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Reprinted from
JOURNAL OF THE AMERICAN SOCIETY OF FARM MANAGERS AND RURAL APPRAISERS
April, 1944

Soil Fertility and National Nutrition

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"AN EMPTY stomach knows no laws," says the Russian proverb. If another proverb dare be coined to reinforce it, we might add that *for every party in the parlor there must be a cook in the kitchen.* Food is the basis of nutrition. Regardless of whether we are thinking on a level of necessity or of luxury, food is of universal interest and, more recently, of national and international concern.

Food is fabricated soil fertility. As there are some children who do not know that milk commonly comes from the cow or the goat, so there are some people who do not appreciate how completely dependent we are on the soil for our food. Many adults of pre-rationing days thought no further than that food came in packages from the meat market or the grocery. There is still less appreciation of the fact that the different kinds of food and the differences in nutritive qualities of the same food are a matter of the differences in soil fertility from which these foods were fabricated. We need, then, to take a view of food differences in kind and quality on a larger or national—if not international—scale in order to appreciate the soil fertility differences as they occasion food differences within our own more limited localities.

Nutrition and growth are matters of building a body and of keeping it going. This involves our provision of the building materials for construction or growth and of the combustible materials for heat and energy. In feeding standards for farm animals, for example, the nutritive ratio usually calls for about six parts of energy-suppliers, namely, carbohydrates and fats, to one part of protein, or building material. Even that building material is of energy nature as indicated by its chemical composition when proteins are roughly a case of the carbohydrates into which nitrogen, phosphorus, and sulfur have been chemically compounded. Feeding standards also call for minerals more readily connected in our thinking with the soil, and for some vitamins of especial interest more recently.

It is within the plant and not within the animal where this synthesis of protein from carbohydrates takes place. It is within the plant that the carbohydrate is synthesized by sunshine energy operating through chlorophyl within the leaf. It is into these carbohydrate compounds that soil water and carbon dioxide from the air are fabricated by photosynthesis within the plants. This fabrication is the great agricultural-chemical industry that is agriculture itself. Potassium coming from the soil plays a big part serving as a kind of carbohydrate catalyst, so that it does not occur in the carbohydrate or final product itself.

The fabrication of the protein within the plant is not so directly con-

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nected with the sunshine as the source of energy serving in this performance. Rather, this is a constructive performance more deeply seated within the plant. Much like our bodies build blood and bone as a body process, so, very probably, the plant respires or consumes some carbohydrates as energy for its synthesis of other carbohydrates into protein. This is the plant's synthetic performance, probably separated from direct use of sunshine energy, if the small amount of protein synthesized in contrast to the large amount of carbohydrate photosynthesized dare give a suggestion. In this internal constructive performance by the plant, calcium from the soil plays a catalytic role much as potassium does in carbohydrate synthesis. We can regularly associate a high calcium demand by the plant with its high protein content, whether a legume or non-legume plant is concerned, just as potassium is associated with carbohydrate construction.

This relation of calcium to protein production is suggested in the need for lime by legumes. Calcium does not appear in the protein compounds, though it is needed for their synthesis. Phosphorus from the soil, sulfur from the soil and nitrogen from the soil, or the air, are fabricated into the carbohydrates in the production of protein. Protein production is thus definitely premised on soil fertility in both process and in product. Carbohydrates, proteins, and minerals too as the elements of food for our nourishment connect more directly with the soil than we as carriers of packages from the grocery store commonly appreciate. Nutrition, whether for lower animals or ourselves as supposedly higher ones, must be built "from the ground up." Soil fertility, or the chemical delivery from the soil, is the basis on which such nutrition must ultimately rest.

Because plant growth is so rapid and, much like "the growth" as Topsy knew it, "just happens," the detailed part played by the soil in making it is not appreciated. That the fertility of the soil should affect the plant as early in its life as seed germination and plant emergence to make this supposed seed quality more effective has only recently been recognized.

The soil's contribution to plant nutrition and to animal and human nutrition is suggested in some measure by the analyses of the human body and plants. The total ash, or the soil's contribution in either the man or the plant body is just about 5 per cent. We are thus about 5 per cent soil and 95 per cent water and fresh air. Plants too are about 95 per cent water, air, and sunshine which may be the basis for the erroneous, but common, belief that we farm the weather rather than the soil. The significance of the 5 per cent as the means of collecting the other 95 per cent is being brought home in connection with the problem of feeding the nation on something more than merely warm air and fair weather.

