Trace Elements and the Production of Proteins

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*Trace Elements and the Production of Proteins

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SUMMARY

Trace elements are focal points of research in the biotic behaviors and biochemical reactions with which they are connected. That trace element function in the activities of the proteins, and possibly vice-versa, is the suggestion from recent research.

They are tools in the plant's synthesis of carbohydrates and conversion of these into proteins and similar compounds. Hence, the magnitude of the plant's ash content of manganese, boron, zinc, copper, cobalt, chlorine, molybdenum, and even iron, does not represent the magnitude of their separate biochemical services. Elucidation of their creative functions is therefore difficult.

As cations, they may be adsorbed on, and exchanged from, the colloidal organo-clay complex of the soil to the plant root for the hydrogen or other ions offered in trade. As anions they may be active much like any other anion within the exchange atmosphere of the colloidal molecule.

The root-hair cell, another colloid, but composed of living protein, represents the dynamic potential for transfer of nutrient elements from the clay into the life processes of the cell protein and all others of the plant. Trace elements are part of the larger suite of ions required as a balanced ration for plant nutrition according to the laws of chemical behavior of the elements regardless of trace amounts or larger.

Higher concentrations of protein in legume plants, resulting from bacterial inoculation affected more ionic exchange from a standardized soil colloid into the plants. Since copper seems necessary for the plant's synthesis of its own protection against fungus attack, and since balanced suites of major nutrient elements grew scab-free potatoes while the unbalanced suites failed, the theory is ventured that the balance of the major nutrients may mean plant protein in quantity and quality for the root hair's more effective movement of trace elements from the soil into itself and the plant.

Better balance of nitrogen and phosphorus in the soil growing corn protected the stored grain against the lesser grain borer. Better balance of calcium and nitrogen in the soil growing spinach protected it from the leaf-eating thrips insect. More calcium on the colloidal clay growing soybeans protected the plants from fungus attack. These were demonstrations under controlled experimental conditions.

Selection of crops for large vegetable yield as replacement for higher-protein ones failing on the same exploited soil may have increased the deficiencies of trace elements in animal rations and human diets. Less of proteins in quantity and quality because of deficient major nutrients, or their imbalances, may bring failure to mobilize trace elements from the soil into the crops. This is a sound postulate when the feeding of a non-legume hay grown separately on a soil gives trace element deficiency of the animals, but feeding it when grown in combination with a legume like alfalfa on the same soil does not.

We are slowly recognizing the problem of the proteins. It has become one of having soils fertile in (a) the major nutrient elements, (b) in organic matter, and also (c) in the trace elements required for the synthesis by the microbes and by the plants of all the essential amino acids in truly complete proteins. Trace elements apparently contribute more to quality than to quantity of nutrition in what we grow, especially the proteins.

Extensive research attention has been given during the last two decades to the trace elements and the proteins, the two parts of the subject accepted for discussion here. Both have been the focal points of intense efforts to understand the natural biotic phenomena with which they are connected. As the result, Nature's secrets are being revealed about the connection between them as they may be reciprocally causes and effects in diverse behaviors by the many forms of life.

The trace elements represent the increasing refinement of our knowledge about the inorganic contributions by the soil

to the support of life processes, both simple and complex. The proteins offer themselves in the many biochemical behaviors to be comprehended in their normalities and abnormalities, since proteins alone are the compounds which carry life. They are the ultimate detail by which microbes, plants, animals and man are chemically organic, living matter. Hence, while the trace elements are the area of maximum inorganic detail in our efforts to understand "the handful of dust," the proteins represent the corresponding degree of curiosity about what the resulting creation is when the warm, moist breath of the climatic forces is blown into that bit of rock converted into soil. Those of us who are concerned with soil as the means of agricultural production visualize the numerous trace elements no less essential in the production of the many kinds of proteins than we consider the more gross soil fertility, the sunshine, the air, the water and all else contributing to plant nutrition and plant growth.

TRACE ELEMENTS VIA PROTEINS ARE TOOLS MORE THAN BUILDING MATERIALS

Very naturally, if any element enters into the chemical structure of proteins, it will be essential for life. Hence, we readily understand why carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur are required for the growth of crop plants and of all other life forms. Magnesium in chlorophyl for photosynthesis, iron in hemoglobin for oxygen-carrying service in respiration, and calcium in the bones of our skeleton give us nine of the ten elements considered essential for many years. The essentiality of more than these of the nearly hundred, or so, known elements was not so readily granted in terms of their recognized functions. This was true of potassium as the tenth on the list. We do not yet know of any organic combinations of potassium in living forms comparable with compounds of phosphorus and sulfur, nor the indispensibility of it in the biochemical processes. It can be partially substituted, but never completely, by other monovalent elements. Only recently has it been accorded more careful quantitive essentiality in matters of human health.

The ten elements so far listed were thought for many years to be all that is required for plant growth. But in recent years, more elements required in amounts equivalent to mere "traces" have been established as essential for plant growth. According to the amounts required, iron may have been the original among the trace elements and was classified long ago as essential because of its known function. Those recently established for only traces needed for plant growth are manganese, boron, zinc, molybdenum and chlorine, or but seven, including iron. Very recently cobalt has been reported essential for the nitrogen-fixing, blue-green algae, which are single-celled bearers of chlorophyl, but not classified so regularly as plants. Since plants absorb about every kind of soluble, inorganic element, the burden of proof is one for us to establish the essentiality for the required functions in which each element plays a role and without which element, therefore, the function fails and the plant cannot survive. The basic problem is one of setting up the conditions for control, and demonstration, of the function in plant growth failure under certainty of complete exclusion of the responsible element aimed to be tested. This involves chemical purity to a degree which we can approach only most laboriously and not always with utmost certainty.

