The Influence of Soil Mineral Elements on Animal Nutrition

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INTRODUCTION

A CENTENNIAL ANNIVERSARY is naturally a significant occasion in the history of an institution in the United States. With the turn of the hundredth year one is reminded that such length of time in prospect seems tremendous. But a corresponding time in retrospect seems short. The prophetic view is never so clear in its portent as is the postmortem. Hindsight has always been much more instructive than foresight. The former makes mental impressions with accompanying stronger and more disturbing emotions, hence is more of a modifier and determiner of our future behavior than is the latter.

But in an agricultural experiment station, where the living, i.e. the biological, more than the dead, or the technological, matters concern us, we have numerous and significant postmortems regularly. This seems more true now with so much emphasis on economics and sociology, when the cleaning away of disasters and the covering of defects of past mistakes occupy our thought almost to the exclusion of the preventive viewpoint. We scarcely have time to look ahead and to catch visions. We miss the chance to theorize as to how man can fit himself on to his agriculture, required to feed all of us, and into the laws of Nature, including both those recorded and those not yet comprehended.

But anniversaries are occasions encouraging us to look ahead, and to profit by means of what is behind the anniversary date. The extrapolation and the reach into the future, however theoretical and short of proof that stretch of vision is, may well "let us study things as they are and not as we have made them. Let us question our beliefs to see whether they really fit the facts. If they don't let's cast them out."[1] Anniversaries are times permitting decided shifts in viewpoints which may be a healthful experience occasionally even for some sections of an Agricultural Experiment Station and a College of Agriculture.

THE SUBJECT

The subject "The Influence of Soil Mineral Elements on Animal Nutrition" as assigned for discussion on this occasion, reminds us that the production of animals and their service to man for his food, clothing and even shelter, is an art older than man's recorded history. The importance of an adequate supply of forage for the well-being of the herds and the flocks, and thereby for man, has long been well recognized. The ancient writings in The Great Book of all books point out the need for grass. They discuss the capacity of the land to grow crops in sufficient support of the cattle lest there be strife between the herdsmen and between the herd owners. There are suggestions from ancient authors (5) to indicate that, even before the Roman era, men were aware that plants are no better than the soils on which they grow, and animals are no healthier than the plants which nourish them. Not quite so long ago, Izaak Walton, in his *The Compleat Angler* pointed out that the soil fertility is a factor in determining the quality of sheep wool, and in the tastiness of the trout. "And so I shall proceed next to tell you" (18) he says, "it is certain that certain fields near Leominster, a town in Herefordshire, are observed to make sheep that graze upon them more fat than the next, and also to bear finer wool; that is to say, that in that year in which they feed in a particular pasture, they shall yield finer wool than they did that year before they came to feed upon it, and coarser again if they shall return to their former pasture; and again return to a finer wool, being fed on the finer

[1] P. H. Hainsworth. *Agriculture, A New Approach*. Page 232. Faber and Faber. London. 1954.

wool ground. Which I tell you that you may better believe that I am certain, if I catch a trout in one meadow he shall be white and faint, and very likely to be lousy; and as certainly as if I catch a trout in the next meadow, he shall be strong and red and lusty and much better meat; trust me, scholar, I have caught many a trout in a particular meadow, that the very shape and enameled color of him was made such as hath joyed me to look on him; and I have then with much pleasure concluded with Solomon, 'Everything is beautiful in its season'."

Izaak Walton in that observation of 300 years ago saw the difference in the health, in the wool, in the quality of the fiber, in the sheen of the body color, in the quality of the muscle meat, and even in the presence or the absence of insect infestations of the beast and the fish in the fields and the streams, all related to the fertility of the soil. Our subject for discussion is then an old and a long familiar theme to the keen observing naturalist even though to us as scientists it may seem still new, strange, and not entirely proved.

