INTERRELATIONSHIPS OF CALCIUM, NITROGEN, AND PHOSPHORUS IN VEGETABLE CROPS

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(WITH TWO FIGURES)

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Coincident with the rapid advances being made in soil science, an increasing interest has been shown in the soil mechanisms as they control plant nutrition, growth, and crop production. One of the most influential factors involved is that of the interaction of nutrients. The equilibrium among ions in the soil and the culture solution has lately been designated as "nutrient-element balance." Emphasis has been placed on the interrelations of essential plant nutrients, on "antagonisms" between specific cations, and on the possible application of such relationships to fertilizer practices in the field.

In the nineteenth century WOLFF (37) noticed that with barley the greatest growth occurred in "complete" nutrient cultures. Excess potassium depressed yields. It was observed, however, that the depression in growth could be overcome by the addition of another nutrient. He noted also that sodium amendments offset the effects of excess potash. LAGATU and MAUME (16) recorded a decrease in the yield of grapes when potassium was omitted from an otherwise balanced fertilizer application. THOMAS (25, 26, 27) substantiated the work of LAGATU and MAUME, and his data further emphasized the importance of proper balance in fertilizer applications with reference to absorption.

Associated with nutrient balance are the frequently demonstrated cationic antagonisms. HOAGLAND (12), LUNDEGÅRDH (18), and RICHARDS (22) summarized the interactions existing in the absorption of potassium, calcium, magnesium, and sodium. Possible ways in which one element in nutrition may substitute for another are outlined by COOPER (6). A decrease in plant growth and an accentuation of mineral element deficiency symptoms by unbalanced soil cations have also been demonstrated by many investigators (7, 8, 17, 21, 28). The concept that a lack of balance may be more harmful to plant growth than a deficiency of two or more nutrients has been suggested. The reports of DAVIDSON and BLAKE (9), and of WAUGH, CULLINAN, and SCOTT (31), and recently those of BROWN (4) on nutrient balance in the peach bear this out. PHILLIPS, SMITH, and HEPLER (20) reached a similar conclusion with the tomato plant.

During the past six years at the Missouri Agricultural Experiment Station, the importance of nutrient balance in obtaining maximum response to fertilizer treatment has been repeatedly observed in nutritional studies with vegetables. This report deals with the yields of some vegetable crops as in-

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fluenced by the balance of calcium, nitrogen, and phosphorus when the plants were grown in cultures of beidellite clay. This is a naturally occurring clay of which most of its readily available nutrient ions have been removed by leaching and H adsorption during continuous weathering.

**Methods**

Spinach, Swiss chard, lettuce, tampala, and tomato plants were grown under controlled greenhouse conditions in glazed gallon crocks using colloidal clay cultures (3) for nutrient media. Variable fertility levels were achieved by titrating the exchangeable ions, in the desired amounts and ratios, onto the original acid clay subsoil or B-horizon of Putnam silt loam, which has an exchange capacity of 28 milliequivalents per 100 grams, 12 of which are hydrogen. Of the remaining 16 milliequivalents of adsorbed nutrients, 12 are calcium and the remaining 4 are composed of smaller quantities of potassium and minor nutrient elements. Although these nutrient cations occupy a considerable portion of the total exchange capacity of the native subsoil, numerous biological tests have demonstrated its contribution of nitrogen and phosphorus to be nil, while practically none of the calcium and potassium is available for plant growth. Various nutrients, held on the clay in exchangeable form, may be provided for plants in any desired ratios and quantities simply by replacing the hydrogen on the clay with selected cations and by using the proper amount of prepared clay in the nutrient substrate. The pH values of the resulting media approximated 6.5. Stability of the clay and its naturally high content of replaceable hydrogen make its use, by simple additions of cations as exchanges for its hydrogen, very convenient for balanced nutrient studies.

