B. P. I.—1. V. P. P.—86.

BULLETIN NO. 1.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY.

B. T. GALLOWAY, Chief.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

ALBERT F. WOODS, Pathologist and Physiologist.

THE RELATION OF LIME AND MAGNESIA TO PLANT GROWTH.

I. LIMING OF SOILS FROM A PHYSIOLOGICAL STANDPOINT.

By OSCAR LOEW, *Expert in Physiological Chemistry.*

II. EXPERIMENTAL STUDY OF THE RELATION OF LIME AND MAGNESIA TO PLANT GROWTH.

By D. W. MAY, *Of the Office of Experiment Stations.*

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BUREAU OF PLANT INDUSTRY.

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Albert F. Woods, *Pathologist and Physiologist.*
F. V. Coville, *Botanist.*
G. B. Brackett, *Pomologist.*
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[1] Detailed to tobacco investigations, Bureau of Soils.
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LETTER OF TRANSMITTAL.

Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., July 16, 1901.

Sir: I transmit herewith the manuscript submitted from the office of the Pathologist and Physiologist of a paper entitled The Relation of Lime and Magnesia to Plant Growth, by Dr. Oscar Loew and Mr. D. W. May, and respectfully recommend that it be published as Bulletin No. 1 of this Bureau.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

Although liming of soils has been practiced for ages and is fairly well understood from the chemical and physical standpoints, comparatively little has been done toward determining the exact physiological explanation of some of the beneficial and injurious effects of liming on the growth of crops. The physiological rôle of calcium and magnesium salts was briefly discussed in Bulletin No. 18 of this office on the Physiological Rôle of Mineral Nutrients. In the present bulletin are brought together many valuable observations on the general subject of liming, especially from the standpoint of the plant. The work, though preliminary, shows quite clearly that magnesium salts are poisonous to our ordinary crops unless accompanied by readily available lime compounds. Under the direction of Dr. Loew, Mr. May, of the Office of Experiment Stations, endeavored to determine experimentally the proper ratio of lime and magnesia for certain crops and soils. The results of these investigations warrant the statement that the amount of available lime and magnesia should be about equal in order to insure maximum growth for most crops. The subject is presented at this time with the hope that it may stimulate investigations along these lines, so important to agriculture. We are under obligations to the Bureau of Chemistry for the chemical analysis of some of the soils and other material used, and to the Bureau of Soils for physical analyses. The manuscript of this bulletin was submitted for publication nearly a year ago, but it has not been practicable to print it until the present time.

Albert F. Woods.

Office of the Pathologist and Physiologist,
Washington, D. C., June 17, 1901.

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I. LIMING OF SOILS FROM A PHYSIOLOGICAL STANDPOINT.

By Oscar Loew,
Expert in Physiological Chemistry.

INTRODUCTION.

The beneficial effect of slaked lime and gypsum in crop production has been known since the early ages. The old Romans as well as the Japanese and Chinese were well acquainted with the practice of liming. The effects, however, were not uniform either on different soils or for different crops, and damage was sometimes incurred by overliming. It is a question of great importance to the farmer to be able to ascertain when his soil needs liming, and how much of the lime or lime compounds to apply; also whether slaked lime, carbonate of lime, or sulphate of lime is the most suitable form, and whether magnesian limestone must be excluded. The quantities of lime required vary, according to circumstances and the nature of the crop, from 500 to 6,000 pounds per acre. Boggy and clay lands require more lime than other soils. It is preferable to add moderate quantities at comparatively short intervals (every three to six years) rather than a very large quantity at once. Heavy soils may be made more porous by the use of slaked lime, and fine sandy soils may gain in firmness, while soils with an acid reaction may become profitably neutralized.

The decomposition of humus in soils is hastened by lime, its nitrogen being liberated as ammonia and becoming available to the plant either as ammonia or as nitrates after nitrification. The process of nitrification is also promoted by the presence of lime. On sour, boggy lands marsh plants can easily be replaced by forage plants after an application of lime. Liming also has great importance in connection with the raising of live stock, since the formation of bone is imperfect where their food is too poor in lime. Again, certain parasitic fungi and insects in the soil are easily killed by the alkaline properties of burnt lime. Lime and gypsum can also in certain cases release such potash in the soil as is still unavailable. This, as well as the enhanced root hair production under the influence of the increased amount of lime, accounts for the greater absorption of potash by the plant on soils rich in lime.

Although for several reasons the burnt lime is superior to carbonate of lime, and even in some cases mentioned can not be replaced by the latter, still there are instances where finely pulverized carbonate of lime can be applied directly with great success, especially on sandy soil.[1] In many other cases the sulphate of lime (gypsum) is the most favorable form, especially when the amount of sulphates in the soil is very small, it often sinking far below 0.1 per cent.

Gypsum furthermore acts very beneficially in preventing the evaporation of ammonia as ammonium carbonate from stable manure by preserving the ammonia as sulphate. Its very beneficial action for many leguminous crops may be especially mentioned.[2]

Slaked lime is the remedy for correcting an acid reaction, while gypsum is the remedy for correcting an alkaline reaction of soils. To soils of certain arid regions of the far West which contain sodium carbonate, rendering them unfit for raising any crops, Hilgard has proposed an addition of gypsum. The gypsum acts upon the sodium carbonate, transforming this into the less injurious sodium sulphate, while the gypsum itself is transformed into calcium carbonate.

While all these applications of lime and lime compounds[3] are well known, a special case, the correction of the injurious effects of a high magnesia content, will be discussed and experiments described in the second part of this report by Mr. D. W. May, a subject which hitherto has not been taken practically into consideration.

INJURIOUS ACTION OF MAGNESIUM SALTS.

An excess of magnesia acts injuriously on plants, an observation made frequently and even long ago. The increase of lime is the only decisive remedy. The plants thrive best when the ratio of lime to magnesia does not pass certain limits. Too little magnesia in relation to lime may retard development, while too much magnesia in relation to lime may injure the crop still more.

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[1] Various authors place the minimum limit of lime in a soil for good returns at 1 per cent, although satisfactory crops have been raised on clay soils with 0.3 per cent, and on sandy soils with 0.1 per cent lime.

A case may be mentioned where liming proved of immense benefit on soil that contained 0.55 per cent lime. "A percentage of gain of 10,000 in beets" was produced as compared with the unlimed soil. Here it was certainly not the physiological rôle of the lime, but an essential improvement of the soil (neutralization, etc.), which led to this result. This case was observed in Rhode Island and described by Wheeler, Hartwell, and Sargent. (Journ. of Amer. Chem. Soc., 1900, p. 153).

A too heavy application of burnt lime on certain soils might destroy not only noxious parasites but also the useful root bacteria of the Leguminosæ. Reports referring, however, to different soils are still contradictory on this point.

[2] The annual amount of gypsum consumed for fertilizing purposes in the United States is estimated by Dr. H. W. Wiley as 75,000 tons.

[3] The question of liming and of fertilizing in general is fully treated in F. H. Storer's "Agriculture in Some of its Relations to Chemistry," New York, 1897, seventh edition.

In drawing inferences from agricultural experiments much attention should be paid to all conditions that might possibly have an influence. For example, while one author reports that a deficiency of lime will cause yellow spots to develop on the leaves of the sugar beet, and consequently decrease the yield of sugar, another asserts that beets richest in lime are poorest in sugar.[1] In such cases it is necessary to ascertain also the amount of the other nutrients, since too much magnesia may influence the results just as certainly as a reduced amount of potash.

In another instance it is reported that calcium nitrate is a less favorable source of nitrogen than sodium nitrate, an observation which may have been made on soils rich in lime and too poor in magnesia, otherwise it would be difficult to understand, since experiments with water cultures have shown calcium nitrate to be an excellent nutrient.

As early as 1814 Davy discussed the question why magnesia sometimes acts injuriously on crops. He wrote: "It has long been known to farmers in the neighborhood of Duncaster that lime made from certain limestone applied to the land often injures the crop considerably. This lime contained magnesia. On mixing some calcined magnesia with soil in which different seeds are sown, it is found that they either die or vegetate in a very imperfect manner." He also states that "lime from magnesian limestone may be applied in large quantities to peats, and where lands have been injured by the application of too large a quantity of magnesian lime peat will be a proper and efficient remedy."[2]

An injurious action was observed with the limestone from quarries near Belvidere, N. J., while other limestones from near Oxford, some distance off, showed very beneficial effects on the same field. The difference between the effects was so striking that it was considered of some importance to investigate the cause. Samples of the two limestones were therefore sent to the U. S. Department of Agriculture, where they were analyzed, with the result that the *injurious limestones* were found to contain 38 to 42 per cent of magnesium carbonate, while the *beneficial limestone* contained not quite 1 per cent of this substance.[3] The explanation, however, that the injurious effects of burnt magnesian limestone are due mainly to the fact that the caustic magnesia turns much more slowly into carbonate than the caustic lime can not be the correct one, neither can the hypothesis be accepted that the injurious effect is due to the formation of hydraulic cement in the soil, since the effect is less noxious on clay soil than on sandy soil, while just the reverse should be expected if that hypothesis were correct.

Very injurious effects have been reported from manuring with precipitated magnisium carbonate, these being ascribed, however, to the

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[1] Hollrung, Die Zuckerindustrie, 1898.

[2] Elements of Agricultural Chemistry, 2d ed., p. 322.

[3] Report of the Commissioner of Agriculture, Washington, D. C., 1876, p. 142.

change in the mechanical conditions of the soil.[1] Ad. Mayer[2] mentions sterility in a soil rich in magnesia. On the other hand Heiden[3] states some instances where magnesite and even magnesium sulphate exerted a beneficial effect. Kellner[4] reports a beneficial effect from magnesian limestone,[5] and Larbaletrier and Malpeaux[6] describe a case in which magnesium sulphate proved very efficient.

Just as contradictory are the reports on the effects of the application of kainit and carnallit, both of which contain salts of potassium and magnesium. The former, however, contains more potassium sulphate than the latter. The effects were frequently found to be injurious when these salts were applied in the spring, while the application in the autumn proved beneficial. Thus Fleischer[7] observed that kainit yielded a 5 per cent larger crop of potatoes when applied in the autumn than when applied in the spring. Other observers[8] reported a decrease in the percentage of starch in potatoes when kainit was applied in the late spring and also claimed that the quality was impaired. Liebenberg[9] finally reports a decrease in the yield of meadows when kainit was applied even in the autumn. In the latter case the perennial roots of the grasses came directly in contact with the fresh fertilizer, while in the previous cases the rains of winter had a chance to wash out or modify the injurious magnesium salt before the crops were planted or seeds were sown. Other authors[10] also report an injurious effect from kainit on meadows, no matter whether applied alone or in conjunction with other fertilizers. However, very many favorable results from the use of kainit on other soils and other crops have been published. Schultz-Lupitz has observed that the injurious effects of the crude potassium salts of Stassfurt (kainit, carnallit, etc.) can be counteracted by liming the soils, but he gave no explanation for this interesting fact. That the application of lime would be in such cases the proper remedy was inferred by the writer[11] from his theory before he knew of the successful experiments of the author just mentioned. It was claimed at that time that the occasional injury caused by the Stassfurt salts was due to their chlorid content,

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[1] Centralbl. f. Agriculturchemie, 1870.

[2] Vorlesungen, 3d ed., Vol. II, p. 111. Dejardin reports that an increase of the magnesia content in the soil favors the resistance of the vine to Phylloxera, but this remedy applied to a soil poor in lime may prove dangerous to the plants. On the other hand Wheeler reports that liming the soil promotes the scab of the potato. See also Bul. No. 18, U. S. Dept. Agr., Div. Veg. Phys. and Path.

[3] Landw. Vers. Stat., 1869; also Pincus, ibid., 1868, p. 402.

[4] Sächsische Landw. Zeitsch., 1895, No. 24.

[5] Similar results were reported by Völker in England (Griffiths, Treatise on Manure, 1889, p. 235), and Muntz and Girard in France (Les Engrais, 1891, p. 333), and finally by Patterson in Maryland (Bul. No. 66, of the Md. Agr. Ex. Sta., p. 130).

[6] Centralbl. f. Agriculturchemie, 1896, p. 434.

[7] Bot. Jahresber. f. 1886. [8] Jahresber. f. Agriculturchemie, 1896, p. 222.

[9] Ibid., p. 219. [10] Ibid., p. 216. [11] Landw. Vers. Stat., 1892.

but this is certainly only a subordinate cause. The evil effects are mainly due to their high magnesia content, which will do little harm on soils rich in lime and poor in magnesia, but produces much injury on soils poor in lime rather than in magnesia. The more magnesia in relation to lime present in a soil the more injurious a certain additional quantity of magnesium compounds will prove. With the Stassfurt salts containing magnesium sulphate and chlorid this must be much more evident when they are applied in spring than when applied in autumn, since during the winter a part of the magnesium salts can be washed out as already stated or else turned into the less noxious carbonate. To foretell whether magnesium limestone or the crude salts of Stassfurt would prove to be injurious manures the analysis of the soil would give the proper answer.