That the list of trace elements will be extended may well be anticipated. This has been the experience even during the last couple of years when chlorine was added for plants, and cobalt was included for blue-green algae, especially for the latter's function of nitrogen-fixation. In order to establish essentialtiy of only trace amounts of an inorganic element, we must measure and with higher degrees of refinement than ever measured before, some function for which the smallest variation in amount (usually absence and presence) of the element is responsible. In the legume plants, like the subterranean clover, the symbiotic fixation of nitrogen by the microbial Rhizobia species in the nodules on its roots failed, and consequently the plant growth failed, unless the molbydenum deficiency in the soil was corrected by amounts as small as one-sixteenth of an ounce per acre. Here the readily observable symptoms as gross as crop failure, indicated the essentiality of a trace element in a function representing both microbes and plants in their synthesis of nitrogen into the proteins.

In case of the trace element iodine, demonstrated as essential for animals, its service is in the body's synthesis of thyroxine, the hormone produced by the thyroid gland without which metabolism and growth of the body fail. Iodine is associated with nitrogen in this chemical compound which, like the many other hormones, suggests itself as made up of protein molecules travelling through the blood from one organ or tissue to another and serving by catalytic action, or some similar way, as regulators of the many body functions. It is in connection with the functions of proteins that trace elements have demonstrated their essentiality, hence it is in the multiplying research on these life-carrying compounds by which we may hope to elucidate the roles and essentialities of the trace elements coming as inorganics from the soil and contributing themselves as fertility to the synthesis of the organics representing the growth of all life forms.

According as more means for detecting and measuring smaller and smaller amounts of elements are designed and discovered, the list of those essential trace elements found in living tissues and fluids will be a constant challenge to determine their essentiality. In the case of milk, the list of elements known earlier to be in it included calcium, magnesium, potassium, sodium, phosphorus, chlorine, iron, copper, manganese, and iodine, both major and minor elements all recognized as essentials. The natural deficiencies of iron, copper and manganese in milk were a decided help in the research in the trace elements. But when the spectrograph came along, this list of trace elements in milk was extended to include also silicon, boron, titanium, vanadium, rubidium, lithium, selenium, barium, strontium, chromium, molybdenum, lead and silver. That these are all essential in feeding mammalian off-

spring remains a challenge to our lack of knowledge as to what inorganic elements, and how much of each, milk must supply to give complete nourishment in its protein transfer from mother to young. For these items we have no complete theories regarding how or where they function. Nevertheless, as we use some of them as soil treatments, as feed or as food—even in excess and with resulting damage—doubtless our observations will provoke theories and thus advance research, accordingly, to extend the list.

CHEMICAL CATIONS AND ANIONS INTERACTING ON CLAY AND PLANT ROOTS INCLUDE THE TRACE ELEMENTS

Enough has already been said about this subject to make the essential point, as Schweigert puts it, that the "trace elements function in biological systems and events, no matter whether the processes are in the nature of energy transformations, a stimulus, a synthesis, or a destruction; whether detoxification of an organ, or part of an organ, takes place; or whether substances must be translocated, transferred, split-up, or reconstructed. The trace elements are mainly concerned with the activation of enzymes."[8] In Schweigert's listing of some hundred-fifty enzymes, five of the seven trace elements (those other than boron and iodine) are connected with many of them serving (a) as activators in ways not understood, (b) as integrants in some function, (c) as active in the enzyme, or (d) as the added part of some compound by which it becomes an enzyme. The functions in which the enzymes serve include oxidation, reduction, hydrolysis, transferences of parts of compounds to others, lysis, synthesis and various other vital performances.

Lists of the same trace elements, and many others, are active in the root hair cell. Their activities include not only the cell's metabolic functions, but also absorption of the nutrient ions through the cell membrane by contact with the colloidal clay of the soil from which the inorganic ions are exchanged via the carbonic acid surrounding the root as the result of its excretion of respired carbon dioxide. It is the well-considered assumption that the root-hair proteins play their role as the chemical means of moving inorganic fertility elements, both cations and anions, through the cell-wall of the root hair, and that these are moved within the plant similarly through their absorption on the colloidal proteins. Thus, since proteins are amphotyric, i.e. both negative and positive in their ionization of the carboxyl and amino groups respectively, proteins within the plant move the trace elements, cations and anions, from the soil into the plant. This is the postulate by means of which the explanations were built to equate the root hair as one cell against the clay molecules with active cations adsorbed there on a much less active silicate anion. Thus by single cell concepts we visualize how major and trace elements are held on the soil and moved from there into the root as nutrition for it and the entire plant. With our thinking reduced to the single cell scale, we can see the root hair as the equivalent in biochemical and biophysical principles of all the plant cells combined. Trace elements must function in connection with protein production in the cell of the root hair first and in other plant cells second.

Trace elements going from the adsorption atmosphere of the soil's colloidal particle into the plant root are each a part of a larger suite of cations and anions. Their complete effect on the plant is not an addition of their separate effects. Rather, it is an integration of the possible interractions of all the ions on each other, both cations and anions, and both nutrients and non-nutrients, in the colloidal atmosphere of the clay surface-root surface contact. Then, finally, it is the resultant effect of all that on the protein of the root hair cell. As cations (iron, manganese, zinc, copper and cobalt) and as anions (boron, molybdenum and chlorine) they must be viewed also in relation to the corresponding ionized groups of the major elements.

