seems to have been physiological in the case of cowpeas,and in the case of wheat there seems to have been little injury if any as the 1907 crop showed a benefit and the 1908 crop came out even with the check.

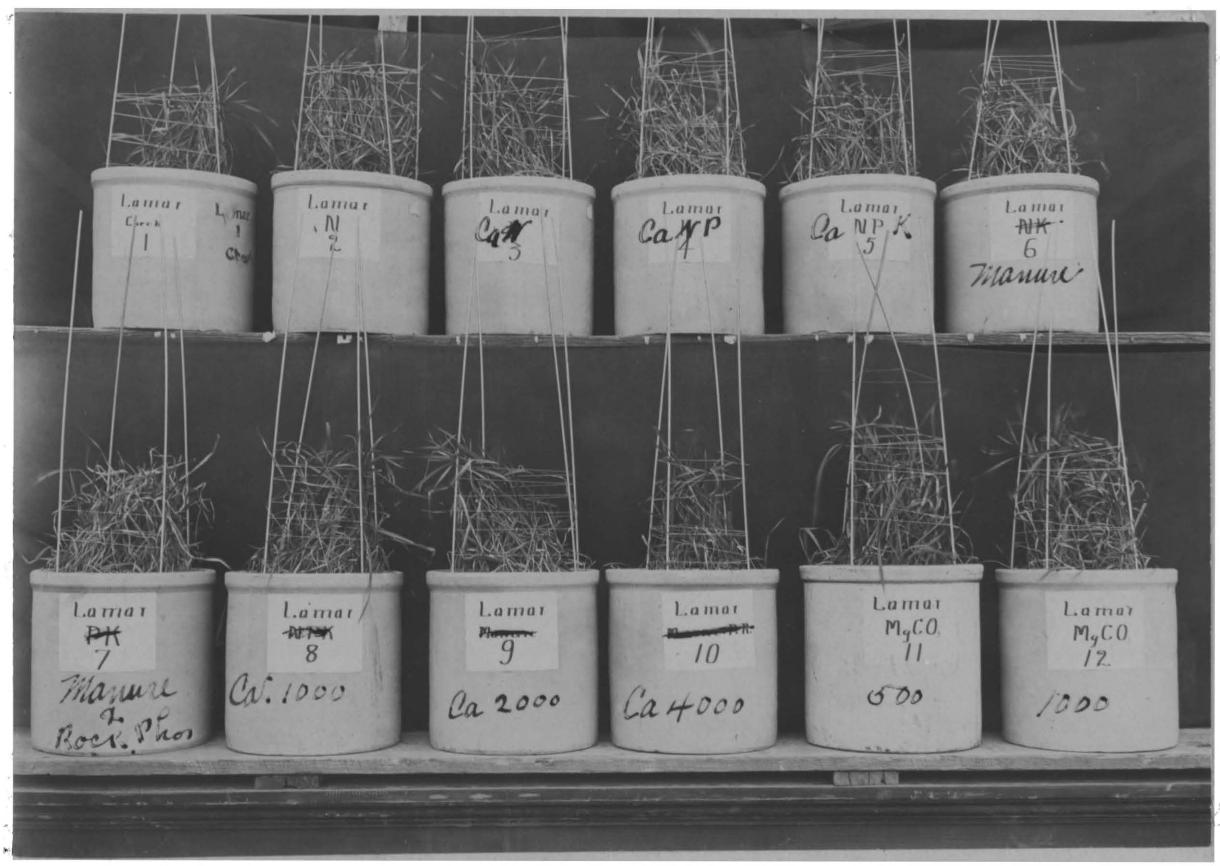
POT CULTURE ON LAMAR SOIL.

This is a gray silt loam, fine in texture, low in fertility and badly in need of drainage. It was added to this test be - cause of its approximate sameness in its lime magnesium con- tent (See Table VIII). It was handled, in all respects of treat ment, the same as the ADRIAN soil, being planted first to wheat then to cowpeas. In the third planting, however, corn was sub- stituted for wheat and grew in the season of 1908. The growth of the 1907 wheat was not satisfactory, but each pot of the series was subjected to exactly the same conditions of moisture and temperature and whatever differences of growth there may be shown is indigative of what the final result would have been had they gone on to maturity.

In studying the effect of lime and magnesium on the growth of this series it will be noted that both lime and magnesium stimulated the growth very markedly, indicating that they were very efficient fertilizers on this soil. But if the growth on the lime magnesium treated pots be compared it will be seen that those treated with magnesium are again in the lead, as was the case with the first culture of wheat on the Adrian soil. Now it just happens that a series of field experiments have been in progress on this soil for a number of years and it is known that all this land is acid, also that liberal additions of lime have yielded remunerative returns. Therefore, it is but

natural to suspect that the lime has functioned only in connection with the soil acids present. Nothing else can be said for it since the other elements,phosphorus and potassium,existed in limited quantities,and if lime had liberated potassium as it sometimes does there would have been a reversed difference in the growth of pots #2 and #3. If on the other hand it had reverted the phosphorus as it sometimes does the growth of the lime treated pots would have been below the check.

WHEAT IN POT CULTURE PLATE IV.



WHEAT ON LAMAR SOIL. WINTER 1907. SHOWING THE EFFECT OF LIME AND MAGNESIUM TREATMENT.

The lime seems to have done nothing but neutralize the soil acids. Then what is to be said of magnesium? In lesser amounts it has stimulated growth beyond that of lime. Has it functioned as a chemical stimulant or acted as a corrector of the soil's acidity? Without doubt it has done both, for calcium and magnesium belong to the same group of "Alkaline Earths" and have several things in common, among them the ability to precipitate certain of the acid groups. Then it will be remembered that Reed and Loew discovered magnesium to be exceptionally abundant in the most active growing parts of plants. Thus indicating that it entered actively into the process of growth.

On this soil the residual effects are directly opposit to those on the Adrian soil, the growth of the peas being very satisfactory. On the Adrian soil the tendency of the two elements was to hinder growth, on this soil they bouyed it up. By consulting the table the lime is seen to have exceeded the check pot by 47.1 % as against 20.7 % for the magnesium.

COWPEAS IN POT CULTURE PLATE V.

COWPEAS ON LAMAR SOIL. SUMMER OF 1907. SHOWING THE EFFECTS OF LIME AND MAGNESIUM. PEAS SOWN AFTER WHEAT THE SOIL NOT BEING REFERTILIZED.

In the fall of 1907 the soil in each pot of this series was turned out,sifted,reset and refertilized. During the process it was ascertained that the texture of the soil had remained almost entirely unchanged and was in an excellent condition. Thus we know that the enclosed soil in each pot was well aerated, and should have given maximum results. Corn was planted on this series Dec.24 and harvested Mar.21. In this growing period of 87 days it did not make a very abundant growth. This,however, may have been due to the green house conditions,but the final results were sufficiently marked to index the effect of the fertilizer. By a study of the green weights of the corn in TABLE IX it will be seen that the lime magnesium treatment exceeded the growth of the check by a small margin. The limed pots by an average of 21.9 % and the magnesium by an average of 11.1 % a difference of 10.8 % in favor of the lime. This difference of growth shows very plainly the relative effect of these two elements on this soil.

It is gratifying to observe at the outset such a close balance between these two elements,and too,when it is known that soil is such an eratic substance to get consistant results from. The next results to be considered will be from soil in which the lime element predominates.

GREEN HOUSE POT CULTURE, COWPEAS, WHEAT, CORN. TABLE X.

		VICTORIA.					POPLAR BLUFF.			ELDORADO SPRINGS.		
		Cowpeas	Wheat				Cowpeas	Corn		Cowpeas	Corn	
Pot No.	Treatment.	Dry Wt.	No. of Stalks	Hight In.	Wt. Per Head	Wt. Per 20 H'ds	Dry Wt	No St'ks	Wt St'ks	Dry Wt.	No. St'ks	Wt. St'ks
1	Check	14.1	9	25	16.9	37.5	14.4	4	58.2	9.0	4	23.5
2	N	16.4	7	30	24.8	70.9	10.6	4	102.9	10.2	4	24.1
3	Ca, N	18.1	10	29	24.6	49.2	15.9	4	89.9	7.5	4	26.4
4	Ca, N, P	20.1	9	29	27.0	60.0	17.4	4	112.0	14.9	4	28.8
5	Ca, N, P, K,	21.1	10	24	22.6	45.2	19.0	4	108.8	15.3	4	45.4
6	Manure	17.0	10	25	29.1	58.2	18.9	4	153.7	14.5	4	73.0
7	M'nr. & Rock	25.9	10	27	29.1	58.2	20.5	4	142.2	16.2	4	64.8
8	Ca, 1000#	12.8	10	27	16.3	32.6	15.4	4	59.4	8.1	4	14.5
9	Ca, 2000#	15.9	10	26	20.0	40.0	12.2	4	50.0	7.9	4	16.3
10	Ca, 4000#	16.5	10	23	18.1	45.2	13.5	4	24.3	8.6	4	20.8
11	MgCo3 500 #	15.2	12	23	15.0	24.5						
12	MgCo3 1000#	14.2	9	26	22.3	49.5						
13	MgSo4 500#	13.2	10	26	15.8	31.6						
14	MgSo4 1000#	14.5	10	25	18.1	36.2						
15	MgSo4, 1000 CaCo3, 1000	15.9	10	19	21.9	43.8						

POT CULTURE ON VICTORIA SOIL.

This soil was selected because of the preponderance of lime over magnesium in the top seven inches,which is shown by the analysis,in table VIII,to be in the ratio of 5 : 2. It is a fine sandy loam,brown in color,shallow and contains but little humus. It had been severely farmed for a long number of years and was in bad physical condition when sampled for this work. In the field tests it has responded to phosphatic fertilizers which is as one would expect knowing the small quantity of that substance found in it.

This soil was handled at the greenhouse in the same manner as was all the other soils,and it was planted to wheat at the same time the other series was planted,being subjected to similar conditions throughout. On account of its defficiency in humus it required more water to keep it moist and also more cultivation to keep it in good heart than did any of the other soils under observation. For this reason growth was not so abundant as on the other soils,and the effects of the fertilizers do not stand out so prominently,yet a little difference in the lime magnesium treatment is present,the lime slightly above the magnesium and both above the check. It is interesting to note how these fertilizers effected growth. Knowing the soil to contain a normal amount of lime,6240 pounds,one would expect a large addition of that substance to decreaseplant growth,but

on the contrary increases in direct proportion. The magnesium does the same, which is as we would expect. The sulphate giving the better results in the 1907 wheat and the carbonate in the cowpeas with a return to the sulphate in the 1908 wheat. It is also interesting to note that where both lime and magnesium have been added together in like amounts the resulting growth in such cases has been largely augmented. By a glance at pots No. 15 in the Adrian, Lamar, Victoria and Cuba series this fact will be readily seen.

POT CULTURES OF WHEAT PLATE VI.