The total amount of lime contained in the earth's crust is larger than that of magnesia. The calculation of F. W. Clarke gives as approximate numbers: Lime, 5.29 per cent; magnesia, 4.49 per cent; or, calcium, 3.77 per cent; magnesium, 2.68 per cent. But since the compounds of these elements are not uniformly distributed through the earth's crust, regions exist in which magnesia predominates over lime and others in which lime predominates over magnesia. Manifold variations have indeed been observed. Frequent manuring has, of course, changed these proportions from olden times in the uppermost stratum of the cultivated parts. The dung of animals fed with seeds, such as, for example, maize, oats, and barley, will of course be relatively richer in magnesia than that of animals fed mainly on grass, straw, and various other foliage. The latter manure will contain relatively more lime than the former. Thus, even without having recourse to direct liming, the lime content of cultivated land is often unintentionally increased. In the average fresh barnyard manure there is contained, according to Ville, 80 per cent of water, and among the mineral constituents 0.56 per cent lime and 0.24 per cent magnesia, forming a ratio of 1:0.43.

But while in the crust of the earth as a whole, as well as in most of the spring waters, lime predominates over magnesia, the reverse is observed in the oceans. Sea water contains about 3½ per cent of soluble salts in the following proportions: Sodium chlorid, 78; magnesium chlorid, 11; magnesium sulphate, 5; calcium sulphate, 4; potassium sulphate, 2; traces of iodides, bromides, phosphates, etc.[1]

[1] Marret calculates the following amounts for 1,000 parts of sea water (quoted by Liebig, Agriculturchemie.)

Sodium chlorid	26.660
Sodium sulphate	4.660
Potassium chlorid	1.232
Magnesium chlorid	5.152
Calcium sulphate	1.500

In the sea water, therefore, we find a proportion of lime to magnesia of approximately 1:3.8, a ratio which would prove injurious for many land plants in water culture. The marine plants, such as diatoms and fucoids, which in all probability require lime for building up certain of their organized structures, must then have means of accumulating lime compounds in order to counteract an injurious influence of the magnesium compounds entering their cells. Indeed, the ashes of marine algæ show more lime than magnesia, as seen from the following:[1]

Percentage of lime and magnesia in marine plants.

Marine plants.	Percentage of lime.	Percentage of magnesia.
Fucus vesiculosus	9.7	7.1
Fucus nodosus	12.8	10.9
Fucus serratus	16.3	11.6
Laminaria digitata	11.8	7.4

It is well known that a high lime content of the soil favors some plant species more than others, and may even injure certain plants, as the yellow lupin. According to Heinrich,[2] a soil containing 0.46 per cent carbonate of lime will injure the lupin, while 0.5 per cent carbonate of magnesia will prevent its development entirely. Hilgard mentions for the southern part of the United States the linden tree, wild plum tree, and the tulip tree (Liriodendron) as indicative of a soil rich in lime.[3] On the other hand, the southern pines and certain kinds of oak and Vaccinium are indicative of a lack of lime in the soil.[4] With certain other plants some variations in growth depend on the abundance or deficiency of lime in the soil, as Hilgard has pointed out for *Quercus ferruginea* and *Q. obtusiloba*. This author has also called attention to the lower growth but richer yield in seeds and fruits on soils with a high lime content. But, on the other hand, a deficiency of lime may also reduce the size of certain organs. Thus the leaves of young pine trees reach only half the normal length when lime salts are deficient, as Honda and the writer have observed.[5]

It is a natural and logical conclusion that an analysis of soil properly made with regard to the absorbing capacities of the plant roots must

[1] Gödechens, Ann. Chim. Pharm., 1854, Vol. LIV.

Some marine algæ, such as certain members of the Florideæ, exert a powerful attraction upon the lime salts (by probably containing certain organic acids yielding insoluble lime salts), depositing much calcium carbonate in the cell walls.

[2] Jahresber., f. Agr. Chem., 1896, p. 239.

[3] In Europe *Gentiana ciliata* is one of the characteristic lime-soil plants.

[4] The coast pine (Strand Kiefer) can grow in Europe only on soil poor in lime (Grandeau and Fliche, 1878).

[5] Bull. College of Agr., Tokyo, Vol. II, No. 8.

yield the means to properly estimate the quality of the soil. Such an analysis must not only regard the absolute quantities of phosphoric acid, sulphuric acid, potassa, lime, magnesia, iron, and nitrogen compounds, but must also consider the fineness or coarseness of the division of the nutritive materials and their solubility in dilute organic acids. But the writer must add that there is another important factor in the valuation of soils, and that is the ratio of the easily assimilable amounts of lime and magnesia in the finer particles. Many attacks have been made upon the use of analyses of soil for purposes of valuation, but this opposition can only relate to certain analyses, such as made in the old method of treating the soil with concentrated hydrochloric acid.[1] Such analyses will not show exactly the amount of nutrients available for the next crop, but mainly indicate the whole amount of nutrients available within a longer period.

Every farmer ought to know the ratio of the easily assimilable portion of lime to magnesia in his soil, as with such knowledge he can tell when liming is needed and if magnesian limestone will prove injurious. Soils with much magnesia are more to be feared than those with too little. There may be soils with but little available magnesium carbonate which still produce excellent crops, for in this connection it must be remembered that water containing carbonic acid can dissolve more magnesium carbonate than calcium carbonate. Treadwell and Reuter[2] found that 1 liter of water will hold 0.385 gram calcium bicarbonate in solution, while it will contain 1.954 grams of magnesium bicarbonate, besides 0.715 gram neutral magnesium carbonate.

When it is further remembered that magnesia is more movable in plants than lime, and that therefore one and the same molecule of magnesia can serve repeatedly as a carrier of phosphoric acid for the formation of nucleo-proteids and lecithin, it will not appear strange that a soil can still produce certain crops when the content of magnesia is very much smaller than that of the lime. This is especially true when such plants are grown as are capable of excluding any absorbed excess of lime from further physiological influence by transforming it into the nearly insoluble calcium oxalate. The situation is far different, however, on a soil that contains a considerable excess of magnesia over lime, and here a proper correction is an absolute necessity.

[1] Compare also the interesting results of Thoms. Agric. Centralbl., 1898, p. 155, whose theoretical inferences from soil analyses were in full accord with the practical observation on the fertility of various domains.

[2] Zeitschr. f. Anorg. Chem., 1898, Vol. XVII, p. 170.

THEORETICAL DISCUSSION OF THE FUNCTIONS OF LIME AND MAGNESIA.

The physiological rôle of lime and magnesia was fully discussed in a previous bulletin,[1] hence a few lines touching the chief points will suffice here. The lime is, according to the theory of the writer, necessary for the formation of certain calcium compounds of nucleo-proteids required in the organized structures of nuclei and chlorophyll bodies, while the magnesia serves for the assimilation of phosphoric acid, since magnesium phosphate can give up its phosphoric acid more easily than any other phosphate that occurs in plant juices. While calcium is fixed in the organized structure, magnesium is movable, since it serves mainly in the form of secondary phosphate as carrier of assimilable phosphoric acid, which rôle can be repeated various times.

It follows from this theory that, in the case of an excess of lime being taken up, the assimilation of phosphoric acid will be rendered more difficult, since this acid will chiefly combine with the lime, and the chances for the formation of magnesium phosphate will thus be diminished. The effect will be the same as if the amount of available phosphoric acid in the soil were lessened—that is, the growth of the plant will be retarded and even starvation phenomena may set in. Many plants avoid this evil effect of an excess of lime in the juices by the precipitation of a part of the lime as oxalate, as mentioned above, while others[2] secrete it as carbonate, contained also in cystoliths.

If, on the other hand, magnesia is taken up in considerable excess over lime a poisonous action is observed. Plants succumb soon when placed in diluted solution of magnesium salts and no other, but calcium salts can prevent this effect. In fact, magnesium salts can exercise their nutritive functions only in presence of a sufficient amount of calcium salts. The plants can not, as with lime, turn an excess of magnesia into an insoluble form and thus render it innocuous. Only in certain cases may the formation of globoids or of insoluble magnesium protein compounds come into consideration.

The injurious action of magnesium salts has been previously explained by the writer,[3] as follows: The calcium nucleo-proteids of the organized structures are transformed by the presence of soluble magnesium salts into magnesium compounds, while the calcium of the former enters into combination with the acid of the magnesium salt. By the transformation of the organized calcium nucleo-proteids into magnesium nucleo-proteids the capacity for imbibition will change, which must lead to a disturbance in the structure which will prove fatal. Only the simultaneous presence of dissolved lime salts can prevent this

[1] Bul. No. 18, the physiological rôle of mineral nutrients, U. S. Dept. Agr., Div. Veg. Phys. and Path., pp. 28, 37, 42, 47, and 60.

[2] Saxifragineæ, Plumbagineæ, and some ferns secrete calcium carbonate on their epidermis.

[3] Bul. No. 18., U. S. Dept. Agr., Div. Veg. Phys. and Path.

effect, according to the law of mass. The writer noted, for example, among other observations, that certain algæ, such as Spirogyra, died in five days in a solution of 1 per 1,000 magnesium nitrate, while they remained alive for a number of weeks in this solution when 0.3 per 1,000 calcium nitrate was added. Of course, magnesium in form of carbonate or phosphate in the soil would act injuriously in much less degree than the soluble magnesium nitrate, or sulphate; but nevertheless injury will show in time.

How much, however, the result is influenced by the degree of fineness of these compounds may be judged from the observation of Ulbricht[1] that a large amount of the commercial precipitated basic magnesium carbonate acts much more injuriously than finely powdered magnesite, and that slaked lime in excess diminished the yield in lupin more than an excess of powdered marl. This author also described cases in which a rich manuring with lime depressed the yield, and further observed that a proper liming will remedy the evil effect of magnesium chlorid.

Also Atterberg (1892) observed injurious effects of large applications of magnesia upon oats on marsh soil and the prevention of this injury by liming. But previous to these authors E. Wolff[2] had observed on the one hand an injurious effect of burnt magnesia, and on the other the depression of the yield by a too excessive liming.

Heinrich observed a decrease of the crop of the yellow lupin of 36 per cent after adding as much as 0.5 per cent gypsum to the soil (quoted by Ulbricht, l. c.) and Ulbricht observed by adding only 0.011 per cent gypsum, a gain of 10.6 per cent of the lupin crop, and 21.5 per cent of the buckwheat crop, while with red clover and with timothy a gain of only 1.5 per cent was noted.

The crop of the yellow lupin was further considerably decreased in the experiments of Ulbricht by the application of 500 and 1,000 kilograms of lime to the morgen (1.6 acres). Also burnt magnesian limestone with 40 per cent magnesia had an injurious effect not only for lupin but for barley and vetch when applied in the amount of 500 kilograms to the morgen. A diminution of the lime one-half and of magnesia one-fourth, or an appropriate mixture of pure limestone with magnesian limestone, might have resulted in a favorable harvest. Lime and magnesia can exert their indispensable nutritive functions only in a certain dependence upon each other. Hence a certain ratio between these two nutrients will produce the most favorable results,[3] while a great excess of the one in the finest portion of the soil will lead to starvation and of the other to poisonous phenomena.

[1] Landw. Vers. Stat., Vol. LII, p. 383 (1899). The basic properties of precipitated magnesium carbonate and of slaked lime are soon destroyed by the carbonic acid dissolved in the water of the soil.

[2] Grundlagen des Ackerbaues, 2d ed., p. 598.

[3] This ratio will differ somewhat with different crops.

THE RATIO BETWEEN LIME AND MAGNESIA IN SOILS OF DIFFERENT COUNTRIES.

Although soil analyses made in the old way do not permit of distinguishing between those compounds in the soils that are present in a very easily assimilable condition and those that are not so easily available, nevertheless a short review of the composition of soils of various countries might be made, since it will show at least what extremes of the lime and magnesia content might eventually, in case of fine distribution, be encountered by the roots. May it be distinctly understood, however, that it is beyond the scope of this bulletin to consider all the literature on soil analyses. This would have an essential value only if all the analyses were made in the manner indicated below.

SOILS OF AMERICA.

Soils of Alabama.—Bulletin No. 5, of the Agricultural Experiment Station at Auburn, Ala., gives analyses of soils and subsoils of eight different counties of that State. In three of these soils and four of the subsoils the content of magnesia exceeds that of lime:

	Per cent.
Maximum of lime	3.742
Maximum of magnesia	.671
Minimum of lime	.031
Minimum of magnesia	.005

Soils of Louisiana.—A report published by the Louisiana State University on geology and agriculture, Baton Rouge, La., 1893, contains in the first part ten analyses of soils of northern Louisiana, from five different districts. These soils are poor, but yield fair returns when judiciously manured. From these analyses, it is seen that the soils are mostly poor in lime and magnesia. In five cases the content of magnesia exceeds that of lime:

	Per cent.
Maximum of lime	0.145
Maximum of magnesia	.180
Minimum of lime	.009
Minimum of magnesia	.011

In Part II of that report forty-five analyses of soils and subsoils from different formations and districts are communicated. In sixteen cases magnesia predominates over lime, but this excess is small in eleven of them. Omitting the rich calcareous soils, Nos. 22 and 23, there is found:

	Per cent.
Maximum of lime	2.580
Maximum of magnesia	2.140
Minimum of lime	.033
Minimum of magnesia	.023

In most of the very fertile *alluvial* soils of Louisiana the amounts of lime and magnesia are nearly equal, and only in three cases out of twelve (subsoils included) is there an undue preponderance of magnesia.

Soils of various States and sections.—As to Florida, North Carolina, South Carolina, and Georgia, and some States of the arid regions, a review on the composition of soils by Hilgard[1] was consulted, and the average ratio of lime to magnesia calculated from these data, as follows:

Ratio of lime to magnesia in certain soils.

