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Soil Acidity As Calcium (Fertility) Deficiency

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TRANSACTIONS

VOLUME I

SOIL ACIDITY AS CALCIUM (FERTILITY) DEFICIENCY[1]

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For all too many years our concept of the soil conditions called "soil acidity," and of the relation of these to plant nutrition, has been one which originated in the greenhouses and chemical laboratories dealing with solutions, and one mentally transplanted to the soil. It carried the belief that soil acidity *per se* is detrimental to plants. It provoked the conclusion of the converse, namely, that neutrality, therefore, must be beneficial. Such was the concept that gained wide popular acceptance, and unleashed in agricultural practice the extensive war on soil acidity with the carbonate of calcium as the ammunition for its annihilation.

Now that we have (*a*) found the hydrogen ion in potentially large numbers as a common cation part of the clay molecule, (*b*) measured this highly active element ionized from there in varying degrees to give different pH values, and (*c*) recognized its origin abundantly in the respiratory processes of the soil microbes and of the plant roots themselves, a newer concept is replacing this older one. We now consider those conditions called "soil acidity" as fertility deficiencies, of which calcium (and magnesium) is a prominent one.

We are coming to see the active hydrogen—even if it is not a plant nutrient when coming via the soil—as the major force in the many chemo-dynamics of the soil through which plant nutrition results. The activities of this ion are the major force in bringing about (*a*) the decomposition of the mineral reserves in the silt separates for increased availability of their nutrient contents, (*b*) the formation of the clay separate as a result of the mineral breakdown, (*c*) the adsorption on the clay of many essential nutrient ions made active as a consequence of that mineral decomposition, and (*d*) the exchange of these from the clay-organic-colloid to the microbes and the plant roots for nutritional services to these living forms.

When the world's population has located itself mainly on what is considered the "acid" soils; and when life is scant on those of alkaline reaction, even those of much less degree of this opposite to the acid; it seems high time to re-examine the simple chemical solution concept of acidity-neutrality-alkalinity, considered as bad-good-bad condition, respectively, for plant nutrition. This reconsideration seems especially necessary when these reaction differences, as only such with no other accompanying differences, are transplanted into the soil. It is, therefore, proposed here to defend the thesis (*a*) that an acid reaction of most soils is not a hindrance, but rather a help, to plant nutrition via the provision of the essential nutrient ions, (*b*) that it is only under significant hydrogen ion activity that the processes of mineral breakdown, clay formation and fertility

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delivery can be carried on, and (*c*) that the respiration of plant roots and microbes generates active hydrogen to maintain the flow of nutrient cations from the soil's rocks and minerals in the assembly line of agricultural production.

Soil acidity is not a hindrance when fertility is present

At the outset, let us accept the widely experienced and correctly interpreted observation, namely, that in Nature there are less and less of the more nutritious herbages, especially the legumes serving for growing young livestock and for multiplying its numbers, according as the natural degree of soil acidity goes higher. Let us also note that in waging the fight on soil acidity, it was probably more good fortune than wisdom when the carbonates of calcium and magnesium rather than of sodium or other alkalies and alkaline earths were chosen for soil treatments to drive the hydrogen out. After the years of growing concern about soil acidity, there is gradually dawning the broader concept, namely, that the increasing degree of acidity is merely the reciprocal of the real trouble, namely, the decreasing store of the soil fertility. While the earlier concept of soil acidity as the hydrogen's damage may now be slowly going into the discard, it has served, nevertheless, as the means by which the later one evolved, and, with it, our concept of at least some of the mechanisms—including the hydrogen as a part in them—by which the soil, rather than a solution within it, serves to deliver its fertility and to nourish the plants.

It was the modified Comber method (16)* of testing soils for the degree of acidity (the thiocyanate method) which served early to point out that liming a soil is helpful in growing clovers and other legumes because it applies the plant nutrient calcium and not because it applies carbonate for bringing about a reduction of the degree of acidity. Two fields, failing to grow clover, on the same farm were tested for their degree of acidity and were found highly acid. Two tons per acre of ten-mesh, agricultural limestone, were applied on each of them in the autumn ahead of the wheat seeding. The clover seeding followed the next spring with an excellent stubble crop of this legume as the result the next autumn. The soil test, repeated at that season, showed the soil nearly neutral for the one upland field of silt loam. The test, however, for the bottomland, a clay soil, showed still the same degree of acidity after liming and clover establishment as that which prevailed before the soil treatment. Here the clover had resulted from the same kind of liming which removed the acidity in the one field of upland soil with its low exchange or buffering capacity, but which brought about no change in reaction in the other field of bottomland soil with a high exchange or high buffering capacity. Here was some of the first evidence that it is an erroneous explanation of the effects of liming the soil, when we say that this practice is beneficial because it reduces the degree of acidity or lowers the pH value. Here was evidence that the presence of acidity is not a hindrance to clover growing if the fertility (calcium) is present.