THE ECOLOGICAL, OR DEDUCTIVE APPROACH

In dealing with this subject, "The Influence of Soil Mineral Elements on Animal Nutrition," one might consider two methods of approach, either (a) the inductive one which would study each inorganic element and tabulate its nutritional services to the plant and to the animal under experiment and then from that collection of data would piece together and tell the final story; or (b) the deductive one, which may be considered the ecological approach. In the latter, by studying Nature's pattern of animal placement in different areas, i.e. according to the ecological pattern, we would learn the soil differences as to mineral elements representing causes of animal presence and animal absence according to the natural processes of evolution. This is a qualitative attack and not a quantitative one. It notes the presence or absence of certain products and not how much or how well. In this discussion we shall use mainly the ecological or the deductive approach as a good beginning. We shall observe and investigate Nature's pattern and by both deduction and experimental inductions find reasons for Her locating animals on some soils and not on others. Then we might possibly deduce, therefrom, the roles of the different minerals, or the soil fertility elements in plant nutrition and thereby in animal nutrition, at least by the way they cause animal absence or the animal's failure to survive.

In this approach we shall accept the American bison's presence in great herds upon the Plains as evidence of a fairly good array of mineral elements in the soil there, or, at least, of very good combined influence on animal nutrition through the virgin forages grown there. It avoids the distorted view of nutrition which too often is mainly a fattening process, and then one of a castrated male with a very limited life span, demonstrating all too little of nutrition for the procreation and survival of the species.

By using this soil pattern with the areas of soil minerals of high and favorable influence on the survival of the bison as the guide and starting point, we are impressed with the large land areas of virgin soils of mineral or fertility contents too deficient in only one or two nutrient elements for the survival of this quadraped. We should also be impressed by the applicability of those ecological facts to our cattle herds and other livestock when the bison on those soils was duplicating our domestic animals in many details of their physiological complexities: (a) of growth, (b) of body protection against disease, and (c) of reproduction of high fecundity for survival of the species without the help (or interference) of man and his agriculture.

THE ANATOMY OF THE RUMINANT CONNECTS IT MORE CLOSELY WITH THE SOIL

Since the bison is a ruminant and the herds of the Plains lived by forages, or roughages, in considerable bulk and not by masses of grains and other concentrates, our view of the animals in this discussion may well be limited to the ruminants also. With the paunch as a digestive or fermenting vat at the head-end rather than the tail-end of the cow's alimentary canal, the forage she ingests brings with it the soil microflora and microfauna for action in the anaerobic conditions there. By that fact she lets us connect her more closely with the soil. She profits by those symbiotic microbial relations, especially when her ingestion of urea within limits and its service as protein supplement bears the suggestion that its chemical structure with the amino nitrogen attached to the carbon serves so much more efficiently than does ammonia nitrogen or other nitrogen forms not so closely similar to the amino acid structure of protein as is urea. That she has some advantage for survival on forages only by that particular anatomical arrangement and microbial symbiosis of the paunch is suggested by the close companionship in which the pig and the chicken have always held her as one of the barnyard family by following on the heels of the cow so closely to feed on her droppings of dung but not of the urine. When the pig and the chicken have their microbial digestive helps within the alimentary canal at the tail-end of it, they are not so closely connected with, nor so completely supported by, the soil as the cow is. That the flora and fauna of the cow's paunch respond to the differences in "ash" minerals coming in the forage as feed from the soils of differing fertility was illustrated by the higher amounts of volatile fatty acids resulting from the same ration in the rumen (artificial) according as there was added the ash of alfalfa grown on the more fertile soil types or the soil more carefully fertilized (12).

We may well consider the bison as the early ruminant fauna outlining a pattern of animal survival according to fertility pattern exhibited by the mineral or inorganic elements in the soil. Then by considering the cow as a physiological duplicate to be scattered for her survival over the same geographic area, the problem does not necessarily require our being certain that we can prescribe the array of soil fertility elements complete enough in list and functions to give certain specific results for economic management of the herds of cattle. It would be also a vain presumption to believe that we have obtained that much organized knowledge about the soil and its capacity for creating livestock. Rather by studying the soils and their natural flora in the areas where, and by which, the bison survived in contrast to the fringes and areas outside of his concentration where he was extinguished, we can detect more nearly one or two inorganic elements of which the shortage may be limiting the forage production in amount and in quality for the survival of our agricultural ruminant, the cow. Even then the problem soon becomes one of combinations and permutations, rather than single element research, in a long list when several fertility elements may be missing and many more of them may be in imbalance for the growth of the forages of sufficient quality for even ruminant species survival under the handicap of our domestication.