States.	Ratio of lime to magnesia.	Range of percentage.
Florida	1:0.30	
North Carolina	1:0.91	0.07 to 0.14 per cent lime.
South Carolina	1:1.09	0.02 to 0.15 per cent magnesia.
Georgia	1:1.30	
California	1:1.38	
Washington	1:0.85	1 to 2 per cent lime.
Montana	1:0.60	1 to 1.5 per cent magnesia.
Wyoming	1:0.54	

The soils of the arid regions of the four last-named States contain much more lime and magnesia and also more potassa and soda than the soils of the four first-named States of the humid regions, while the differences in the contents of phosphoric acid, sulphuric acid, and ferric oxide are not so marked. It must be pointed out, further, that Hilgard omitted intentionally all typical calcareous or limestone soils from consideration.

A comparatively small number of soils of Arizona, Utah, New Mexico, and Colorado have thus far been analyzed, but in most of these cases lime preponderates over magnesia. In Bulletin No. 33 of the Colorado Agricultural Experiment Station are mentioned five analyses of soils of which two show more magnesia than lime, and in Bulletin No. 9, of the same station, are mentioned analyses of soils from seven different localities, of which only one shows more magnesia than lime. The excess of magnesia over lime in these three cases is but small. In the last mentioned seven analyses the maximum of lime is 3.69 per cent, of magnesia 1.61; the minimum of lime is 0.68, of magnesia 0.54 per cent.

Of Utah soils, six samples were analyzed from Sanpete County[2] which show from 8 to 22 per cent of lime and only 0.13 to 1.8 per cent of magnesia. Of seven specimens of soils from Clarke County, none contained more magnesia than lime, the maximum of lime being

[1] A report on the relation of soil to climate, by E. W. Hilgard, U. S. Dept. of Agr., Weather Bureau Bul. No. 3, Washington, 1892.

[2] Agr. Exp. Station Bul. No. 52, Logan, Utah. As to Arizona soils, some analyses are contained in Bul. No. 28 of the Agr. Exp. Station of Arizona.

2.75 per cent, of magnesia 1.71 per cent; the minimum of lime 0.87 per cent, of magnesia 0.52 per cent.

Recent analyses of soils of Oregon[1] show a prevalence of magnesia over lime in certain districts; in one sample from Washington County even 0.90 per cent of magnesia for only 0.13 per cent of lime was found.

Some analyses of soils of Nevada show a considerable excess of lime over magnesia.[2] This seems to be true also in Wyoming.[3]

Soils from British Columbia.[4]—Of thirteen samples analyzed, only four contained more magnesia than lime. The minimum of lime was 0.73 per cent, of magnesia 0.32 per cent; the maxima, 1.86 and 1.55 per cent, respectively. The ratio of lime to magnesia varies from 1:0.5 to 1:1.1.

Soils of Texas.—The analyses of twenty-two soils from Texas[5] show generally a considerable preponderance of lime over magnesia. This is also the case in Michigan.[6] Of twenty-nine different soils analyzed, not one contained more magnesia than lime, but the percentage of each of these oxides amounts in many cases to less than 1 per cent.

Soils of Minnesota and North Dakota.—In Minnesota and North Dakota lime predominates in the majority of cases over magnesia, to judge from the analyses made thus far. Only in the southeastern part of Minnesota magnesia predominates in most cases over lime. Snyder[7] mentions as an average of two hundred Minnesota soils a lime content of 2.16 per cent and an average magnesia content of 0.55 per cent; hence the amount of lime is about four times as large as that of magnesia. In certain cases, however, the magnesia content exceeded the lime content by one-half. The minimum lime observed was 0.16 per cent, that of magnesia 0.10 per cent.

As to North Dakota, there exist soils exceedingly rich in lime in the valleys of the Cheyenne, of the Red River, and of the Mouse River. In these cases the magnesia content remains below 2 per cent, while the lime content amounts from 18 to 23 per cent.[8] A case with a relatively large excess of magnesia over lime was observed in the James River Valley, namely, 0.14 per cent of lime for 1.38 per cent of magnesia; hence the amount of magnesia exceeded that of lime nearly tenfold. Of thirty cases in all, the magnesia exceeded the lime only in eight.

[1] Oregon Agr. Exp. Station Bul. No. 20.

[2] Nevada Agr. Exp. Station Bul. No. 19.

[3] Wyoming Agr. Exp. Station Bul. No. 6.

[4] Experimental Farms Report, 1895, p. 200. These soils were never manured except incidentally by the droppings of animals when in pasture.

[5] Texas Agr. Exp. Station Bul. No. 25.

[6] Michigan Agr. Exp. Station Bul. No. 99.

[7] Minnesota Agr. Exp. Sta. Bul. No. 41, p. 32.

[8] Analyses of A. F. Ladd, North Dakota Agr. Exp. Sta. Bul. No. 22.

Soils of Tennessee.—The Agricultural Experiment Station Bulletin, Vol. X, No. 3, Knoxville, Tenn., 1897, contains the mechanical and chemical analyses of fifteen soils and eleven subsoils. In fully twenty-one of these twenty-six soil analyses, the magnesia content is larger than that of lime. This excess is in some cases but small, but in some unduly large. Thus, the sandstone soil of Grundy County shows 0.073 per cent of lime and 0.291 per cent of magnesia, or nearly four times as much magnesia as lime. Very correctly the reporting chemist, Charles F. Vanderford, remarks, on page 38, that "it is certain that dolomite (magnesian limestone) soils are much more easily injured by working when too wet than the soils in which magnesia is less prominently a constituent; and it is also a fact that dolomite soils readily and happily respond to an application of lime from a high-grade calcium carbonate." The soils of Arkansas show partially the same characteristics as those of Tennessee, but further information regarding them is desirable.

Soils of Rhode Island.—The Agricultural Experiment Station Bulletin No. 72, Kingston, R. I., contains seven analyses of the soils of that State, but only one of these soils shows an excess (a moderate one) of magnesia over lime:

	Per cent.
Maximum of lime	1.295
Maximum of magnesia	1.141
Minimum of lime	0.252
Minimum of magnesia	0.209

Bulletin No. 68 and the Seventh Annual Report of the Rhode Island Experiment Station contain two analyses showing a preponderance of lime over magnesia.[1]

Soils from South America.—The writer's search for a number of soil analyses of South America was not crowned with much success. It may, however, be mentioned that two samples of very fertile soils of Paraguay[2] showed an excess of lime over magnesia: Lime, 0.138 and 0.355 per cent; magnesia, 0.036 and 0.065 per cent.

SOILS FROM EUROPEAN COUNTRIES.

Soils from Russia.—The analyses of ten samples of the "Black earth,"[3] celebrated for its high degree of fertility, show from 0.66 to 2.16 per cent of lime and from 0.23 to 1.39 per cent of magnesia, and in not a single instance more magnesia than lime. The amount of phosphoric acid runs from 0.09 to 1.66 per cent, that of potassa from

[1] Soils of Bermuda are generally rich in lime, one sample of which contains as much as 51.4 per cent lime for only 0.756 per cent magnesia.

[2] Jahresber. f. Agr. Chem., 1873.

[3] Ibid., 1873.

0.13 to 1.44 per cent. Very probably the mechanical condition of these soils is also very favorable.

Soils from Italy.—The analyses of soils from Italy, in the literature available to the writer, show a general preponderance of lime over magnesia.[1] Some of these are limestone soils, containing from 11 to 19 per cent of lime. One of them shows only 0.09 per cent of magnesia for 11.04 per cent of lime, or a proportion of lime to magnesia of 1:0.008. In most of the soils analyzed the amount of magnesia is less than one-half of that of lime.

Soils from Germany.—The analyses made of German soils relate in the majority of cases to lands manured for centuries. Liming is also an operation extensively practiced there. Nevertheless, there occur large districts that require liming, as in the northern part of the Odenwald.[2] Of thirty-seven samples of soils of this district, however, only two were found to contain more magnesia than lime, and this excess was moderate. The alluvium of the Rhine frequently contains more magnesia than lime. Thus Wohltman[3] has analyzed, for purposes of valuation, soils belonging to seven different degrees of fertility. Of these, only the first-class soil showed, besides a larger proportion of potassa and phosphoric acid, more lime than magnesia, while the soils from the second to the seventh class contained from one and one-fourth to eight times more magnesia than lime. On the other hand the Rhine deposit at Langenau (Hessia) contains eight times more lime than magnesia, as seen from the analysis of E. Schulze, 1873.

Many soils of the province of Brandenburg are very poor in lime (Ulbricht). An excess of magnesia over lime exists in the Berleburg district in Westfalen,[4] while in other parts of that province lime predominates over magnesia. On the other hand, in thirty samples of humus soils of Hanover and neighboring districts lime predominates over magnesia.[5]

	Per cent.
Maximum of lime	3.93
Maximum of magnesia	.39
Minimum of lime	.01
Minimum of magnesia	.01

The limestone soils of the best wine-producing districts are often very rich in lime, not only in western Germany but also at the mouth

[1] These soils serve to a great extent for the culture of tobacco. Cf. work of N. Sparano; Guida Agrario-Merceologica, Rome, 1899.

[2] Lüdecke, Jahresbericht f. Agriculturchemie, 1898.

[3] Centralbl. f. Agriculturchemie, 1897.

[4] Jahresber. f. Agriculturchemie, 1873. Also in certain Bohemian districts magnesia predominates over lime. Ibid., 1875 and 1876.

[5] Analysis by Alberti, ibid., 1873 and 1874.

of the Rhone.[1] In the eleven vineyard soils analyzed by A. Hilger[2] calcium carbonate was found from 3.1 to 69.6 per cent, and magnesium carbonate from 0.9 to 5.1 per cent. In not a single instance did the amount of magnesia exceed that of lime.

A great number of soils have been analyzed in Germany, but many of the publications are not available to the writer. It may, however, be mentioned that in even some recent German publications on the composition of certain soils and their need of manure, so little attention was paid to the amount of magnesia that this was not even quantitatively determined, while potassa, lime, and phosphoric acid were.

Soils from Hungary.—Bela von Bittó[3] determined the lime and magnesia in soil and subsoil from forty-three localities in Hungary, and of the eighty-four analyses mentioned, there are only seventeen showing an excess of magnesia over lime. Comparing all those analyses there is found:

	Per cent.
Maximum of lime	25.44
Maximum of magnesia	3.81
Minimum of lime	.14
Minimum of magnesia	.08

The range of proportion between the amounts of lime and magnesia is 1:0.02 to 1:3. In most cases of the excess of magnesia over lime, however, this excess is but small and does not amount to more than one-half. These soils have been manured for years, either with animal dung or with commercial fertilizers; hence, often considerable differences of composition occur in the same formation between surface soil and subsoil, especially in the relation of the lime and magnesia content.

From the observations of the above author it follows that the greatest yield was obtained on those soils in which the amount of magnesia either was smaller than that of lime or exceeded the latter only very moderately. It is to be regretted, however, that the mechanical condition and the amount of the other nutrients were not investigated, thereby permitting more reliable inferences.

From the analyses of Hungarian soils by Tolles[4] it is seen that either the lime predominates over magnesia or if magnesia is in excess, it is but moderate, not reaching one and one-half times that of lime.

SOILS FROM ASIATIC COUNTRIES.

Soils from Japan.—A great number of soils have been analyzed in the laboratory of the geological survey of Japan, and very valuable reports have been issued on that subject by the Imperial Japanese

[1] Analysis by Alberti, Jahresber. f. Agriculturchemie, 1873 and 1874.

[2] Ibid., 1879 and 1886.

[3] Landw. Vers.-Stat., Vol. L, p. 245.

[4] Ibid., Vol. XLII, p. 409, 1893.

Government. Some typical soils show the following percentages of lime and magnesia:

Percentages of lime and magnesia in some typical soils of Japan.

Soils.	Per cent of lime.	Per cent of magnesia.
Clay soil—I	0.96	0.87
Clay soil—II	0.99	2.12
Gneiss loam	0.39	0.04
Trachyte loam	0.1–1.0	0.1–1.3
Andesite lava	1.7–4.0	1.3–3.0
Diabas soil	0.90	1.87
Basalt tufa	2.21	1.38

The last-mentioned soil is described as an excellent one. While in this case the ratio of lime to magnesia is as 1:0.6, there occur soils which contain more than double as much magnesia as lime.

Soils from India.—The soils from the Indo-Gangetic alluvium[1] are almost without any pebbles. One of the most fertile soils shows the proportion of 0.47 per cent lime to 0.32 per cent magnesia, or 1:0.67. The highest percentage of lime (limestone soils excluded) was found to be 2.07 per cent, and of magnesia 1.97 per cent. The ratio of lime to magnesia varies from 1:0.56 to 1:2.35 among the eleven samples analyzed.

In the brown alluvial soils from Madras lime occurs partly as carbonate and partly as hydrous silicate. The amount of lime varied in ten samples from 0.05 to 1.23 per cent, and that of magnesia from 0.20 to 1.87 per cent, and the ratio of lime to magnesia from 1:1.52 to 1:1.42. It was not stated whether these loams and sandy soils contained the magnesia only as carbonate or partially as silicate; neither is mention made about fertility and the principal crops raised. Of seven samples of red soils from Madras, only one contained more lime than magnesia, and in one of them the amount of magnesia (1.1 per cent) exceeded that of lime (0.1 per cent) eleven times.