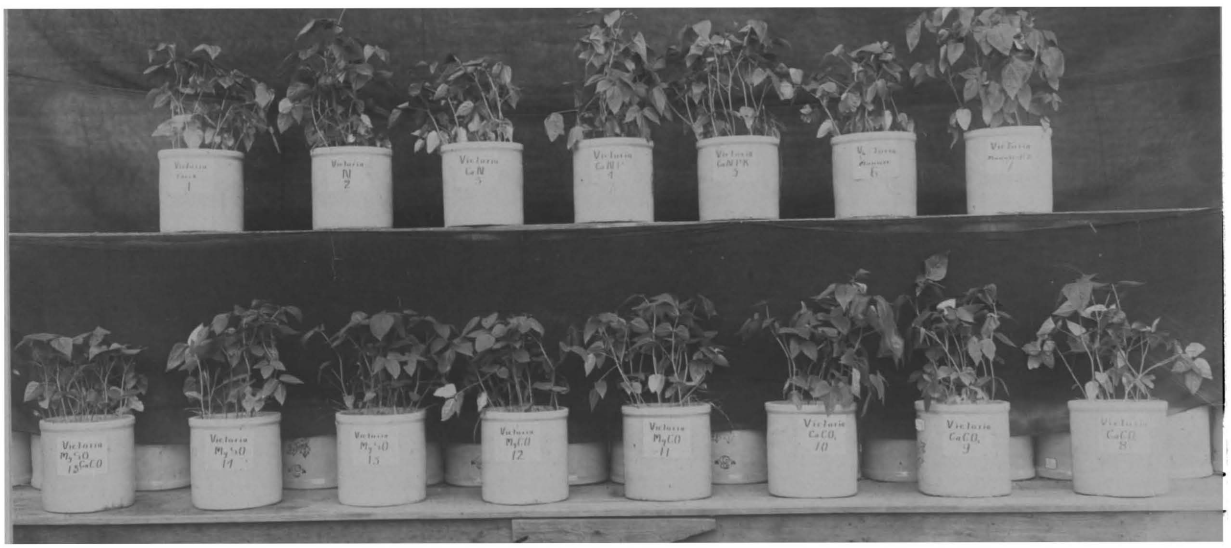
WHEAT ON VICTORIA SOIL IN WINTER OF 1907. PHOTOGRAPH TAKEN IN JUNE.

Tests on this soil have always been eratic. In the field this has been due to a nonuniformity of the soil, and in the

greenhouse to the lack of humus and the tendency for the soil to bake, therefore, any discussion of the effects of any treatments on this soil would be a matter of pure guess.

Below is appended a photograph of the 1907 cowpeas. A glance at this and the preceeding photograph will give one a fair idea of the behavior of this soil.

COWPEAS IN POT CULTURE. PLATE VII.



COWPEAS ON VICTORIA SOIL. SUMMER OF 1907.

The 1908 crop of wheat was considerably better than the other two crops. Unfortunately we can not present a photograph of it but a reference to TABLE X will show that the yield was good, and that all other fertilizers had a considerable bearing on the yields excepting lime and magnesium which did not seem to effect the results either way. The three limed pots standing on an average of 2.1 grams ahead of the check and the five magnesium treated pots standing but 0.4 gram below. Evident-

ly the lime did not benefit the soil and just as surely the magnesium did not injure it. Therefore, the common notion that magnesium is injurious to soils is not always infallible, as the results from this and the previous series will plainly bear out. On the other hand, magnesium did not do on this soil what was expected of it in the beginning, that is, to make up in plant growth for the native deficency of that substance in that soil.

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POT CULTURES ON POPLAR BLUFF SOIL.

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This is a swamp soil ashy white in color and very loose in texture. It contains very little humus or clay and is very caustic in its nature. The white color and its light mealy nature leads one to suspect the soil to be heavily charged with magnesium. For this reason it was added to this test, but upon making a chemical determination of the lime magnesium content it was found that the lime was dominant in a small degree, 6,346 pounds of lime as against 4,135 pounds of magnesium. From this it will be seen that the lime magnesium content is below the average amount it should be in ordinary soils. Considering the previous results we should expect that the addition of both of these elements would increase plant growth very markedly, but as a matter of fact they did not nor did the other fertilizers produce any discernable differenceson the 1907 series of wheat.

The dominating influence here seems to be due to drainage and the first good thorough ventilation this soil ever had. The following plate will emphasize this statement.

POT CULTURES ON POPLAR BLUFF SOIL PLATE VII.

WHEAT ON SWAMP SOIL FROM POPLAR BLUFF MISSOURI. SHOWING THE INFLUENCE OF SUFFICIENT DRAINAGE OVER FERTILIZERS. 1907 CULTURES IN GREENHOUSE AT COLUMBIA MISSOURI.

All the succeeding crops on this soil showed very plainly the effects of the fertilizers added. Unfortunately there were no pots containing magnesium made up for this series,but after seeing the effect of lime on cowpea growth it was decided to make some separate tests of magnesium in solutions from this soil.

The growth of cowpeas in this series was very satisfactory and in the field tests of this soil they made a very decided success. The pots were planted July 8 and harvested about October first. The leaves had just begun to fall and the table of

dry weights for this soil on page 40 will not be quite as acurate as the photograph which follows.

POT CULTURES ON POPLAR BLUFF SOIL. PLATE V111.

COWPEAS ON ASHY SWAMP SOIL FROM POPLAR BLUFF MISSOURI. SUMMER OF 1907.

By observing the above photograph it will be seen that the growth on pots Nos.8, 9 and 10 are smaller than on any others excepting the check and the nitrogen treated pot number 2. The check produced 14.4 grams of dry matter while pot No.8 with 1000 pounds of lime per acre produced 15.4, No.9 with 2000 pounds produced 12.2 and Mo. 10 with 4000 pounds produced 13.5 grams. By this it will be seen that the limed pots yielded a smaller average than the check and knowing this to be a s swamp soil one would expect it to be sour and muggy,therefore, responding to lime treatment.

Turning our attention to the 1908 crop of corn a radical difference is encountered which may be due to a second application of fertilizers. This second application practically doubled the quantity in the pots and is nodoubt responsible for the great differences shown in the succeeding crop of corn.

It will be readily seen by the appearance of the corn in the following plate that such application of lime was detrimental to this soil.

POT CULTURE ON POPLAR BLUFF SOIL. PLATE IX.

CORN ON SWAMP SOIL IN GREENHOUSE. WINTER OF 1908.

By studying the column of green weights of the Poplar Bluff corn in Table X it will be seen that in every case where lime was applied in the absence of phosphorus it reduced the resultant growth very markedly. Even the presence of nitrogen had little effect. The weight of the nitrogen treated pot No.2 was 102.9 grams that of the lime nitrogen treated pot was89.9 as against the check which weighed 58.2 grams. In this consideration note the constant decrease in growth,in the lime treated pots,as the lime increases by application. Pot No.8 with 1000 pounds of lime yielded 59.4,pot 9 with 2000 pounds of lime yielded50.0 and pot 10 with 4000 pounds of lime yielded but 24.3 grams of green corn.

In the case of such decreased growth in the presence of lime,it was suspected that the soil had been made too alkaline and had resulted in reducing the nitrate forming bacteria to

such an extent as to interfere with plant growth. Accordingly determinations were made to ascertain the acidity or alkalinity of the soil in the limed pots, and also to find the quantity of nitrates present. From the results of these determinations there appears to be no great variation either way from the neutral point, surely not enough to effect the growth of the plant or the bacteria to any appreciable extent. But the great surprise came in the large quantity of nitrates found present. Thus it would seem that something else besides a lack of nitrogen is ailing this soil. The table of determinations follows.

DETERMINATIONS IN POPLAR BLUFF SOIL SHOWING AMOUNT OF NITRATES PRESENT; ALSO AMOUNT OF LIME NECESSARY TO CORRECT THE ACIDITY.

No. of Pot.	Treatment	Lime required to neutralize 1 acre.	Nitrate present in parts per million.
1	Check	360 Pounds	4.08 Parts
8	Ca 1000 #	40 "	5.52 "
9	Ca 2000 #	0 "	3.60 "
10	Ca 4000 #	0 "	6.32 "

According to this table the quantity of nitrates present are very considerable and growth should not be deficient on their account. Yet in spite of this the yield of corn decreased constantly as the quantity of lime and nitrates increased.

In summing up the results of this test several things may be attributed to the use of lime. First it neutralized the

soil acidity. Second, it permitted the process of nitrification to proceed rapidly,-in all probability aided nitrification, and Third, it evidently caused a reversion of all the available phosphates in the soil. In support of this theory is presented the excellent physical condition of the soil, the great quantity of nitrates present in it, and the abundance of growth in the other pots where lime was not added. A more conclusive test of this soil will be presented when the discussion of the water cultures are reached.

CULTURE STUDIES ON ELDORARO SPRINGS SOIL.

This is a sandy soil deriving its origin from the red sand stones in west foot-hills of the Ozark mountains. There is but little humus in it and apparently much less of the other elements of fertility. It is reddish gray in color, light, friable and leachy. A chemical analysis showed it to contain only small amounts of lime and magnesium. 6,209 pounds of the former and 4,162 pounds of the latter per acre.

It was shipped to the greenhouse in the late fall of 1906 and stored until sown to wheat the following winter. It was treated in all respects similar to the other soil series. The wheat came up without delay and started into growth evenly. But it was not long before differences began to show, which grew larger as time went on. A glance at the plate below will

show the comparative growth.

WHEAT ON ELDORADO SPRINGS SOIL. PLATE X.

WHEAT GROWN IN WINTER OF 1907 ON ELDORADO SPRINGS SOIL SHOWING EFFECTS OF LIME IN CONTRAST TO OTHER FERTILIZERS.

A study of the individual pots will show that lime has reduced the growth wherever applied. Pot No.2 with an application of nitrogen is better than No3 with lime and nitrogen,and the check too is better than No.3. The influence of all the other fertilizers stand out in prominent contrast with these.

The effect of lime upon the growth of cowpeas may be seen in the following plate.

COWPEAS ON ELDORADO SPRINGS SOIL. PLATE XI.

COWPEAS SHOWING THE RESIDUAL EFFECT OF LIMING.

SUMMER OF 1907.

By observing the above plate it will be seen that the add-

ition of lime effected the growth of cowpeas exactly the same as it did the wheat. A close study of the plants in the individual pots did not reveal the appearance of any physiological injury,-only a much reduced plant growth. A glance at the dry weights for cowpeas on this soil,Table X, will show all limed pots to have produced below the check.

These pots rested until December when the soil was turned out,weighed and refertilized,the same quantity being used as in the first instance. After all this corn was planted on the series. The accoppanying plate will show this corn.

CORN ON ELDORADO SPRINGS SOIL PLATE XII.

CORN SHOWING THE EFFECT OF LIMING, WINTER OF 1908.

Tha above photograph shows the corn after growth during January and February. The corn was germinated before planting and a great deal of care was taken to select grains near the same size and having the same degree of germination. There was practically no differance in their coming up but after a few days those in the limed pots began to fall behind and from that

time on the difference grew wider. When this photograph was taken the leaves on the limed pots were turning yellow,those on the under side having already dropped. It was very evident in this case that the disturbance was physiological.

That this soil does not need liming is evident,and in support of this several reasons may be suggested. First,lime is not needed to improve the texture of the soil. Second,the acidity of this soil is not so marked as to need liming. See the following table.

DETERMINATIONS IN ELDORADO SPRINGS SOIL TO FIND THE AMOUNT OF NITRATES PRESENT AND ALSO TO FIND THE AMOUNT OF LIME NECESSARY TO CORRECT THE ACIDITY.

No.of pot	Treatment	Lime required to neutralize 1 acre		Nitrates present in parts per million.	
1	Check	630	Pounds	5.92	Parts
8	Ca 1000#	240	"	12.88	"
9	Ca 2000#	170	"	23.52	"
10	Ca 4000#	20	"	84.48	"

(These determinations were made by Mr.H.H.Krusekopf).