As a test of this error in reasoning, a field of "acid" soil was put to soybeans—a supposedly acid-tolerant legume—by using calcium

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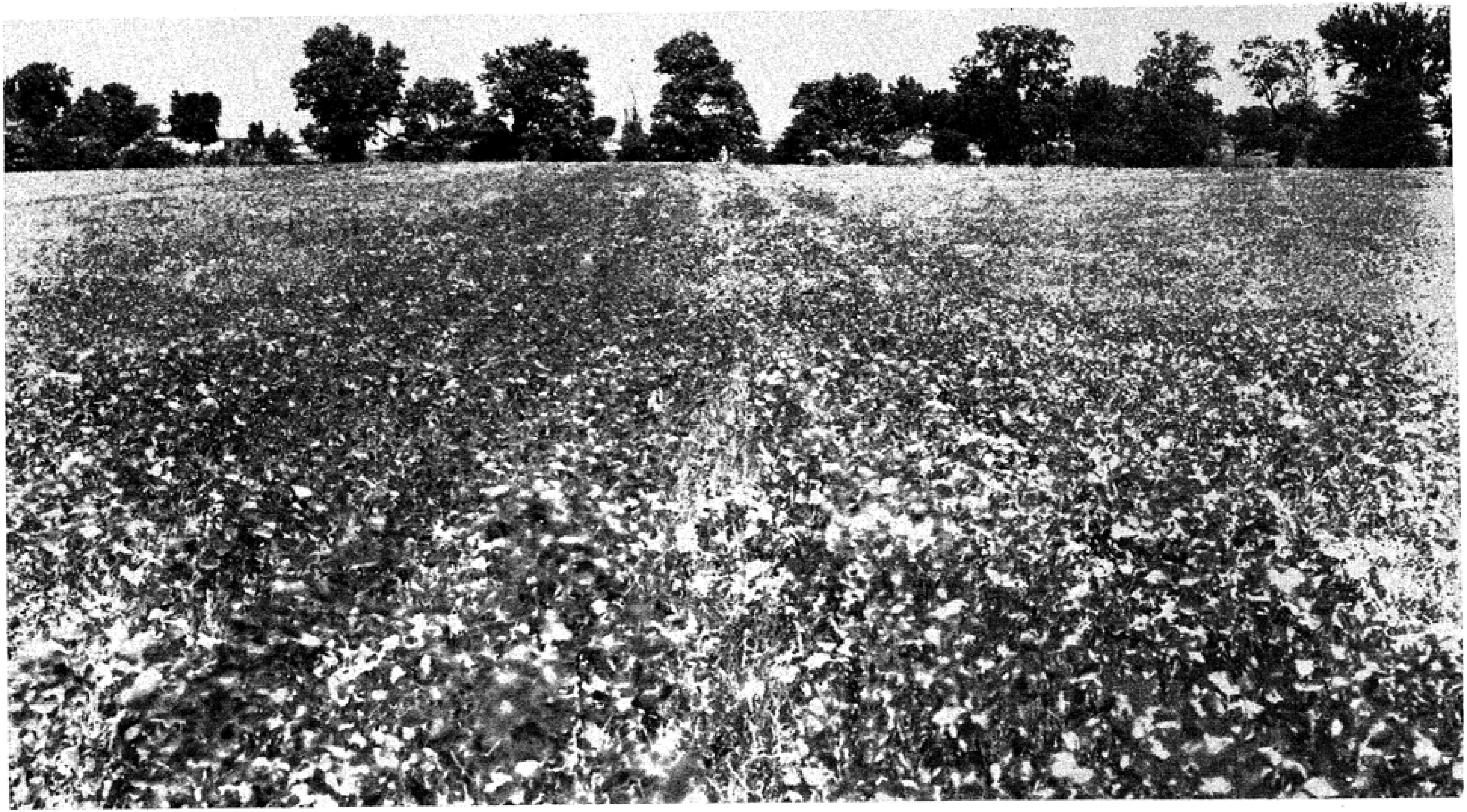
*Numbers in parenthesis refer to references in the "Literature Cited".



Applications of calcium chloride, calcium nitrate, and calcium hydroxide (right to left) gave improved growth and nitrogen fixation by soybeans on this "acid" soil, irrespective of the resulting increase in its acidity by the first two and the decrease of it by the third of these treatments.

chloride, calcium nitrate, and calcium hydroxide as successive treatments applied through one side of the fertilizer attachment of the drill at seeding (1, 2). Each of these treatments applied calcium. Regardless of whether the soil was made more acid in case of the first two, or reduced in its acidity in the case of the last one, of these treatments, the soybean plants grew larger, were greener, gave better nodulation and nitrogen-fixing, and brought about more stable nature of the plant tissues under microtomic sectioning wherever any one of these calcium-carrying salts was applied.

As additional test of the physiological effects of the lime because of the calcium going through the plant rather than the carbonate through the soil for acid neutralization, some finely pulverized limestone was drilled with clover seedings of inoculated seeds on acid soils (4). Clover was well established by drilling limestone with the seeds. Nodule production occurred on the roots in the soil at significant depths below, and distances from, the location of limestone in the drill row. Determinations of the pH around the nodules at these depths found this as low as 5·0. Here were legume root growth and excellent nodulation on all roots in soils of high degree of acidity as the result of merely growing some of the roots in contact with calcium in limited soil volumes or in only a few focal points. If lime is required for nodulation, this certainly occurred not where the acidity of the soil around the nodule was neutralized, but where the nodule-producing bacteria met a root of nutritional contents for mutual benefits, to which the calcium, taken by the plant roots in some other part of the soil made its contributions.

Separation of the lime's effects as a nutrient from those as neutralizer of acid makes the soil's exchange capacity a major factor in fertility

By means of electrodialized colloidal clay (7), which is a hydrogen-saturated clay at a pH of 3·6 when free of cations other than hydrogen, it is possible to titrate this to any desired degree of calcium (or other cation) saturation, or to any pH figure between 3·6 and 7·0 with all the cations adsorbed and none in solution. Since the amount of clay in the suspension can be controlled, then by taking a given volume of known concentration of clay to be mixed with sand, any given amount of exchangeable calcium (or other cation) can be so offered per plant. One can, then, choose the degree of acidity, or pH and keep it under control, and independently of that can also control the amount of supplied calcium by merely putting into the sand more or less of the clay of the chosen pH. By means of this colloidal clay technique, nitrogen fixation and other physiological processes of plants have been studied to segregate the various effects of the hydrogen ion on plant nutrition.