THE INTERPRETATION OF THE SOIL AS COMPLETE ANIMAL NUTRITION CHALLENGES WISDOM OF BOTH COW AND MAN

In considering the soil mineral elements in animal nutrition by way of the ecological pattern of the area like the United States, the size of the problem is already disheartening when, (a) by the soil as a contributor to animal feeding in a concentrated way like agriculture, less than 10 percent of the earth's crust serves for farming; and (b) by the plants, only about 5 percent of the sun's energy is used; and (c) by the animals, less than 25 percent of their feed is converted by the livestock into food for our use. This would indicate that all the weathering, all the geological, all the volcanic, or other changes on the earth's surface have not been philanthropically getting the chemical array of soil minerals collected into the soil with nutrition of domestic or even wild animals in prospect everywhere.

In considering the subject of the close nutritional connection between soil fertility and animal nutrition then, should we be appalled when the soil hinders the survival of so many domestic animals because of their multiplying numbers of diseases, their increasing degeneration, and their failing reproduction? Should we not recognize our lack of knowledge of how the animals feed themselves in Nature or how we survived when the cow as a perambulating soil chemist and soil tester went ahead of the plow to lead us to fertile soils on our westward march? Recognizing that scant collection of facts, not even organized into a science on that subject, we would seemingly have ample reason in humility to congratulate the cow on her survival in spite of us when we changed the order and have now put the plow ahead of the cow while we are acting as the chemists and the soil testers presuming to serve in the creation of her species. That we have learned about some few of the soil minerals to be applied separately, as fertilizers, for better animal nutrition by way of the forage crops we grow, indicates the magnitude of the problem. That we have not yet juggled all the nutrient elements of the soil into the proper combination; that we have not yet found the collection of crop plants to be grown on that suite of them in the field, should not be at all surprising. If then we have not arrived at the level of knowledge giving complete diagnosis of the cow's deficient health and failing reproduction, or if we have not yet written the complete prescription in commercial fertilizers from the chemist's shop by which the problems of animal nutrition will shift into regular and satisfactory profit, we should not be appalled. The many processes of creation which originate in the handful of dust have not had much more elucidation in terms of physiological chemistry even today than was implied in that allegorically reported way of merely starting them from the soil as given us in the record of a few thousand years ago. The past century has opened our minds to the soil fertility as potential plant and animal nutrition, but the *modus operandi* of each of the essential or non-essential elements in that service is a challenge remaining to be met in the next hundred years and reported at the next centennial celebration.

ESSENTIAL ELEMENTS REPRESENT WIDELY DIFFERENT GROUPS AND PROPERTIES IN THEIR CLASSIFICATION

At the outset it may be well to list the so-called "essential" elements for plant growth included up to this moment in our growing knowledge of them periodically well summarized (7). It might be well to characterize them by groupings according to certain chemical properties, reactions, or services in the physiology of the microbes, plants and animals. Among those composing most of the plant bulk, thereby the most combustible plant parts, are carbon, hydrogen and oxygen. These make up the carbohydrates into which by reductive changes three others are combined, namely nitrogen, sulfur and phosphorus. These changes of the carbohydrates, which are serving as starter compounds in the plant's synthetic performances, make the proteins and other compounds closely associated with them like the enzymes, the hormones, etc. Of these six elements just listed, four, namely the carbon, hydrogen, oxygen and nitrogen are commonly considered as coming, not from the soil, but from the atmosphere and water in the ultimate. But while the plant nitrogen of ultimate atmospheric origin, is taken by most of them from the soils via organic matter transformed there, so we are realizing slowly that carbon, hydrogen, and oxygen, also of ultimate atmospheric origin, may be going more directly into the plant as organic compounds taken from the soil. The soil is the medium through which the fertility contributions from the atmosphere make their way. These six elements are spoken of as constituents of the "structural organic" part of the crops.