It is remarkable that there is such little growth in these limed pots when one considers the enormous quantity of organic nitrogen present. The lime has certainly reacted on the other elements of fertility and thrown them out of solution. That the addition of both phosphorus and potassium to this soil is needed

is shown by their effect on pots Nos.4 and 5.(Plates X,XI & XII). From a general survey of this soil one would draw the conclusion that it was very deficient in these two elements,considering the sandy,open,leachy nature and the stunted vegetation in its native growth. One would also conclude from its red color that it was heavily charged with iron. Remembering the statements of Voorhees (Bul.210, N.J.)and Loew (Bul No.1 B.P.I.)that soils containing an abundance of iron or aluminium would have a tendency to revert its phosphorus to the tri-calcic form in the presence of sufficient calcium,one could not help believing such an occurance in this instance.

It is extremely unfortunate that several pots treated with magnesium were not added to this series in the begining. And to make up for this deficiency some water culture work in solutions from this soil was done later. This work will be taken up in part three of this paper.

GREEN HOUSE POT CULTURE. CORN, COWPEAS, WHEAT. TABLE XI.

		HARRISONVILLE			CUBA					SALEM		
		Cowpeas	Corn		Cowpeas	Wheat				Corn		
Pot No.	Treatment.	Dry Wt.	No. St'ks	Wt. St'ks	Dry Wt.	No. St'ks	Height	Wt. Per Head	Wt. Per 20 He'ds	No St'ks	Wt. St'ks	
1	Check	11.1	4	30.6	8.6	13	22	10.8	24.3	4	84.2	Ckeck
2	N	12.2	4	37.2	7.9	7	28	15.1	45.5	4	59.1	N
3	Ca, N	10.0	4	30.1	10.0	9	25	16.1	35.7	4	113.0	P
4	Ca, N, P,	17.0	4	61.1	10.9	11	27	20.7	37.6	4	87.6	K
5	Ca, N, P, K,	11.3	4	40.2	13.2	10	30	28.5	57.0	4	35.7	Ca
6	Manure	16.5	4	90.4	17.6	8	36	47.4	118.5	4	134.1	NP
7	Manure & Rock Phos.	18.2	4	107.1	18.8	9	36	44.2	98.2	4	170.6	NPK
8	Ca, 1000#	10.4	4	20.0	10.2	8	36	13.8	34.5	4	80.5	CaNPK
9	Ca, 2000#	10.0	4	14.9	8.6	8	24	13.8	34.5	4	187.5	Manure
10	Ca, 4000#	10.9	4	28.4	9.5	10	29	8.0	16.0	4	204.4	Manure Rock P.
11	MgCo3 500#				14.4	9	36	19.3	42.9	4		
12	MgCo3 1000#				14.0	10	34	26.6	53.2			
13	MgSo4 500#				13.6	12	30	21.0	33.3			
14	MgSo4 1000#				12.1	13	34	18.0	27.6			
15	MgSo4 1000 CaCo3 1000				15.2	12	28	17.5	29.1			

POT CULTURE STUDIES ON HARRISONVILLE SOIL.

The first three of the following four soils were chosen because of the excess of magnesium over lime in them,and it will be remembered that the first three soils discussed were about equal in their lime magnesium content,while the second three discussed contained lime in excess of the magnesium.

This soil came from Harrisonville in Cass county,which is just south of Kansas City. It lies in the only strip of glaciated country south of the Missouri river..These samples were taken from a flat prairie which was underlaid with limestone. The soil is deep,black and rich and presents almost the ideal in physical structure. The field from which these samples were taken had recently been in clover and was consequently in good heart and rich in humus. These samples were composited and treated like all the other series before it was sown to wheat,which was done about February first. The growth of the plants was very satisfactory with differences showing up greatest in the presence of phosphorus.

The lime treatment did not enhance the growth as was expected,falling considerable below the yield of the check. The lime nitrogen culture was slightly below that treated with nitrogen alone. And cultures Nos. 8,9 and 10 present a decrease in yield as the application of lime increases. This was entirely unexpected for with the large quantity of humus present in this

soil one would anticipate the presence of soil acids and hence the need of lime. The following plate illustrates the growth.

WHEAT IN POT CULTURE PLATE XIII

FIRST CULTURE OF WHEAT ON HARRISONVILLE SOIL.

WINTER OF 1907. SHOWING THE EFFECTS OF LIMING.

The residual effect of the lime treatment on cowpeas was not materially differentfrom that of the wheat. Their slight growth went to prove that additions of lime was not beneficial in this soil,-in fact is slightly injurious. By examining the table of dry weights for cowpeas (Table XL,Page 54)it will be seen that the check culture stood ahead of all the limed cultures,as well as the culture which was treated with both lime and nitrogen. There was no discoloration of the plants

due to liming and the reduced growth was not a physiological disturbance. The relative effects of the fertilizers may be seen in the photograph.

COWPEAS IN POT CULTURE. PLATE XIV.

RESIDUAL EFFECT OF LIME ON COWPEAS GROWN IN HARRISONVILLE SOIL. SUMMER OF 1907.

This soil like all the balance of the series was resifted, refertilized, reset and planted to corn in the early part of 1908 It grew through the months of January and February and produced a much better vegetative growth than the other soils, but the same cultural differences were present in the corn as was found in the wheat and cowpeas. The green weights for corn (Table XI) will show that the check had produced better than any of the pots treated with lime. This was not as we expected of the treatment on this soil, as magnesium was predominant, we should expect lime to balance up the ratio. But instead it proved injurious and we shall have to make the same acqusition here as was made in the other series. It is interesting to note that the percent of injury due to liming this soil is greater than in the Poplar Bluff or Eldorado Springs soils. Reference will be made to this in a later discussion.

POT CULTURES ON CUBA SOIL.

In this soil magnesium predominated over lime in a much greater porportion than in any other of the soils tested. It was taken in Crawford County Missouri,from a little expanse of high prairie which was skirted by rough,rocky hills that were covered with stunted growths of black oak. The soil in this particular field which we sampled was black,with a fairly good depth and contained a medium degree of fertility. Field tests for a number of years showed a need of humus and phosphorus. Lime also did some good but not enough to pay for its cost and application.

Pot cultures were set up from composited samples of this soil and sown to wheat in 1907. The conditions and length of growing period were exactly the same with this series as in all the other series described. The growth itself was good,with all fertilized pots showing improvement over the check. By observing the photograph on the following page it will be seen that the magnesium treated cultures far out ranked those of lime. In this case just exactly the unexpected happened. With a soil containing magnesium 43 percent in excess of lime one would expect a further addition of that element to be injurious. But an interesting surprise resulted,especially if one is a believer in the theories of Loew and his Japanese co-workers, who strongly maintain the necessity of a one to one ratio of

the two elements. The following photograph will show this yield.

WHEAT CULTURES ON CUBA SOIL. PLATE XV.

THE EFFECTS OF LIME AND MAGNESIUM ON WHEAT IN CUBA SOIL. WINTER OF 1907, GREENHOUSE CULTURES.

By observing the growth of cowpeas, which were grown on this soil during the summer following the harvesting of the wheat, it will be seen that the magnesium treated pots were again producing better growth than those which were limed. The amount of growth in the five magnesium treated pots was 46.3 percent larger than in the limed pots, which were 9.6 percent better than the check, making the first five pots 60.4 percent better than the check. Thus it would seem that cowpeas are not injured but rather respond to the treatment of magnesium.

COWPEAS ON CUBA SOIL SUMMER 1907. PLATE XVI.

THE RESIDUAL EFFECT OF LIME AND MAGNESIUM.

The succeeding crop of wheat during the winter of 1908 showed the same increase in the magnesium treated cultures. This will be very plain by a little study of Table VIII,(page 54). In this table the check is seen to have produced 24.3 grams,and against this the limed pots Nos. 8, 9, and 10 produced 34.5,34.5 and 16.0 grams respectfully,while those treated withmagnesium,Nos. 11, 12, 13, 14 and 15 produced 42.9, 53.2, 33.3, 27.6, and 29.1 respectfully. By these results it will be seen that the amount of growth decreases as the quantity of treatment increases,and it will be interesting to note that in every instance where lime and magnesium were added together a very muchly enhanced growth resulted.

There is also some other interesting things in these results,when the differently treated cultures are studied in relation to the native elements of fertility in this soil, In considering the preponderance of magnesium over lime in this soil one would expect it to require a liberal application of the latter.in order to obtain maximum results. However such

treatment failed to respond and the cause of the failure will have to be sought elsewhere. Going back to Table VIII it will be found that both phosphorus and nitrogen in the Cuba soil exceeds these elements in both the Adrian and Victoria soils. Also that the growth on the Adrian and Victoria soils gave a slight advantage to the limed cultures, and while liming this soil gave an advantage it was about four times inferior to the magnesium treatment. Now would not one be led to suspect that when lime was applied to soils rich in humus a large part of its available energy would be spent in neutralizing the soil acids thus leaving a reduced quantity to be active in reverting the available phosphorus in such soils.

The action of lime in all the series thus far considered can be traced out only by a close study of the humus content of those soils. And in every case but one where a soil with a high humus content was limed the final result was in favor of liming, and always by a large percent. On the other hand where humus was deficient a posative injury resulted and the extent of the injury seemed to be influenced by the amount of phosphorus present. This condition would therefore lead us to believe that the relation was not so much the ratio between lime and magnesium as it is the ratio between lime and humus and magnesium and phosphorus. In support of this argument two more soils will be considered, one exceedingly low in humus the other higher in humus than any other soil yet discussed.

WIRE BASKET CULTURES ON UNIONVILLE SOIL.

This is a dark, nearly black prairie loam, silty in texture and underlaid by a greasy clay subsoil. The soil is about eight inches deep and grades gradually into a sticky clay. It is quite fertile, containing a higher quantity of humus than any of the other soils yet considered. The result of two chemical analyses gave magnesium the predominance over lime by 860 pounds per acre. It is a noteworthy co-incidence that in the two best soils studied magnesium should exceed the lime.

Observing the slight and sometimes uncertain benefit or injury done on some of the preceeding series led to a more violent application of lime and magnesium to this soil. A new formula was necessary, which was devised and carried out in wire baskets. The soil was handled as were all other soils excepting the nitrogen, phosphorus and potassium, which was added to all in the same quantities, excepting of course the check. Manure was added at the rate of 20 tons per acre, Bone meal at the rate of 600 pounds and Dried Blood 400 pounds with Potassium Sulphate 200 pounds per acre. This is a rather heroic treatment but it was not known at this time that so much plant food would effect the lime magnesium treatment. Then in order to show up the most striking effect of the lime magnesium treatment these two elements were added in extremely large to ordinary amounts. The following table will show how these were added.

FORMULA No.1 TABLE XII.

Pot	Lime treatment.	Magnesium treatment.
1	Check	Check
2	Calcium Carbonate 10 tons	Magnesium Carbonate 10 tons
3	" " 5 "	" " 5 "
4	" " $2\frac{1}{2}$ "	" " $2\frac{1}{2}$ "
5	" " $2\frac{1}{2}$ "	" " $\frac{1}{4}$ "
6	" " $2\frac{1}{2}$ "	" " $\frac{1}{2}$ "
7	" " $2\frac{1}{2}$ "	" " $1\frac{1}{4}$ "
8	" " $1\frac{1}{4}$ "	" " $2\frac{1}{2}$ "
9	" " $\frac{1}{2}$ "	" " $2\frac{1}{2}$ "
10	" " $\frac{1}{4}$ "	" " $2\frac{1}{2}$ "

TABLE OF LIME AND MAGNESIUM TREATMENT UNIONVILLE SOIL. WINTER 1908.