In eighteen samples of the black cotton soils of Regur the amount of lime varied from 1.16 to 5.35 per cent, that of magnesia from 1.79 to 3.09 per cent, and the proportion of lime to magnesia from 1:005 to 1:2. In the twelve samples of laterite soils analyzed the amount of lime varied from 0.14 to 1.5 per cent, that of magnesia from 0.2 to 0.81 per cent, and the ratio of lime to magnesia from 1:0.4 to 1:2.

In five samples of manured coffee soils the amount of lime varied from 0.3 to 0.44 per cent, that of magnesia from 0.38 to 0.66 per cent, and the ratio of lime to magnesia from 1:1.2 to 1:1.5. In eleven samples of tea soils the amount of lime varied from 0.03 to 0.25 per cent, that of magnesia from 0.08 to 1.08 per cent.

[1] Analyses from T. W. Leather, in the Calcutta Agricultural Ledger, 1898, No. 2.

Recently four analyses of soils of southern India were published by C. Massey,[1] which show a considerable preponderance of lime over magnesia in that part of the country: Lime, 0.836, 0.993, 0.825, and 0.999 per cent; magnesia, 0.210, 0.300, 0.255, and 0.352 per cent. It may be mentioned further that tobacco soils of Sumatra and Java, when extracted with acetic acid (diluted 1:5), yield more than twice as much lime as magnesia, according to Van Bemmelen's analysis (1890). Again, soils of Asia Minor used near Smyrna and Erbeiti for the culture of figs contains more lime than magnesia.[2]

SOILS FROM AFRICAN COUNTRIES.

Analyses were recently published of soils of Cameroon, Senegambia, and German East Africa.[3] In the five samples of Cameroon soils, as well as in the three samples of Senegambian soils, there is noticed a great deficiency of lime. The amount present ranges from 0.026 to to 0.174 per cent. Further, there is a considerable excess of magnesia over lime, amounting even to eleven fold and more. These soils would doubtless be much benefited by liming.

Among the seventeen samples of soils from German East Africa there are not less than thirteen in which lime predominates over magnesia. Maximum of lime, 0.893 per cent; of magnesia, 0.530 per cent.

Also eight samples of soils from different parts of the Congo State were analyzed,[4] four of these showing an excess of magnesia over lime.

SOILS FROM AUSTRALIA.

Of analyses of Australian soils, two only, made by Mr. F. B. Guthrie,[5] are available. These soils were taken from the same field and were of a light sandy loam. While the crop (barley) was of good growth on one, it showed bare and stunted spots on the other. The mechanical analyses and the amounts of potash, phosphoric acid, and nitrogen in the two soils were very similar. The only difference of any moment shown by the analyses was in the content of lime. In the good soil it was 0.065 per cent; in the inferior, 0.015 per cent. The analyst recommends liming the inferior soil. Unfortunately, the magnesia was not determined, as it would probably throw more light on the causes of the inequalities in the two soils.

RIVER DEPOSITS.

It may, in addition, be mentioned that such river deposits as are highly esteemed for their fertilizing properties contain more lime than magnesia. The quantities of potassa and phosphoric acid present in

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[1] Chemical News, 1895, Vol. LXXI, p. 261.

[2] Cal. Agr. Exp. Stat. Bul. No. 101.

[3] Jahresber. f. Agriculturchemie, p. 49, 1897.

[4] Ibid., 1896.

[5] Agr. Gaz. New South Wales, 10, 1899, No. 2, p. 166.

these sediments is by no means large, that of the former varying from 0.10 per cent (Colorado) to 0.28 per cent (Rio Grande), that of the latter from 0.092 per cent (Rio Grande) to 0.27 per cent (Colorado, near Fort Yuma, Ariz.). The amount of lime and magnesia in some of these sediments was found as follows:

Amount of lime and magnesia in some river sediments.

Rivers.	Per cent of lime.	Per cent of magnesia.
Nile, Egypt[1]	1.725	0.046
Rio Grande, New Mexico[2]	4.384	0.080
Colorado River, Nevada, near Cottonwood Island[2]	7.000	0.690

[1] Knop (1873) mentions, in his analyses from two different localities on the Nile, calcium carbonate, 3.30 and 4 per cent, and magnesium carbonate, 0.78 and 0.28 per cent. The analysis in the table relates to another locality.

[2] Annual report of the U. S. Geographical Surveys west of the 100th Meridian, Capt. George M. Wheeler in charge, Washington, 1875. The sediment of the Colorado River from the vicinity of Fort Yuma, Ariz., was analyzed in the Agr. Exp. Sta. of Arizona, Bul. No. 6.

Sediments in western Switzerland claimed to be very fertile, deposited by the Morges, the Sionne, and the Borgne, show lime, 2.34, 21.70, and 22.82 per cent; magnesia, 1.16, 1.25, and 1.12 per cent.

It will be seen from the above review—

(1) That the ratio of lime to magnesia ranges between wide limits.

(2) That in the majority of cases lime predominates over magnesia.

(3) That in all the instances of great fertility the soil never shows any marked excess of magnesia over lime, but, on the contrary, generally more lime than magnesia.

In many of the above-cited instances, however, safe agricultural conclusions can not be drawn, since the mode of analysis (treatment with hydrochloric acid) does not admit of distinguishing between easily and difficultly available mineral nutrients.

SOME SPECIAL PHYSIOLOGICAL CASES RELATING TO THE RATIO BETWEEN LIME AND MAGNESIA.

Some physiological instances may now be considered which relate to the ratio between lime and magnesia.

Knop[1] infers from his investigations with barley that two molecules of calcium nitrate should be present in the culture solution for one molecule of magnesium sulphate, which would correspond nearly to the proportion of 1 part of lime to 0.5 of magnesia. E. Wolff calculates, however, for the minima of lime and magnesia required for the production of the dry matter of the oat plant 0.25 per cent lime and 0.20 per cent magnesia, or a ratio 1:0.8.

[1] Centralbl. f. Agriculturchemie, 1861, pp. 465, 564, and 945.

In experiments with maize, Knop found that the lime requirement of this plant is relatively larger than that of barley. From the data given the suitable proportion of lime to magnesia would be 1:0.25. Stohmann differs, however, on this point, and applies the ratio of lime to magnesia as 1:0.6.

As to the tobacco plant, cultivated for its abundant foliage and topped to prevent seed production, it is natural to suppose that it requires more lime in proportion to magnesia than the cereals generally do. The percentage amounts of lime and magnesia from a number of ash analyses of tobacco leaf may here be mentioned. In 100 parts of ash are contained:

Percentage of lime and magnesia in ash of tobacco leaf.

Leaf.	Per cent of lime.	Per cent of magnesia.
Virginia tobacco[1]	31.12	8.58
Virginia tobacco	47.27	10.16
Virginia tobacco	32.56	14.69
Virginia tobacco	37.36	6.37
Kentucky tobacco	35.35	9.35
Hungarian tobacco[2]	27.1 to 60.3	6.1 to 24.8
German tobacco	39.53	9.61

[1] Kissling, der Tabak, p. 41. [2] Botan. Jahresber., 1881.

It will be seen from these few data that while the amounts of lime and magnesia show a wide range there is always a considerable excess of the former over the latter. It might not be far from the truth to assume that the average lime content of the tobacco leaf is about four times that of magnesia. This would agree fairly well with the ratio shown by the analyses of H. Smith of Massachusetts tobaccos. The soils, however, should contain still more than four times the amount of lime compared with that of magnesia.

Comparing that ratio with that found in the tobacco soils considerable discrepancies are observed. From analyses of tobacco soils published by William Frear[1] the following data relative to the lime and magnesia content may be quoted:

Percentage of lime and magnesia content of certain tobacco soils.

Element.	Lancaster, Pa.		New Milford, Conn.	Granville County, N. C.	Sumatra.
	I.	II.	III.	IV.	V.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lime	0.61	0.41	0.32	0.07	0.77
Magnesia	1.26	2.05	0.78	0.02	0.37

[1] The soil of Lancaster County limestone belt in its relation to tobacco culture, Penn. State College Ann. Rept., 1894, p. 160.

The lime content of these soils is not only very low when the high lime requirement of the tobacco leaf is considered, but in the first three cases of the five mentioned the soils contain less lime than magnesia. Lime would prove of great benefit here, avoiding, however, magnesian limestone. On soil IV, however, magnesian limestone may be successfully applied.

Tobacco soils in general must possess not only a proper chemical composition, but also a very satisfactory mechanical condition.[1]

The rapid growth and the relatively large leaf surface make tobacco more susceptible to the mechanical condition of the soil than most crops, since the roots require conditions for a rapid spreading. It would be of considerable interest in this regard to make a comparative investigation of the soils of Vuelta Abajo and Vuelta Ariba in Cuba. The two valleys are not separated by a great distance, but the former produces a tobacco far superior to that of the latter.

That certain chemical qualities of tobacco are dependent upon a certain ratio of lime to magnesia seems to receive an illustration from the fact that in Italy the soils for raising tobacco are exceedingly rich in lime and sometimes very poor in magnesia. There it was observed that tobacco called Spagnuolo develops better odor (but not always a better aroma in smoking) when the amount of magnesia was increased by irrigating with water containing magnesium salts.[2] This is also asserted for the Shiras tobacco from Persia.[3]

The grape also requires a considerable amount of lime, exceeding very much that of magnesia, as seen from the following data taken from Wolff's Tables:[4]

Percentages of lime and magnesia required by the grape.

Parts of vine, etc.	Lime in the ash.	Magnesia in the ash.	Total ash in dry matter.
	Per cent.	*Per cent.*	*Per cent.*
Foliage (in August)[1]	25.69	10.30	1.45
Wood (in February)[1]	30.41	7.19	1.27
Wine (Riesling)[1]	7.43	0.67	0.28
Upper wood	40.17	6.17	2.91
Lower wood	37.92	8.24	2.70
Upper leaves	48.17	7.35	6.96
Lower leaves	50.89	7.00	8.47

[1] The soil from which these samples were derived contained 0.018 per cent of lime and 0.002 per cent of magnesia, both soluble in cold concentrated hydrochloric acid.

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[1] Compare especially the publications of Milton Whitney on tobacco soils, Bul. No. 4, Weather Bureau, and No. 11, Division of Soils, U. S. Dept. Agr. The above remarks are made for the condition that the lime and magnesia content are equally well assimilable in these soils.

[2] Sparano, Guida Agrario-Meteorologica, Roma, 1899.

[3] Kew Garden Bulletin, 1895.

[4] Aschen-Analysen, II, Berlin, 1880.

For one hectare of vineyard there would be annually required 45.48 kilograms of lime and 16.92 kilograms of magnesia, or nearly two and two-thirds times as much lime as magnesia.[1] It happens, however, that in the soils of the vineyards often a very different ratio prevails, and especially that their lime content runs very high. It was observed in France that soils too rich in lime (18 per cent and over) produced the "yellows" in the vines, and that spraying the leaves with a diluted (1 per cent) solution of ferrous sulphate cured the disease.[2] The high content of calcium carbonate of the soil probably neutralized the acid secretions of the roots, and thus frustrated the absorption of the iron compounds from the soil. Neither magnesium nor ammonium sulphate were observed to have any curative effect in these cases.[3] The question whether a great excess of lime can under other conditions interfere with the absorption of the iron deserves further attention.

Another cause of the "yellows" appears to be sometimes a lack of lime in the soil, since in certain districts of France, les Pouilles and l'Aude, slacked lime has been applied for the last fifty years to the affected foilage with much success, as Meunier, Cachard, and Gos report.[4]

Further causes of the "yellows" may be a lack of magnesia or of phosphoric acid or of nitrogen. Stohman[5] mentions that plants cultivated for some time without any supply of nitrogen compounds lose the normal green of the leaves, and that a supply of ammonium nitrate will remedy the evil. Knop[6] observed that an excess of calcium nitrate, as well as of magnesium nitrate, in culture solutions, can cause yellowing of the leaves, and that in such cases an addition of ammonium sulphate had a curative effect. Stohman, however, does not fully agree, since he was unable to cure such cases by ammonium nitrate.

The writer showed years ago that a kind of "yellows" is produced by a lack of phosphate.[7] Algæ turned gradually yellow in culture solutions in which phosphoric acid was absent, and the addition of a trace of secondary sodium phosphate sufficed to restore the normal green color.

In regard to the dependence of full development upon the ratio of lime and magnesia, an interesting observation on the chestnut tree may be mentioned. Grandeau and Fliche[8] analyzed leaves and branches of a tree in normal healthy development and of another of

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[1] Wolff's Tables, II, p. 63.

[2] Jahrbuch der Deutschen Landw. Gesellschaft, Vol. VIII, p. 437.

[3] The French grape vines are much more susceptible to the "yellows" after being grafted with the American vine than they are before, as Lüdecke mentions. The varieties Jaques and Riparia appear to be unable to thrive on soil with more than 18 per cent of lime, but Rupestric is capable of it.

[4] Le Progrès Agricole et Viticole, 1899, No. 31.

[5] Chem. Centralbl., 1861, p. 597.

[6] Ibid., p. 476.

[7] Botan. Centralbl., 1891, p. 371.