The usual procedure followed in setting up the colloidal clay cultures was the preparation of a series of clay aliquots to which were added 5, 10, 20, and 40 milliequivalents of nitrogen in the form of ammonium nitrate. To each of these levels of nitrogen there was added calcium, as calcium acetate, in variable amounts to provide 0, 5, 10, 20, and 40 m.e. of calcium. This provided, then, twenty soil treatments giving four levels of nitrogen, each of which had combined with it five variable amounts of calcium as additions to the supply native in the initial clay. To each of these individual treatments were added other nutrients in constant quantities. The additions consisted of 20 m.e. each of potassium and phosphorus and 6 m.e. each of magnesium and sulphate (table I). Growth responses indicated that sufficient quantities of all trace elements are supplied by the native clay subsoil employed as an adsorptive media, the absolute amounts varying, of course, directly with the quantity of clay used. Effects of the variable quantities of colloid in the several treatments, since they might influence diversely the physical properties of the growing media, were reduced to a minimum by blending the clay with large quantities of pure sand or other chemically inert material. Single treatments were replicated at least three times, but usually ten times. Variations in plant growth within individual
treatments were extremely small, resulting from the degree of control exercised upon the chemical as well as the physical properties of the substrate. In the more extensive studies involving variable levels of nitrogen, calcium, and phosphorus, aliquots of clay with ammonium nitrate and calcium acetate added in quantities to secure the desired ratios were prepared. Variable phosphorus levels were achieved without altering other nutrient levels, simply by adjusting the quantities of monobasic and dibasic potassium phosphates. Additional potassium, when needed, was supplied as the acetate. Control of nutrient levels was thus achieved with all nutrients other than nitrogen, calcium, and phosphorus constant for all treatments.

**TABLE I**

**NUTRIENTS ADDED TO CLAY TO PROVIDE VARIABLE LEVELS OF CALCIUM AND NITROGEN**

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>MILLIEQUIVALENTS PER PLANT</th>
<th>CLAY PER PLANT</th>
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<td></td>
<td>Ca</td>
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The amount of subsoil clay required to provide the exact exchange capacity for the added nutrients in each treatment was determined beforehand in terms of the known qualities of the clay. Putnam subsoil material was then mixed under moisture with the particular nutrients and homogeneously blended with either pure white quartz sand or "Zonolite." Plants grown in the resulting mixtures were harvested and yields expressed in terms of fresh weights of the tops.

**Results**

The yields, expressed as fresh weights of spinach (Bloomsdale Long Standing), Swiss chard (Lucullus), and head lettuce (Iceberg), grown at variable levels of calcium and nitrogen with all other nutrient constant in...
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variables</th>
<th>Salts used to provide desired milliequivalents of ions</th>
<th>Clay per plant</th>
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<tr>
<td>9</td>
<td>90</td>
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</table>

**TABLE II**

Amounts of nutrient salts (m.e.) and clay used in providing three levels each of nitrogen, calcium, and phosphorus in 27 possible ratios.
all treatments, are given (table III). It is noteworthy that the lowest production occurred in spinach and chard when the highest level of calcium (40 m.e.) was combined with the lowest nitrogen level (5 m.e.) in treatment 4. This reduction in growth was much greater than with a deficiency of both elements, as in treatment 16 or 20. With the highest amount of calcium (40 m.e.) the successive increases of applied nitrogen gave a general increase in the yield with all crops. At the reduced calcium levels of 10 and 20 m.e. and especially at the 0 and 5 m.e. levels increases in the nitrogen from 5 to 10 m.e. and from 10 to 20 m.e. also gave a significant rise in yield, but a further increase to 40 m.e. of nitrogen cut production rather sharply

### TABLE III

**YIELDS OF SPINACH, SWISS CHARD, AND LETTUCE ACCORDING TO VARIABLE LEVELS OF CALCIUM AND NITROGEN**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variables</th>
<th>Fresh weights*</th>
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</table>

* Grams per ten plants.

in all three crops. Yields were a direct function of the total nutrient supply only when the variables were properly balanced. They point out that a high calcium level must be accompanied by adequate amounts of nitrogen, and a high nitrogen level by sufficient amounts of calcium. Results obtained by growing spinach and Swiss chard at levels of 5, 15, and 45 m.e. each of nitrogen, calcium, and phosphorus in all 27 combinations are summarized (table IV). Potassium was held constant at 20 m.e. and magnesium and sulphate at 5 m.e. for each treatment.

