THE INFLUENCE OF CALCIUM AND MAGNESIUM COMPOUNDS ON PLANT GROWTH. PP 589 - 620

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BY

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INFLUENCE OF CALCIUM AND MAGNESIUM COMPOUNDS ON PLANT GROWTH[1]

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INTRODUCTION

Some investigators seem to question the advisibility of using magnesium-bearing minerals in agricultural practices, since they deem magnesium detrimental to optimum plant growth. Magnesium in some forms is detrimental to plant growth. However, the natural carbonates, such as limestones and dolomites, are not detrimental but in reality beneficial to plant growth when applied in amounts sufficient to neutralize soil acidity. Plants were found to grow and mature normally in pure dolomite and limestone.

In scientific circles considerable attention has been paid to the theory that calcium and magnesium must occur in a definite ratio for the optimum production of crops. Loew claims to have proposed this theory in 1892 (15)[3], and much work has been conducted along this line, especially during the last decade. From the data presented in the following pages it will be seen that the ratio, within wide limits, had no effects.

The presence of sufficient quantities of calcium and magnesium in all soils is essential for the profitable production of crops. Various forms and quantities of these two elements may largely control the yields and composition of the harvests.

It is a well-known fact that plants will tolerate larger amounts of an essential element than they require. The quantity of calcium and magnesium taken up by plants is dependent upon the amount available and upon the kind of plants. The silicates of calcium and magnesium are relatively insoluble, while the chlorids are very soluble. Dolomite is denser and less soluble than limestone but more soluble than magnesite. Synthetic compounds of magnesium are more soluble, however, than similar compounds of calcium.

Alfalfa, when grown in sand and soil cultures with varying amounts of calcium and magnesium minerals, such as dolomite and magnesite, also with prepared compounds of these two elements, such as the chlorids, sulphates, and carbonates, was found to contain varying amounts of

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[3] Bibliographic citations in parentheses refer to "Literature cited," p. 616-619.

calcium and magnesium. Some treatments showed as much as 52.5 pounds of calcium and 12.98 pounds of magnesium per ton of dry alfalfa. However, the above amounts were in excess of the absolute requirements, as smaller applications gave as large yields and the alfalfa contained only 28 pounds of calcium and 8 pounds of magnesium per ton of dry matter. On this basis 6 tons of alfalfa with a high-calcium content would contain 315 pounds of calcium and 77.88 pounds of magnesium, or the equivalent of 787.5 pounds of calcium carbonate and 272.5 pounds of magnesium carbonate. Wheat straw, when grown in pure dolomite, contained 14.48 pounds of calcium and 14.6 pounds of magnesium per ton, whereas when grown in the absence of excessive amounts of these two elements the straw contained only 5.96 pounds of calcium and 5.43 pounds of magnesium per ton.

REVIEW OF THE LITERATURE

Solution cultures and pot cultures have contributed largely to our present knowledge of plant nutrition. Woodward (42) found that the solid particles of the soil furnished nourishment to the growing plants and that water acted only as a carrier.

Wolf (4) found by using beans and maize in controlled solutions, that the concentration as well as the kind of salts in the solution effected plant growth. His results show that when the concentration of the external solution was more than 0.25 per cent it became the controlling factor; whereas if less than 0.25 per cent absorption was controlled by the solution within the roots.

Dassonville (1) found that cutinization and lignification of the epidermis of leaves occurred much more rapidly in distilled water than in nutrient solutions; also that the growth of hemp and buckwheat was not influenced by the presence or absence or calcium and magnesium.

The crop is the measure of the resultant of all factors. In accordance with the present knowledge any one or many of the factors can be controlled. Likewise, the total amounts of the elements essential for crop production can be quantitatively determined.

Magnesium is essential for the growth of any living cell. Calcium is likewise essential except for the lower fungi and lower algæ, which alone are able to exist without it. Loew (16, p. 44) shows that neutral oxalates are not poisonous to the lower fungi. He attributes the deleterious effects in higher plants to the change in the structure of the calcium-protein compounds, due to the formation of calcium oxalate, while the disturbance is brought about by the change in imbibition caused by the formation of potassium-protein compounds, and that magnesium may bring about this change provided there is a deficiency in calcium.