Beginning with basket No.5 it will be seen that the lime treatment diminishes as the magnesium increases. Corn and oats were planted on this series and their growth was very satisfactory. The corn grew longest and gave the best results.

CORN CULTURES ON UNIONVILLE SOIL. PLATE No.XVII

Observing the photograph it will be seen that the heavy treatment of ten tons per acre was entirely too strongand five tons was injurious. Two and one half tons of lime and magnesium in No.4 proved to be about right. It will be recalled that a mixture of lime and magnesium in the soils of Victoria and Cuba gave larger returns than any other treatment. Comparing baskets No.5, 6 and 7 with baskets Nos.8, 9 and 10 it will be seen that the first three are slightly better than the last three. This gives the advantage to lime although magnesium exceeded that element in the soil. Under the conditions this is as we should expect for it will be remembered that wherever the humus content was large the addition of lime always produced a larger growth than the addition of magnesium. The next plate is that of oats which are growing under the same treatment.

OAT CULTURE ON UNIONVILLE SOIL PLATE No.XVIII

OATS GROWING ON UNIONVILLE SOIL UNDER HEAVY LIME MAGNESIUM TREATMENT. WINTER 1908.

The results of these oats were identically the same as that of the corn, which shows that both oats and corn yield in this soil to the same influence. Before making a discussion the soil from Salem will be introduced.

POT CULTURES ON SALEM SOIL.

This a typical post oak soil from the Ozark region. It is largely clay and sand,with very little humus. The general texture of the soil is poor and its fertility is also poor. Analysis shows but 2600 pounds of lime,3540 pounds of magnesium and 660 pounds of P2O5.per acre. Loew and his followers would add lime to this soil to equalize the ratio,but in pot culture such addition is the direct cause of the most striking injury in any of the cultures. Compare the wheat and cowpeas on Adrian, Lamar, and Victoria soils with the limed cultures in the following soil.

CORN CULTURE ON SALEM SOIL PLATE No.XVLII

SHOWING THE EFFECT OF LIMING ON SALEM SOIL. POTS Nos. 5 and 8. GREENHOUSE AT COLUMBIA. WINTER 1908.

This is a soil in which there is scarcely any humus,and the results here are certainly in contrast with those obtained on

the Unionville soil. Had both of these soils been tested for acidity they no doubt would have given a strong reaction,as all humus soils do,and as poorly drained clay soils do also. It is largely upon the laboratory test of the soil's reaction that we advocate the addition of lime. And it is conditions of this sort that has led to the conclusion that lime should be added to any and every soil for any and all apparent ills. From the standpoint of economy it is doubtful if such proceedings is advisable,and surely from the standpoint of equalizing the ratio there would be less of judgment than economy.

In the case of the Unionville soil the lime undoubtedly spent its force in neutralizing the soil acids formed by the decay of the native humus together with that of the manure which was applied. Surely it could but little more,and the sweetened condition of the soil was conducive to a healthy plant growth. On the other hand the Salem soil contained but little humus and the lime spent its force on the available mineral elements present. This is certainly borne out in the results of liming Poplar Bluff and Eldorado Springs soils.

Owing to the great variation of soil fertility and texture one can not accurately determine the ratio of these elements in pot culture. It can be determined for individual soils,but the lime magnesium ratio will be as far away as ever. So if accurate results are desired the experimenting with these elements will have to be done with pure chemicals and upon a pure medium. This is what was attempted in the following experiments.

PART III.

PURE CULTURE STUDIES

ON THE

CALCIUM MAGNESIUM RATIO.

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It was evident from the beginning that the exact ratio between calcium and magnesium could never be ascertained by using soil or sand for the supporting medium. Such substances are too variable and uncertain in their composition, and are only useful in so far as their individual selves are concerned. In order therefore, to make such determinations accurate it was necessary to substitute some substance of known composition for the supporting medium and feed the plants with pure chemicals in nutrient solution.

Suitable substances of this kind are not easy to find, but after considerable casting about two were obtained which it was thought would fit the case in hand. They were Carborundum and Graphite, each of which are made in the electric furnace at exceedingly high temperatures. They are non-corrosive in action and comparatively inexpensive. A quantity of Graphite was

obtained and tried out. It was found to be satisfactory as a growing medium but dirty to handle. Samples of carborundum indicate that it would much better that the graphite as it would not blacken and was coarser grained,it approximated sand in structure.

When making up cultures from this graphite it was found to take up water very slowly,and in order to facilitate matters the entire quantity of graphite was placed into large dishpans and enough water added to wet it thoroughly upon standing. When all was ready it was mixed to insure an even moisture content and then weighed out into small sized paraffin baskets. These were calculated to hold one pint and were found to contain 335 grams of air dried graphite and leave sufficient room for manipulation. (Moisture determinations were made of the graphite when the baskets were filled). Three series of ten cultures each were set up in duplicate,making twenty baskets to a series ,or sixty baskets in all. As each series was set up it was labeled 1a,1b and 2a,2b,etc.

Corn,wheat and oats were set to germinate while construction and filling of the baskets and the computationsof solutions were in progress. Molecular solutions were used as the basis and the final solute was made accordingly to the formula from them. The table showing the formula follows together with the proportions used.

FORMULA No. I11. GRAPHITE CULTURES. TABLE No. X111.

Sol	Chemicals used	Molecular weights	Strength of Sol.	Gr. per liter	No. of liters	No. of grams	Times Diluted	Total No. of grams	Total cc of Sol.
A	KNO3	101	M/100	1.01	3	3.03	2	6.06	
	NH4SO4	132	M/200	.66	3	1.98	2	3.96	3,000
	K2HPO4	174	M/200	.87	3	2.67	2	5.22	
B	CaCl2	111	M/100	1.11	1	1.11	4	4.44	1,000
C	MgCl2	95	M/100	.95	1	.95	4	3.70	1,000

HOW THE SOLUTIONS WERE COMPOUNDED. TABLE No. XIV.

Culture	Chemical determinants showing strength and ratio.	Sol.A.	Sol.B	Sol.C	Sol.D	Total.
1a & 1b	Checks--Distilled water				Dist. H2O	500
2a & 2b	CaCl2,M/100:MgCl2,M/100	250	125	125		500
3a & 3b	CaCl2,M/100 : MgCl2,M/200	250	125	62.5	62.5	500
4a & 4b	CaCl2,M/100 : MgCl2,M/400	250	125	31.2	93.7	500
5a & 5b	CaCl2,M/100 : MgCl2,M/800	250	125	15.6	109.3	500
6a & 6b	CaCl2,M/100 : MgCl2,M/1600	250	125	7.8	117.1	500
7a & 7b	CaCl2,M/200 : MgCl2,M/100	250	62.5	125	62.5	500
8a & 8b	CaCl2,M/400 : MgCl2,M/100	250	31.2	125	93.7	500
9a & 9b	CaCl2,M/800 : MgCl2,M/100	250	15.6	125	109.3	500
10a & 10b	CaCl2,M/1600: MgCl2,M/100	250	7.8	125	117.1	500

One hundred cubic centimeters of the nutrient solution,as compounded by the formula on the preceeding page,was added to each basket in the series . This brought the moisture content up to approximately 30 percent which was considered about correct,although graphite will contain 40 percent moisture without excessive saturation. The percent of moisture which was all ready in the graphite was ascertained and deducted when the baskets were brought to standard moisture at the time of sealing them.

An interesting fact was observed with this graphite in relation to its taking up moisture after having once become dry. In such instances it presents all evidences of being oiled,and will collect on the surface of the water which then gathers up into globular masses. Considerable stirring will induce capillary action,but the particles of graphite never appear right, presenting a glossy air tight appearance. The behavior of the mass leads one to suspect polarization similar to the effect of magnetized iron.

When compounding these solutions it was found advisable to make up about twice as much as was necessary for the first round. Solutions thus prepared are ready at any moment and the long tedious qualitative work is thus avoided. After the plants had been growing for two or three weeks it was considered necessary to make a second application of the stock solution inorder to keep them growing in a nearly constant strength of

solutions. The loss by transpiration was from day to day with distilled water.

When the grain had germinated sufficiently to plant the final preparation was made by adding one hundred cubic centimeters of the respective solutions to each basket. Great care was taken to select grains of like size, appearance and degree of germination. Considering the start the plantlets made this was very accurately done. All planting was at a uniform depth, two grains of corn and seven of wheat and oats to a basket. After the plantlets had gotten up an inch or more the tops of the baskets were sealed with paraffined paper. At this time the moisture content was made up to the standard, the baskets reweighed after sealing and this weight kept for all computations there after. Wire baskets crush easily and care must be taken to prevent the sealed cover from loosening and thus permitting evaporation.

CORN CULTURE ON GRAPHITE.

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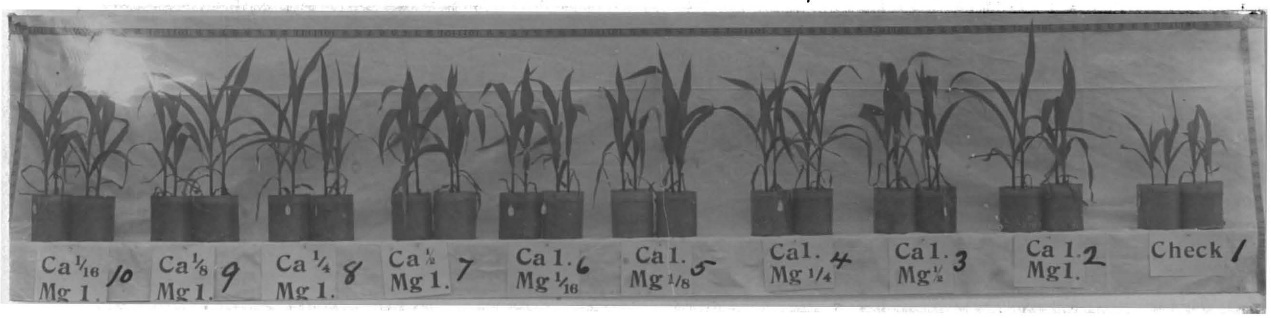
The growth of this corn was very satisfactory, it was planted Jan. 19 and weighed last on Feb. 19. There seemed to be evidence of further development due to these treatments and this series was left unharvested. Owing to permanent absence from the university it was never harvested. But instead the average

transpiration data is presented in Table XV, and a photograph is here presented. The transpiration data in these experiments are not considered very seriously as they admit many errors unless watched closely. Green weights are much to be prefered.

PLATE IXX. CORN GROWING ON GRAPHITE AS A SUB-STRATUM.



GRAPHITE MAKES A GOOD SUB-STRATUM. THERE IS NO PLANT FOOD IN IT. THIS CORN HAS BEEN GROWN ON PURE CHEMICALS.

By observing the above photograph it cannot be said that the cultures (Nos. 3 to 6) bearing the heaviest calcium treatment have produced a more luxurient growth than the last four (No. 7 to 10) which bear the heaviest magnesium treatment. The truth of the matter is the last four had a less number of dead leaves and a thriftier color than those heaviest treated with calcium. The transpiration records gives the calcium treated cultures much the highest rank, 27.1 percent above the ones treated with magnesium, which ranked but 0.2 percent above the check. All calculations are based on culture No. 2 which had a ratio of one to one. Judging from the photograph it would be hard to say which was the superior treatment and in the light of this

FORMULA No. IV. CORN ON GRAPHITE. TABLE No. XV.