Among the latter, we commonly emphasize the interactions and interrelations between calcium and potassium, magnesium and potassium, calcium and magnesium, nitrogen and phosphorus, phosphorus and iron or aluminum, and between many others. Among the trace elements, the interractions are equally as pronounced, with some elements counteracting, whereby one prohibits another's injurious effects at higher concentrations. In the latter there is the illustration of arsenic offsetting the damage by selenium, and of copper counteracting excesses of molybdenum and zinc, but even not then unless in relation to the inorganic sulfate. In animals, the studies of the metabolism, according to E. J. Underwood,[11] of molybdenum seem worthless unless the copper and the inorganic sulfate in the diet are known. In the rat, the copper requirement is affected by the level of zinc. Copper and iron are interrelated in their activities in the building of red blood corpuscles. The level of copper modifies the effect of the iron, and the level of iron, in turn, modifies the effect of copper. Iron going into the plant and likewise manganese is modified by the level of phosphorus. All of this tells us that trace elements, like any other inorganic contribution from the soil to the plant's nutrition, is a part of complex chemistry and biochemistry of which the separate parts cannot be varied without correponding variation in many or all of the others. One factor cannot be varied while all the others remain constant. Older research tactics must be replaced by approaches more inclusive than the single factor techniques.

INTERACTIONS BY PAIRS ARE MAGNIFIED IN BEHAVIORS BY SWARMS

If the problem of plant nutrition is one of soil fertility elements for plant diets as delicately balanced as the nutrition of humans and animals is, then the matter of deficiencies in trace elements for plants might be considered the result of imbalances often in the major elements. Research on these tells us that both imbalances and deficiencies of the major elements may bring failure in the plant's equipping itself to take trace elements from the soil to the same degree as when those are properly balanced.

If we grant the truth of the plausible theory that copper is

needed by plants to grow their antibiotics protecting them from fungus attack,[1] then a demonstration of balanced fertility (calcium in relation to potassium) growing potatoes free from scab, while its imbalance did not,[7] suggests that the balanced fertility may have produced compounds in the root hair moving the trace element, copper, into the potato for its protection against the scab fungus.

It has been demonstrated[2] that inoculation as a means of helping soybeans produce more protein, in contrast to non-inoculation and bacterial absence with less protein in the plants, increased the extent to which the constant stock of exchangeable major cations moved from the refined clay into the plants. Since copper is a cation, we may well postulate that the higher concentration of protein in the potato plants by better balance of fertility was moving more copper into those plants too. Thereby they might be scab-free under balanced fertility but not under the imbalance of it by that difference in copper intake because of imbalance of the major elements. According to such thinking, then, the trace elements may actually be present in the soil when imbalanced plant nutrition in respect to major nutrient elements keeps them out of the plant and leads us to believe the soil deficient in trace elements. By applying the latter, their higher concentrations may or may not move enough of them into the plant to exhibit their effects—either direct or indirect—in protecting it.

If the varied interrelation of calcium to potassium in growing potatoes either protects from, or invites, the fungus scab to suggest the plant's taking, or failing to take, possibly copper from the soil for antibiotic service in the potato plant, in like manner the interrelation of nitrogen and calcium also suggested variable plant protection against insects in the growth of spinach. (Figure 1) Whether trace elements were involved was not tested. But with the effects by calcium of mobilizing other elements from the soil already granted[3] (Figure 2) and with the effects also by proteins for the synthesis of which nitrogen helps, there may have been more of some trace elements moved into this crop to create the specific protective proteins rather than only more crude proteins in general.

In another illustration, the interrelation of the two major elements, nitrogen and phosphorus in better balance in the soil growing corn, were the protection of the grain against damage by the lesser grain borer. (Figure 3) Grown on a highly fertile soil of South Dakota treated with applications of nitrogen only, the sample ear of corn grain under observation in storage was badly damaged while the sample ear grown on the same soil fertilized with both nitrogen and phosphorus and stored in contact with the infested ear was not.