Among the elements more commonly connected with the ash, or non-combustible part of the plant, are the alkalies and the alkaline earths, i.e. potassium and sodium in the former and calcium and magnesium in the latter group. Among the elements required in trace amounts for plants are the heavy metals, manganese, iron, zinc, copper and molybdenum; and the light metal boron, to which may eventually be added the light metal silicon if we ever consider it essential for plants as its general presence in them might lead us to believe, though plants grow without it. Very recently chlorine has been demonstrated as required for plant growth (6). Other elements may be considered essential for the plant when it serves to deliver them within itself as essentials for the animal. In the case of silicon, not considered essential, much of it is found in hoof and hair of the animals. But, since it is one of the chemically sluggish performers, we have not yet decided that it is essential for animal growth even though present in larger measure in plants as, in general, they serve less effectively in animal nutrition. In the above list of seventeen elements essential for plant growth there need to be emphasized the two, namely sodium and chlorine as required for the animals in quantity and then to be added are the iodine, the cobalt, and possibly the fluorine required in trace amounts for animals but not so recognized for plants.

In addition to considering those elements coming from the soil for benefit, one dares not omit the soil-borne elements of which extra supplies there may be entering the plant for harmful effects. Among those considered non-essential but injurious to both plants and animals are arsenic and selenium. Among those both essential in trace amounts and possibly injurious in large amounts are boron, manganese, copper and fluorine.

Among the seventeen elements so far considered essential for plant growth and the three or more required for animals, the ultimate origins of four, that is, carbon, hydrogen, nitrogen, oxygen, in the atmosphere and the hydrosphere may be reason for omitting these four in discussing the soil mineral elements in animal nutrition. If so, we must concern ourselves with only thirteen elements coming from the soil by way of the plants, whether their separate services are known or unknown there, and going into the animal by way of the feed taken. They are going into the animals as combinations within the organic matter composing the forages consumed and not as minerals or salts. For purpose of this discussion let us consider the animal's taking to salts as a case of ministration of relief on our part or a kind of depravity of the animal's appetite equivalent to the chewing of bones occasionally exhibited by some of the starving cattle as an act of desperation.

ELEMENTS' ACTIVITIES FOR RETENTION IN THE SOIL AND ENTRANCE INTO THE PLANT ROOT ARE FOREMOST CRITERIA

As another classification of the mineral elements in animal nutrition, one might list their anatomical location, or their presence in larger amounts of each in different body parts. But more helpful than these "ash analyses" by areas of anatomy, are the location of the elements by physiology or function in the plant first and then in the animal. But rather than undertaking these considerations it would be helpful to note the geo-chemo-dynamics by which the elements are held in the soil and are active there in entering the plant root. Thus we would work in the element's course "from the ground up" to the animal, and not in reverse from the animal back to the soil.

Our knowledge of plant nutrition in terms of the soil-borne elements, in the form of clearer concepts of how these are held in the soil and how their activities move them from there into the plant root, has built itself up for only some of the positively charged ions. Calcium, magnesium, potassium, ammonium, nitrogen, and sodium are in this cation group now that the commonly larger quantities of them have allowed us to connect them with a negatively charged collodial clay molecule and to study their activities there. As for the trace elements with the positive charge, naturally, they can also be held by the clay except for the chlorine as an anion. But their active movement from that site and their nutritional services to the plant have not been demonstrated as is true for the above few. Their trace or limited quantities have kept them outside of the pale of our comprehension and precise tabulation.

Our concepts of how the anions or negatively charged ions of nutritive service to the plants are held in the soil and mobilized into the plant root have not taken on geo-chemical, or physico-chemical, or biochemical stature equivalent of that we now conceive for the major cations. This inorganic half of the nutrient elements, namely the anions, is still in that mental haze regarding basic chemical behaviors which we exhibit when we speak so commonly of "available" or "extractable" nutrients. When the anions are adsorbed on positively charged colloidal plastics, their exchange activities from there into the plant root simulate those of the cations held by and exchanged from the clay colloid. We have been content up to this moment with concepts only of cationic exchange when we know that no cation exists without a corresponding anion and no anion exists without a corresponding cation. We seem oblivious to the fact that for ions in nature there is no contented state of bachelorship.