MECHANICS OF MOBILIZING SOIL FERTILITY FOR PLANT NUTRITION

Soil fertility that serves as the human growth material is mobilized into the plants by processes which have been more clearly understood only recently. The belief is no longer tenable that plant nutrients in solution in soil water are imbibed by plants and taken out while the water is transpired through the leaf. Such a concept of the mechanics of the soil's nutritional service for the plant will no longer fit the recently discovered facts. The total supply of soil nourishment in the solution form would scarcely do more than start the crop. Then, too, if much were in true solution, it would be washed out by leaching rains. Our soils would have been sterile long before this late period of geological history.

It is much more feasible to conceive of the roots in contact with the colloidal clay or the soil humus on which are held the nutrient ions like calcium, magnesium, potassium, and others in forms not removable by water, but exchangeable by other similarly charged ions. Included in the group is hydrogen which is the common cause of acidity. Humus and clay

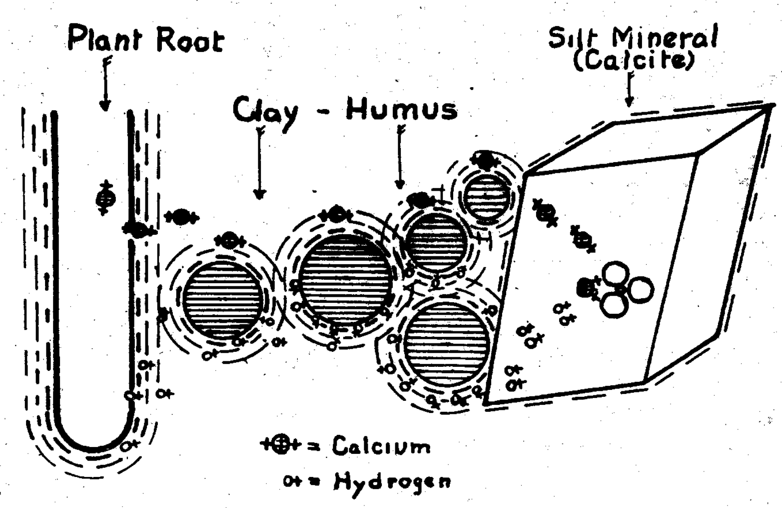

FIGURE 1. Soil fertility is mobilized from the mineral portion of the soil through the colloidal·clay and humus to the plant root. Hydrogen or acidity is offered by the root in exchange. Water presence rather than its movement is a requisite.

as colloid adsorbers take the nutrients, and even hydrogen which is a non-nutrient, out of solution when salts or acids are filtered through the soil. This so-called adsorption by the colloid and exchange to the plant root are the basic but characteristic performances of the clay and humus on which soil fertility and plant nutrition depend.

It is this feature of their extensive surfaces and particular chemical natures that makes plant nutrition possible to magnitudes far greater than simple solution would permit. The adsorbed supply of calcium, magnesium, etc., on the clay colloid is this "jobber's" stock that can be quickly delivered to the roots as they come along and offer the hydrogen from their own surfaces in exchange for what is on the clay surfaces. The amounts of nutrients this jobber delivers depend on how much there is in its stock rather than on how much water flows past in transit to the root. Transpiration as a water loss by the plant is apparently as far removed from nu-