[8] Wolff's Tables, II, p. 102.

poor and meager development. From the figures given a considerable difference in the content of potash, lime, and magnesia will be noticed. Lime is increased in the latter case, while magnesia and potash are diminished.

Percentage of potash, lime, magnesia, etc., in leaves and branches of chestnut tree.

Parts of tree.	Total ash.	In 100 parts of ash.			
		Potash.	Lime.	Magnesia.	Phosphoric acid.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Normal leaves	4.8	21.67	45.37	6.63	12.32
Poorly developed leaves	7.8	5.76	74.55	3.70	12.50
Normal branches	4.74	11.65	73.26	3.99	4.53
Poorly developed branches	5.71	2.69	87.30	2.07	4.27

The amount of magnesia relative to lime is considerably smaller in the poorly developed leaves and branches than in the normal ones of the chestnut, as seen from the following figures:

	Magnesia to 100 parts lime.
Healthy leaves	14.8
Poorly developed leaves	4.9
Healthy branches	5.4
Poorly developed branches	2.3

A plant of special agricultural importance is the sugar beet. In comparing the lime and magnesia of this plant with that of others some data of interest are observed.[1] In 1,000 parts dry matter are contained:

Percentage of lime and magnesia to 1,000 parts dry matter in sugar beets and other plants.

I. GRASSES.

Content.	Per cent.	Plants, etc.
Minimum of magnesia	1.41	Young winter wheat (2).
Maximum of magnesia	6.50	Maize in flowering stage (7).
Minimum of lime	2.71	Winter wheat in flowering stage (7).
Maximum of lime	16.46	Rye grass (7).

II. CLOVER AND OTHER FODDER HERBS.

Content.	Per cent.	Plants, etc.
Minimum of magnesia	3.34	Seradella in the flowering stage (3).
Maximum of magnesia	10.90	Buckwheat, flowering (17).
Minimum of lime	10.52	Lupin hay (3).
Maximum of lime	38.61	Red clover, flowering (13).

III. LEAVES OF THE ROOT CROPS.

Content.	Per cent.	Plants, etc.
Minimum of magnesia	4.61	Leaves of turnips (10).
Maximum of magnesia	16.86	Leaves of sugar beet (25).
Minimum of lime	16.34	Leaves of the common beet (18).
Maximum of lime	44.52	Carrot (8).

[1] Wolff's Tables, II.

Percentage of lime and magnesia to 1,000 parts dry matter in sugar beets, etc.—Continued.

IV. ROOT CROPS.

Minimum of magnesia	1.43	Topinambur (2).
Maximum of magnesia	8.26	Common beet (19).
Minimum of lime	1.00	Potato (59).
Maximum of lime	8.49	Turnips (13).

NOTE.—The numbers in parentheses indicate the numbers of analyses that served for calculation of the average. A few plants of subordinate interest were excluded from comparison.

It is seen from these data that among the leaves of the plants of the three groups here considered (comprising in Wolff's Tables seventy species from various families), the sugar beet leaves contain the highest amount of magnesia, and, further, that among the leaves of root crops the common beet contains the maximum of magnesia in the roots and the minimum of lime in the leaves. From Wolff's Tables, I (page 170), it can further be learned that of all the leaves there considered those of the common beet and the sugar beet show, in relation to the amount of lime present, the largest amount of magnesia.

Average lime and magnesia content to 1,000 parts dry matter in sugar and common beet leaves.

Plant.	Parts of lime.	Parts of magnesia.
Sugar beet leaves[1]	25.76	26.34
Common beet leaves[1]	16.84	14.44
Sugar beet leaves[2]	30.06	16.86
Common beet leaves[2]	16.34	14.62

[1] Wolff's Tables, I, p. 170. [2] Wolff's Tables, II, p. 145.

It may be of some interest also to compare the ratio between lime and magnesia in leaves of various other plants. The following ratios were calculated from the average data given in Wolff's Tables:

Comparison of ratio of lime and magnesia in various plants.

Plant, etc.	Total ash in 1,000 parts dry matter.	Ratio of lime to magnesia.
	Per cent.	
Wheat, flowering	69.6	1:0.68
Clover, flowering	68.6	1:0.31
Alfalfa, flowering	73.8	1:0.12
Lupin	41.0	1:0.37
Potato plant	85.8	1:0.50
Turnip	116.4	1:0.12
Carrot[1]	55.8	1:0.10
Lettuce	180.3	1:0.44
Sugar cane	23.6	1:0.95
Sugar beet[2]	148.8	1:0.56
Sugar beet[1]	175.8	1:1.02
Common beet	153.4	1:0.90

[1] Wolff's Tables, I. [2] Wolff's Tables, II.

The roots of the sugar beet contain only about one-fourth as much ash as the leaves, but relative to the lime more magnesia than the leaves.[1]

Lime and magnesia content to 1,000 parts of dry matter of root of sugar and common beet.

Plant.	Total ash.	Lime.	Magnesia.	Ratio of lime to magnesia.
	Per cent.	*Per cent.*	*Per cent.*	
Sugar beet[1]	38.3	2.33	3.01	1:1.3
Common beet	75.8	2.83	8.26	1:2.9

[1] Recent publications mention a smaller amount of magnesia.

The transformation of the common beet into the sugar beet seems to be connected with a small decrease of the magnesia content in the root and an increase of lime in the leaf. (See table above.)

It is further of considerable interest that *the seeds of the common beet and sugar beet are among those richest in magnesia.* From Wolff's Tables, II, p. 142, containing the averages of sixty-seven different seeds and fruits, it will be seen that for 1,000 parts of dry matter of seed the *magnesia* content was from 0.12 parts (horse chestnut) to 10.02 parts, *which maximum belongs to the seed of the common beet.* For 1,000 parts of the seeds of the *sugar beet the magnesia content amounts to 8.55 parts, which number is only surpassed by that for the almond (8.65 parts).* The lime content of those seeds is a moderate one, 8.83 and 11.89 parts, respectively, for 1,000 parts of dry matter, while the extremes are 0.15 (winter barley) and 33.05 (carrot).

The sugar beet belongs to those crops that are rich in mineral matter, since the ash varies from 14 to 20 per cent and over. It can, therefore, not create surprise to see beets still grow on soils which by a certain content of soluble salts interfere seriously with other crops, as grasses and legumes. Hilgard and Loughridge[2] made experiments on lands considerably impregnated with alkali salts in southern California, and inferred that sugar beets may even be raised on soils containing as much as 12,000 pounds of alkali salts per acre to the depth of 3 feet. These salts consisted of sulphates, nitrates, chlorides, and carbonates, but the chlorid content did not exceed 500 pounds per acre.

Champion and Pellet found that for the formation of 100 pounds of sugar in beets the whole plant must consume:

	Pounds.		Pounds.
Phosphoric acid	1 to 1.2	Lime	1.5 to 1.6
Potash	5 to 6.0	Magnesia	1.2 to 1.4
Soda	1.5 to 2.0	Nitrogen	2.7 to 3.5

[1] Wolff's Tables, II.

[2] Report of the Cal. Expt. Sta., 1894 and 1895.

From all these considerations we can infer that for the culture of the sugar beet one of the many conditions of success is a magnesia content nearly equaling the lime content of the soil.

Numerous manuring experiments have been made, with more or less success, to ascertain the best development of the sugar beet to insure the maximum production of saccharose. Some attention should also be paid to the regulation of the ratio between lime and magnesia in the soil, as this may prove of great importance.

CORRECTION OF LIME AND MAGNESIA CONTENT IN SOILS.

Although there are crops which require a relatively large amount of magnesia when roots, tubers, and seeds are richer in magnesia than in lime, yet the entire plants of any crop require more lime than magnesia, since the stalks and leaves show a preponderance of lime; hence such soils would, other things being equal, be best adapted for agricultural purposes which show a preponderance of lime over magnesia, at least in the finer particles available to the plant roots. The amounts of lime and magnesia, in kilograms, extracted from one hectar (nearly 2.5 acres) of ground by various plants in one year[1] are in average as follows:

Lime and magnesia extracted from soil by various plants.

Plants, etc.	Lime.	Magnesia.
	Kilograms.	*Kilograms.*
Cereals	16	10
Tobacco	30	15
Potato	40	20
Common beet	40	27
Vine	46	17
Legumes	50	12
Pine forest	70	9

Since, however, the roots come into direct contact with only a relatively small portion of the soil, the absolute amount of available lime and magnesia must be very much greater than would follow from the data in the table.

The review of soils above given leaves no doubt that lime preponderates over magnesia in most soils, and that the very best soils show, among other advantages, this peculiarity. But, nevertheless, cases are not infrequent in which the amount of magnesia is larger than that of lime. As long as this excess is only moderate no evil effects may be noticed, but they become evident when this relative excess is considerable. A correction of the soil by liming for the physiological needs of the crops will then be in order. The nature of the crops and the depth to which the roots penetrate will serve as a basis for the extent of

[1] Ebermayer, Chemie der Pflanzen, Vol. I.

liming. An undesirable increase of magnesia is often caused by the manuring with crude potassium salts of Stassfurt, as above pointed out. In this case also liming furnishes the remedy.[1]

This correction grows in importance with the absolute amount of magnesia contained in the soils,[2] since the poisonous effect of magnesia grows with the concentration. It is therefore clear that the determination and balancing of the available amount of magnesia and lime in the soils is necessary for successful farming on apparently infertile soils. The amount, however, available for the next crop is not obtained by treating the entire soil with concentrated hydrochloric acid, since compounds are thereby dissolved which the roots can not utilize before their further disintegration or final distribution. The system of Dyer, consisting in the treatment of the soil with 1 per cent citric acid for seven days after "neutralization" of the carbonates, is apparently more in accord with the dissolving power of the roots, but Lemmermann[3] has shown for potassa that even 5 per cent hydrochloric acid does not extract all that is available for certain plants. This may hold good also for lime and magnesia whenever they are present, not as carbonates, but wholly or partially as hydrous silicates. Since Daikuhara[4] has observed for phosphoric acid that soils treated with acetic, citric, or oxalic acids in 1 per cent solution are only partially deprived of the phosphoric acid available for barley, it will be best to follow the system of Thoms—that is, to treat the soil with a hydrochloric acid of 10 per cent. However, with that modification only that portion of a soil that passes through a 0.5 cm. sieve is thus treated,[5] and the percentage in this fine sand, silt, and clay only is determined. It will be best to mix 200 grams of this fine portion in a 1-liter flask with 400 c. c. of the 10 per cent hydrochloric acid, and let the mixture stand, with frequent shaking, for one day at the ordinary temperature. Water is then added to fill up to 1 liter, and, after well mixing and filtering, certain portions of the filtrate

[1] P. Wagner very correctly remarks (Jahresbericht für Agrikultur Chemie, 1897, p. 254): "The successful application of the crude Stassfurt salts containing chlorid and sulphate of magnesium presumes a soil rich in carbonate of calcium. More attention has to be paid to the magnesia content of the Stassfurt salts than has hitherto been the case. Under certain circumstances the magnesia content can act very favorably, while a too rich manuring with magnesia salts may prove injurious." This is exactly what follows from the writer's theory published five years previous to Wagner's utterances.

[2] The excess of magnesia over lime in soils never reaches such proportions as, on the other hand, the excess of lime over magnesia may do. Thus, there frequently exist soils with 20 per cent to 40 per cent of carbonate of lime, while soils with over 5 per cent of carbonate of magnesia are rarely found.

[3] Landw. Vers. Stat., Vol. XLIX, p. 33.

[4] Private communication.

[5] Still more correct results might be obtained by using a 0.2 cm. sieve, but this must be determined by further tests.

serve for the determination of the available nutrients. The results are calculated for the whole soil. Thus, the easily available amounts of lime and magnesia will be at least approximately obtained. It will be impossible to obtain numbers that are constants of availability, since the roots of different species have also different powers of absorption. Nilsen and Eggertz[1] found that a very fertile soil became, after extraction with 2 per cent hydrochloric acid, sterile for barley, but not yet sterile for oats. A treatment of the soil with acid of double the strength was necessary to render it sterile for oats.

As regards the separation of the soil into a finer and coarser portion, it must be mentioned that experiments have proved that the finer particles come principally into consideration in regard to fertility. Larger particles may be attacked along their surface only, but will not be dissolved by one year's growth of vegetation.

Should the analyses not show, as above assumed, an excess of magnesia, but, on the contrary, an amount of available magnesia far below that of lime in the fine particles of the soil, an addition of finely ground unburned magnesite or unburned pulverized magnesian limestone should be made. The application of artificially precipitated basic magnesium carbonate or burned magnesia can not be recommended, since they are not only too expensive for the purposes of agriculture, but also very injurious, being easily absorbed, owing to their very fine pulverulent condition.

The above-mentioned experiments of Ulbricht furnish abundant proof of the considerable differences in the action of powdered magnesite and precipitated magnesium carbonate.

Finally, the analysis may show a lack of lime as well as of magnesia. Soils occur, indeed, with less than 0.1 per cent of these nutrients. Manuring with a mixture of marl and magnesite or with pulverized magnesian limestone containing less than 40 per cent magnesia is then in order.

If the ratio of lime and magnesia in the soils is judicially regulated, great benefit to agriculture will result and an essential step forward be made.

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[1] Landw. Vers. Stat., 1891, Vol. XXXVIII, p. 344.