Likewise our concepts of what organic compounds may be taken directly from the soil are not well developed though for the inorganic anions like nitrate and sulfate we look to decaying organic matter of the soil. For the anion phosphate, we know little more than its "fixed" or "extractable" states, yet it is highly essential in the transformation of carbohydrates both in photosynthesis and in respiration (4). The most neglected anion may perhaps be the bicarbonate with its origin in respiration, when this is so universally present in the rhizosphere and when plant nutrition is so readily disturbed by very small amounts of fertilizer anions (chlorides and sulfates) applied on soils of lower contents of decaying organic matter. The neglect of the anions in our thinking seems to be as serious as is the neglect of the carbon compounds or the organic substances taken by the plant root as compounds directly from the soil. This latter, however, is a growing phase of our knowledge and may be all the more significant if it is connected, as some observations suggest, with protein snythesis by the plant, especially with possibly the amino acids tryptophane and methionine, so commonly deficient in forages and feeds (3).

THE LIMITING ELEMENT IS LIMITING MORE THAN ITSELF

The single element as a lone variable is the standard scientific procedure in research. However, in biological behaviors, like plant nutrition, the single varied element for plant root entrance does not vary in plant entrance itself without inducing variation in the entrance there of many others and consequent variations in the amounts of them in the final growth products (1) (14). In the cationic suite on the colloidal clay these interrelations and intereffects of the cations are demonstrated by the fact that while calcium occurs in amounts up to 60 or 85 percent of the soil's cation exchange capacity (9), magnesium makes up 6 to 8 percent, and potassium but 2 to 5 percent for good plant growth (8), yet the plant contains more potassium than of either of the other two. Also, a small variation in the potassium supply when both of the other two are constant, gives variations in the amounts of these divalents, calcium and magnasium, entering into the plant. This holds true not only under experimental control but is also demonstrated in the ecological array of plants according to the increasing degree of development of the soil under the climatic forces of rainfall and temperature (2).

Other interrelations and intereffects not only between two, but between multiple cations suggest themselves as a regular order according to increasing numbers of studies of plant nutrition using the colloidal clay and the amberlite absorption techniques for control of cations and anions, respectively, for test of the resulting variations in the plant's composition in either the inorganic or organic aspects. A growing knowledge of the significance of these ratios of exchangeable cations and their activities measured by means of soil tests and specially constructed membrane electrodes respectively (11) for the nutrition of different plants, and their respective chemical compositions, is rendering much help in managing the fertility of the soil as a balanced diet for plants with emphasis on their photosynthesis of carbohydrates mainly or on also their biosynthesis of more proteins. We are gradually modifying the plant's composition by different balances in fertility for different final plant make-up much as we balance the animal ration differently when we grow an animal than when we fatten it.

In some recent studies, the variation of the exchangeable amounts in the soil of any one of five of the inorganic nutrient elements offered brome grass induced variation not only in the entrance into the plant of the other four nutrient elements from the soil, but also gave varied synthesis by the plant of each of the sixteen measured organic compounds. These latter included four carbohydrates and twelve amino acids (13). With reference to the carbohydrate synthesis by these experimental plants, the soil-borne element, potassium, influenced the accumulation of metabolizable sugars. When potassium was high, the sugars and starch in the plants were high. But when the soil nitrogen was high, the metabolizable sugars were present in still much higher concentrations. An interdependence of these two soil-borne elements, namely, potassium and nitrogen, was thus clearly demonstrated for carbohydrate synthesis. When phosphorus, however, was the variable and both nitrogen and potassium were constant, there occurred wide variations in the concentrations of the several carbohydrate fractions, that is, the reducing sugars, the non-reducing sugars, the starch and the hemi-cellulose. That calcium played a part in the cycle of carbohydrate synthesis, a belief not held by many, was clearly established by the fact that carbohydrates as metabolizable sugars were higher in concentration in the brome grass when calcium and the other soil-borne elements were high than when calcium was low with the others all higher. These four elements, potassium, nitrogen, phosphorus, and calcium, each as a single variable modified the array in the plant of the four fractions of the carbohydrates.