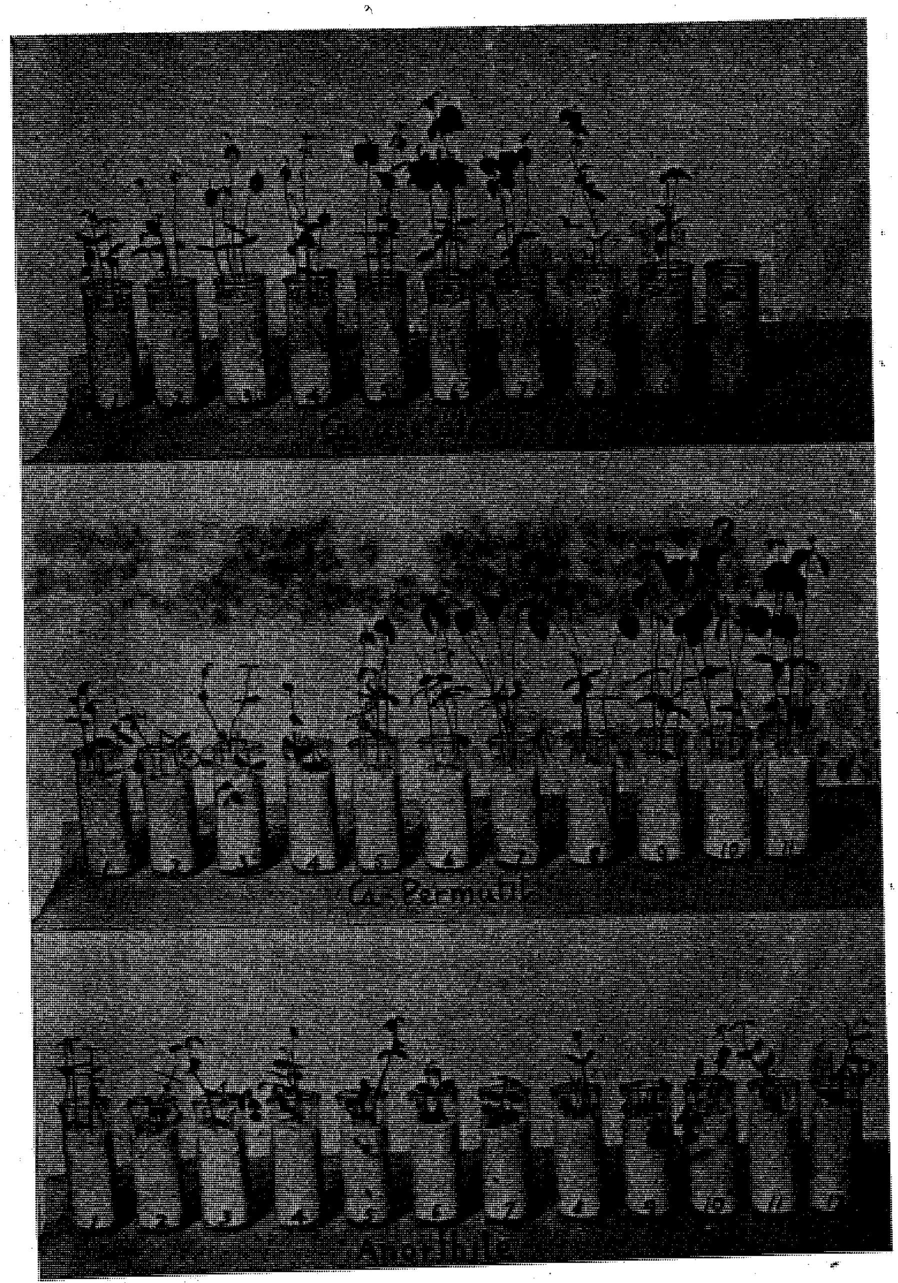

FIGURE 2. Colloidal permutit as a deliverer of increasing amounts of calcium (left to right) is more effective than either the solution form (above) or the mineral form (below) of calcium.

trients going into the root as the amount of moisture in our breaths on a frosty morning is separated from the nature and amount of breakfast in our stomachs.

NUTRIENTS DEPLETION RESULTS IN SOIL ACIDITY TO WEATHER MINERAL RESERVES

That the clay delivers its nutrient ion content quickly is illustrated by the fact that a single crop of soybeans nourished by a colloidal clay-sand medium could take more than one half of the nutrient store from the clay in less than six weeks. The clay took in exchange a large store of hydrogen or acidity. The clay, which originally carried approximately all the nutrient ions it could, was shifted to carry in its stock about all the hydrogen or acidity it could. This hydrogen amounted to almost two-thirds of the clay's entire absorption capacity.

In terms of soil acidity this was a real occasion for alarm. The soil had dropped to a pH figure of almost 4.0. Yet in spite of this supposedly terrible degree of acidity, the soybeans had grown so well that one-fourth of their total nitrogen content had been fixed or taken from the atmosphere. The occasion for alarm, however, as in the case of all of our farm soils, is not in the advent of the hydrogen or the acidity but in the exit of soil fertility. The hydrogen ion itself is not injurious to the plant. In fact the world's population is most concentrated over acid soils. Natural, excessive soil acidity is disastrous not because it represents an enemy coming in but because it reflects our indifference to the going out of the soil fertility on which our national nutrition of high order must depend.