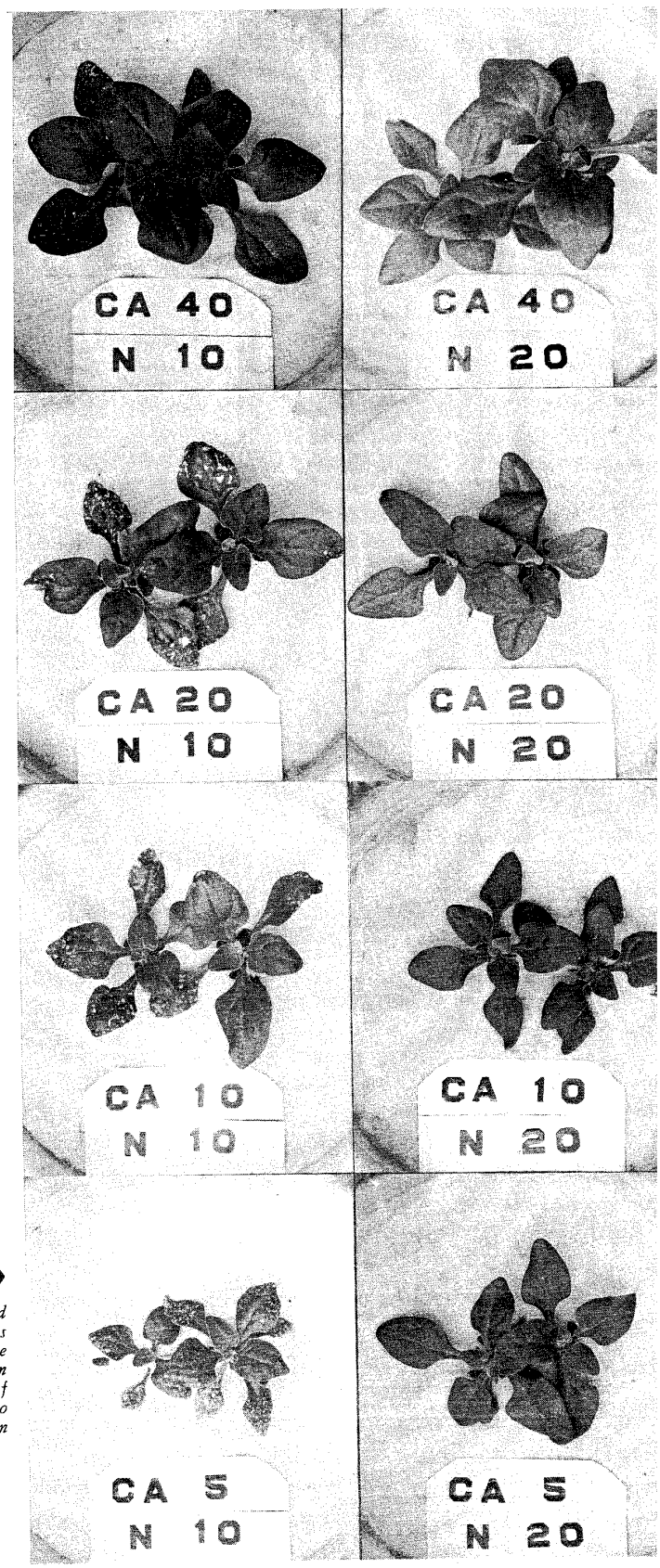

Figure 1. Spinach with 10 milligram equivalents and less of nitrogen offered in the soil was attacked by the thrips insects. (Photos on the left). Plants with 20 milligram equivalents and more in the same experiment were "immune" from insects. (Photos on the right). Even under low nitrogen or insufficient protein for self-protection, according as the 10 M.E. of nitrogen were combined with increasing amounts of calcium (from lower to upper photos on left) there was more self-protection against thrips grown into the plants and less insect attack resulted.

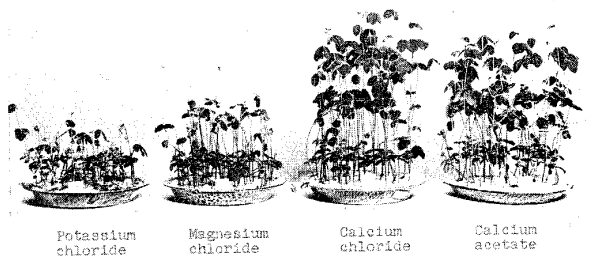

Figure 2—Calcium, in either the chloride or the acetate form, was more active in mobilizing the growth activities of these young soybeans into a healthy start than were potassium and magnesium.

Here again we have the demonstration exhibiting no clearly specific cause, save the suggestion that higher protein possibly of a particular quality in the plant was probably a cause per se, or was a help within the plant root for moving more fertility in kind and quantity, including more trace elements, from the soil into the plants and was causally connected only indirectly. Again, then, the soil with balanced fertility may have mobilized more of the inorganics into the plant or may have facilitated syntheses of special protective organics. The services by the soil directly and by the plant directly, or by the two in their interrelations, brought about the protection of the plant via nutrition for which a trace element like copper has long been believed of service only in terms of a poison sprayed on the leaf surfaces.

Magnesium and calcium in their interactions with the protein of the cells of the intestinal wall of our own bodies may be theoretical grounds for interpreting the purging effects by Epsom salts as action other than merely dehydration by a salt. When salts other than the magnesium sulfate taken in equal quantities do not purge, it seems more logical to consider the Epsom salt effects as a case where magnesium is exchanging places with the calcium in the colloid of the intestinal cell wall and contents to make that membrane, and more, a magnesium colloid. As such, it would not necessarily keep water, calcium, and other matters from flowing out through the intestinal wall and from its blood stream into the intestinal tract by which the purge would be brought about. The duration of the purge would represent the time required for the blood stream to remove the magnesium from the intestinal wall and to replace it with calcium by which the former normal, non-purging intestinal wall is restored. That such exchange of magnesium for calcium takes place is suggested by the increase of the magnesium in the blood during the purge. That blood calcium is lowered is suggested by some types of arthritis for which such purges have been considered hazardous.

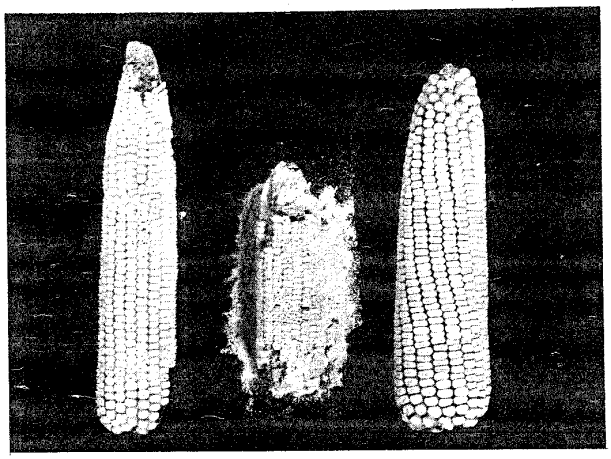

Figure 3—Grown on soil fertilized with nitrogen only, the representative hybrid ear of corn (center) was taken by the Lesser Grain Borer, but grown on the same soil fertilized with both nitrogen and phosphorus the representative hybrid ear (left) was attacked only where the two ears were in contact for two years. The open-pollinated ear in contact for six months has one borer hole as the damage to date.

The plant root hair in contact with a colloidal clay of low saturation by calcium has demonstrated the losses to the clay from the planted seeds' supply of nitrogen, of phosphorus and of potassium. It has been possible, thereby, to grow what looked like a good "hay crop" of soybean plants on so-called "acid" soil which was low in its calcium and other fertility elements while the crop was building up the soils' supply of nitrogen, phosphorus and potassium (none others tested) through losses of these from the supply in the planted seed. What seems like a good fortune in building up the fertility of the soil by planting and growing a legume for hay is a misfortune for the survival of the soybean species. Grown on such soil, it could not make seed enough to procreate itself in the next crop. There is still greater misfortune for any poor cow that consuming the crop, almost like a hay-baler, could not get the equivalent of protein and its accompanying essentials she would have obtained had she eaten the seed originally planted. Root hair cells in contact with the clay illustrate the many possible interactions between all the inorganic elements on the clay, and then between these and the organic contents of the root hair cell. All these illustrate the complexity of the biochemical requirements for protein production in growing healthy plants, animals and man.