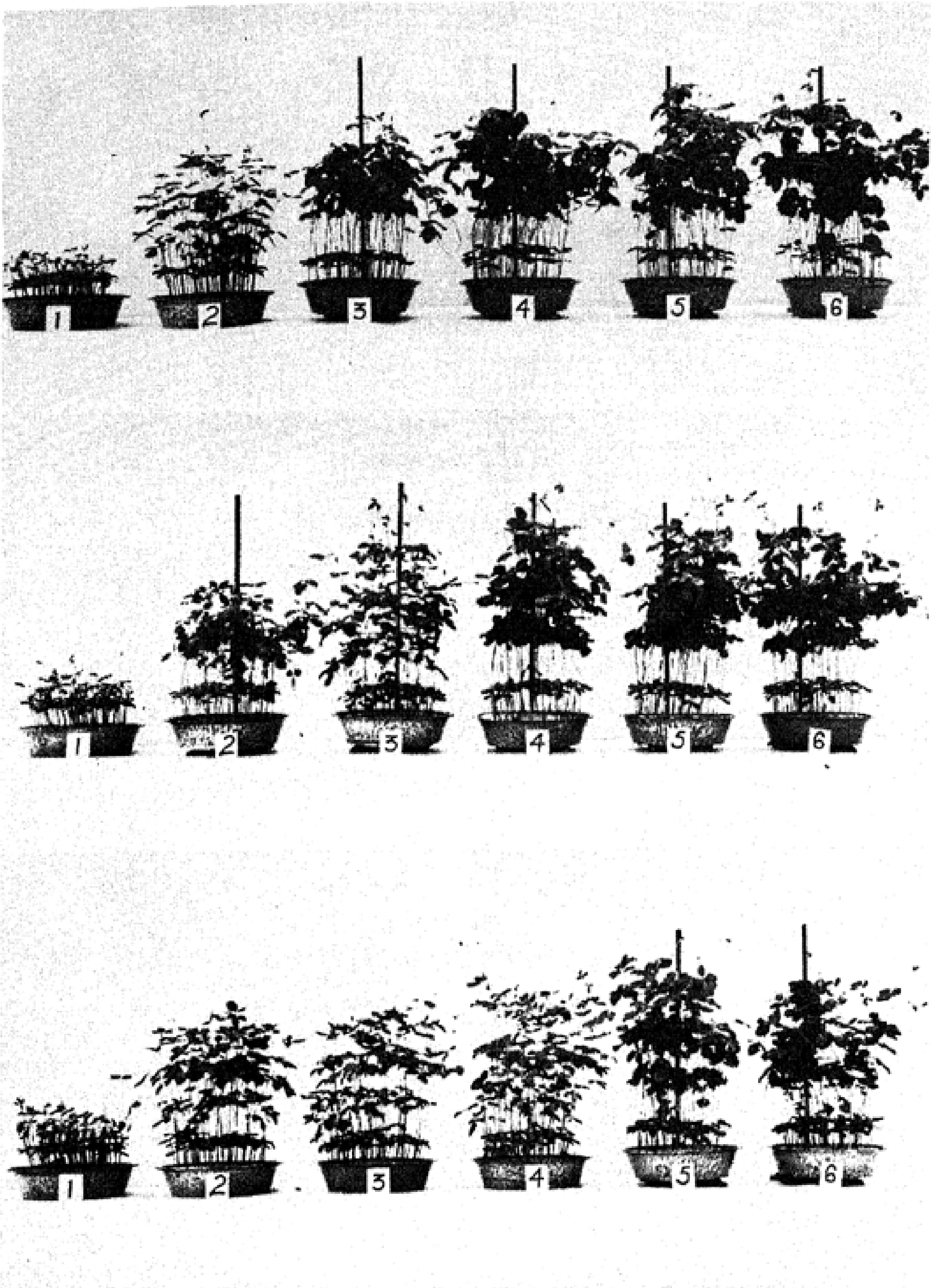
It was by means of this technique that the exchange capacity of the soil demonstrated its significance in the effects on the soil and the plants when liming to fertilize with calcium or to fertilize with any other nutrient element. For example, by putting into given constant amounts of sand, increasing amounts of clay of any chosen pH, or thereby a clay of any chosen degree of calcium saturation, this gives

Increasing the amount of calcium offered the plants by increasing the colloidal clay (pH 4·4) in the quartz sand (left to right) in the glass containers made the difference between poor and good growths, and between attacks by a fungus and immunity to it.

an increase in the exchange capacity of this artificial soil and by that means the amounts of calcium (or other nutrients) offered the plants can be increased while the pH remains a constant. Thus, the pH is eliminated and is consequently not mistaken as a measure of the amounts of calcium (or of other nutrients and hydrogen) offered to the plants growing in the given soil volume. By this it is demonstrated that the pH cannot be construed as of any value in determining the amount of lime to be supplied either as nutrition or as neutralization of soil acidity. This points out, then, that a knowledge of the soil's exchange capacity is necessary if the degree of hydrogen saturation is to be quantitatively interpreted as total hydrogen and conversely as totals of the cations other than hydrogen exchangeable from the soil. The exchange capacity of the soil becomes the important property when quantitatively interpreting soil tests of exchangeable ions.

By means of this colloidal clay technique, permitting varied control of the pH of the clay as well as varied control of the amounts of calcium or other cations on the clay, studies of plant nutrition in relation to the hydrogen ion have been extensively carried out (3). When a series of the clays was prepared to include the pH values going from 4·0 to 6·5 by increments of ·5 pH, and the amounts of each of these six clays were taken so as to give ·05 milligram equivalents of calcium per soybean plant, the plant growth was poor at the four pH values of 5·5 and lower, but it was good at the two pH values of 6·0 and higher. When twice as much of each of these clays was put into the sand to offer ·10 milligram equivalents of calcium per plant, the corresponding pH values differentiating between poor and good plant growth as above were 5·0 and 5·5, respectively. But when four times as much clay was put into the sand offering ·20 milligram equivalents for root contact, the dividing pH figures between poor and good plant growth were 4·5 and 5·0.