In the amino acids synthesis, calcium played a fundamental role. Plants grown on high calcium and high-nitrogen soils were higher in the individual amino acids than those grown on soil low in calcium, but adequately supplied with the nitrogen. High concentrations of several of the amino acids found in the brome grass were the resultants of high calcium, moderate potassium, and high anion fertilization, namely with phosphorous, sulfur, and nitrogen. More amino acids were produced in less bulk of the brome grass than on other treatments of much higher yields of bulk. Wide differences in the relative distribution of amino acids were shown to depend very decidedly on the soil treatment.

In this study the amounts of total nitrogen as percentage of dry weight were sorely discredited as a criterion of protein quality as amino acids in the crops. Several of the amino acids essential for animal nutrition, namely isoleucine, threonine, methionine and tryptophane were quite low with high-nitrogen and high-calcium treatments of the soil, yet the total nitrogen of the plants was high. In these cases most of the nitrogen was present in aspartic acid, arginine and lysine. It was shown that the application of nitrogen to the soil and the high nitrogen concentrations of the plant would not guarantee the presence of a good array of the amino acids essential for good animal nutrition.

Several amino acids were present in almost the same relative amounts in each treatment, and though variable in concentrations with soil treatments, they were present in more or less constant ratios. This held true for methionine and tryptophane in relation to some of the others. Isoleucine and threonine suggested a similar behavior. This fact suggested that these amino acids, particularly methionine, which was invariably in low concentrations, could be used as an index of protein quality with more reliability than could the concentration of the total nitrogen.

Thus, while we are apt to believe that we are setting a single element as a limiting or controlled one in the fertility of the soil as a simple, scientific experimental procedure, we cannot speak with truth of it as if a single variable were the cause of the varied plant's composition when the variations of the other fertility elements entering the plants from the soil are contemporaneously so extensive and so numerous. Thus we are in no position to single out any inorganic fertility element in the soil and believe that its variation there can be measured as a specific influence on animal nutrition so directly as ash delivery of it in the forage fed. Not even nitrogen analyses, multiplied by a factor and called crude protein, can bear much significance. The influence of any single element on animal nutrition must be viewed in terms of its service within the plant through which the synthetic performances by the forage crop render this vegetative mass more nearly a balanced diet for (a) the growing of animals, (b) the making of them more healthy, and (c) the encouragement of their more fecund reproduction. It is in these helps toward the survival of the species more than helps in serving our whims or particular desires for a certain effect, like fattening only, that we need to learn more about soil fertility as plant nutrition in order that this soil property may be more helpful in animal nutrition.

THE TRACE ELEMENTS AND THE ESSENTIAL AMINO ACIDS UNDER BIOASSAY

When the different carbohydrates, including reducing sugars, non-reducing sugars, starch, and hemi-cellulose are not each a specific requirement in supplying energy for the ruminant but serve quite interchangeably, and when the proteins are very probably a matter of a set of specific amounts and kinds of amino acids, it would seem quite clear that the production of more complete proteins in terms of those essential amino acids should be the measure of the influences by the soil-mineral elements on animal nutrition. When there has always been such serious need in humid regions for protein supplements even in the feeding for fattening purposes, this need suggests that we should visualize, not a shortage of crude proteins or nitrogenous compounds, but such of the limiting amino acids in animal nutrition connected with some limiting inorganic elements in the soil as the cause of the trouble.