PLANT PRODUCTS, MICROBES AND TRACE ELEMENTS EVEN IN THE ANIMAL RUMEN

That the deficiency of trace elements may be due to the kind of crop which we select for its bounteous growth rather than one of higher protein content, not so easily grown without soil fertility additions, was emphatically exhibited in a report by Dr. H. J. Lee, of Australia.[4] Now that the popular grass plant, Phalaris tuberosa, after its introduction there some thirty years ago, has extended itself in pure stands and in combination with other species to over 200,000 unirrigated acres (annual rainfall 17-20 inches), the sheep and cattle become afflicated and die with a staggers syndrome

ascribed to the toxicity of this popular grass species. Diluted sufficiently with lucerne, subterranean clover or other more proteinaceous fodder species there is no toxicity. The animal damage and deaths result from some toxic principle within the plant—not stored in the tuber—during its active growth and made harmless as the plant dries off.

The trace element cobalt, administered as a soluble salt to the grazing sheep frequently, Dr. Lee reports, "will completely protect the animals against phalaris staggers even when they are grazed continuously on pure stands of phalaris. During the course of our various experiments 77 sheep have been dosed at least once each week, with a total of 28 mg. of Co (as $CoCl_2 \cdot 6H_2O$) per week. Not one of these animals developed staggers, whereas 52 of 78 comparable untreated sheep developed the malady under the same grazing conditions." Also, "when the frequency of the administration is increased, minute amounts of cobalt have proved entirely effective. Thus as little as .05 mg of Co, when drenched each morning and evening, completely prevented the onset of staggers when all the untreated controls succumbed to the malady."

That the cobalt functioned as prevention via the microbial processes within the rumen of the digestive tract is suggested when "in another experiment it has been shown that frequent intravenous injections of cobalt chloride solution had no effect whatsoever on the incidence of staggers. Even though the amounts injected were sufficient to load the tissues of the sheep about ten times the normal concentration of this element."

Further, "it is known that cobalt injected intravenously is excreted in part into the small intestine, being conveyed there mainly via the bile, and that it is to be found in appreciable concentrations in the large intestines. From these considerations it is apparent that, cobalt does not act systemically nor yet within the intestines, but rather that its preventive effect depends upon the maintenance of a certain minimal concentration of cobalt within the rumen."

Still further Dr. Lee reports that "This is a specific activity of cobalt. We have shown experimentally that sheep that were dosed twice each week with a composite mixture of the approximate soluble salts of copper, zinc, manganese, iron, molybdenum, boron, magnesium, nickel and titanium, at the rate of 35 mg. of each of the elements developed severe symptoms of staggers while confined to a phalaris pasture, whereas comparable animals in the same flock which were drenched with cobalt chloride at the same rate remained unaffected."

That the health of animals depends on delicately adjusted interactions between fertility of the soil, microbes, and plants is well illustrated in the reports from research in Australia and other reports on trace elements. There is the further significant suggestion that the deficiency of trace elements coming from the soil through the plant may not necessarily be remedied by using the hypodermic needle to put the deficient trace element into the system when such an introduction of it by-passes the alimentary tract, the portal vein, and the liver or the combination for normal physiological censorship before introduction into the blood stream. Bringing trace elements along Nature's assembly line from soil, to plant, and to animal or man is a procedure not yet understood fully enough to believe we are as completely in control of it as we are in the production of some non-living industrial output.

TRACE ELEMENTS FOR HUMANS AND AS SOIL TREATMENTS FOR ANIMALS GIVE PROTECTIVE PROTEINS

Elements deficient or out of balance, regardless of whether they are trace or major elements, will bring on failing functions with the resulting poor growth, insufficient protection against "disease," and poor reproduction. Such conditions mean deficiencies and imbalances in the essential organic compounds which are synthesized by the help of the elements. They mean less organic compounds in the soil from decay of the preceding crops grown there which may be taken directly by the root hair cells as organic "starter" compounds from which the plant's biochemical construction takes off in building all else that is the plant tissue, growing in mass and

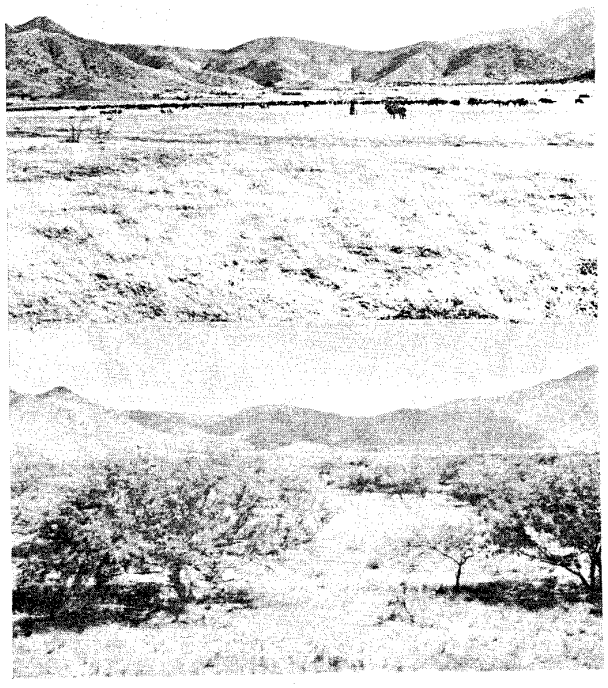

Figure 4—The ecological climax of protein-rich grass discovered in the valley of the Santa Rita Mts. in 1903 (upper photo) was not a cattleman's paradise very long (lower photo 1943) when the fertility removal in the crop and failure to return the equivalent of the annual crop's organic matter prohibited its continued growth but allowed the mesquite to take over.

protecting itself against digestion by some other life forms like bacteria, fungi and even insects, if not also viruses.