Thus, had one seen the plant growth of only the first series, it would have been logical to report that the soybean plant is " disturbed by," or " sensitive to," a pH of 5·5, and " requires " a pH of 6·0. Had one seen only the second series, it would have seemed logical to refute these reported figures and to contend that this plant species is disturbed by a pH of 5·0, but not by the required one of 5·5. Then, similarly had one seen only the third series, the contradiction of both preceding sets of figures given above would have been expectable, and the claims anticipated that soybeans are not disturbed seriously by soil acidity until the degree of it becomes as severe as pH 4·5. Here would have been apparent grounds for claiming that the soybean is an " acid-tolerant " crop. However, in this third series, which exhibited higher " tolerance " of a degree of acidity by ten times more than that " tolerated " in the first series, this " tolerance " was brought about by merely quadrupling the exchange capacity in the constant volume of sand-clay soil. Increasing the nutrition as calcium by four times was the counteraction or the antidote for an increase of degree of acidity, or hydrogen-ion concentration, by ten times.



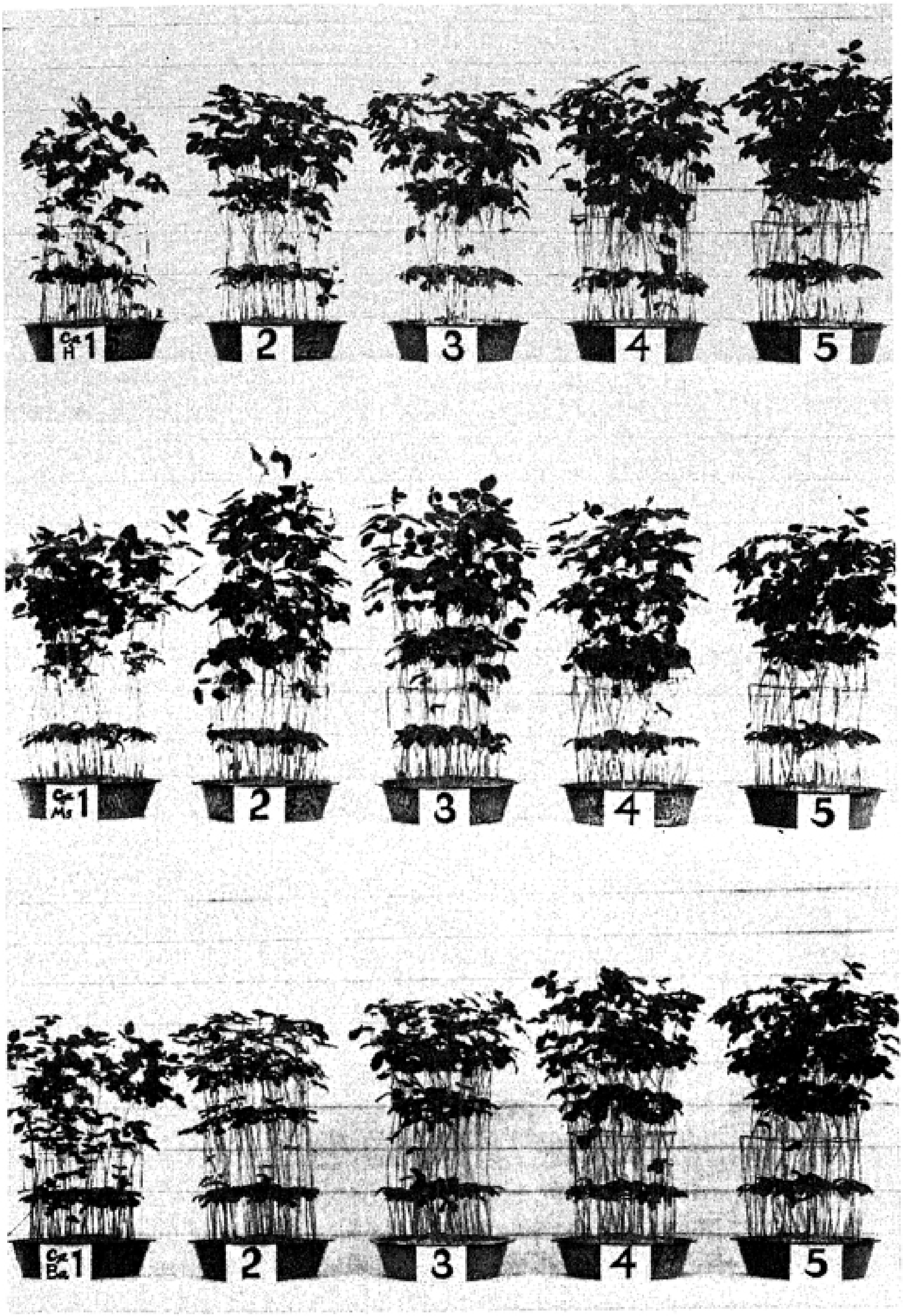
Decreasing degrees of acidity (increasing degree of saturation of the clay by calcium) were offered the soybeans (pH, left to right, 4·0 ; 4·5 ; 5·0 ; 5·5 ; 6·0 ; 6·5).
There was an increasing amount of calcium offered as a constant per horizontal row by putting more clay into the sand-clay medium in going from the lower to the upper one, viz. : ·05 ; ·10 ; and ·20 milligram equivalents per plant.