Culture	Chemical determinants showing strength and ratio.	Amount Transp.	Average Transp.	Compar'tv Transp'on	%Comp'tv Transp.
1a & 1b	Check, Distilled water.	95.7 81.2	88.4	100	100
2a &2b	$CaCl_2$,1 : $MgCl_2$,1	109.3 105.5	107.4	121.4	Due to
3a & 3b	$CaCl_2$,1 : $MgCl_2$,½	108.9 124.0	116.4	136.6	lime
4a & 4b	$CaCl_2$,1 : $MgCl_2$,¼	113.3 115.2	114.2	129.1	138.5
5a & 5b	$CaCl_2$,1 : $MgCl_2$,1/8	125.0 128.3	126.6	143.1	due to magnes
6a & 6b	$CaCl_2$,1 : $MgCl_2$,1/16	123.5 133.8	128.6	145.4	ium.
7a & 7b	$CaCl_2$,½ : $MgCl_2$,1	94.4 96.3	95.3	107.7	
8a & 8b	$CaCl_2$,¼ : $MgCl_2$,1	116.3 108.3	112.3	127.0	
9a & 9b	$CaCl_2$,1/8: $MgCl_2$,1	114.0 109.3	111.6	126.2	121.2
10a & 10b	$CaCl_2$,1/16: $MgCl_2$,1	110.6 105.7	107.6	121.6	

AVERAGE BENEFIT OF MAGNESIUM .2 %, AVERAGE BENEFIT OF LIME 27.3 %

experiment one would not be justified in saying that either treatment was the better,or even to suspect that there existed a ratio between the two elements. Certainly magnesium has not been injurious in this test,even in its heaviest application.

The treatment of these cultures were all uniform . They were placed into a shallow flat until the plants were well started then they were transferred to a sunny place with plenty of room. In repetitions of this experiment it will be more satisfactory to grow but one plant in a basket,then the excessive mass of roots would be avoided. Corn roots frequently push themselves through the covering of paraffin and if care is not taken this will cause serious errors.

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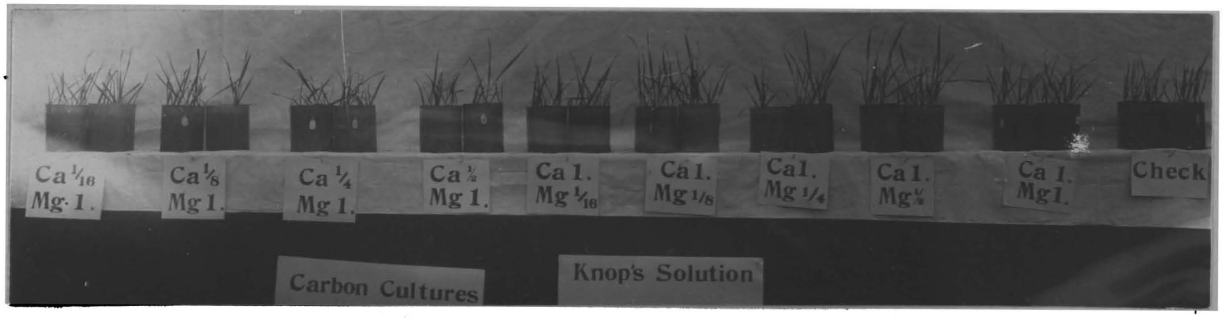
OAT CULTURES ON GRAPHITE.

The growth of the oats was not satisfactory,although they were given the best of care. The graphite was the same,was handled the same and at the same time as that in which the corn grew,and the solutions were poured from the same bottle. Any differences in the growth of the oats may be correctly ascribed to the effect of the solutions. In the first place the general growth of the plants were not good,only one or two cultures did produce anything like a fair growth.

OATS GROWING ON GRAPHITE. PLATE XX.

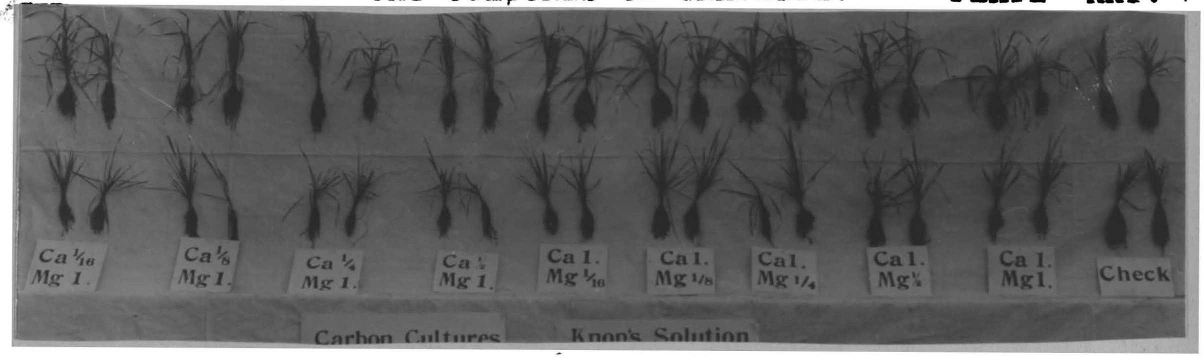


OATS GROWING ON GRAPHITE AS A SUB-STRATUM, DEMONSTRATING THE RELATION OF CALCIUM AND MAGNESIUM TO PLANT GROWTH. GREENHOUSE UNIVERSITY OF MISSOURI. WINTER 1908.

The above photograph was taken after the plants had grown a period of thirty days. The growth could hardly have been inhibited by too strong solutions as they contained but 4,165 parts per million of soluable salts. The difference shows plainly in favor of the calcium treatment, even culture No.1 with a ratio of one to one shows a marked falling off from the cultures having excessive magnesium in them. Several of the plants in the magnesium treated cultures died outright, and many more were brownish red showing marked physiological disturbance. This disturbance also extended on up into the calcium treated cultures, but not to such a marked degree. The plantlets were shaken out of the graphite and the root growth studied to observe the effect of the treatment upon them. The accompanying photograph on the succeeding page illustrates the root growth. In it the calcium treated cultures produced the heavier development, and what is more strange to say the roots in the check cultures

were finer, longer and much more numerous than any of the others.

OAT CULTURES ON GRAPHITE. PLATE XXI.



OATS AND WHEAT GROWN IN GRAPHITE SHOWING ROOT DEVELOPMENT. WHEAT ABOVE OATS BELOW.

A glance at the green weights of the tops (Table XVI) on the following page will show a one percent injury due to the addition of magnesium. As the calcium decreases in these cultures the green weights of the individual treatments do not vary in proportion either way, but as the magnesium decreases in the calcium treated cultures the green weights of those cultures increase until the last one which falls short.

The results of this test indicate plainly that magnesium was injurious to the growth of oats. This is the third time that oats have been used in testing this ratio and the second time that magnesium has given reduced yields. It may be therefore, that oats cannot endure an excess of even a moderate amount of magnesium in their physiological economy, but this point will require considerable testing before being settled. The following table presents a digest of the transpiration and green weights.

FORMULA No. V. OATS ON GRAPHITE. TABLE No.XVI.

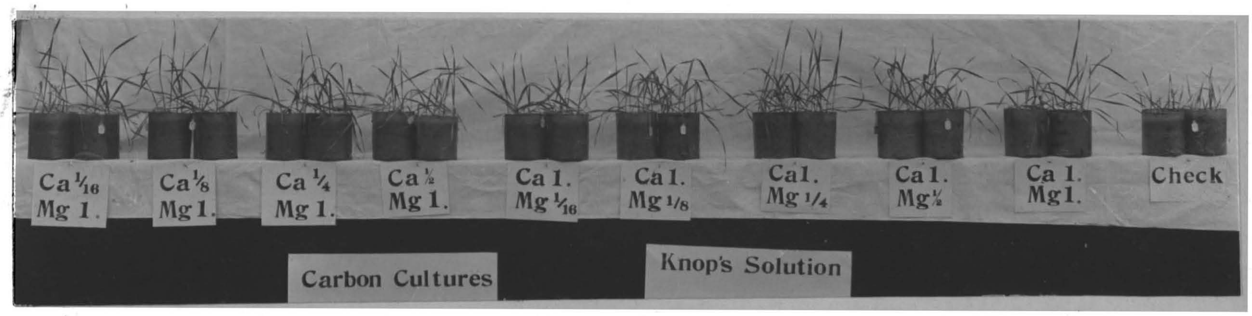
Culture	Ratio	Amount transp.	Average transp.	No. plants	Green wt.	Average wt.	Compar growth	Comparative % of growth.
1a & 1b	Checks	93.4 91.2	92.3	7	0.7 1.6	1.15	100	100
2a & 2b	Ca 1 : Mg 1	83.2 83.8	83.5	7	1.2 1.4	1.32	113.7	113.7
3a & 3b	Ca 1 : Mg $\frac{1}{2}$	102.2 102.6	102.3	7	1.2 1.5	1.37	119.0	
4a & 4b	Ca 1 : Mg $\frac{1}{4}$	87.2 98.2	92.7	7	1.5 1.4	1.47	127.7	118.3
5a & 5b	Ca 1 : Mg1/8	89.5 101.1	95.3	7	1.3 1.8	1.55	134.6	
6a & 6b	Ca 1 :Mg1/16	88.0 81.1	84.5	7	1.0 1.1	1.06	92.1	
7a & 7b	Ca$\frac{1}{2}$: Mg 1	69.2 65.3	67.2	7	1.2 1.4	1.3	112.9	
8a & 8b	Ca$\frac{1}{4}$: Mg 1	69.1 80.3	74.7	7	1.48 1.2	1.41	114.7	112.7
9a & 9b	Ca1/8: Mg 1	92.4 54.7	73.5	7	1.05 1.4	1.27	110.3	
10a& 10b	Ca1/16:Mg1	83.6 76.4	79.9	7	1.2 1.4	1.30	112.9	

INJURY DUE TO MAGNESIUM 1.0 %, BENEFIT DUE TO CALCIUM 4.6 %.

WHEAT CULTURES ON GRAPHITE.

The growth of the wheat was very satisfactory. Much more so than that of the oats. It grew 29 days before being harvested, but had made sufficient growth to show the differences of treatment. This culture was made up in the same way and handled the same in every respect. By observing the photograph one would get the impression that the calcium treated cultures were again giving the best yields, but a reference to the table on the following page will show that these cultures fell behind the magnesium cultures by 11.7 percent.

WHEAT CULTURES ON GRAPHITE. PLATE XXII.



WHEAT ON GRAPHITE DEMONSTRATING THE CALCIUM MAGNESIUM RATIO. WINTER 1908.

A little study of the column of comparative growths in the table will show that the green weights do not vary in any very definite relation to the calcium magnesium treatment. By reference to Plate XXI, Page 76, it will be seen again that there is no relation between the effects of the two treatments. The table of transpiration and green weights is presented on the following page.

FORMULA No. VI. WHEAT ON GRAPHITE. TABLE No. XVII.