II. EXPERIMENTAL STUDY OF THE RELATION OF LIME AND MAGNESIA TO PLANT GROWTH.

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INTRODUCTION.

The wide distribution of lime and magnesia in soils is very evident from the tables of analyses presented in the first part of this bulletin. The fact that these elements are in some degree present in all soils and able to supply the direct needs of plants has probably been the reason for the neglect of the extended study of their relations to each other.

THE RÔLE OF LIME IN THE SOIL.

The necessity of lime and magnesia in plant production is a fact that has long been recognized. The favorable influence of lime on certain soils has led to the very common agricultural practice of liming. The presence of lime may serve several purposes. It supplies this necessary element in the construction of plant tissue, hastens the decomposition of organic matter, facilitates the assimilation of other elements, and produces favorable physical conditions in the soil. It also causes an increased bacteriological and fungous growth in the soil, in some cases favorable to plants, as in reducing the club-root of the turnip and cabbage,[1] and sometimes unfavorable, as increasing the scab of potatoes.[2] Deherain mentions that agriculture in some sections of France has by the use of lime undergone an entire revolution.

Lime may then serve in plant production in several rôles, which may be denominated physical, chemical, and physiological. Physically, it may be of benefit when added to stiff, retentive clays, rendering them mellow, better drained, and more easily cultivated. Chemically, it will render available and within the ability of the plant to absorb certain necessary elements locked up in an insoluble combination. Physiologically, it has a necessary rôle to play in carrying on the functions of plant growth and the building up of cells. It is the latter rôle of the element in connection with magnesia that this paper deals.

THE RÔLE OF MAGNESIA IN THE SOIL.

Certain experiments as well as the percentage of magnesia found in plants, especially in the seeds, prove the necessity of this element in plant production. Besides being a necessary constituent of plants, it plays a physiological rôle, serving especially in aiding the assimilation

[1] Campbell, Board Agr. Rpt., Great Britain, 1894–95.
[2] Wheeler, Rhode Island Rpt., 1896.

of phosphoric acid, as already pointed out. It is not the province of this report to discuss at any length the physiological action of lime and magnesia. That subject is presented in detail in the first part of this bulletin, in which Dr. Loew, from the results of investigations, draws the conclusion that where magnesia is in excess, the lime, as the stronger base, will combine with the acid of the magnesium salt, while the magnesia will enter into the place which the lime had occupied in the organized structure. Again, if lime salts are in great excess the formation of magnesium phosphate, and consequently the assimilation of phosphoric acid will be retarded.

An excess of magnesia in soils may exert a poisonous action upon plants. This has been noticed in applying limestone containing a large percentage of magnesia. Again, the continued application of potassic fertilizers as kainit and carnallit containing magnesia has in some instances rendered the soil unfit for agricultural purposes. This is probably due to the raising of the magnesia content of the soil, as may be done by continued application of certain crude potash salts. A sample examined by the writer contained 9.37 per cent of magnesia. The difference in the lime and magnesia content may also be influenced in another way. Goessman reports[1] an increased loss of lime from soils to which muriate of potash was applied. The analysis of drainage water from such plats showed a large percentage of calcium chlorid.

Magnesia is found naturally in alkali soils of the arid districts and possibly in soils of the humid regions to such an extent as to render them barren of any vegetation. It is also highly probable that the magnesia content of a great many soils is excessive to such an extent as to hinder them in producing maximum crops.

THE OBJECT OF THE EXPERIMENTS.

The object of the work herein reported was to study the effect of varying amounts of calcium and magnesium salts on the growth of economic plants, and especially the ameliorating effects of lime salts in overcoming the noxious results of an excess of magnesia. It was also sought to determine the ratio between the two bases which best promote the early germination and quick development of plants. This might throw some light on the question of liming, as giving some indication of the amount of lime to be supplied, and in other cases pointing out the danger of adding an excessive amount of magnesia through applying certain limestone and potassic fertilizers containing that base. Another point sought to be brought out is the form in which lime best acts in counteracting the noxious effects of an excess of magnesia and also the testing of chemical nutrients other than lime in ameliorating such evil results.

The experiments described were begun in 1899, and cultures of the

[1] Mass. Hatch. Exp. Sta. Bulletin No. 38.

different plants in the various media were continued up to June, 1901. Not only does it take some time to get assured results in culture experiments, but owing to the various elements involved in many soils employed it is necessary to have accumulative evidence to warrant safe deductions. In making the experiments, water, sand, and soil cultures were employed and comparisons made of many trials in the different media used. In the sand and soil cultures the calcium and magnesium were incorporated as carbonates, sulphates, and nitrates. In water cultures the more soluble salts of nitrates and sulphates were employed. In comparing the two bases the molecular weights have been used for reasons readily apparent. If there is a ratio of effect between the two elements the molecular weight is the better basis of estimating it, but in agricultural practice the actual weight, as a matter of course, would be found the more practicable. However, as may be readily seen, one ratio may be quickly estimated from the other.

LIME AND MAGNESIA AS NITRATES AND SULPHATES IN WATER CULTURES.

The following series of water cultures were made in bottles holding 250 c. c., the stem of the plant being supported by a cotton plug in the mouth of the bottle. The bottles were placed in a box covered with sand to exclude light from the roots. The plant used was a variety of cowpea which had been sprouted in clean sawdust.

These experiments were preliminary and made not alone for the evidence shown by the results attained, but as a basis to guide in more extended trials. It was not attempted to bring the plants to maturity in the small amounts of culture media used, but to carry them beyond the point where a direct physiological result would appear from the addition of the various percentages of the lime and magnesia salts employed.

The following solutions of magnesium and calcium salts were made up with distilled water, and plants 5 cm. high were set July 17. The results are shown in the following table:

Results of experiments with cowpeas set July 17.

No. of bottle.	July 17.		July 20.	July 23.
	Solution.	Per cent.	Condition.	Condition.
1	Check		Healthy	Drooping.
2	MgO as $MgSO_4$	0.2	Dejected	Dead.
3	MgO as $Mg(NO_3)_2$	0.1	Leaves shriveled	Dying.
4	CaO as $Ca(NO_3)_2$	0.1	Healthy	Healthy.
5	MgO as $Mg(NO_3)_2$	0.05	Healthy	Healthy.
	CaO as $Ca(NO_3)_2$	0.05		
6	MgO as $Mg(NO_3)_2$	0.05	Healthy	Healthy.
	CaO as $Ca(NO_3)_2$	0.1		
7	MgO as $MgSO_4$	0.1	Healthy	Dead.
	K_2O as K_2SO_4	0.1		

On July 23 there were added to the bottles containing plants still living, viz, No. 4, No. 5, and No. 6, 2 c. c. of a 14 per cent nutrient solution, made up as follows:

	Per cent.		Per cent.
KH_2PO_4	5	NaCl	1.25
KNO_3	5	$FeSO_4$	0.25
$(NH_4)_2SO_4$	2.5		

On August 13, twenty-seven days from the time the plants had been set in the culture solutions, they had attained a growth as follows:

No. bottle.	Solution.	Per cent.	Height.	Roots.
			Cm.	*Cm.*
4	CaO	0.1	19	7
5	MgO	0.05	24	8
	CaO	0.05		
6	MgO	0.05	17	7
	CaO	0.1		

The plants in the solutions containing both lime and magnesia were of normal appearance and growth. The plant in No. 4, with 0.1 per cent of lime and no magnesia, exhibited red spots on the leaves, and appeared as though the physiological processes had been interfered with.

On July 30 another series was started, using the cowpea, sprouted as before, and 9 cm. high. To each bottle was added 1 c. c. of a nutrient solution of the composition used in the previous experiment. The following table shows the additional nutrients added and the results:

Results of experiments with cowpeas set July 30.

No. of bottle.	July 30.		August 4.	August 7.	August 13.
	Solution.	Per cent.	Condition.	Condition.	Condition.
8	Check		Growing	Dying at top	Dead. Height, 20 cm. Roots, 8 cm.
9	MgO as $Mg(NO_3)_2$	0.1	Growing	Dying at top	Dying. Height, 24 cm. Roots, 7 cm.
10	MgO as $Mg(NO_3)_2$	0.1	Growing	Healthy	Healthy. Height, 18 cm. Roots, 11 cm.
	CaO as $Ca(NO_3)_2$	0.05			
11	MgO as $Mg(NO_3)_2$	0.1	Growing	Healthy	Healthy. Height, 35 cm. Roots, 10 cm.
	CaO as $Ca(NO_3)_2$	0.1			
12	MgO as $Mg(NO_3)_2$	0.1	Growing	Healthy	Healthy. Height, 28 cm. Roots, 10 cm.
	CaO as $Ca(NO_3)_2$	0.2			
13	MgO as $Mg(NO_3)_2$	0.1	Drooping	Dying	Dead. Height, 25 cm.
	FeO as $FeSO_4$	0.02			
14	MgO as $Mg(NO_3)_2$	0.1	Growing	Healthy	Dead. Height, 28 cm.
	Na_2O as $NaNO_3$	0.1			
15	MgO as $MgSO_4$	0.1	Growing	Dejected	Dead. Height, 28 cm.

In this series the cotyledons were attached to the plants when reset, and they, together with the nutrients in the solutions, enabled all the plants to make same growth. However, without exception, they were soon overcome by the noxious influence of magnesia in the absence of lime, while those in solutions containing lime preserved a normal appearance.

On August 13 a series of cultures were started, using cowpeas 30 cm. high. The plants had been sprouted in clean sawdust, and had exhausted the substance stored in the cotyledons. One cubic centimeter of the nutrient solution was added to each bottle, the additional nutrients added, and the results are shown in the following table:

Results of experiments with cowpeas set August 13.

No. of bottle.	August 13. Solution.	Per cent.	August 20. Condition.	August 27. Condition.	September 6. Condition.
16	Check	....	Dejected	Dying	Dead.
17	MgO as $Mg(NO_3)_2$	0.1	Growing	Dying	Dead.
18	CaO as $Ca(NO_3)_2$	0.1	Growing	Healthy	Growth ceased, leaves curling.
19	MgO as $Mg(NO_3)_2$ CaO as $Ca(NO_3)_2$	0.05 0.05	Growing	Healthy	Healthy.
20	MgO as $Mg(NO_3)_2$ CaO as $Ca(NO_3)_2$	0.05 0.1	Growing	Healthy	Healthy.
21	Na_2O as Na_2CO_3 CaO as $Ca(NO_3)_2$	0.05 0.1	Growing	Healthy	Healthy.
22	MgO as $Mg(NO_3)_2$ K_2O as KNO_3	0.1 0.1	Growing	Dying	Dead.
23	MgO as $Mg(NO_3)_2$ CaO as $Ca(NO_3)_2$	0.1 0.05	Growing	Healthy	Healthy.
24	MgO as $Mg(NO_3)_2$ CaO as $Ca(NO_3)_2$	0.1 0.1	Growing	Healthy	Healthy.
25	MgO as $Mg(NO_3)_2$ CaO as $Ca(NO_3)_2$	0.1 0.2	Growing	Healthy	Healthy.
26	MgO as $Mg(NO_3)_2$ FeO as $FeSO_4$	0.1 0.02	Growing	Dropping leaves.	Dead.
27	MgO as $Mg(NO_3)_2$ Na_2O as $NaNO_3$	0.1 0.1	Growing	Dying	Dead.
28	MgO as $MgSO_4$	0.1	Growing	Dying	Dead.

In these experiments, with lime and magnesia in solutions, the results under like conditions were very uniform throughout. When the death of the plant ensued there was first noted a shrinkage of the leaf, followed by a browning of the root system and a stoppage in the development. The growth of root hairs, especially, was hindered. As plants sprouted in solid media and transferred to water cultures throw out a different kind of root hair in order to adapt themselves to the new media, it is probable that the first injury in the magnesia solution lies in the deterrent action of that element upon this process.

While the action of magnesia in the absence of lime proved poisonous, the absence of magnesia with lime present when a certain point was reached resulted in the arrested development of the plant. The action of both elements were not in such excess as to produce a physical effect, but rather a physiological one.

The experiments also show that potassium, sodium, and iron salts do not serve in the place of calcium salts in overcoming noxious effects of an excess of magnesia. In general, the potassium and sodium, both as nitrate and sulphate, seemed to reduce to some extent the toxicity of the magnesia, but not to such an extent as to justify their employment in actual practice. The iron sulphate, on the contrary, appeared to increase the toxicity of the excess of magnesia. Loew has already pointed out[1] that magnesia as nitrate and sulphate is alone more noxious to plants than sodium or potassium alone.

In order to test the influence of an excess of magnesia upon the stem and foliage, a series of water cultures were made, using herbaceous branches, about 30 cm. in length, of the privet (*Ligustrum vulgare*). The solutions were made up and the results were as reported in the following table:

Results of experiments with privet set August 23.

No. of bottle.	August 23.		September 15.	October 4.
	Solution.	Per cent.	Condition.	Condition.
29	Distilled water	....	Normal	Normal.
30	MgO as $MgSO_4$	0.2	Few upper leaves left	
31	MgO as $Mg(NO_3)_2$	0.2	Stem blackened; leaves fallen.	
32	CaO as $Ca(NO_3)_2$	0.2	Leaves curled and mostly fallen.	
33	MgO as $Mg(NO_3)_2$ CaO as $Ca(NO_3)_2$	0.1 0.1	Leaves slightly curled	Leaves mostly fallen; color normal.
34	MgO as $MgSO_4$	0.2	Stem blackened; leaves fallen.	
35	MgO as $MgSO_4$ CaO as $Ca(NO_3)_2$	0.1 0.1	Normal	Normal.