If the supply of soil fertility in the readily exchangeable or deliverable amount can be so rapidly and extensively exhausted by plant growth in but six weeks, you will immediately be raising the question "How can a soil produce two, three, or more crops or continue to be productive? What is the reserve fertility from which the clay or humus, as the jobber, can restock its supply?" It is in this respect that the weather or climate with its different rainfalls and temperatures enters into the picture. Here too must be considered the original rock and minerals from which soil was formed. The reserve fertility of the soil is in the mineral crystal part, mainly the silt and the sand. Whether these are nutrient-bearing minerals or only the non-nutrient quartz determines whether the soil has or has not the nutrient reserve.

Recent experiments by Dr. E. R. Graham have demonstrated that as the clay becomes acid there is an exchange between this acid and the nutrient ions in the silt minerals, just as there is an exchange between the plant root with its acidity and the nutrient-carrying clay. Through this exchange there is illustrated the mechanisms by which the plant root passes hydrogen, or acid, to the clay or humus to be passed from there to the silt and the sand minerals for action on these and release of their nutrients that are passed in the reverse direction to the clay and to the plant for its nourishment.

Soils Slow Down and Threaten to Wear Out

This mechanism of plant nutrition makes it understandable how soils wear out. We see soils as a chemical factory or as an industry using chemical reactions to produce soil fertility in the active ionic forms of calcium, magnesium, potassium, and other nutrient elements delivered from the silt and the sand by way of colloidal clay to the plant roots. We can see that the supply of reserve minerals carrying water-insoluble nutrients will all be dissolved out by this process of natural acid treatment and extraction by the crop. When this exhaustion occurs, it is then that the soil is no longer fertile and crop failure is inevitable.

On Sanborn Field at Columbia, Missouri, Plot 9, which has been in continuous wheat without soil treatment since 1888, furnishes an interesting illustration. For some years after 1888 the yield of grain on this plot declined gradually. In the late years this plot has been a *producer only in alternate* years. We can see that the nutrient reserve in the plot is now being delivered from the silt mineral by the clay so slowly that when the clay is exhausted of its nutrients just before a wheat harvest in July there is not sufficient reserve fertility mobilized from the mineral reserve by the clay before the following October to start the next crop in the seeding of that month. Here are the signs by this soil indicating its gradual fertility exhaustion. This soil must have a year of extra time to bring about the fertility mobilization in quantities sufficient to start the wheat. The rate of fertility mobilization is too low for annual cropping to a seed crop.

Perhaps similar situations are involved when older fruit trees become alternate year bearers, or when forest trees do not provide seeds annually. Very probably soil fertility as nutrient minerals required by animals in their reproductive processes is not coming rapidly enough from the soil reserve to the clay, to the plant roots, to the crops as forage feeds, and to the animals when they become delayed breeders or shy breeders. It is this nutrient-delivering business, or this provision of soil fertility in ample quantities and at liberal rates that is basic to our national well-being. We must understand these soil processes in kind and rate if we are to view the future clearsightedly as to our place as a nation in the global program now in prospect.

Soils Are Made by Climatic Forces

Soil may be said to be merely a temporary rest-stop of the rock while rainfall and temperature are breaking it down and moving it to the sea in solution. This solution of the rock is more rapid because rainfall takes carbon dioxide from the air to form carbonic acid. This acid is a more effective rock solvent than water alone. Rock is thus disintegrated and decomposed to clay while part goes into true solution to pass on to the ocean. As there is more water and as the temperatures are higher, the soils are different in their kinds of clay, in the amounts of clay, and in the reserve minerals they contain. The extent to which the rocks have experienced more effect of climate makes for what may be called greater soil