Culture	Ratio	Amount transp.	Average transp.	Compar. transp.	Green wt.	Average wt.	Compar. growth	compar. % gr'th	Days gr'th
1a & 1b	Checks	99.6 101.3	100.4	100	.88 2.2	1.54	100	100	29
2a & 2b	Ca 1 : Mg 1	116.1 204.8	160.4	159.7	0.9 3.03	1.96	127.2	127.2	29
3a & 3b	Ca 1 : Mg ½	279.3 177.0	228.1	227.1	2.1 2.6	2.35	152.5	Do to lime 149.4	29
4a & 4b	Ca 1 : Mg ¼	204.6 177.0	190.8	190.0	2.2 2.1	2.15	139.5		29
5a & 5b	Ca 1 : Mg/8	301.7 194.3	248.0	247.0	2.62 2.1	2.36	153.2		29
6a & 6b	Ca 1 : Mg/16	206.7 198.4	200.5	199.6	2.15 2.56	2.35	152.5		29
7a & 7b	Ca ½ : Mg 1	304.9 269.1	287.0	286.9	3.22 2.66	2.94	190.8	Do to magnesium. 161.1	29
8a & 8b	Ca ¼ : Mg 1	199.4 357.2	278.3	277.1	2.21 2.33	2.27	147.3		
9a & 9b	Ca/8 : Mg 1	267.8 182.4	225.1	224.1	2.24 2.38	2.31	149.9		29
10a&10b	Ca.16 : Mg 1	243.7 226.2	234.9	233.9	2.45 2.38	2.41	156.4		

Benefit due to calcium 22.2 %, Benefit due to Magnesium 33.9 %

PURE CULTURES IN AGAR-AGAR.

Graphite cultures are fairly accurate to work with,a great deal more so than soil,but neither is sufficient for painstaking accuracy is required. In studies of this kind solid substances are objectionable because of the fact that they remove by absorption or adhesion certain of the elements of nutrition. This is objectionable because the elements removed might be the very ones upon which special emphasis or specific determinations may be making. And were such to happen in this particular instance the ratio for which we are endeavoring to establish would surely be disturbed. For these reasons some substance was desired which would permit the nutrients to be distributed uniformly throughout the mass and at the same time serve as a supporting medium. The substance Agar-Agar seems to fulfill the purpose in an ideal way,and was therefore given a trial. This body is pure cellulose,jelly like in form when melted in water. It has but but one objection,that of not admitting air to the growing roots within it.

Ordinary drinking glasses were employed as containers instead of paraffined baskets. Glass would be less susceptible to corrasion by the solute,and too would be a more stable vessel. The light was excluded by tightly wrapping the glasses in jackets made from carbon black paper. After which the nutrients were compounded and the Agar Agar poured in while hot.

The components of this solute were calculated and compounded as accurately as possible,and all variations of growth,except from outside influences,should be ascribed to the action of the elements in question. These solutions were built up on the molecular basis and diluted according to the formula,which was constructed as near as possible to meet the plant's needs. This formula was arbitrarily derived and is shown on the next page.

The chlorides of calcium and magnesium were used in all the pure cultures where the ratio of these two elements had been previously tested,and all the differences noted by such tests were usually so slight as to fall within the limit of error. In the following trials it was thought best to use a radical in connection with the calcium and magnesium which would magnify these respective differences to an unmistakable degree. By carefully observing the manner of compounding the solutions it will be seen that a splendid opportunity for such an experiment is presented. As for example,in solution No.2,with the ratio Ca 1: Mg 1,we have present the maximum amount of both elements,while in solution No.6,Ca 1:Mg/16,we have the ratio at its widest point. Therefore, the ratio,like an Isosceles Triangle,diminishes both ways,and whichever of these elements has the grater stimulative effect on plant growth should augment that growth when in the presence of a radical possessing the most essential qualities for growth. In the particular instance at hand it was decided to use the element phosphorus as this radical.

FORMULA VII. CULTURES ON AGAR-AGAR. TABLE No. VIII.

Sol.	Chemicals	Molecular weight.	Strength	Grams per liter	No. of liters	No. of grams	Times diluted	Total No. of grams
	$(NH_4)_2SO_4$	132	M/400	.33	7	2.31	2	4.62
A.	KNO_3	101	M/100	1.01	7	7.07	2	14.14
	$FeCl_3$		trace					
B.	$CaHPO_4\ 2H_2O$	172	M/100	1.72	3	5.16	4	20.64
C.	$MgHPO_4\ 7H_2O$	246	M/100	2.46	3	7.38	4	29.52
D.	Distilled water							
E.	Agar-Agar		2 %	20	7	140	3	420

This solution may be criticised for being too heavy. It carries 5,520 parts of salts per million.

Solution A, remained constant in series I, was diluted twice in series II, and three times in series III.

Solutions B, C, and D remained constant throughout.

HOW THE SOLUTIONS WERE COMPOUNDED. TABLE XIX.

Culture	Chemical determinants showing strength and ratio.	Sol.A.	Sol.B.	Sol.C.	Sol.D.	Sol.E.	Total
1a & 1b	Checks- Distilled water.					167.	500
2a & 2b	$CaHPO_4/1$: $MgHPO_4/1$	166.6	83.3	83.3		167	500
3a & 3b	$CaHPO_4/1$: $MgHPO_4/2$	166.6	83.3	41.6	41.6	167	500
4a & 4b	$CaHPO_4/1$: $MgHPO_4/4$	166.6	83.3	20.8	62.2	167	500
5a & 5b	$CaHPO_4/1$: $MgHPO_4/8$	166.6	83.3	10.4	72.6	167	500
6a & 6b	$CaHPO_4/1$: $MgHPO_4/16$	166.6	83.3	5.2	77.8	168	500
7a & 7b	$CaHPO_4/2$: $MgHPO_4/1$	166.6	41.6	83.3	41.6	167	500
8a & 8b	$CaHPO_4/4$: $MgHPO_4/1$	166.6	20.8	83.3	62.2	167	500
9a & 9b	$CaHPO_4/8$: $MgHPO_4/1$	166.6	10.4	83.3	72.6	167	500
10a:10b	$CaHPO_4/16$: $MgHPO_4/1$	166.6	5.2	83.3	77.8	167	500

Solution A,is made up of ammonium sulphate,potassium nitrate and ferric chloride. This is the standard solution in the three series discussed. Solution B,is the calcium phosphate and C,is the magnesium phosphate. D is the distilled water and C, is a 2 % solution of Agar-Agar.

The element phosphorus is probably the most active in the formation of new tissue and fortunately this element exists as a radical of calcium and magnesium., We were anxious to employ it in at least one trial because of the fact that Loew and Reed found both magnesium and phosphorus closely related in the formation of new tissue. Were the above true it would naturally be inferred that in a case of this kind the stronger magnesium-treated cultures would out-rank the stronger calcium-treated cultures. In the final out come of the test this supposition was borne out beyond a question of a doubt,as the following table will show.

Before making an examination of the table a word of explanation is due. After following up the results of these experiments for some time a feeling grew up that the relation of calcium and magnesium to plant growth was not so important as was the relation of these elements to the quantity of the other plant foods in the solute. Therefore,in making up this test Solution A, which bore all the nutrients except the two in question,was diluted once in series two, and twice in series three,thus making series one twice as strong as series two,and four times stronger than series three.

The following table shows the results in this proportion.

FORMULA VIII. WHEAT CULTURES IN AGAR-AGAR. TABLE XX.

Culture	Ratio	SERIES I. av'ge wt.	SERIES I. % Grwth	SERIES I. Com'pd growth	SERIES II. Av'ge wt.	SERIES II. % growth	SERIES II. Com'pd growth	SERIES III. Av'ge wt.	SERIES III. % growth	SERIES III. Com'pd growth
1a & 1b	Check	3.2	50.8		2.7	57.4		2.0	47.6	
2a & 2b	Ca 1 : Mg 1	6.3	100.0	100	4.7	100.0	100	4.2	100.0	100
3a & 3b	Ca 1 : Mg 1	5.4	85.7		5.1	106.4		3.0	71.4	
4a & 4b	Ca 1 : Mg/4	5.8	92.0	82.5	6.2	131.9	120.7	4.2	100.0	97.2
5a & 5b	Ca 1 : Mg/8	5.0	79.3		6.2	131.9		3.7	88.0	
6a & 6b	Ca 1 : Mg/16	4.6	73.0		5.3	112.9		4.0	95.2	
7a & 7b	Ca/2 : Mg 1	7.0	111.1		6.3	134.0		4.7	111.9	
8A& 8b	Ca/4 : Mg 1	6.3	100.0	102.8	6.2	131.9	139.8	4.1	97.6	116.5
9a & 9b	Ca/8 : Mg 1	6.0	95.2		6.6	140.4		4.8	114.2	
10a&10b	Ca/16 : Mg 1	6.6	104.7		7.2	153.1		4.8	114.2	

In series 1, the benefit of magnesium over calcium was 20.3 percent, in series II, it was 19.1 percent and in series III, it was 18.3 percent.

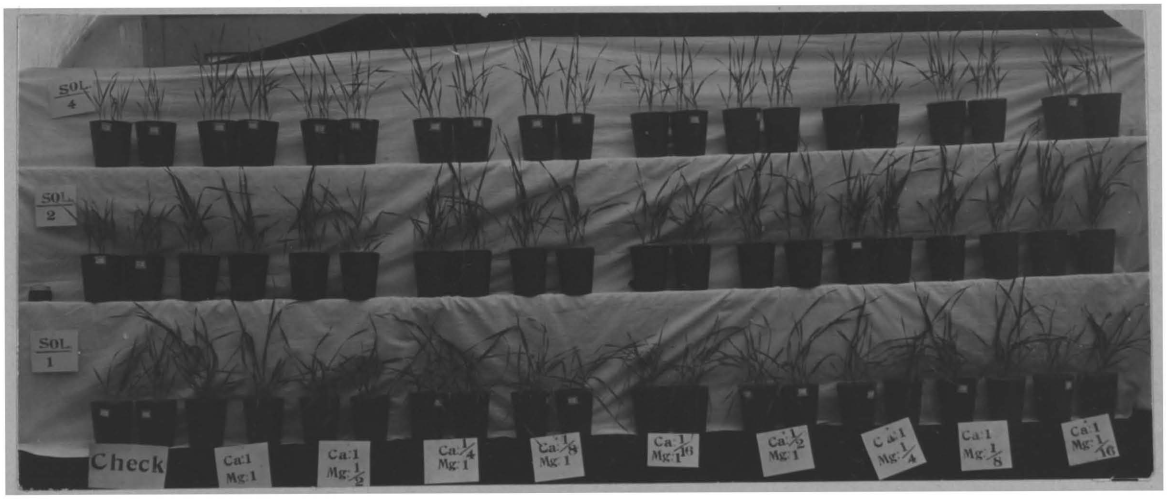
This method of testing is hard to manipulate, but is very satisfactory when watched closely. Considerable skill is required to set it up accurately.

In all respects the results of this experiment,as is shown by the preceeding table,were just as we had anticipated. With reference to the magnification of the differences of growth between the two elements,and also with regard to the supposition that magnesium and phosphorus compounds functioned together in the development of plant tissue. Our third supposition,which was mentioned in a former wxperiment,was also indicated as correct, i.e. that the ratio is not so much between calcium and magnesium as it is between magnesium and the other elements of fertility,as in the case of soils,or the solute in the case of pure cultures. A full conclusion,however,could scarcely be drawn from the results of this test alone,because the phosphorus,which is regarded as the most active element of plant growth,was introduced the same in all three of the series. But where we do base our conclusion is upon the fact that the magnesium-phosphorus treated cultures were 19.2 percent in excess of that from the calcium-phosphorus treated cultures,and that this percent of growth decreased as the dilution of the principle elements of the solute increases. It will be recalled from our experience in the previous soil cultures,that growth was always augmented by the addition of magnesium to a soil rich in phosphorus and humus,and that such growth was decreased by the addition of magnesium to soils deficient in these elements. Were this indication to be proven true it would do-a-way with the time honored saying"The relation of lime and magnesium to plant growth".