Plants lose fertility back to acid (infertile) soils or gain it from these according to their degree of saturation

Equally as interesting as this preceding observation of what has erroneously been called " toleration " of acidity by plants, were the changes in the reactions, or pH values, of these colloidal clays as a result of growing the soybean crop for a time extending scarcely from planting to the blooming stage. The measurements of the pH values of all the sand-clay mixtures after they had grown the crop showed a shift of the reaction toward neutrality from the initial pH values of 4·0, 4·5, and 5·0, and a shift toward more acidity from the initial pH values of 5·5, 6·0, and 6·5. These shifts were greater in the last three cases according as the initial value was higher. As a consequence, the pH in these soils resulting finally from the crop's growth in them was almost the same, namely, near 5·5, for all the different sand-clay mixtures that originally were pH 5·0, 5·5, 6·0, and 6·5. The first of these resulted from a decrease, and the last three from an increase in the degree of acidity. Here the plant growth modified and determined the degree of acidity of the soil, and not vice versa.

Chemical analyses of the crops, in comparison with those of the seed, showed that they had all taken calcium from the clay-sand mixture in consequence of their growth. The amounts taken were about the same for all those cases of pH 4·0, 4·5, and 5·0. If this calcium removal represented an exchange of it to the plant for hydrogen from the roots, this hydrogen added to the clay should have lowered its pH figure below the initial values, and to about the same amount for all these three of them. The amounts of calcium taken from the soil, however, by the soybeans growing at pH values 5·5, 6·0, and 6·5 increased with these increasing pH values. This was not in agreement with, but was more than the equivalence represented by, the increasing degree of acidity of the soil resulting from the crop growth. In only one case was the increasing degree of acidity equal to or slightly more than the increasing degree of calcium removal. In only one case was there a suggestion that the hydrogen going from the root to the soil was replacing nearly exactly the calcium taken from there by the root. The extra cations, besides the hydrogen, going in the reverse from the root to the soil in exchange for the calcium were shown in later studies to include potassium and nitrogen (10), since in respect to these two elements, the total crop (tops and roots) contained less than was in the planted seed.

Here, then, there was an interchange of cations, including hydrogen and others from the roots to the clay as well as from the clay to the roots. The final hay crop contained less nitrogen, potassium, and phosphorus than was in the planted seed. As for the calcium, this was found moving only in one direction, namely, from the clay to the roots, when the plants were growing or even barely surviving. Calcium was moving into the plants in larger total amounts at any given pH of the soil when the exchange capacity of that soil was pushed higher by increasing the clay in the sand-clay soil. Calcium was taken both in larger totals from, and at larger percentages of, the same exchangeable supply offered, according as there were increasing degrees of saturation of the clay by that calcium, or with higher pH values, only when these were 5·5 and above. Thus, the delivery of calcium from the soil to the crop was more efficient in terms of the applied calcium according as the soil was more highly saturated by it, or of higher pH values above this figure of pH 5·5 for this particular clay. This suggests that the efficient use of a given amount of lime calls for its application so as to give highly saturated, limited soil volumes rather than an infinite distribution throughout the soil of



Increasing calcium saturation (40, 60, 75, 87·5 *and* 97 *per cent., left to right*) *of the clay colloid in the clay-sand soil offering the same amount of exchangeable calcium per plant, gave increasing plant growth accordingly, but irrespective of the accompanying decrease in soil acidity* (*upper row*) *or the accompanying neutrality* (*lower two rows*).

the entire root zone. Drilling the lime well down into the soil for root contact and for fertilizing effects is suggested as better practice than mixing it throughout the entire soil body for effects in acid neutralization.

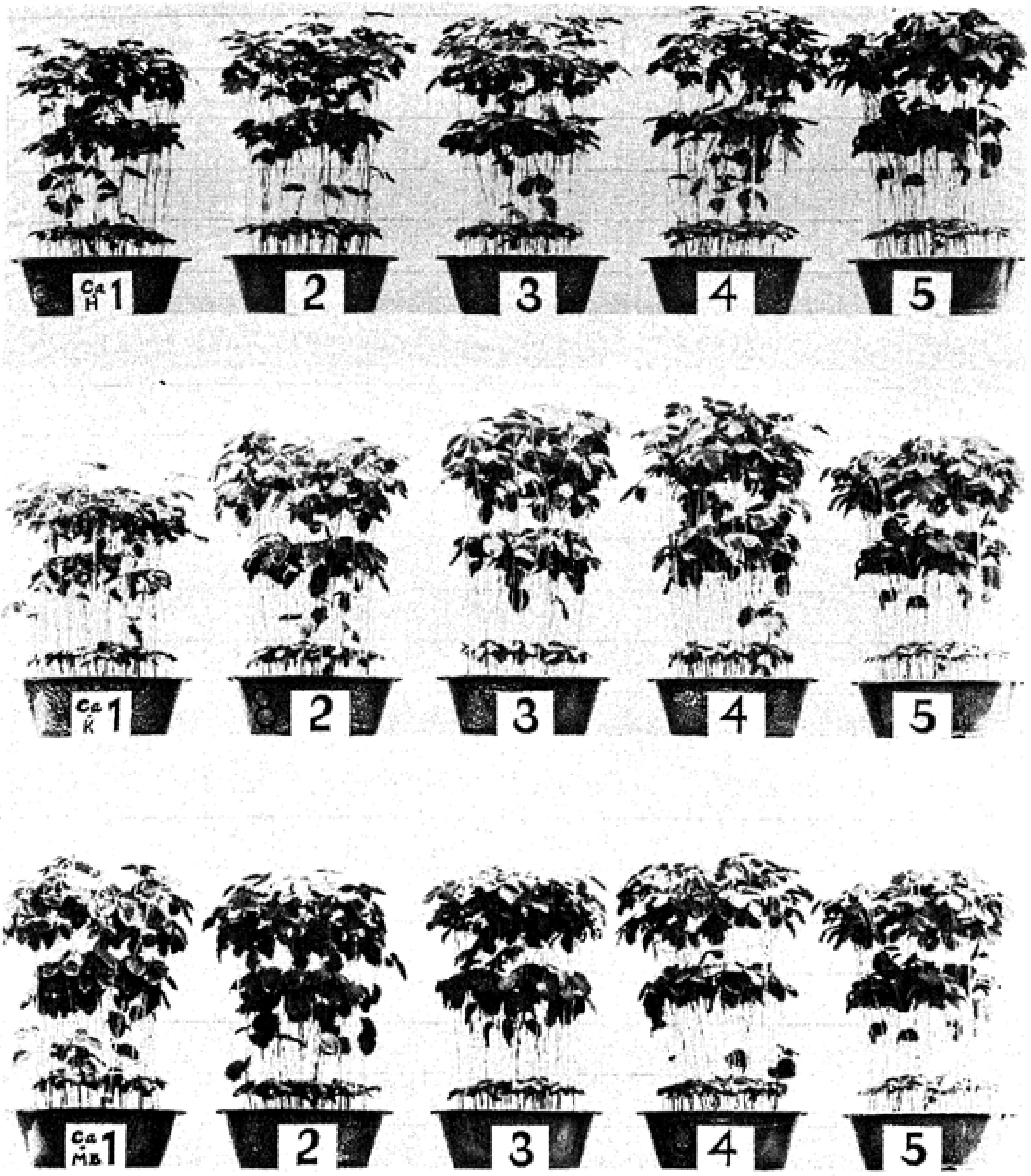
Relative degree of saturation of the colloid by the different ions, and this of each in relation to the others, influences their activities in plant nutrition