Although responses to nitrogen and phosphorus were outstanding, calcium exerted appreciable influence. Considering calcium, the largest growth
occurred at the moderate (15 m.e.) level of calcium combined with the highest of nitrogen (treatments 4-6 inclusive). At a low nitrogen level for both crops (treatments 19-27) and at a medium level of nitrogen for Swiss chard (treatments 10-18) an improvement in growth was obtained when the calcium was reduced to its lowest figure. A rather marked reduction in the yield of both vegetables was noted as the calcium was increased in combination with the lowest nitrogen level.

### TABLE IV

**Yields of Spinach and Swiss Chard According to Variable Levels of Nitrogen, Calcium, and Phosphorus**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variables</th>
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</table>

* Grams per five plants.

Increments of phosphorus applied to cultures low in nitrogen (5 and 15 m.e.) failed to give the yield increases possible at high nitrogen (45 m.e.). Conversely, the response to increasing nitrogen was largely governed by the phosphorus supply. When additional calcium was supplied to cultures low in phosphorus, the deficiency of phosphorus was accentuated (compare treatments 12, 15, 18 and 21, 24, 27). The best nutrient-element balance for yield increase was attained in treatment 4, with 45 m.e. as the level of nitrogen and phosphorus and with 15 m.e. as that for calcium. The lack
of balance with reference to plant growth was most evident in treatment 21 where 45 m.e. of calcium were combined with 5 m.e. each of nitrogen and phosphorus.

Responses by the tomato plant (variety Marglobe) to combinations of three variable levels of nitrogen, calcium, and phosphorus are portrayed (fig. 1). Yields expressed as fresh weights of vegetation are given (table V). The plants were grown at 5, 15, and 45 m.e. each of nitrogen, calcium, and phosphorus in 27 different combinations. It is evident that a lack of balance among the nutrients was more detrimental than a deficiency in all.

TABLE V

<table>
<thead>
<tr>
<th>PHOSPHORUS</th>
<th>NITROGEN 5 M.E.</th>
<th>NITROGEN 15 M.E.</th>
<th>NITROGEN 45 M.E.</th>
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<td>CALCIUM, M.E.</td>
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<td>m.e.</td>
<td>gm.</td>
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<td>gm.</td>
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<td>34.0</td>
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* Grams per three plants.
The data indicate that phosphorus deficiency in the plants at the 5 m.e. level of this nutrient was greatly accentuated by high calcium and high nitrogen. With the low level of phosphorus, an increase in the nitrogen from 15 to 45 m.e. depressed the yields. Similarly, at 5 m.e. of phosphorus (and constant osmotic pressure) the increases of calcium gave decreasing yields.

The phosphorus response in tomato nutrition (fig. 1), was dependent almost entirely upon the soil nitrogen supply. By contrast, addition of nitrogen to the soil decreased or increased yields depending on the amount of phosphorus present. With respect to increasing amounts of calcium applied at a high nitrogen and a high or medium phosphorus level, the effects were first an increase and then, with further additions of calcium, a decrease in production. At low phosphorus and high nitrogen levels, the calcium additions progressively diminished yields. In the tomato as with other crops, growth was determined not so much by the total quantities of nutrients added as by the balance relations existing among the elements.

Tampala (Amaranthus gangeticus) was grown at nutrient levels of 15, 45, and 90 m.e., each of nitrogen, calcium, and phosphorus in all possible combinations. The nutrient salt additions and clay aliquots were set up in accordance with the scheme as outlined (table II). The resulting plant growth and yields of the crop are presented (fig. 2 and table VI). The influence on the yields by a proper balance among the nutrients was again clearly demonstrated. Phosphorus additions either increased, had little effect on, or decreased the growth, depending on the nitrogen and calcium levels. At 15 m.e. of nitrogen, increased phosphorus depressed the yields at all three calcium levels; at 45 m.e. of nitrogen there was little influence, whereas at 90 m.e. of nitrogen, a very significant yield increase was noted. When only 15 m.e. of nitrogen were provided, the addition of calcium accen-
TABLE VI

YIELDS OF TAMPA LA PLANTS ACCORDING TO VARIABLE LEVELS OF NITROGEN, CALCIUM, AND PHOSPHORUS*

<table>
<thead>
<tr>
<th>NITROGEN 15 M.E.</th>
<th>NITROGEN 45 M.E.</th>
<th>NITROGEN 90 M.E.</th>
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</table>

* Grams per five plants.