From the foregoing tables it will be noticed that an excess of magnesium salts in the absence of calcium salts proved noxious to the extent of killing the plant. Where calcium salts were used without magnesium the plant made a slow growth for a while, but later ceased growing and exhibited phenomena of starvation—the development being arrested and the leaves assuming a light shade of green. Where the magnesium and calcium were used in conjunction, the plants in every instance made a healthy growth. In such combination the best final growth was made in a solution where the lime was in moderate excess of the magnesia, and the total amount of soluble salts, including nutrient, did not exceed 0.3 per cent.

[1] Bul. No. 18, U. S. Dept. Agr., Veg., Phys., and Path.: "Physiological rôle of chemical nutrients."

The uniformity in the favorable results with the different lime salts in overcoming the poisonous effects of an excess of magnesia indicate that the action was due to the basic and not to the acid radical. Should there be a favorable action of the acid radical in this relation it would appear in cases where a magnesium salt was employed with such an acid radical. The uniform toxic effect of the magnesia in excess without lime, and the elimination of that effect in the presence of lime, indicate that the acid radical of the salt has none or at least very little influence in the matter aside from favoring solubility, as further experiments prove. Lime appears to be the only antidote, as far as the elements were tested, for combating an excessive amount of magnesia.

LIME AND MAGNESIA AS CARBONATES IN SAND CULTURE.

In order to further study the relation of lime and magnesia to each other in their effect upon plant growth other experiments were planned.

To 60 kilograms of clean, white quartz sand there were added the following compounds:

	Per cent.
CaO as $CaCO_3$	0.4
P_2O_5 as $Ca_3(PO_4)_2$	0.2
H_2SO_4 as $CaSO_4$	0.1
$FeSO_4$	0.1

To 30 kilograms of the sand there were added MgO as $MgCO_3$, 0.1 per cent; and to the remaining 30 kilograms, MgO as $MgCO_3$, 1 per cent. The chemicals were rubbed up in a mortar, added to a small portion of the sand, and then to the whole amount. The sand was put into twelve pots, holding 5 kilograms each. Those with the minimum amount of magnesia were marked *1A* to *6A*, inclusive; those with the maximum amount, *7B* to *12B*, inclusive.

EXPERIMENTS WITH TOBACCO.

In the first series, marked *A*, the portion of CaO to MgO was 15 to 1. In the second series, marked *B*, the porportion of CaO to MgO was 3 to 5. On January 6, tobacco plants 5 cm. high were taken from rich soil, the roots carefully washed, and were set in the sand. A nutrient solution was made up consisting of KNO_3, 10 per cent; NH_4NO_3, 10 per cent; H_2KPO_4, 1 per cent. There was added each week to each pot 1 c. c. of this solution.

The plants in the *A* pots continued to grow, were of normal appearance, and good color. The plants in the *B* pots ceased growing after they were planted; the lower leaves turned yellow and died, the upper contracted, became thickened and wrinkled, and acquired a deeper shade of green.

On March 7, when the experiment was closed, the plants in *A* pots were healthy, of good color, and with twelve to thirteen leaves; height, from 16 to 20 cm. Plants in *B* pots were nearly dead, apparently atrophied, with from two to three leaves, and were from 3 to 4 cm. high. For samples of these plants, see Pl. I.

A very similar experiment was made as follows: To 20 kilograms of sand, washed with dilute hydrochloric acid, there was added nutrients, as in the preceding case, except that in the *A* pots the percentage of MgO as carbonate was increased, making the proportion of CaO to MgO as 10 to 1, while in the *B* pots the proportion of CaO to MgO was as 1 to 2, the total amount of the MgO being 1 per cent of the whole culture medium. The nutrient solution was added each week as in the previous case. The pots were watered with distilled water.

On February 8 tobacco plants grown in rich soil, and about 5 cm. high, were taken, the roots carefully washed, and set in the sand in 3 pots of each series. In the remaining 6 pots barley was planted.

On March 7 the tobacco plants in *A* pots were in healthy, normal condition, height 7 to 10 cm., of good color, thrifty, and with seven to eight leaves. The tobacco plants in *B* pots were stunted, 2½ to 4 cm. high, lower leaves dead or dying, upper leaves dark green, thickened, and wrinkled. The plants were apparently dying by atrophy; number of leaves, three to four.

The barley in the *A* pots was 14 to 27 cm. high and in a normal, healthy condition. The plants in the *B* pots were 4 to 5 cm. high and diseased.

In these experiments the action of an excess of magnesia in the soil seemed to result in the cessation of growth in the plant and the thickening and wrinkling of the leaf, at the same time the leaf assumed a deeper shade of green and showed a tendency to curl. The roots showed little development, were without root hairs, and after some time became shriveled, and assumed a dark brown color.

To the pots in the preceding experiment marked *B* and containing 1 per cent of MgO as carbonate there was now added enough CaO as carbonate to make the proportion of CaO to MgO in three as 1 to 1 and in the other three as 2 to 1. This was done with the object in view of determining the effect of calcium carbonate in overcoming the noxious influence of an excess of magnesium carbonate.

EXPERIMENTS WITH BARLEY.

On April 21 the pots were planted to barley which was sprouting on the 26th. On May 7 the plants were of good color, but on the 8th became slightly yellow, and upon examination showed an unhealthy root system. On May 23 the plants were making no growth and were removed.

On May 26 tobacco plants 7 cm. high were set in the same pots and barley was also replanted. June 4 the tobacco was making no growth

TOBACCO FROM SAND CULTURES.

Upper plants, excess of magnesia; lower plants, excess of lime.

and lower leaves were dying. To one pot of each proportion there was added daily until June 18 one-fourth gram, or a total amount of 3.5 grams of CaO as nitrate. On June 9 the plants were all making but little growth, those in pots to which the nitrate was added making the best appearance. June 25 the roots of the tobacco and barley were dead. The barley had made a growth of from 7 to 10 cm.; tobacco, no growth at all.

EXPERIMENTS WITH OATS, WHEAT, AND BEANS.

In the same soils trials were made with oats, wheat, and beans with similar unsatisfactory results. It appeared as time passed that the calcium carbonate had a slight influence in overcoming the toxicity of the magnesia, but its effect was of slow action. In these experiments the magnesia was very finely divided, and it is believed that the failure in this instance was due to the great fineness of the magnesia preparation and its greater solubility over the lime. In one of the pots in this experiment 0.4 per cent of $CaSO_4$ was added. In this case the plants continued to grow in a normal manner, while in the pots to which the sulphate had not been added the injurious results continued. This addition of the sulphate permitted of the due action of the lime by presenting it in a more finely divided and more soluble form.

C. Schreiber[1] found that when lime was lacking in certain experiments germination was much retarded. Potatoes under these conditions were found after three or four months in almost the same state as when planted. In overcoming this the action of calcium sulphate was much more effective than the action of burnt lime and carbonate of lime. In experiments with two fertilizers, the first containing dicalcium phosphate, sulphate of lime, and carbonate of magnesia, the second, phosphate of soda, carbonate of lime and magnesia, in every case the yield was much lower with the latter. This was due, the author states, to the action of the carbonate of lime and magnesia in rendering the phosphate of soda insoluble. At the Rhode Island experiment station, where various forms of lime were tested for neutralizing acid soils, the carbonate was found to be most effective.

The experiments of the writer with the carbonate show that in overcoming the noxious effects of magnesia its action was very slow, owing apparently to its not being in a finely divided condition and its difficult solubility. At the New York State experiment station[2] no results were obtained on sorghum with carbonate of lime applied the same season. Wheeler states[3] that calcium sulphate is believed to act more energetically than carbonate of lime, air-slacked or water-slacked lime in liberating potash for the use of plants in soil.

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[1] Revue Agronomique, Vol. IV, No. 1.

[2] Report New York State Exp. Sta. for 1891.

[3] Farmers' Bulletin No. 77.

LIME AND MAGNESIA AS CARBONATES IN SOIL CULTURES.

To further test the influence of calcium and magnesium as carbonates on the growth of plants soil cultures were made. In this experiment a sea-island cotton soil was employed, consisting largely of sand with some silt and clay. The particles were finely divided, 1 kilogram passing through a 2-mm. sieve, leaving a residue of only 1½ grams. Analyses showed a large amount of iron but a very small amount of lime and magnesia.

To the soil there was added:

	Per cent.		Per cent.
KH_2PO_4	0.2	$(NH_4)_2SO_4$	0.2
KCl	0.1	KNO_3	0.1

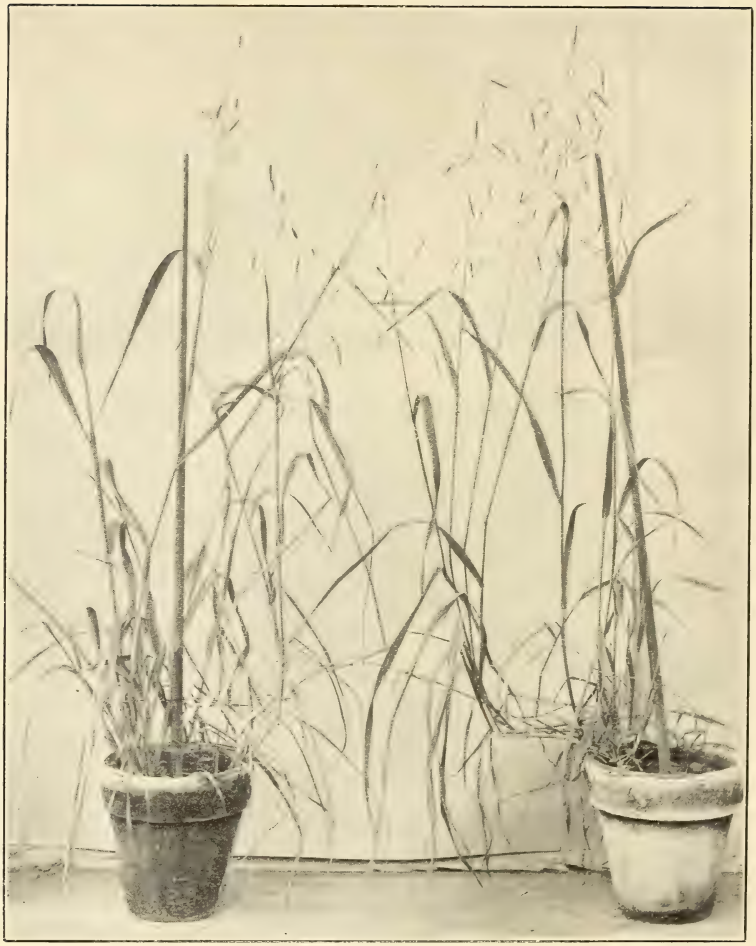
The soil was put into twenty pots, a series of nine in duplicate and two extra. Lime and magnesia as carbonate was incorporated, as in the following schedule:

No. pot.	CaO.	MgO.
	Per cent.	*Per cent.*
1	0.9	0.1
2	0.8	0.2
3	0.7	0.3
4	0.6	0.4
5	0.5	0.5
6	0.4	0.6
7	0.3	0.7
8	0.2	0.8
9	0.1	0.9
10	0.8	0.2
11	0.2	0.8

EXPERIMENTS WITH OATS AND COWPEAS.

One series of pots, Nos. 1 to 9, holding 1 kilogram each of soil, was planted to oats, the other to cowpeas, and were watered with distilled water. The seed germinated first and plants were best beginning with the pots containing the largest amount of lime and the smallest amount of magnesia, and ranging down in thriftiness to those containing the smallest amount of lime and the greatest amount of magnesia. Later the best growth of both oats and cowpeas was in the soils containing CaO 0.8 per cent and MgO 0.2 per cent. In all cases where the CaO was 0.6 per cent and less and the MgO was 0.4 per cent and more the plants made a very sickly growth or else died outright. In the two extra pots planted to tobacco, No. 10, with CaO 0.8 per cent and MgO 0.2 per cent, the plant made a normal growth, while in No. 11, with CaO 0.2 per cent and MgO 0.8 per cent, the plant became atrophied and died. In these cases the action of the lime in counteracting the noxious influence of the magnesia was at most very limited.

To further test the matter, there was added to five pots containing 0.5, 0.7, 0.8, and 0.9 per cent of MgO 0.4 per cent of CaO as sulphate,



OATS IN STERILE MAGNESIUM SOILS RENDERED FERTILE BY THE ADDITION OF $MgSO_4$.

making the proportion of CaO as sulphate to MgO as carbonate as follows: 4 to 5, 4 to 6, 4 to 7, 4 to 8, and 4 to 9, respectively, or, counting the calcium carbonate previously added, CaO to MgO as 9 to 5, 8 to 6, 7 to 7, 6 to 8, and 5 to 9. In the pots oats were replanted, and in the course of nine days were uniformly sprouted in each pot. They continued to grow, were of good color, thrifty, and were free from shriveling of the root system, as was the case before the calcium sulphate was added. These plants were brought to maturity, producing seed. (See Pl. II.) The growth in the five pots appeared to be normal except in the last, containing a total of CaO 0.5 per cent, or as sulphate 0.4, and MgO 0.9 per cent. Here, while there was a moderate development of the plant, it did not show the thrifty condition of the other plants in the soils containing more lime, indicating that there was not enough calcium in soluble form to wholly counteract the injurious effects of the magnesia.