Because the degree of saturation of the colloidal complex by calcium exhibited its significance in the efficiencies with which the constant amount of exchangeable calcium was passed to the plants, studies of the increasing degree of calcium saturation with reciprocally decreasing degrees of saturation of other cations were undertaken, using constant amounts of exchangeable calcium offered to the soybean crops grown by means of the colloidal clay technique (14). In the first trial, the percentages of calcium saturation were 40, 60, 75, 87·5, and 97 reciprocally combined (*a*) in one series with hydrogen, (*b*) in another with magnesium, and (*c*) in another with barium. In the hydrogen series, this increasing degree of calcium saturation represented a corresponding decreasing degree of hydrogen saturation or decreasing degree of acidity as increasing pH values, namely, 5·10, 5·50, 5·90, 6·45, and 6·85, respectively. In the other two series this increasing calcium saturation represented no ranges in degree of acidity, since all the clays were made nearly neutral by means of cations other than hydrogen, namely, (*a*) magnesium, a nutrient, and (*b*) barium, a non-nutrient, and both similar to calcium in many of their properties.

The plant growth increased nearly 50% ; the nodule production increased by more than 50% ; and the calcium uptake increased by more than 100%, as a result of the increase in calcium saturation, regardless of whether there was at the outset a range in the degree of acidity in the series or whether all the soils were nearly neutral. Since the increasing efficiency of calcium, as measured by the increase of plant growth, of numbers of nodules, and of calcium taken from the same exchangeable amount in the soil, resulted from the increasing degree of saturation of the colloid by it, regardless of whether the soils were of differing degrees of acidity or all nearly neutral, there can scarcely be much disturbing significance, either hindrance or help, ascribed to the hydrogen ion as an acidity factor when these other active inorganic cations of fertility or non-fertility values are associated with it.

As a comparison of the behaviour of calcium when associated with the highly active hydrogen in contrast to its behaviour when associated with a much less active or less ionized cation, the large, positively charged ion of methylene blue was adsorbed on the clay with the calcium as the reciprocal to it in its increasing degrees of saturation of the clay colloid. There were three series, similar to the preceding ones, as regards the constant amounts of total exchangeable calcium as increasing percentage saturations, but this combined with decreasing percentage saturations of (*a*) hydrogen in one series, (*b*) potassium in another, and (*c*) methylene blue in still another.

In the first two series, the plant growth increased by nearly 50%,



Increasing calcium saturation (40, 60, 75, 87·5 *and* 97 *percent., left to right) of the clay colloid in the clay-sand soil offering the same amount of exchangeable calcium per plant, gave increasing plant growth accordingly when the inorganic hydrogen and potassium were the accompanying ions. But the saturation degree was without effect and the plant growth reflected the constant amount of exchangeable calcium when methylene blue was the accompanying ion.*

the nodulation by the same degree, and the uptake of calcium by almost 100%, according to the increasing calcium saturation and the reciprocally decreasing saturation of these other two accompanying active, inorganic ions, one of which made the soils in the series decreasingly acid and the other made all of them nearly neutral. But in the third series, where the reciprocally decreasing saturation was the result of the inactive, large, organic ion of methylene blue, also making all the soils in the series neutral, the constant amounts of exchangeable calcium, regardless of the differing degrees of saturation by it, gave nearly constant weights of crops, constant numbers of nodules, and delivery of calcium suggesting larger amounts as the saturation degree of the colloid by it was smaller. All these results from the calcium in this series were nearly the equal of the maxima in all the other series for it, regardless of whether accompanied by hydrogen, magnesium, potassium, or barium.