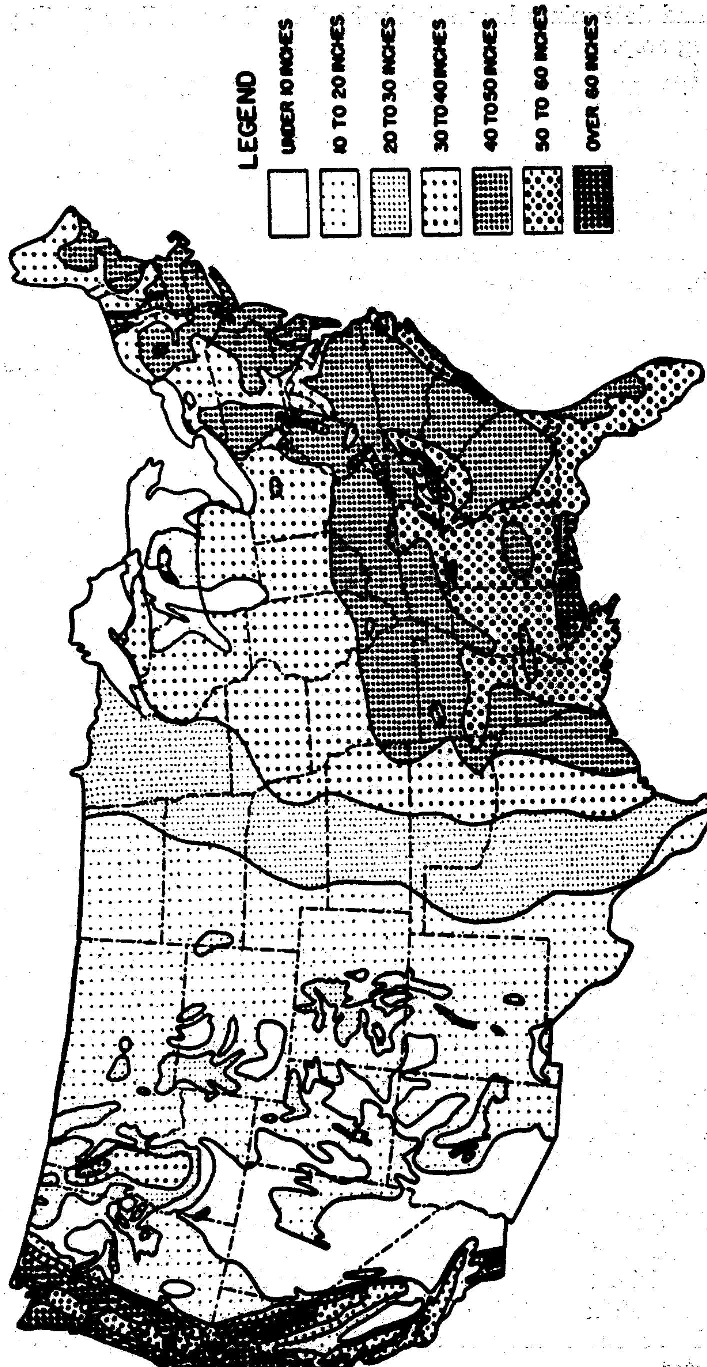

FIGURE 3. Variable amounts of rainfall mean soils that have undergone different degrees of construction or destruction by this water treatment.

maturity and determines how effectively the soil can deliver fertility for the growing crop.

The United States, exclusive of the extreme western coast, exhibit increasing rainfall in going from west to east. In this climatic feature as it determines our soil fertility, there is much that bears on regional differences too often disregarded but deserving of recognition in a national program of agriculture and food production.

The effectiveness of rainfall in weathering rocks into soil is not directly commensurate with the annual amount of rainfall. Rainfall is more nearly effective in terms of the *water going through* the soil or the rainfall as