That this test was accurate is evidenced by the fact of such close agreement of the percentage increase over the calcium treated cultures in the three series. (See foot note on page85)

In order to show the experiment we present here a photograph of it while growing.

WHEAT IN AGAR-AGAR, PURE CULTURES. PLATE XXIII.



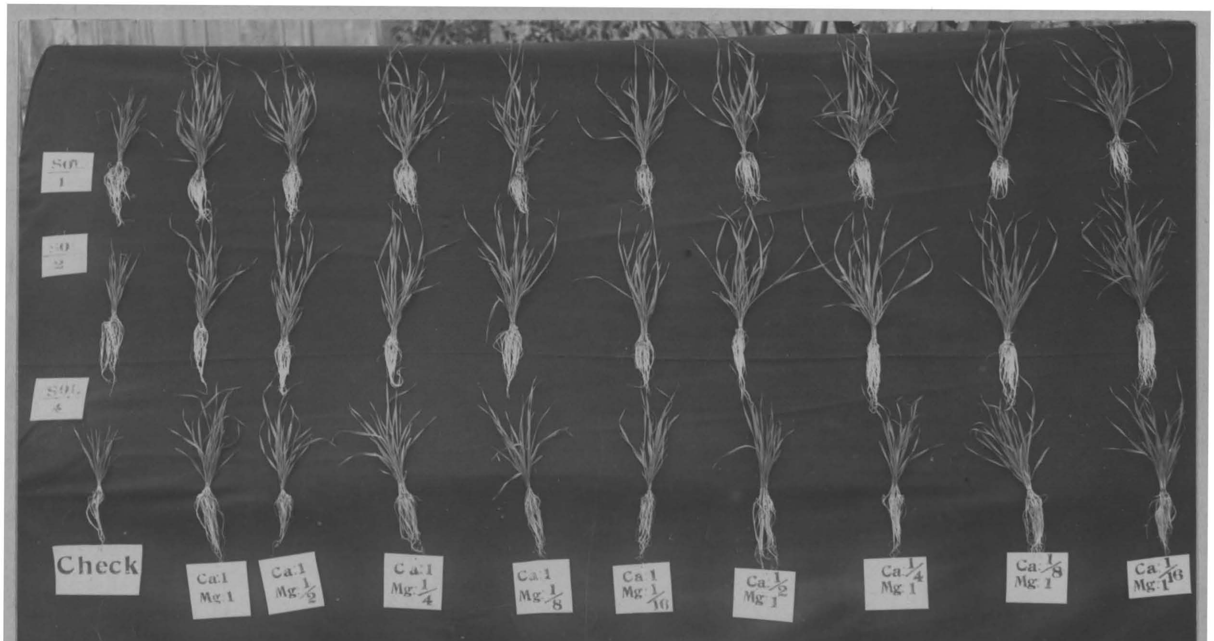
GETTING DOWN ON BRASS TACKS.

The solutions are calculated and compounded in such a way that the proper dilution is reached when the melted Agar-Agar is poured in. Germinated wheat is then inserted just sufficiently to cover the growing portion.

From the above photograph it is plain to be seen that the quantity of growth increases with the increase of magnesium . As was expected series three which was grown in the fourth dilution presented a lighter growth than series one. Another fact in support of our third supposition is forcibly brought out here. Series

No.1,growing under full strength presented a benefit due to magnesium over lime of 20.3 percent, No.2,with half strength gave a benefit of 19.1 percent and No.3,gave a benefit of 18.3 percent. These figures are given on the percentage basis and do not take into account the great difference of vegetable growth between the two. The above figures indicate that the ratio of benefit due to magnesium was directly in proportion to the amount of potassium in the solute. In this case we say potassium instead of nitrogen,because we have an abundance of nitrogen and a very limited quantity of potassium in Solution A,which we diluted. Aside from the top growth it was interesting to note the root growth and a photograph is here presented.

PLATE XXIV. SHOWING THE ROOTS OF WHEAT GROWN IN AGAR-AGAR.



The root growth like that of the tops increases with the increase of magnesium. Distilled water was kept on top of the Agar Agar to prevent cracking. This method is entirely satisfactory.

PURE CULTURES IN AGAR-AGAR,-continued.

The preceeding test of the calcium-magnesium ratio in Agar-Agar was the last to be completed in the laboratories of the University of Missouri. The following four tests were set up and completed in the agricultural laboratory of the State Normal School at Maryville,Missouri. And while the apparatus of this department was not very elaborate,the supply of chemicals were purchased new from Eimer and Amend and were of the highest purity.

In the previous test the phosphorus radical was used in combination with the calcium and magnesium,while in the present trial the nitrate radical of the two elements was employed. This was done inorder to determine whether or not the phosphorus radical did function with magnesium to produce an increase of growth over the calcium,and also to see if the nitrogen radical would function in a similar manner. In order that the amount of nitrogen in the cultures should be the same,the distilled water that was always used to make up the shortage,which occurred as the ratio of the two elements varied,was made to carry an amount of nitrate exactly equal in porportion to the shortage of the lesser determinant. When the experiment was planned it was intended to dilute the standard solution as was done in the previous test,but instead the determinant solutions B, C, and D were each diluted once as the series were being set up,and such dilution resulted directly oppositeto that of the foregoing test.

FORMULA No. IX. CULTURES ON AGAR-AGAR, CONTINUED. TABLE XXI.

Sol.	Chemicals	Molecular weight	Strength	Grams to liter	No. of liters	No. of grams	Times diluted	Total No. of grams.
A.	NH_4Cl	53.5	M/400	.135	2.45	.33	3	.99
	K_2HPO_4	174	M/100	1.74	2.45	4.26	3	12.78
	K_2SO_4	174	M/200	.87	2.45	2.13	3	6.39
	$Fe(OH)_3$		trace					
B.	$Ca(NO_3)_2$	164	M/200	.82	.735	.60	6	3.61
C.	$Mg(NO_3)_2$	148	M/200	.74	.735	.54	6	3.25
D.	KNO_3	101	M/100	1.01	11.094	1.10	6	6.60
E.	Agar-Agar		2%	20	4.2	84	3	254

Water, redistilled from glass, was used in the above solutions, and inorder to eliminate any poisonous substances, which may have volatilized over with the steam, the water was shaken up with a quantity of ferric hydrate. This process was made complete by placing the water and hydrate into a large aspirator and attaching the filter pump which was then left to bubble over night. This also aerated the water which was necessary since Agar-Agar does not admit air to growing roots.

HOW THE SOLUTIONS WERE COMPOUNDED. TABLE XXII.

Culture	Chemical determinants showing strength and ratio.	Sol.A.	Sol.B.	Sol.C.	Sol. D.	Sol.E.	Total
1a & 1b	Checks				140	70	210
2a & 2b	$Ca(NO_3)_2$,1 ; $Mg(NO_3)_2$,1	70	35	35		70	210
3a & 3b	$Ca(NO_3)_2$,1 : $Mg(NO_3)_2$,/2	70	35	17.5	17.5	70	210
4a & 4b	$Ca(NO_3)_2$,1 : $Mg(NO_3)_2$,/4	70	35	8.7	25.3	70	210
5a & 5b	$Ca(NO_3)_2$,1 : $Mg(NO_3)_2$,/8	70	35	4.3	30.7	70	210
6a & 6b	$Ca(NO_3)_2$,1 : $Mg(NO_3)_2$,/16	70	35	2.1	32.9	70	210
7a & 7b	$Ca(NO_3)_2$,/2: $Mg(NO_3)_2$, 1	70	17.5	35	17.5	70	210
8a & 8b	$Ca(NO_3)_2$,/4 : $Mg(NO_3)_2$,1	70	8.7	35	25.3	70	210
9a & 9b	$Ca(NO_3)_2$,/8 : $Mg(NO_3)_2$,1	70	4.3	35	30.7	70	210
10a&10b	$Ca(NO_3)_2$,/16: $Mg(NO_3)_2$,1	70	2.1	35	32.9	70	210

Enough potassium nitrate was added in Solution D to just balance the amount omitted by solutions B and C by reason of their variation.

FORMULA No. X. WHEAT IN AGAR-AGAR - CONTINUED. TABLE XXII.

Culture	Ratio	SERIES I. Av'ge wt.	% growth	Com'pd growth	SERIES II. Av'ge Wt.	% growth	Com'pd growth	SERIES III. Av'ge wt.	% growth	Com'pd growth
1a & 1b	Checks	.93	37.6	37.6	.92	38.7	38.7	992	35.5	35.5
2a & 2b	Ca 1 : Mg 1	2.47	100.0	100	2.39	100.0	100.0	2.31	100.0	100.0
3a & 3b	Ca 1 : Mg/2	2.17	87.9		2.38	99.5		2.60	112.1	
4a & 4b	Ca 1 : Mg/4	2.16	87.4	91.4	2.23	93.3	92.7	2.30	99.9	97.2
5a & 5b	Ca 1 : Mg/8	2.35	95.1		2.11	88.2		1.94	83.9	
6a & 6b	Ca 1 : Mg/16	2.36	95.4		2.25	94.1		2.15	93.0	
7a & 7b	Ca/2 : Mg 1	1.15	61.1		1.83	76.5		2215	93.0	
8a & 8b	Ca/4 : Mg 1	1.73	70.0	68.8	1.89	79.0	77.0	2.06	89.2	85.5
9a & 9b	Ca/8 : Mg 1	1.71	69.2		1.88	78.6		2.05	88.7	
10a&10b	Ca/16: Mg 1	1.78	72.0		1.77	74.0		1.65	71.4	

Benefit of LIME over magnesium 22.6 %, Benefit in seriesII, 15.7 %,series III 11.7 %. Average benefit of all three series 16.6 percent.

The above result was secured by using the nitrate radical of calcium and magnesium, This is the first pure culture to indicate a benefit in favor of calcium.

In the previous test the greatest benefit occurred when the magnesium-phosphorus ingredient was present in its greatest proportion to the balance of the nutrients in the solute, but to the contrary in this test, the greatest injury was manifest when the magnesium nitrate ingredient was present in the greatest proportion to the balance of the nutrients in the solute. Therefore, it would seem from this, that the nitrate and phosphate radicals of magnesium perform antagonistic functions when employed in nutrient solutions, at least they were more antagonistic than are the corresponding compounds of calcium. The table below will show at once the relations of the two compounds to the growth of wheat.

These results were calculated on the basis of growth which was produced on the one to one ratio of the two determinants.

COMPARATIVE RESULTS OF THE NITRATE AND PHOSPHATE RADICALS OF CALCIUM AND MAGNESIUM ON THE GROWTH OF WHEAT.

	BENEFIT %	INJURY %
$MgHPO_4$	17.7	0.0
$CaHPO_4$	0.2	0.0
$Mg(NO_3)_2$	0.0	17.5
$Ca(NO_3)_2$	0.0	6.3

AGAR-AGAR CULTURES, SEE TABLES XX AND XXII.

These results are especially interesting since lime and nitrogen has been lately exploited as a very fine fertilizer and

too,from the fact that differences so wide should arise from a combination of two such important elements in plant development.

The accompanying photograph sets forth the appearance of the cultures at the close of the experiment. Note how the magnesium treated wheat stands up,on the right end,as against the calcium treated on the left end.

WHEAT CULTURES IN AGAR-AGAR. PLATE XXV.

THE NITRATES OF CALCIUM AND MAGNESIUM WERE USED, AGRICULTURE LABORATORY,MARYVILLE, MISSOURI.