In these two trials with the six plant series, there was again demonstrated the increase in the degree of acidity of the soil resulting from the crop growth. This demonstrates the fact that the removal of fertility from the clay in the clay-quartz medium increases the hydrogen presence there or increases the degree of its acidity. For the two series in which the decreasing hydrogen saturation of the clay, or the increasing pH values, accompanied the increasing degree of calcium saturation, the growth of the crop for the six weeks lowered the initial pH values by the following amounts, ·20, ·20, ·60, 1·10, and 1·65 respectively for the units of decreasing hydrogen saturation. In the three neutral series, made so with decreasing degrees of saturation by (*a*) magnesium, (*b*) barium, and (*c*) potassium accompanying the increasing calcium saturation, the pH values were lowered as a result of the crop growth by amounts varying from 1·10 to 1·60. In the case of the series with methylene blue, here, too, the crop growth made the soils more acid by pH amounts as much as 1·30 to 1·60. By the growth of a single crop for six weeks on these soils that were initially neutral, the degree of acidity was increased by amounts approaching even a hundred times. Acidity can scarcely be much hindrance when the very crop growth itself increases the degree of acidity to such magnitudes.

Hydrogen, or acidity, helps in mobilizing other cations (possibly anions) from the soil colloid into the plant roots

The association of the active calcium with the inactive methylene blue molecule reported above, presented the concept that the activities of any adsorbed ion resulting in its entrance into the plant are determined not only *per se*, that is, by its chemo-dynamics, but also according as these are modified by the activities of other ions by which it is accompanied. From these results there arose the concept that not only the activity of the hydrogen ion deserves measurement by its glass electrode, but that plant nutrition in terms of calcium will be better understood when the calcium activity can be measured by a similar electrode, or if we can have a pCa as an activity measurement for calcium, and similar measurements for other ions just as we have pH for activity of the hydrogen ion.

As a partial measure of the influence on the calcium activity by some of the cations associated with this element in the suite of ions on the colloidal complex of the soil, some calculations were made of the efficiency with which the exchangeable calcium on the colloidal clay was moved into the soybean plants in some studies (*a*) using increasing degrees of saturation of a constant amount of clay by calcium and thereby offering increasing amounts to the crop (15), and (*b*) using increasing degrees of saturation on decreasing amounts of clay to offer constant amounts of calcium to the crop (14). In both studies the calcium was associated with (*a*) decreasing hydrogen and thereby decreasing degree of acidity, and (*b*) decreasing barium and thereby with all soils nearly neutral.

When the decreasing hydrogen was associated with the increasing saturation of the clay by calcium in both of these cases, the exchangeable calcium moved into the soybean crop with a higher efficiency than when barium was the accompanying ion as is shown in Table I. Here is the suggestion that as the hydrogen is adsorbed on the colloid and comes into the suite of ions held there, it may serve to push off or make more active, the other cations on the clay. Thus, the presence of hydrogen of no nutritional service itself, and too long considered a detriment, becomes a benefit in that it mobilizes the other cations of fertility value into the plant more efficiently.

That the active hydrogen ion on the colloidal clay serves to move larger shares of the other cations (nutrient ions) from the colloidal complex into the plant root was clearly demonstrated by growing spinach on two five-pot series of similar soils, one of which series was acid at pH 5·2, and the other was nearly neutral at pH 6·8 (6). The amounts of the separate nutrient ions put on the clay as chlorides to make the acid series and as oxides and hydroxides to make the neutral one, were duplicates throughout the series except for the calcium. This was put on as increasing amounts from 0 to 12 milligram equivalents by increments of three.

The spinach crop grown on the acid series showed a general yield increase with more calcium applied. More significant, however, were the much higher totals and higher concentrations of the soil-borne, inorganic nutrient elements, namely, calcium, magnesium, strontium and manganese, for this crop on the acid series than for that on the initially neutral soil. Also, as a result of both the increasing amounts of calcium added and the increasingly higher degree of saturation by calcium of the colloidal clay, there were increasing totals, and increasing concentrations of these elements in this vegetable crop, which was not the case for it when growing on the soil initially neutral. On all soils, the amounts of phosphorus and potassium did not show such clear correlations. They followed more nearly the crop yields.

Table I

Degree of saturation by			In plants %		Total mgms.		Efficiency	
Calcium	Hydrogen (acid)	Barium (neutral)	(acid)	(neutral)	(acid)	(neutral)	(acid)	(neutral)
Increasing saturation with amount of clay constant								
40	60	60	·507	·386	25·2	23·9	12·6	11·9
60	40	40	·651	·594	44·8	38·0	22·4	19·0
75	25	25	·702	·672	50·9	47·0	25·4	23·5
87·5	12·5	12·5	·764	·707	57·1	56·2	28·5	28·1
Increasing saturation with amount of exchangeable calcium constant.								
25	75	75	·27	·29	40·27	1·20	40·2	31·2
50	50	50	·55	·31	85·54	45·54	40·7	22·7
75	25	25	·71	·66	122·40	104·84	40·8	34·9

Table I. The increasing degree of saturation of the soil colloid by calcium was more efficient in moving calcium into the soybean plants when hydrogen (acid) rather than barium (neutral) was the reciprocal of the calcium.

The oxalate contents of the spinach, by combination with which calcium and magnesium become highly insoluble, and thereby indigestible, as a synthetic product of the plant's processes were even more interesting than the uptake of the six inorganic elements contributed from the soil (17). The oxalate contents of the plants from the acid soil were higher than of those from the neutral soil. Also, they increased with the increments of calcium on the former, but not on the latter soil. However, when matched against the equivalents of the crop's contents of calcium and magnesium combined, the oxalate there in case of the acid soils was less than required to make both of these alkaline earths insoluble. On the neutral soil it was more than enough. Here was evidence that the acidity of the soil is a help, and not a hindrance, not only in the transportation of the inorganic elements from the soil into the crop plants, but also in the plants' synthetic creations through which the soil fertility serves first in plant nutrition and then later in the nutrition of animals and man.