Detrimental nitrogen deficiencies at all three phosphorus levels. Plants grown with 90 m.e. of nitrogen and 15 m.e. of phosphorus gave noticeably reduced yields, especially when this lack of balance was aggravated by calcium additions.

Discussion

In the experiments on nutrient-element balance for growing plants by the sand and/or solution culture method reported to date, it was impossible to control total concentrations of solutions (4) and hence their osmotic pressures as the ions were varied. On the other hand, if the concentrations were held constant (28), then an increase or decrease in one nutrient ion required that other ions be varied (11, 24). Exact interpretation of results in terms of a single ion is extremely difficult with sand and solution cultures.

As an approach to the accurate study of nutrient balance, the clay technique of plant growing is admirably adapted. The advantages of this method, and of using other ion adsorptive materials, for refined control of nutritional experiments with vegetables have previously been outlined (1, 2, 3, 5, 14). Not only do ion adsorptive materials permit the addition of each major cation separately as a carbonate, hydroxide, or acetate without changing other ionic concentrations, but clay holds also the anion of phosphorus in an adsorbed form (13). Studies conducted by GRAHAM and ALBRECHT (10) have shown that the nitrate anion may be adsorbed by certain synthetic resins. The adsorbed nitrate was available to plants as readily as were adsorbed cations. Corn plants grew equally well when nitrogen was added in the adsorbed form as in solution. JENNY (15) demonstrated by growing lettuce that adsorbed nitrates were superior to soluble nitrates in amounts above 20 m.e. per plant. The possibility of combining cation and anion adsorptive materials should not be overlooked in plant nutritional studies.

Physical structures of the clay cultures have not gone without consideration. Variations in nutrient levels and colloid content must have a minimum effect on the physical properties of the soil. When combined with...
large quantities of leached white sand, the clay adheres to the surface of sand particles making up only a small fraction of the total body. Thus the physical properties of the media are not greatly affected. Even a more ideal culture mixture with reference to physical structure can be had by blending clay with "Zonolite." This heat-treated mineral silicate is readily available in several forms as a common insulating material, has a high water-holding capacity, and is practically inert chemically. Its use in combination with clay in nutrient cultures of restricted volume facilitates the addition of large quantities of clay loaded with nutrient ions. At the same time, a physical soil structure is created which is easily penetrable throughout by plant roots, has a high water-holding capacity, and is sufficiently porous for adequate aeration.

Nutrient balance only as it affects yields of some vegetable crops has been emphasized in this report. A few variable levels and combinations of levels of nitrogen, calcium, and phosphorus have thus far been utilized in the approach to fertility balance in nutrition of vegetable crops. These are the nutrient elements most commonly deficient in Missouri soils. An influence of the balance of nitrogen and calcium on the vitamin, mineral, and oxalate contents has been shown (32, 33, 34). Some of the possibilities of disease (19, 23, 29, 30, 36) and insect (35) control through balanced soil fertility have been demonstrated. The approach offered by the colloidal clay technique of growing plants, provides a means of studying nutrient balance relations in their many ramifications, heretofore not fully appreciated by students of plant nutrition.

Summary

1. The influence of nutrient-element balance on the growth and production of vegetation in spinach, Swiss chard, lettuce, tampala, and tomato was studied by means of growing the plants in cultures prepared by blending colloidal clay with sand or chemically inert "Zonolite." Variable levels of nitrogen, calcium, and phosphorus were supplied.

2. Growth responses by the plants were found to be dependent on relative proportion as well as absolute amounts of variable nutrient elements present in the substrate. Yields were increased, not affected, or depressed by a particular ion, depending on the levels at which the other ions were present in the media. A lack of balance was demonstrated to be more detrimental to plant growth than a deficiency of all the variable nutrients.

3. Advantages of colloidal clay cultures as a means of approach to the study of nutrient-element balance are outlined. Maximum flexibility of variables is possible without concomitant alterations in osmotic pressures or physical properties of the media.

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