Reed (29) found calcium to be necessary to the activity and growth of chlorophyll-containing organs. Willstätter (40) has pursued in detail the study of chlorophyll and finds it to be a magnesium compound with generally three times as much green pigment as yellow pigment. He found that the magnesium content of chlorophyll was constant in both land and sea plants; therefore, it must function other than as a catalyzer. Pfeffer (27, p. 425), Macdougall (17, p. 219), Peirce (26, p. 100) and others believe magnesium and calcium play an important and necessary function in plant synthesis and cell formation, but are unable to assign any specific rôle to either of these elements.

There has been considerable contention as to whether calcium could be replaced by other members of the group. Haselhoff (7) grew beans and maize in solutions containing varying quantities of calcium and strontium and concluded that strontium seemed to take the place of calcium, replacing it only when the supply of calcium was inadequate. But it must be remembered that he first used calcium and strontium together in the solution and later reduced the calcium. However, Loew (16, p. 48) was unable to substantiate these results when he used species of Tradescantia.

Loew explains the toxicity between calcium and magnesium as being due to the formation of an insoluble condition of the phosphoric acid being fixed by the calcium, and that the framework (15) of the nucleus and plastids is a double organic salt of calcium and magnesium. However, Meurer (19) and Nathansohn (23) offer another explanation: Cells being selective in their absorption of ions can check osmosis before a balance is reached between the solution within and without the cell, and the absorption of salts does not increase proportionally with the increase of concentration of the outside solution. Osterhout (24) using calcium nitrate and magnesium nitrate was unable to substantiate Loew's assertion.

Considerable work has been done upon the antagonism of respective salts for each other in solution. Kearney (11, p. 20) shows that calcium salts are most beneficial in reducing toxicity. Lipman (14) reports toxicity between magnesium and sodium but not between magnesium and calcium.

Numerous investigators have sought answers to the proposed theory of a lime-magnesia ratio with just as numerous and conflicting results. Solutions, pot cultures of soil and sand, and field soils have all been employed in attempts to settle the controversy. Ulbricht (34) showed that yellow lupines, barley, and vetch were injured by applications of lime, especially when it contained high percentages of magnesia. Magnesia apparently increased the proportional yield of grain in the case of barley and lupines. Dojarenko (2), however, concluded that the theory of a definite calcium-magnesium ratio was not tenable, as many Russian soils containing great excesses of calcium over magnesium were benefited by liming.

The results of water and soil cultures by Gössel (6) failed to substantiate the theory of a definite ratio of calcium to magnesium. He obtained the highest yields for beans and barley with water cultures when the ratio of lime to magnesia was 0.04 to 1, and concluded that the effect of liming is dependent upon the character of the soil and not upon a definite ratio of lime to magnesia. About this same time the Japanese investigators (22) were actively engaged with the problem. However, their results all seem to bear out the theory of a definite ratio.

Konovalov (12), a Russian investigator, reports studies with barley, millet, oats, and maize, varying the ratio of calcium oxid to magnesium oxid, as follows: 13.4 to 1, 6.7 to 1, 3.3 to 1, 0.8 to 1, and 0.4 to 1. He found that the yields tended to increase with the increase of lime application, provided the magnesia content remained constant. Notwithstanding these results, Voelcker (35, 36, 37) states that the ratio is best at 1 to 1.