While the plants in the pots to which calcium sulphate had been added were growing, the pots containing the carbonates were replanted from time to time. The injurious results were continuous during the several months, the calcium carbonate not being able during a period of that length to counteract the effect of the excess of magnesia.

LIME AND MAGNESIUM AS NITRATES IN SAND CULTURES.

In order to test the two bases, calcium and magnesium, in a more soluble form, sand cultures were made in which these two elements were applied in the form of nitrates. These series of cultures were made to test the relation of the two bases to each other, and to find that ratio between the two that offered the best conditions for the growth of plants.

There was added to 30 kilograms of pure white sterilized sand the following:

	Per cent.
K_2HPO_4	0.1
KH_2PO_4	0.1
KNO_3	0.2
$(NH_4)_2SO_4$	0.1
$FeSO_4$	Trace.

These salts were finely powdered, mixed with a small quantity of sand, and then with the whole. The sand was put into sixteen pots, in two series of eight each, and calcium and magnesium nitrates added in solution in such proportion as to correspond to the following ratios:

To 2 *A* pots, MgO, 0.8 per cent; CaO, 0.1 per cent.
B pots, MgO, 0.7 per cent; CaO, 0.2 per cent.
C pots, MgO, 0.6 per cent; CaO, 0.3 per cent.
D pots, MgO, 0.5 per cent; CaO, 0.4 per cent.
E pots, MgO, 0.4 per cent; CaO, 0.5 per cent.
F pots, MgO, 0.3 per cent; CaO, 0.6 per cent.
G pots, MgO, 0.2 per cent; CaO, 0.7 per cent.
H pots, MgO, 0.1 per cent; CaO, 0.8 per cent.

EXPERIMENTS WITH WHEAT AND OATS.

On July 11 the pots were planted to wheat. On July 18 the wheat plants had made growths as follows:

MgO.	CaO.	Growth.
Per cent.	*Per cent.*	*Centimeters.*
0.1	0.8	2.5
0.2	0.7	2.5
0.3	0.6	12
0.4	0.5	18
0.5	0.4	15
0.6	0.3	5
0.7	0.2	5
0.8	0.1	2.5

On July 23 the growths made were comparatively as reported above (see Pl. III, fig. 1).

On August 6 the plants in one series of pots were taken up and the root system examined, with the following results: In pots with—

MgO.	CaO.	Growth.	Condition.
Per cent.	*Per cent.*	*Centimeters.*	
0.1	0.8	6	Bushy, poorly developed.
0.2	0.7	6	Bushy, poorly developed.
0.3	0.6	16	Bushy, well developed.
0.4	0.5	16	Bushy, well developed.
0.5	0.4	7	Poorly developed.
0.6	0.3	3	No root hairs.
0.7	0.2	3	No root hairs.
0.8	0.1	4	No root hairs.

As in the growth above ground, the root systems showed the most favorable conditions to be present where the amount of soluble CaO was slightly in excess of the soluble MgO. Where the CaO was in great excess the root system was apparently healthy, but poorly developed. When the MgO was in greatest excess the root system showed an unhealthy condition, the absence of root hairs, and later the shrinkage and discoloration of the larger portion of the root.

On August 20, forty days from the time of planting, the wheat in the remaining series of eight pots, with the exception of the extremes, had become more equal in height. The general thriftiness of the plants, however, appeared to range as before reported, the pots with lime moderately in excess of magnesia making the best growth, the plants in the pot with MgO 0.4 per cent and CaO 0.5 per cent being larger and stronger, and the thriftiness ranging from this ratio down to MgO 0.2 and CaO 0.7, and MgO 0.7 and CaO 0.2 per cent. In the two extreme pots the plants were dead.

FIG 1.—WHEAT IN SAND CULTURES.

Pots from left to right ranging in MgO 0.8 to 0.1, CaO 0.1 to 0.8 per cent as nitrates.

FIG. 2.—COWPEAS IN SOILS SHOWING EFFECT OF VARIABLE APPLICATIONS OF LIME AND MAGNESIA.

It will be observed that the amounts of soluble salts in this experiment were very largely in excess of the needs of the plants. They were made so in order to thoroughly test the capacity of the lime in counteracting the noxious influence of the magnesia, and the bases were not added with the view of conserving the best conditions of plant growth or with the idea of bringing them to their full development.

The experiments tend to show that the most favorable condition for the growth of wheat is in the soil where the amount of available lime is in moderate excess over the amount of available magnesia. If the amount of magnesia is too small in the presence of a larger percentage of lime the plant shows phenomena, apparently, of starvation. If the amount of magnesia is excessive, with a deficiency of lime, the magnesia exerts a poisonous influence upon the plant.

The Deutsche Landwirtschaftliche Presse[1] states that calcium carbonate in the soil to the amount of 0.46 per cent had an injurious effect upon lupins, and that this was overcome by an application of kainit. The action of kainit in this case was probably due to its magnesia content.

In a trial with oats in these series of pots the results were as with wheat—the germination was quickest and growth best in the pots with MgO 0.4 and CaO 0.5 per cent.

EXPERIMENTS WITH COWPEAS.

After the removal of the wheat one series of pots was planted to cowpeas and one to tobacco. With the cowpeas the results of the most favorable ratio of lime to magnesia was the same as with wheat. The seed germinated in the same order, the ratio of CaO 0.5 and MgO 0.4 being the more favorable, and the growth of plants decreasing from that pot to the two extremes. The cowpeas, however, appeared to be more tolerant of the excess of the two salts in the extreme pots, and after germination the plants grew better than the wheat plants. Since the cowpea contains more of the mineral nutrients stored up in its seeds than wheat grains, the evil effects of an excess of magnesia or lack of lime in the soil can be better counteracted up to a certain stage in the development of the plant.

EXPERIMENTS WITH TOBACCO.

To the second series of eight pots tobacco plants about 5 cm. high were transplanted from soil. Beginning with the pot containing CaO 0.8 and MgO 0.1 per cent, the plant started into quickest growth, showing the greediness of this plant for lime. Later, however, this plant became spindling and of light color, while the plants in the pots

[1] Vol. 23, Nos. 91 and 92.

with MgO 0.2 per cent, CaO 0.7 per cent, MgO 0.3 per cent, and CaO 0.6 per cent made a better growth and were of normal proportions and of good color.

The figures for the best proportions of lime to magnesia in soils for the early germination and quick development of plants refer, of course, to the soluble amounts—that is, to that portion directly available to the immediate needs of the plant. These figures are therefore arbitrary in agricultural practice, owing to the variation of the solubility of these elements in the soil. It will also be noticed that soluble magnesia in excess of soluble lime in small amounts may have a deterrent action upon plant growth while not becoming noxious to the extent of killing the plant. Also, lime may be in a great excess over magnesia, and yet there may be enough of the latter element available to respond to all the requirements of the plant.

LIME AS SULPHATE AND MAGNESIA AS CARBONATE IN SOIL CULTURES.

From the preceding experiments the favorable action of gypsum in counteracting the toxic action of magnesia is apparent. From an agricultural standpoint it is, besides, the most available form for liming because of its cheapness as compared with other of the more soluble forms of lime.

To further test the action of gypsum in combination with an excess of magnesia, cultures were made up in iron pots holding 30 kilograms each. The soil had the following composition:

	Per cent.		Per cent.
Fine gravel	0.65	Silt	21.79
Coarse sand	4.20	Clay	9.80
Medium sand	9.40	Loss on ignition	3.67
Fine sand	30.55		
Very fine sand	20.14	Total	100.20

Soluble in 1.115 per cent hydrochloric acid: CaO, 0.14 per cent; MgO, 0.144 per cent.

Four pots were made up as follows, using magnesia where applied as carbonate and lime as sulphate:

No. pot.	Solution.	Per cent.
1	Check	
2	CaO	0.8
3	MgO	0.2
	CaO	0.8
4	MgO	0.68
	CaO	0.2

EXPERIMENTS WITH COWPEAS.

The four pots were planted to cowpeas April 12. On April 22 plants were up in Nos. 1, 2, and 3, and on the 25th in No. 4. On May 15 the plants were all thrifty, and the following shows the growths on that date and on June 14:

GROWTH ON MAY 15.	Centimeters.	GROWTH ON JUNE 14.	Centimeters.
Nos. 1 and 2	20	No. 1	34
No. 3	18	No. 2	35
No. 4	15	No. 3	34
		No. 4	19

Nos. 1, 2, and 3 were very much alike in general thriftiness and were of a uniform dark-green color. No. 4 was spindling and of a light-green color. On June 26, one and one-half months from planting, a photograph was taken of the four pots. (See Pl. III, fig. 2.) No. 1 is the check; No. 2, CaO, as sulphate, 0.8 per cent; No. 3, CaO, as sulphate, 0.8 per cent; MgO, as carbonate, 0.2 per cent; No. 4, CaO, as sulphate, 0.2 per cent; MgO, as carbonate, 0.68 per cent.

It will be noticed that the addition of an excess of calcium sulphate did not cause a deterrent effect in the presence of 0.144 of soluble magnesia, nor did the addition of more magnesia in No. 3 produce a favorable effect over the check, showing that the magnesia already present was sufficient for the plants grown. As shown by the check, No. 1, 0.14 per cent of soluble lime was also sufficient for the direct needs of the plant. In No. 4, with the addition of 0.68 per cent of magnesium carbonate and 0.2 per cent of calcium sulphate, the noxious influence of the former is apparent. While not sufficient to cause the death of the plants, it hindered their growth to such an extent as to preclude the possibility of the production of a profitable crop.

While liming may be profitably carried on for bettering the physical condition of soil, the correction of acidity, and other reasons, it may also in certain cases be beneficial from a physiological standpoint. The need for it may be surmised from an analysis of the soil. Though only the soluble lime and magnesia affect the immediate growth of plants in a given soil, it is apparent that where one element is in great excess of the other it will naturally be present in larger proportion in the soil solution.

When the magnesia content of the soil is large and the application of calcium sulphate is expensive, the determination of the soluble salts would be advisable before liming. However, in that case the application of lime, though lessened, would be of only temporary advantage, as successive applications would be needed. In this connection, it would be of value to construct a table showing the curve of solubility of lime and magnesium salts in the same culture medium or solution.

The experiments herein reported show that where the lime and magnesia are in a wholly soluble condition, the plants germinated quickest and made the more rapid growth where the lime was in slight excess over the magnesia. In actual practice the case can not be governed so closely, for then we are dealing with a very complex combination—the soil. Moreover, it is hard to determine at each stage the form in which the lime and magnesia exists in the soil. Again, different plants are variously affected by an excess of magnesia in soils. In practice, therefore, it is difficult to lay down hard and fast rules for liming the soils for physiological results.

As borne out by experiments, gypsum appears to be, all things considered, the most available form of lime to apply in overcoming the noxious influence of an excess of magnesia. An excess of gypsum is little to be feared, as the plant seems to be able to use magnesia if present in sufficient amount for its direct needs, whether gypsum be present in large amount or small. On the other hand, a lack of lime in a soluble form is more to be guarded against, for in this case the magnesia, if in a certain excess, will be assimilated to the detriment of the plant. Magnesium carbonate we found might be in a slight excess over calcium sulphate, and normal healthy growth of the plant be made. However, this excess should be small, not greater, with cereals, than 2 to 1. With cowpeas, as shown, a ratio of MgO as carbonate 0.68 to CaO as sulphate 0.2 per cent, while not toxic to the extent of killing the plant, was so injurious as to prevent profitable growth. In these cases the solubility of the salts in the soil were not determined. In liming, therefore, for any purpose, it is advisable to know the lime and magnesia content of the soil, both the soluble and total, as well as the content in the fertilizer applied. Underliming is more to be guarded against than overliming, care being taken that magnesian limestone is not applied where an excess of magnesia is already present.

SUMMARY.

Soil analyses show that lime and magnesia are widely distributed in soils and generally in sufficient quantities for the direct needs of plants. They are not always in the best proportions to each other, from a physiological standpoint, for favoring plant growth.

Magnesia in a soil in great excess over lime in a finely divided or soluble condition is noxious to the growth of plants. With a great excess of lime over magnesia the physiological action of the plant is hindered and it exhibits phenomena of starvation. An excess of lime counteracts the poisonous effects of magnesia, while the more favorable proportion of the two bases obviates the poor nutrition of the plant.

The best proportion of soluble lime to soluble magnesia for the germination and growth of plants is about molecular weight 5 to 4, or actual weight 7 to 4.

The more soluble forms of magnesia, as nitrate and sulphate, are in excess more injurious to plants than the less soluble as carbonate, while the more soluble forms of lime as sulphate and nitrate are more efficient in overcoming the noxious effects of magnesia than less soluble forms as carbonate.

In applying fertilizers containing magnesia, as in the crude potash salts, liming should be carried on in conjunction unless the soil is known to contain an excess of lime. Where the lime content of the soil is about equal to or less than the magnesia content, lime in a finely divided form, as sulphate, should be supplied with the fertilizer in an amount in excess of the magnesia present in the latter.

In liming soils the amount of lime and magnesia should be first determined in both the soil and the material applied. In this way only can the process be intelligently carried out and the best ratio between the two bases for the promotion of the growth of crops be maintained.

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