Soil acidity serves to process the applied minerals as well as those natural in the silt and thereby to restock the clay with active fertility

In our mechanical analyses of soils, the three separates, namely, sand, silt, and clay have not been emphasized for their differing potential contributions to fertility according to the humid or arid climates they represent. When the clay is the colloidal, dynamic separate which takes up, and gives off, nutrient cations but offers none of significance by its own chemical decompositions (5); and when the exchangeable supply of fertility in the soils of low exchange capacity is exhausted so quickly by a few successive crops (10); we must look to the silt and sand separates as the source from which the fertility store on the colloidal clay is regularly renewed.

For that renewal, the sand separate can offer little because of its large particle size and limited total surface for acid-clay contact. Its insolubility and hardness, by virtue of which it naturally remained as large particles, testify to its high potential in quartz as its mineral component and thereby little or no fertility value. The silt separate may well be expected to offer more to the clay because of smaller particle size or more surface for contact. Silt is of the size sufficiently smaller to be windblown. It is brought to the humid regions from the dry, unweathered areas by that means. By virtue of such origin it is more apt to be an extensive collection of minerals other-than-quartz containing more nearly all the elements of fertility. It is the silt loam soils in the semi-humid areas, or under moderate degrees of soil development, which have grown the legumes naturally and have given us the protein food supplies most abundantly (9).

By mixing specially prepared silt minerals with a colloidal clay suspension of controlled degree of acidity (11, 12), or by putting the moist silts into a collodion tube and immersing this into the acid colloidal clay, it has been demonstrated that the acidity of the clay serves like any other acid to decompose the silt minerals. The active hydrogen from the clay passed through the membrane. It decomposed the minerals, while the cations so released passed in the opposite direction, were adsorbed on the clay, and from there were taken up by the plant roots with plant growth according to the differing degrees of development the silts had undergone.

Thus, the acid clay is offering its active hydrogen as an agency decomposing the silt minerals, releasing cations from these reserve supplies, and developing more clay thereby. It suggests that our productive soils have been those with the proper mineral mixtures in their silts as reserves of fertility rather than silts as merely fortunate physical makeup for easy tillage. It suggests also more significance in windblown soils of the semi-humid areas for the fertility value of their origin in arid regions than we have been wont to believe.

That soil acidity should serve for decomposition of the soil's reserve minerals and for making their fertility contents available for plant use, should be no new concept, when we realize that liming the soil is that very same process. Particle sizes, of ten-mesh and smaller, of limestone applied on the soil are calcareous minerals being processed there by means of soil acidity. They are being so processed in order to make their calcium or magnesium contents available as fertility at various focal points throughout the soil rather than to change degree of acidity of the entire soil volume. The former, as a kind of heterogeneity (8) and not the latter as a distinct homogeneity, appears as the more logical concept of the soil as continued source of plant nutrition. All too long, however,has liming the soil been viewed not in terms of the soil acid as a means of processing this application of a calcium (magnesium) fertilizer, but rather in terms of this carbonate carrier as a means of neutralizing the soil acid. Liming is merely an illustration of how agriculture is an industrial chemical industry using mainly soil acids to provide the raw, starting materials for its creative business.

SUMMARY

In summary, then, it now seems evident that our research efforts on soil acidity for these many years would have been more fruitful and earlier for agricultural production if that research had been guided by the concept that the increasing degree of soil acidity is disturbing to our protein-producing crops because this soil condition represents not a disturbance by the increasing hydrogen, but by the decreasing fertility within the suite of ions adsorbed on the clay among which suite, in a productive soil, calcium occupies the major part. This concept visualizes the hydrogen ion, originating around the soil microbe and around the plant root because of their respirations excreting carbon dioxide, as the cation which they offer to the clay colloid through contact exchange for its stock of nutrient cations. A high degree of hydrogen saturation of the clay, then, is the result of the high concentration of this ion being built up around the microbial or root hair cells as well, when it can no longer be exchanged for other cations in the environment. A high degree of hydrogen saturation of the clay, then, is simply a high degree of fertility deficiency both there and in its immediate environment, including the silt and sand separates. That there is an increasing degree of hydrogen concentration built up around the root as the fertility in its environment decreases has been demonstrated by the research of Dr. E. R. GRAHAM and W. L. BAKER (13).

It is simple to conceive, then, that the higher hydrogen concentrations built up on the clay by plant root activities of plant growth serve as the acid reagent for reserve mineral breakdown and nutrient cation exchange from there to the clay for the hydrogen from it. In this concept, the plant root is merely treating the soil with the acid generated by the root's own respiration; this acid then flows from the root to the clay; and, under higher concentrations resulting there, flows on to the mineral reserves (present naturally or applied as limestone, rock phosphate, etc). As a result of this acid treatment of the soil by the growing plant roots and the microbes, the fertility reserves are "made available" or they are moved out from their mineral crystalline forms into the active ionic conditions to make their way, under their own power of ionic activity and ionic exchanges in the opposite direction going from the mineral reserves to the clay, and to the plant roots for plant nutrition.

Thus, since the forms of life finding their nourishment in the soil do so by trading the hydrogen for it, it should be no other disturbance to our thinking when a soil is highly loaded with acidity than to tell us that when this occurs the soil has given up its fertility to microbial and plant crops for it. Soil acidity, then, is the regular natural result of crop production, and its accumulation is merely the result of our failure to restock the mineral reserves (of which limestone is only one) by which that acidity would neutralize itself in keeping more fertility flowing out from these restored resources and along the assembly lines of agricultural production.

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