Meyer (20, 21) found that with buckwheat and oats the dependence of maximum yields on a definite ratio of calcium to magnesium could not be proved even in the case of soils containing more calcium than magnesium or vice versa. Undoubtedly the most extensive investigations regarding a definite calcium-magnesium ratio have been conducted by Lemmerman (13) et al. They used six different soils and grew vetch, oats, barley, rye, wheat, clover, mustard, and buckwheat, with the investigations extending over three years, 1907 to 1909, inclusive. From the standpoint of yields the ratio had no effects within wide limits. Stewart (33) reports soils having 16.88 per cent of calcium oxid and 6.1 per cent of magnesium oxid which were cropped for 40 years without the addition of fertilizers, except in the case of sugar beets, which received manure. The 8-year average yields are 80 bushels for oats, 50.4 bushels for wheat, 262.3 bushels for potatoes, and 21.8 tons for sugar beets.

Wartiadi (38) used sand and water cultures with wheat and barley and found that calcium and magnesium were beneficial or detrimental in proportion to their relative amounts in the culture solution. Russell (30, p. 144) finds no connection between the lime-magnesia ratio and the productivity of the soil. Haselhoff (8) also failed to substantiate Loew's theory, while Hopkins (9, pp. 170–171) found magnesium carbonate beneficial up to 0.8 per cent when added alone and in connection with calcium sulphate in such amounts as to maintain a ratio of 4 to 7, respectively, of magnesium oxid and calcium oxid.

Gile (3) reports that with the chlorids of calcium and magnesium at low concentrations the ratio exerted no influence, while at high concentrations it was effective. Good yields of pineapples (4) were produced from soils in Porfo Rico when the ratio varied between 1 to 13 and 73 to 1; and in one field where the ratio of calcium oxid to magnesium oxid was 1,461 to 1 a yield of 60 tons of sugar cane was realized.

Pisciotta (28), an Italian investigator, reports the analysis of 60 soils which show a wide variation in the lime-magnesia ratio, due to the variation in the lime content. Patterson (25) found that magnesian lime, which is claimed to be poisonous, gave the highest yields.

In summing up the literature studies previously mentioned, it will be seen that Loew and his associates and Japanese students maintain the theory of a definite lime-magnesia ratio, as do Ulbricht and Wartiadi, whereas Dojarenko, Gössel, Konovalov, Meyer, Lemmerman, Haselhoff, Gile, and Patterson claim that a definite ration of lime to magnesia is not tenable and, furthermore, lacks substantiation.

Lemmerman et al. have undoubtedly conducted the most extensive investigations upon this subject and conclude that there is no correlation between maximum crop productions and the ratio of lime to magnesia. Soils reported by Russell and by Gile show wide variations in the lime-magnesia ratio, also in the percentages of these two elements, and that there fails to be any correlation between the productivity of a soil and its ratio of lime to magnesia.

Solution cultures show that a specific ratio of lime to magnesia is not equally effective in dilute solutions and in concentrated solutions. This indicates that the effectiveness is dependent upon the total balance of all the salts in solution instead of merely the ratio of calcium to magnesium.

The preponderance of evidence appears to be against a definite ratio of lime to magnesia, especially with respect to soil cultures in pots and under field conditions. What really seems of first magnitude is the resultant of all factors—that is, the climate, the plant, and structure, reaction, micro-organic activity, and composition of the soil.

EXPERIMENTAL WORK

These experiments were planned with the idea of studying the effects of calcium and magnesium upon plant growth when applied in different natural and in artificially prepared forms. Studies were made to determine the amount of calcium and magnesium which the plants could tolerate. The relation between the ratios of these two elements in the plants, in the soils, and in the materials applied was also studied.

Dolomite, limestone, magnesite, calcareous soils, and brown silt loam were used as sources of the natural forms, while prepared materials, such as the carbonates, chlorids, and sulphates, served as sources of the artificial forms. Increasing amounts of the various forms were used, also a variance in the ratio of calcium to magnesium was employed. The earlier applications varied from 0.1 to 0.6 per cent of magnesium added in magnesium carbonate and in magnesite. Later the following amounts were employed: 2, 6, and 10 per cent of magnesium in magnesite; 10 and 12.7 per cent of magnesium in dolomite; 0.1, 0.01, and 0.001 per cent of magnesium in the carbonates, chlorids, and sulphates. In each series sand or soil was used as a control.