With this view as the theory, it seemed well to test the shifted ratios of calcium to other elements, for example, as these modify plant compositions, since it has been the common concept that calcium-deficient (acid) soils do not grow the more proteinaceous or leguminous crops as the better feeds. By varying the amounts of the exchangeable calcium only, or of other ions in ratio to calcium, many changes were brought about in the crop's composition, as both inorganic and organic criteria can measure them, to say nothing of the wide, readily visible differences in the mass and appearances of the crop (20). It has been extensively demonstrated that the photosynthetic performances of piling up carbohydrate bulk as forages are influenced by variations in the supplies and ratios of the inorganic fertility elements. The high yields of low-protein corn running well over the hundred-bushel-per-acre mark and the increasing yields of low protein or "soft wheat" are ample evidence. But the concentration even of crude protein in that bulk is disturbed decidedly by the soil's inorganic fertility, while more disturbed is the protein which results in seed production. Still more modified by the inorganic and organic fertility of the soil is the specific array of amino acids within especially the forage but also in the seed. We need to judge the influence of the inorganic fertility according as it prompts the synthesis by the plants of a balanced suite of required amino acids in the feed crops we grow.

When we burn the vegetation in sulfuric acid in our chemical determination of crude protein and assume that all of the nitrogen is protein nitrogen, we forget that some of the nitrogen may serve in metabolism of the animal, as is true for the amino nitrogen of tryptophane, while an equal part of nitrogen in that amino acid is eliminated in unchanged chemical structure as is the indole ring nitrogen of that essential part of complete protein. In this case of the measure of the crude protein represented for tryptophane, then, we make an error of 100 percent as regards metabolizable nitrogen. For this reason it has been deemed a more refined measure of the influence of the soil fertility on animal nourishment by way of the vegetation grown, to study the shift in amino acid array in forages as influenced by the inorganic soil fertility (15) (16).

Of particular interest have been the trace elements as they influence the amino acids, tryptophane and methionine (10). Of course, the sulfur of the soil in relation to the latter, has been challenging since methionine is the significant sulfur-containing amino acid. Tryptophane synthesis by alfalfa and soybeans was decreased when magnesium, boron, manganese and iron were withheld. The effects were shown to be similar whether in nutrient solution or in colloidal clay cultures.

The synthesis of methionine by these same legumes, alfalfa and soybeans, showed regular increase with the increased addition of sulfur to give the characteristic sigmoid curve. Here again these effects were exhibited by both the solution and the soil cultures. Sudan grass increased its methionine content also when flowers of sulfur were the fertilizer treatment of the soil. The increase of this particular amino acid occurred when there was not necessarily a significant increase in the total nitrogen. All of this indicates that we cannot expect the array of the amino acids to be contingent on a certain percent of total nitrogen. These two commonly deficient amino acids, tryptophane and methionine, may be increased in relation to some of the other amino acids, while in relation to others they seem to maintain a nearly constant ratio.

Timothy hay in its assay by rabbits demonstrated nicely that the fertilization with trace elements in addition to the major elements, according to soil tests, gave wide variation in the efficiency of the hay, supplemented by wheat, for adding weight to growing weanlings. But even with the trace elements, the wheat-timothy hay combination allowed the heat wave of 1954 to kill off the rabbits, when the stock rabbits on the same wheat supplemented by green grass suffered no losses by such death.

Relative to the possible protein in question, the addition of dried skim milk powder to the wheat-timothy hay was also an antidote for the dangerous heat wave, as was the green grass. As a repeat of the experiment under the extended heat wave, red clover hay was substituted for the timothy hay after the fatalities on the latter had mounted to 30 percent in contrast to 70 percent in the first experiment. There were no fatalities by the accommodating heat wave after the red clover was substituted. Accordingly, red clover hay and dried skim milk powder appeared as equals in preventing deaths from the heat wave by rabbits fed on wheat and timothy hay fertilized by full treatments including the separate trace elements, manganese, boron, copper, zinc, molybdenum, and then by all of these in combination.

There is the suggestion that the timothy hay, one of the grasses, under full fertilization including even trace elements is not equal to the red clover for synthesizing some of the compounds required by the nutrition of the rabbit if it is to survive the higher temperatures of the summer. But there is also the suggestion that red clover, one of the once-favored forage feeds but now about extinct on the farms, can synthesize some organic help for the survival of the rabbit on dry feed during a severe summer heat wave.