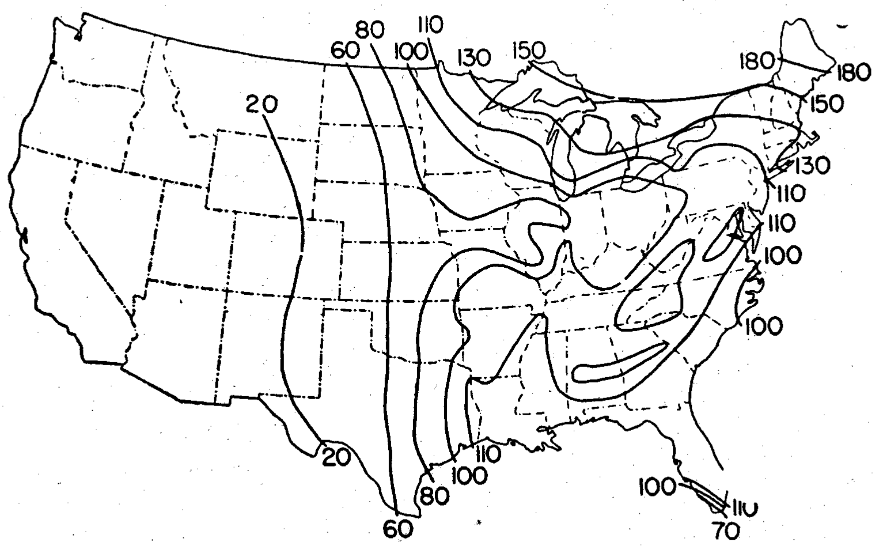

FIGURE 4. The effectiveness of water in making soils is reduced by evaporation. Rainfall divided by evaporation from free water surface gives cornbelt states with soils similar to the prairie states (Transeau).

inches minus the runoff and the evaporation measured in the same units. Professor Transeau of Ohio has given us a map of the United States showing the lines of similar ratios of rainfall to evaporation from free water surface. There is a suggestion in his map that the soils of Missouri, Iowa, and Illinois are similar to those of the mid-land region of the United States including the Dakotas, Nebraska, Kansas, Oklahoma, and Texas. The prairie belt is in reality a matter of the soil in terms of rainfall and temperature. Because of the high evaporation in some of these more eastern of the mid-continental states, they have soils that are not more leached than those in Kansas, Nebraska, or the states commonly known as distinctly prairie states even though these more eastern ones may have higher rainfalls. The climatic features after all are responsible for the different soils, as one readily recognizes from a map of the soils of the United States.