When in the ecological climax of any crop in nature, we observe that the plants are a pure stand without crop rotations, without crop removal, and are without weeds, fungus diseases, or insect attacks, where no poisonous chemical sprays have ever been used, are we not compelled to believe that when conditions other than those prevail, the plant nutrition must be falling much lower than that of the same kind of plants in the climax? Must we not grant the failure of the plants to synthesize the proteins and all else by which they protect themselves in the climax? (Figure 4). Should we not believe, also, that in failing to protect themselves they are correspondingly lower in the nutrition they represent in our use of them as our food? Fighting diseases and pests with poisons is a case of calling in pathology to explain where the failing physiology because of its failing support by complete nutrition is unknown and not considered.

Brucellosis in animals (and humans) suggests itself as an illustration of our undue emphasis on symptoms and pathology when the cow's failing conception, her abortion of the embryo-calf, and all else of symptoms associated with this so-called "contagious disease" are ascribed to the Brucella microorganisms harbored initially in the vaginal tract. Much is made of the protein by-products from this microorganism taken into the bloodstream and their provocation there of the body's production of counteracting proteins which agglutinate with laboratory cultured products from the isolated microorganisms. It is not commonly questioned whether the contemporaneous association of the vaginal infection and failing calf crop are truly causally connected; whether the disease is really contagious; or whether both might have a common cause in the nutritional deficiencies, including deficiencies of the trace elements. Yet, the fertilizing of the soil with all elements considered helpful, including the generous application of the trace elements, shifted a badly infected dairy herd from its failing reproduction to complete conception under minimum male services and with calf crops nearly 100 percent. Seventeen heifers and their calves, all of which were produced during four years of contact with the marked herd after proper feeding by soil treatment for it, remained free of the microorganisms for which the other animals were about to be condemned to death. Here is a case where a "contagious disease" apparently was prevented by the best of soil treatments including the trace elements. At the same time, patients with undulant fever given trace element therapy under guarded diets and controlled activities soon shifted from ailing bodies to those of buoyant health and ebullient enthusiasm and testimony for the virtues of trace elements as food supplements.[6]

Since protection of the body depends on specific proteins (antibodies) the synthesis of which is brought about by the introduction of the correspondingly foreign proteins (inoculation for a desired immunization); and since any proteins are built up by combinations of amino acids as proteins taken into the body and digested out of food; we are dealing, in the main, with the problem of always having ready, or providing quickly, the required amino acids. Since the human body does not synthesize these from the elements, it cannot build antibodies (compounds also of amino acids) hastily unless ample supplies of the required compounds are in the body's stores. If the body cannot build antibodies or immunity, must that not be due to shortages of the amino acids required for this construction?

When an allergic reaction occurs, must we not interpret that as due to the shortage of the amino acids (proteins) required to help the body handle the foreign, or causative, protein and thus preventing that severe reaction? Such shortages may result, seemingly, from the body's failure to have equipped itself earlier in life for such occasions. When a baby cannot take foods of promiscuous kinds, but must take each new or foreign one in the order of development of physiological processes or the body mechanisms to handle it, does it not seem probable, that when the body does not meet a certain protein early in life, it is passing up the occasion for establishing the necessary mechanisms for counteracting such foreigners, and that those mechanisms may never be established? It seems clear, then that the animals and humans must depend much on the amino acids delivered to them, while the microbes and the plants may synthesize them from the elements and simpler compounds. Accordingly, then, the protein problem is one of the major elements, the trace elements and the organic matter in the soil and above it by which the amino acids are synthesized by the growing plants and the microbes.

MANAGEMENT OF SOIL AND CROPS FOR GROWING REQUIRED AMINO ACIDS OFFERS HOPE

If crops are to be managed for their output of amino acids for us, then attention must go; first, to the amino acids about

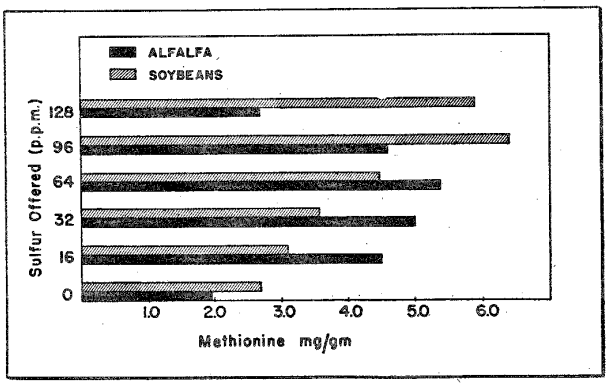

Figure 5—Sulfur as a neglected soil fertility element demonstrated its effect on the concentration of the commonly deficient amino acid methionine in the two legume crops, alfalfa and soybeans.

NITROGEN DISTRIBUTION AS LYSINE AND ASPARTIC ACID IN BROME GRASS HAY

REED, SHELDON AND ALBRECHT-UNIVERSITY OF MISSOURI (1953)

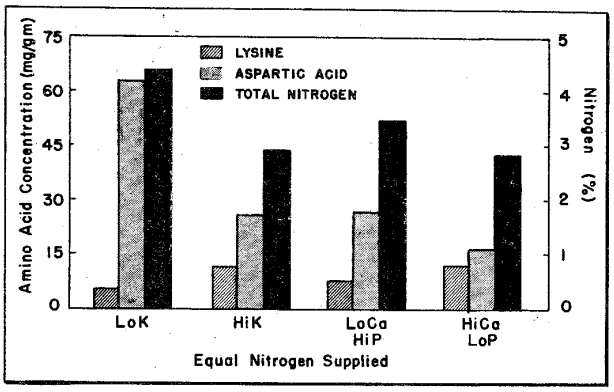

Figure 6—That the nitrogen in a non-legume like brome grass hay may vary without correlation to some of the different amino acids, especially the commonly deficient lysine, has been demonstrated. Total nitrogen as the index of "crude" protein does not give any suggestion as to the quality of protein in terms of the respective amino acid.

which we need be concerned, namely, the three most commonly deficient, tryptophane, methionine, and lysine; second, to the choice of those crops given to higher protein delivery and such in a wide array of amino acids; and, third, to the balance of soil fertility in both major and trace elements, through which those three commonly deficient amino acids may be increased in the plant's output of protein for life processes of higher order primarily for its own survival and secondarily for ours.