Relative to the vitamins in the green grass in contrast to the dry timothy and red clover hays, no assays were made for their content of these essentials. In some previous studies of ascorbic acid in spinach, according to the decreasing amounts of calcium and nitrogen offered as soil fertility, there was the suggestion of increased concentration of ascorbic acid with partial decrease in fertility, and then a decided decrease of this vitamin with further lowering of the fertility. There was thus a striking correlation of vitamin C with the mineral composition of the plant as dependent on the fertility of the soil in that respect (19).

Whether the rabbit discriminates in feed choice according to the vitamin C concentration was not tested. But that rabbits feeding on cracked corn grain will select the germ in preference to the endosperm to increase the protein in their feed consumption was well demonstrated. By limiting the hay as a supplement to cracked corn and supplying a fresh grain allotment after 25, 50, and 75 percent of the total had been consumed, the rabbits' discrimination had increased the protein in the part consumed by 12, 6, and 3 percent, respectively, according to weights and analyses of the remnant grain samples. Accordingly, as the higher discrimination was exercised, the gain in weight per unit of feed was less. This suggests that the rabbit does not choose to be fattened by the starch of the corn if there is protein to be selected in preference.

SUMMARY

Acccording to the preceding details reported in studies aimed to interpret the soil fertility as nutrition for the plants and the animals consuming the plants, we have not seen so much influence by the soil on animal nutrition when merely increased vegetative bulk as larger yields by the crop and increased animal weight by fattening have been the criteria aiming to interpret the influence of the mineral fertility content of the soil as it modifies the animal nutrition. Ash analyses of the crop, or of the animal, have not served as significant indicators of the influences by the soil fertility on agricultural products or their values as feed and food. They have demonstrated such in rumenology. Crude protein as an ash analysis of nitrogen multiplied by an arbitrary factor has also been disappointing. But when the protein as a suite of essential amino acids in the plants is considered, then the fertility of the soil suggests that it has influence on what organic compounds the plant synthesizes, especially the array of amino acids required as complete protein. Different crops differ in their potentiality of synthesizing these in array suggesting better animal nutrition in some crops than in others through these more complete arrays of amino acids.

Nature has given its different life forms a decidedly high safety factor. For example, we have two lungs and two kidneys, yet we find no manifestation in the malfunction of the first until there is malfunction of the second. As the result of this safety factor, subclinical troubles in animals must be numerous but go un-

recognized. So in this problem of providing the soil minerals in proper balance for animal and human nutrition, two aspects deserve special mention (1); "There is danger in assuming that no degree of deficiency exists in the absence of common incidence of observable, recognizable symptoms usually associated with gross deficiency;" and (2) "The effects of mineral deficiency are not confined to those conditions directly due to the deficiency (7)." We now recognize hidden hungers and the side or secondary reactions in organic chemistry as well as the primary one. So the soil as the starting point in agricultural production may also start many side reactions along its assembly line, working up from the soil through the microbe and the plant to the animal's nutrition. Consequently, deficiencies of subclinical magnitude have been multiplying with the decline of soil fertility, to where the incidence of the microbe is a biological suggestion of incipient body degeneration started by hidden hungers. For too long a time we have fought the microbe as if it were the entire "disease." Soil deficiencies may well be setting up the invitations for the microbes and all that we are prone to label "disease."

We are slowly coming to see that the increasing deficiencies in the soil under its cultivation have shifted the crops we grow to those of less protein and less inorganic contents. They are thereby giving less complete nutrition for the animal's self-preservation when higher fertility of the soil has been demonstrating itself as protection for the plants against fungi and insects. The larger ecological pattern has exhibited the soil as a factor via the mineral fertility elements in locating the wild animals in specific soil areas (17).

But only slowly are we cataloguing enough influences by the soil fertility on animal nutrition to catch a glimpse of the possibilities of growing healthy animals by more attention to management of the fertility of the soil with that objective as well as significant yields of crop mass per acre in mind. Perhaps we will have to wait for another centennial before enough facts about fertile soils as the basis of healthy animals can be catalogued to give us emphasis on the prevention of animal diseases via a few elements of soil origin for proper nutrition in place of cure and relief via myriads of drugs.

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