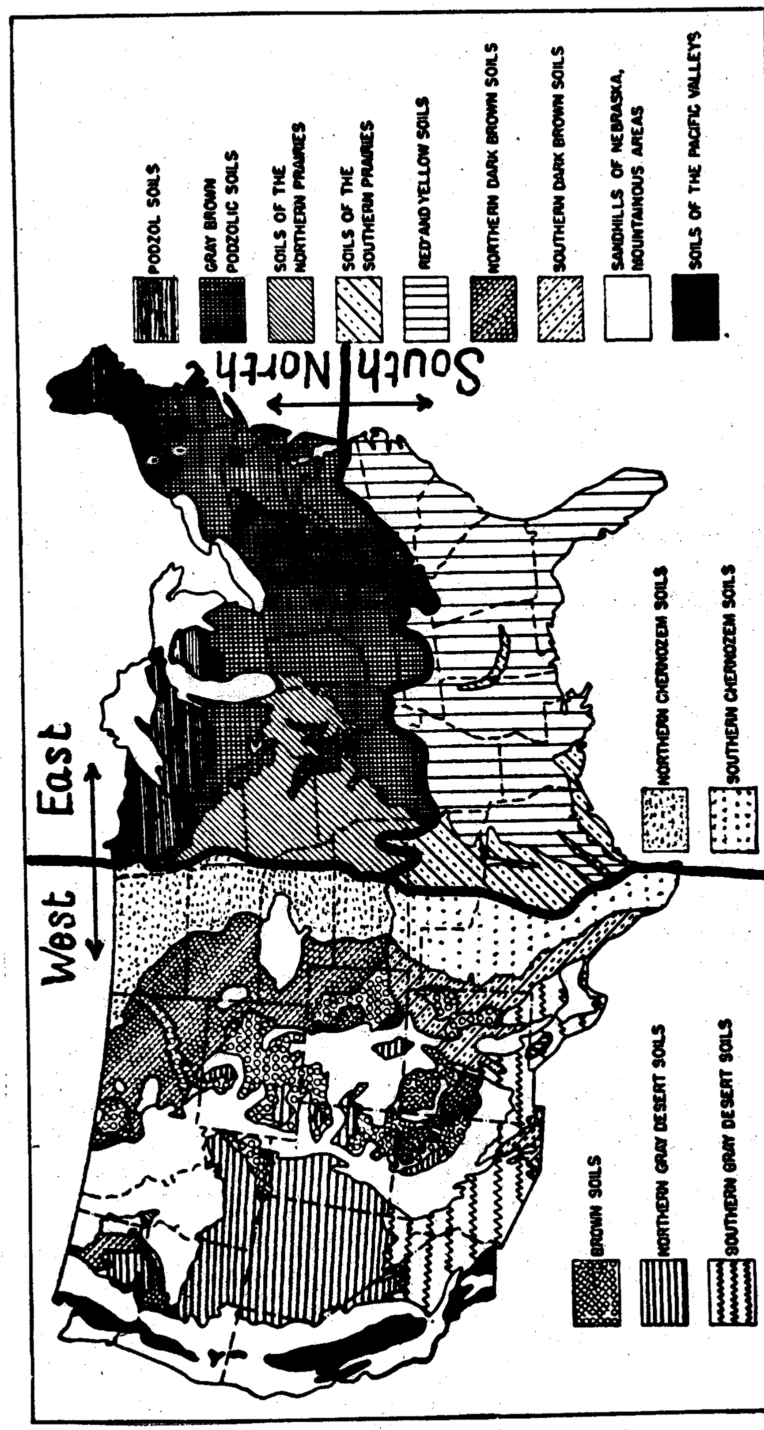

FIGURE 5. The United States divide themselves into an East and a West, a North and a South, because the soils make the division. The fertile chernozem soils once supported bison and cattle later. The soil pattern is basic in terms of the food it provides.

Quality and Quantity of Vegetation Are Controlled by Soil Fertility More Than by Climate

Climatic differences are commonly credited as the cause of differences in vegetation. There is the general belief that plants are very sensitive to how cold or warm, or how wet or dry they are. It is often emphasized that forests are common in eastern United States because the distribution of the annual rainfall is ample to keep perennial vegetation like trees growing throughout the year. We likewise associate prairies with periodic droughts, which permit only grass vegetation that can accommodate itself by means of dormancy during such times. More significant in terms of plant, animal, and human nutrition, are the differences in soil fertility according to climatic forces and the differences in chemical composition of the vegetation in agreement with this. Our attention should be directed

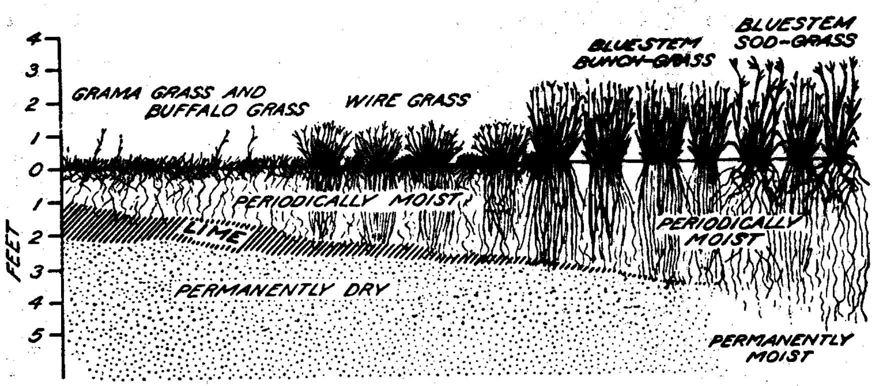

Figure 6. Vegetation (left to right) of Kansas (West to East) is related in its composition to the greater access to the fertility of the soil rather than to the increasing rainfall (17-37 inches West to East).

to the chemical composition of the vegetation, whether natural or introduced, as it is made up more extensively of liberal fertility offerings from within the soil and is consequently more nutritious, or as it is made up largely of air, water, and weather from above the soil to be mainly wood and non-nutritious.

If one studies Kansas with variation in its annual rainfall from 17 to 37 inches in going from west to east along an isotherm, the succession in natural prairie vegetation may well be pictured as consisting of the following series: namely, grama grass, buffalo grass, wire grass, bluestem plus bunch grass, and bluestem and sod grass, which is as Dr. Schantz reported it twenty years ago. He also pointed out that in western Kansas the lime carbonate horizon within the soil profile is met at a depth of one foot. At that location this horizon had a thickness of this same figure. It was met only at greater depths and was of less thickness in going to eastern Kansas where, under heavier rainfall, this lime carbonate horizon disappears. That the buffalo grass was the chosen feed of the bison because it is more nutritious through growth on the more calcareous soils is much more readily pictured as the real reason for the thundering buffalo herds on the short grass region while fewer of these beasts occurred where the larger bluestem provided greater yield but of less nutritive services in consequence of the less calcareous and less fertile soils.