Research work directed along these lines of modifying the plant's output of amino acids by using the colloidal clay

TRYPTOPHANE CONCENTRATION IN REDTOP HAY ACCORDING TO CALCIUM AND PHOSPHORUS SUPPLIED

SHELDON, BLUE AND ALBRECHT-UNIVERSITY OF MISSOURI

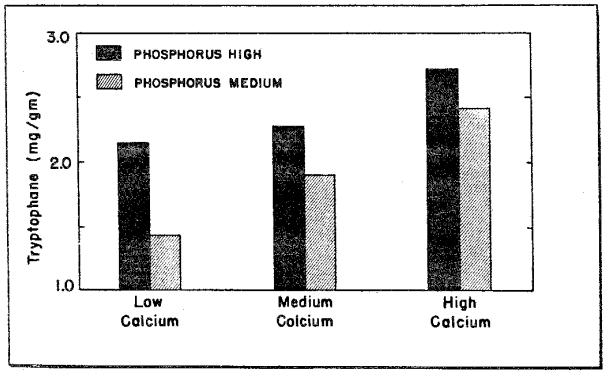

Figure 7—The major elements in their relations to each other modify the synthesis and concentration of tryptophane in non-legumes. When the phosphorus offered by the soil was low the increased offerings of calcium did not give as high a concentration of this essential amino acid as when the phosphorus was also high.

CONCENTRATION OF TRYPTOPHANE IN HAYS ACCORDING TO BORON SUPPLIED

SHELDON, BLUE AND ALBRECHT-UNIVERSITY OF MISSOURI

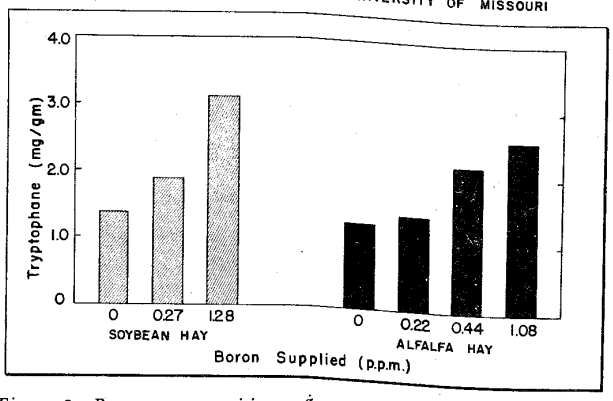

Figure 8—Boron as a nutritient offered the soybeans and alfalfa in higher amounts served to give higher concentrations to the commonly deficient amino acid, tryptophane.

technique for accurate control of the offerings in exchangeable soil fertility, and in nutrient solutions, has demonstrated that more methionine, the sulfur-containing amino acid, could be grown into legumes like soybeans and alfalfa by increasing the sulfur in the soil when all other elements were ample.[10] Alfalfa pushed its concentration of this amino acid higher also on taking more sulfur from the soil. (Figure 5)

Tryptophane was related to the magnesium, the increase of which in the soil served to increase the concentration of this amino acid in the legume crop. But it has not yet been demonstrated clearly that tryptophane's concentration could be increased unless most of the amino acids (those measured readily) were increased to keep them in a more nearly constant ratio[9]. The concentration of this amino acid was not related necessarily to that of the nitrogen in the plants. (Figure 6). Tryptophane in red top hay, a non-legume, increased decidedly as the calcium offered was increased. That concentration was higher as the variation in calcium was demonstrated at higher levels of phosphorus in the soil. (Figure 7). Both alfalfa and soybeans carried higher concentrations of tryptophane as the soil offered more boron. (Figure 8). Other trace elements were also effective in the increase of tryptophane synthesis. (Figure 9).

Lysine has not yet been fitted into a relation to any factor suggesting the latter's significance in modifying the concentration of this one of the diamino constituents of the proteins. The trace elements were prominent in their effects toward increasing the amino acids in these legumes. To date these correlations have not become specific enough to connect one trace element with one amino acid necessarily more significantly than with any others in each case.

In alfalfa, sulfur deficiency in the soil has long been known to be disturbing to its growth. This deficiency, studied in relation to eighteen amino acids in alfalfa, demonstrated the

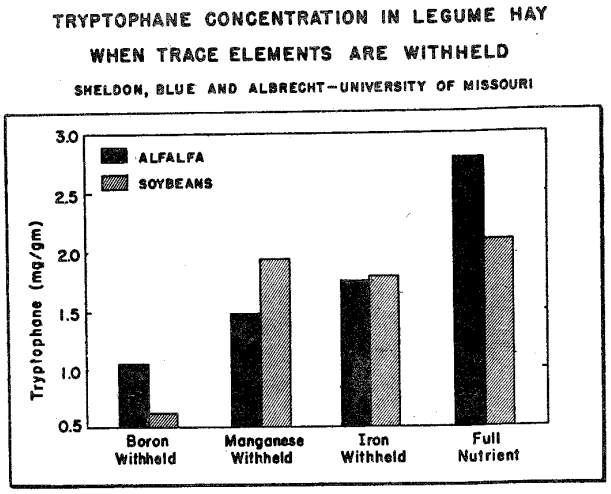

Figure 9—Withholding any one of the four trace elements tested, held down the concentration of tryptophane in the two legume plants alfalfa and soybeans. The wide variations in this essential amino acid suggest possible protein deficiencies in the hay as feed when the soil is deficient in trace elements going into these crops.

reduction in their concentrations in the dry matter for sixteen of them[5]. Sulfur deficiency in the soil increased the concentrations of but two of them, a doubtful amount of arginine, a six carbon, diamino acid, but a decided amount of aspartic acid, a four-carbon acid. The dry weight of the alfalfa represented by these two acids which were increased was the equivalent of the combined reduction of about ten of the other amino acids. This would suggest the role of aspartic acid as possible source of the others if the enzymes for its conversion into them were activated by the higher sulfur in the soil. (Figure 6). Sulfur as a deficiency may be responsible directly for the failure of this conversion, or indirectly through some other role of sulfur.