The results of the last two tests may have been due in part to chemical influences other than that of the nitrate and phosphate radicals of the two elements in question. Recent investigations by Osterhout, Loew, Aso and others on the subject of "The Importance of Physiologically Balanced Solutions for Plants" has begun to throw considerable light on the relative action of certain minerals commonly occurring in plant solutions. Osterhout in his investigations (Botanical Gazette, February 1908) has

discovered that a definite relation existed between magnesium and potassium, which if not maintained would prove injurious. He further ascertained that either element when used alone was highly poisonous and that potassium was much more so than magnesium. When mixed together, however, it was found that the ratio favored the larger quantity of potassium, in the ratio of 10 : 1 for liverworts and 4 : 1 for wheat. Taking these results and applying them to the two tests in question we find, with reference to the phosphorus radical (Formula VII), two courses open for a conclusion, the first is that the phosphorus radical antagonized the excess of magnesium which was in excess of potassium in the ratio of 4 : 1 thus assisting the final outcome, and the second is that the phosphorus and magnesium functioned together in the production of those excellent results. (Table XX).

Considering the case of the nitrate radicals (Formula XXII) we again have two courses open for conclusions. In this case potassium is in the ascendency with the ratio of 6 : 1 over magnesium. This combination resulted in a positive injury to the plants, and the injury was due to the excess of potassium, which exceeded the proper ratio by fifty percent, or to the combination of nitrogen and magnesium. The potassium in all probability assisted in the injury, but the greater blame apparently falls upon the nitrate. Especially do we think this since that injury also resulted, although to a lesser degree, in the calcium treated cultures of the same test.

Excess potassium was omitted in the succeeding experiment.

FORMULA No. IX. SALEM SOIL EXTRACT IN AGAR-AGAR. PLTABLE No. XXIII.

Sol.	Chemical	Molecular wt.	Strength	Gr'm to liter	Liters used	No. of grams	Total c.c. solution
A.	NH_4Cl	53.5	M/400	.13	5.28	.68	
	$FeSO_4,7H_2O$	278	M/800	.34	5.28	1.79	
	$KHPO_4$	136	M/100	1.36	5.28	7.18	
	Dist. H_2O				4.28		4280
	Soil extract				1.00		1000
B.	$Ca(NO_3)_2$	164	M/50	3.28	5.28	17.31	1110
C.	$Mg(NO_3)_2$	148	M/50	2.96	5.28	15.62	1110
D.	NH_4NO_3	80	M/25	3.2	5.28	16.89	1300
E	Agar-Agar		2%	20	5.28	105	1760

CULTURES IN SALEM SOIL EXTRACT.

Bearing in mind the recent ill effects of excessive additions of potassium, an endeavor was made in this instance to eliminate as much of this element as would be possible and be consistant with plant growth. The same chemicals excepting the mono-calcium phosphate was substituted for the di-calcium phosphate, and one fifth of the solute was replaced with an extract of Salem soil which was previously discussed on pages 65-6. This extract was made by shaking 500 grams of this soil with one liter of water twice distilled. This mixture was repeatedly shaken and allowed

to stand three weeks before us~~e~~ing. The liquor was then carefully poured off and filtered. This made a very acceptable exttract, though not so accurate as that filtered through the Chamberlain porcelain filter, which filter is especially constructed for this purpose.

This solution was also compounded a little differently than the others were, the total quantity of solution needed was made up as solution A. This was then aliquotly divided up between solutions B, C, D and E to which the proper ingredients were respectfully added.

The wheat was grown in glasses in a manner similar to all other of these tests. It was germinated on a germinator made by filling the meshes of ordinary screen wire nearly full of paraffin and then floating the device by means of corks. This makes an ideal germinator and also permits the rootlets to become accustomed to the water before planting. The growth exhibited no marked differences from other similar trials.

The final results of this test was as we had anticipated from the work of Dr. Osterhout and the results of the tests just completed. The omission of a portion of the potassium in this test reduced the final injury in the magnesium treated cultures from 17.5 to 9.9 percent making a difference of 7.8 points.

The following pages gives the method of making the cultures and their final results.

HOW THE SOLUTIONS WERE COMPOUNDED. TABLE No. XXIV.

Culture	Chemical determinants showing strengths used, &Ratio	Sol.A.	Sol.B.	Sol.C.	Sol.D.	Sol.E.	Total
1a & 1b	Checks - distilled water	160				80	240
2a & 2b	Ca(NO3)2, 1 : Mg(NO3)2, 1	Solution A has been used as a foundation for solutions B,C,D and E.	80	80		80	240
3a & 3b	Ca(NO3)2, 1 : Mg(NO3)2,/2		80	40	40	80	240
4a & 4b	Ca(NO3)2, 1 : Mg(NO3)2,/4		80	20	60	80	240
5a&& 5b	Ca(NO#)2, 1 : Mg(NO3)2,/8		80	10	70	80	240
6a & 6b	Ca(NO3)2, 1 : Mg(NO3)2,/16		80	5	75	80	240
7a & 7b	Ca(NO3)2, 1 : Mg/O-Dist.H2O					80	240
8a & 8b	Ca(NO3)2,/2 : Mg(NO3)2, 1		80	80	40	80	240
9a & 9b	Ca(NO3)2,/4 : Mg(NO3)2, 1		20	80	60	80	240
10a&10b	Ca(NO3)2,/8 : Mg(NO3)2, 1		10	80	70	80	240
11a&11b	Ca(NO3)2,/16: Mg(NO3)2, 1		5	80	75	80	240
12a&12b	Ca/O,Dist,H2O : Mg(NO3)2,1					80	240

Solution 7 was without magnesium and No.12 without calcium.

Solution A was made up and divided into aliquot parts upon which solutions B, C; D, and E were made. This simplyfies matters a good deal.

FORMULA No. X. WHEAT CULTURES ON AGAR-AGAR IN SALEM SOIL EXTRACT. PLATE No. XXV.

Culture	Ratio	No. plants	Green wt.	Average wt.	Compared % of growth	Grand ave-in % growth	final % compared
1a & 1b	Checks	10	1.62	.81	69.2	69.2	69.2
2a & 2b	Ca 1 : Mg 1	"	2.34	1.17	100.0	100.0	100.0
3a & 3b	Ca 1 : Mg/2	"	1.91	.955	81.6	78.8	21.2
4a & 4b	Ca 1 : Mg/4	"	1.90	.95	81.1		
5a & 5b	Ca 1 : Mg/8	"	1.87	.935	79.0		
6a & 6b	Ca 1 : Mg/16	"	1.73	.865	73.8		
7a & 7b	Ca 1 : Mg/0	"	1.64	.82	70.0		30.0
8a & 8b	Ca/2 : Mg 1	"	1.83	.915	78.2	76.7	23.3
9a & 9b	Ca/4 : Mg 1	"	1.86	.93	79.4		
10a&10b	Ca/8 : Mg 1	"	1.81	.905	77.3		
11a&11b	Ca/16: Mg 1	"	1.69	.845	72.2		
12a&12b	Ca/0 : Mg 1	"	1.40	.70	60.1		39.9

The cultures in which both determinants appeared showed an injury on the side of magnesium of 2.1% over calcium; cultures 7 and 12, 9.9% over calcium.

CULTURES ON SOIL EXTRACT FROM POPLAR BLUFF AND ELDORADO SPRINGS.

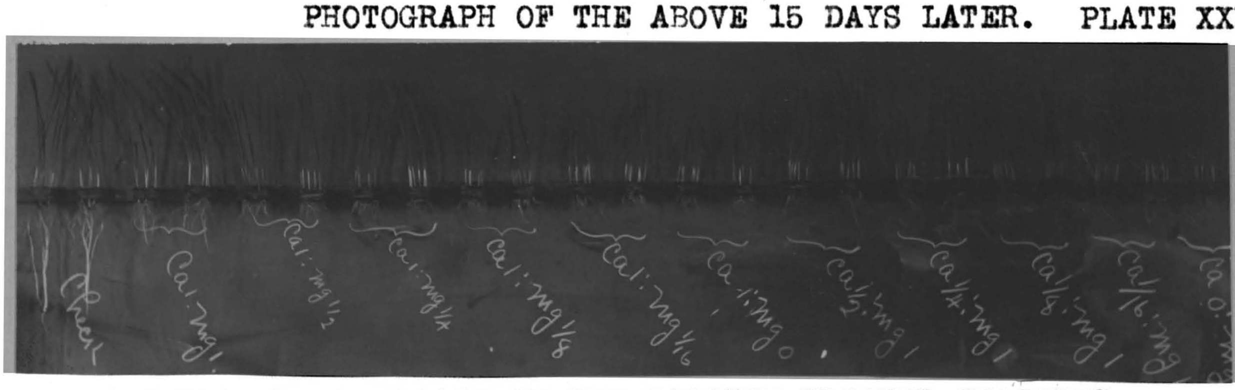
Unfortunately the final record of these two experiments was lost, and as the formula for the solutions was the same as in the last test no space will be taken up with them. Both of these tests gave results favorable to the addition of magnesium, thus bearing out the contention of the discussion regarding similar results secured on this soil by the addition of fertilizer See pages 44 and 53.

Below is two plates showing the appearances of the Poplar Bluff test.

SOIL EXTRACT AS WATER CULTURES. PLATE XXVI.

WHEAT CULTURES ON POPLAR BLUFF EXTRACT, SHOWING THE PLANTS WHEN THEY ARE JUST STARTING.

PHOTOGRAPH OF THE ABOVE 15 DAYS LATER. PLATE XXVII



OBSERVE THE DECREASE IN THE CALCIUM TREATED CULTURES.

These tests were made in bottles filled to the cork with the solution and wrapped with carbon paper to exclude the light. The wheat was germinated in water and was allowed to throw up a sprout about one inch long,which was then inserted through a cork properly notched to recieve them. This is an ideal way to grow plants in water culture. The cork prevents evaporation,holds the plants in place and keeps the roots always in the solution.

This general record of these experiments is concluded with the following plate which shows where the work was done.

SOILS GREENHOUSE UNIVERSITY OF MISSOURI. WHERE

PLATE 28. THE FOREGOING EXPERIMENTS WERE MADE.

SUMMARY.

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In running back over the most salient features of the preceeding experiment the following points may be gathered up and briefly stated.

1. Soil is an absolutly inaccurate medium in which to test the exact relation of the elements found in it,especially the definite relation of these elements to plant growth.

2. Graphite, Agar-Agar and Water Cultures are well suited for painstaking accuracy.

3. Both calcium and magnesium are necessary to plant growth.

4. The common notion that calcium and magnesium should be in the ratio of one to one is erroneous.

5. A ratio between calcium and magnesium undoubtedly exists for the best development of individual plants,but that ratio is not the same for all plants.

6. The most vital part which calcium plays in soils is that of an acid neutralizer and a soil sweetener,and its presence as a plant food or to balance up the ratio of magnesium is purely a secondary matter.

7. In place of stating a ratio for calcium and magnesium in soils there seems to be more need of placing the emphasis for that ratio on magnesium and phosphorus.

8. Magnesium and phosphorus seem to function together in

plant growth.

9. Potassium and magnesium are antagonistic in their relations to plant growth.

10. Magnesium and nitrogen seem to be antagonistic in their relations to plant growth.

11. Magnesium stimulates plant growth more than calcium.

12. The action of calcium and magnesium is not so much their ratio to each other as their ratio to other elements of fertility. Presumably phosphorus and nitrogen.

13. This is a delicate problem and will require a great quantity of time and painstaking work to settle definitely.

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FINIS.

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