The agricultural production of all that is required for nutrition of ourselves and our livestock, via plants and microbes by wise management of our soil already mined for many years, emphasizes the production of the essential amino acids as the major struggle. For this, not only the major fertility elements and gross yields of any kinds of crops will be the true measure or guarantee. Instead, soil fertility refined to the degree of trace elements, both those known and possibly many unknown, must be considered in relation to production of the complete array of amino acids essential for the nutrition of the particular crop, and in turn for the nutrition of animals and man. Trace elements can help as tools. Proteins serve similarly in many cases as enzymes, hormones, antibodies, etc. Trace element behaviors need to be fitted into the chemical order characterizing major elements, with reference to one element's activities influencing those of any others. If all these are studied by means of bioassays using microbes, plants and animals, then the chemical situations will be elucidated to degrees of refined clarity far beyond possibilities by common laboratory measurements.

Integration of the inorganic and the organic, of the chemical and the biochemical, and of other reactions must be extended. Such integration is nature's behavior as illustrated even by trace elements influencing the effects of organic compounds through microbes in the animal rumen. Also much is not recognized in the human body's reactions to "traces" of elements considered essential, to say nothing about the many others, present in the body regularly but not catalogued for their essentiality.

Should we study ecological climaxes more carefully, possibly the essentiality of organic compounds of the soil would be emphasized more. Those might be connected with trace elements, both essential in soils growing foods for better human health through possibly more complete proteins for microbial life in the soil. We would see organic microbial by-products contributing nutrition to plants for better human health as well as for their own.

With increasing allergies, caused supposedly by our failing mechanisms for handling foreign proteins, we need to study the amino acids grown in plants other than crops. Now that we are using only a few trace elements as fertilizers on the soil, while we are dumping the major essentials, calcium, nitrogen, phosphorus, and potassium on generously, we should see the need to connect trace elements with complete proteins. Such knowledge would emphasize the growth of more complete proteins as our food, and for their protective helps and other incidental services in which they and the trace elements connected with them biochemically seem to perform widely.

All of this tells us that "ash" element deficiencies are only a part of nutrition of man and animals. That is true also for nutrition of plants and microbes, even though they synthesize their necessary proteins from the elements. All lower forms of life can use organic compounds and grow more rapidly as those compose the larger share of the feeds. We are not yet well enough informed of all the items our bodies use when we consider their nutrition, hence even knowledge of trace elements and protein production—ever so challenging in their complexity of detail—leaves much that is still unknown if we were to attempt to design nutrition by assembling the separate chemical parts. Regardless of a profound respect for Nature's contributions to our foods via the soils that grow them; for all the various crops that will serve as food; and for our judicious selection of substances either organic or inorganic with which to supplement these, there is still much to be learned if we are to build the best of health possible by means of proper nutrition.

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BIBLIOGRAPHY

1. Albrecht, Wm. A. Trace Elements and Agricultural Production. Jour. of Appl. Nutrition VIII: 352-354. 1955.
2. Hampton, Herbert E. and Wm. A. Albrecht. Nitrogen Fixation, Composition and Growth of Soy Beans in Relation to Variable Amounts of Potassium and Calcium. Mo. Agr. Expt. Sta. Res. Bull. 381, 1944.
3. Klemme, A. W. and Wm. A. Albrecht. Limestone Mobilizes Phosphates into Korean Lespedeza. Jour. Amer. Soc. Agron. 31: 284-286. 1939.
4. Lee, H. J. The Toxcity of Phalaris tuberosa to Sheep and Cattle and The Preventive Role of Cobalt. Seventh Internat. Grassland Congress.

Session No. 9. Micro-Elements and Vitamin Deficiencies in Grazing Animals. pp. 3-11. November 13, 1956, New Zealand.
5. Mertz, E. T., V. L. Singleton and C. L. Garey. The Effect of Sulfur Deficiency on the Amino Acids of Alfalfa. Archives of Biochem. and Biophysics. 38: 139-145. 1952.
6. Pottenger, F. M. Jr. M.D., Ira Allison, M.D., and Wm. A. Albrecht, Ph.D. Brucella Infections. The Merck Report. July, 1949.
7. Schroeder, R. A. and Wm. A. Albrecht. Plant Nutrition and the Hydrogen Ion. II Potato Scab. Soil Science 53: 481-488. 1942.
8. Schweigert, H. A. A Discussion of the Mechanism of the Reaction of Trace Elements. Pflanzenernährung 54: 36ff, 1951. Potash Review. Internat. Potash Inst. Berne, Switzerland. Sept. 1956.
9. Sheldon, V. L., Wm. G. Blue and Wm. A. Albrecht. Biosynthesis of Amino Acids According to the Soil Fertility. I Tryptophane in Forage Crops. Plant and Soil, III: 33-40. 1951.
10. Sheldon, V. L., Wm. G. Blue and Wm. A. Albrecht. Biosynthesis of Amino Acids According to the Soil Fertility. II Metionine Content of Plants and Sulfur Applied. Plant and Soil. III: 361-365. 1951.
11. Underwood, E. J. Trace Elements in Human and Animal Nutrition. Academic Press, New York. 1956.

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