Beneath the surface of the soil and dissociated from the differences in annual rainfall are the differences in soil fertility that give us the high protein content of wheat, mounting to 18 per cent in western Kansas, and low protein content, only 10 per cent in eastern Kansas. Protein production and with it all the other self-generating synthetic performances within the plant are premised on the fertility provided by the soil rather than on the particular temperature or the particular moisture alone. Yields per acre too, even though mainly photosynthetic, are premised on soil fertility more than on any rainfall figure alone when western Kansas suddenly given 25 inches of rainfall produces 40 bushels of high protein wheat, while Missouri with 40 inches of rainfall does well to yield 25 bushels of low protein wheat per acre. The fertility of the soil is basic in both quality and quantity of crop yield, or in both the internal and external crop properties.

PLANT HEALTH IS DEPENDENT ON SOIL FERTILITY

Plant nutrition must be based on high levels of soil fertility and consequent good plant health if production by the crop is to be high. "To be well fed and healthy" is a truism that holds for plants as well as for piggies By using the colloidal clay technique to supply calcium, it was demonstrated that the mere putting of more clay into quartz sand—even though the clay carried so little calcium that it was acid enough to have a pH of 4.4—gave more root-clay contact and correspondingly less of "attack" by a "disease" that suggested "damping

FIGURE 8. Plant health depends on soil fertility. More clay, even though acid pH 4.4, put into the sand to provide more calcium made healthier plants (left to right).

off." Plant starvation was the cause of the plant "disease" in this demonstration. This apparent disease was "cured" by delivering more soil fertility simply through the use of more clay in the sand. This demonstrates that more soil fertility can thus be delivered not only by a higher concentration of it on the clay that makes the clay less acid, but also by more clay in the soil to give more clay surface for root surface contact.

Starvation of the plant may also occur when in the silt or sand there are insufficient mineral reserves to deliver through the clay each of the nutrients at required amounts and rates. Diminished yields of seed crops have not been considered as a form of plant starvation, even before the plant is lowered in its vigor to the level of fungous and bacterial attacks. Diminishing seed yields have been coming with our declining soil fertility but we have not been prone to accept these as indicators or symptoms of plant starvation. We have shifted our cropping schemes more to those crops taken as tonnages of forages by animal harvest, while still further decline in soil fertility makes plant starvation more evident, with some so badly starved as to be victims regularly of fungi and bacteria. We are just beginning to connect these plant starvations with animal and human starvation though they may all be at a slow rate. Starvation symptoms of plants are now being cataloged and are serving as diagnostic helps for soil treatment by means of fertilizers to meet the nutrient deficiencies of the soil. Such soil treatment can prevent plant starvation and disease to say nothing of its service in preventing animal and human starvation.

Future Nutrition Needs to Look to Clay Soils and Their Nutrient Mineral Reserves

In terms of our national problem we need to evaluate our clay soils for their potentialities as to future nutritional services. Civilizations on sandy soils have been shortlived. It is on clay soils where they have long endured. Perhaps the costly labor of tillage has reserved the clay soils against rapid exhaustion of their fertility. It is true that much clay buffers soils against the terrific shocks to their biological and biochemical balances by man's injudicious soil management. Soils with more clay have been more uniformly productive through many years. The big plows, the big horses, that cultivate the "heavy" soils of Great Britain and central or north Europe are not an idiosyncrasy of the peasant farmer. Rather, they are a result of the soil conditions that have paid for these costs by giving continuous and high levels of productivity.

We need also to evaluate the mineral reserve in our soils. Much that is labeled geology or mineralogy can now come to our aid in obtaining an inventory of potentialities in our soil for future food production, particularly if this is to extend its service beyond our own borders. The clay content, the nature of that clay, and the mineral reserves of the soil are our great national resources that deserve inventory now through the soil survey and the Soil Conservation Service with food production and proper nutrition in mind. This inventory seems all the more important. We are about to enter upon a host responsibility to portions of the globe where soil resources have been long exhausted below the fertility levels of our own.

FERTILITY DIFFERS ACCORDING TO SOILS AS THEY ARE IN CONSTRUCTION OR DESTRUCTION

The amount and the nature of the clay, and the reserve mineral contents of the soils of the United States can be assembled or arranged into a larger picture. We can think of our soils as they are under construction

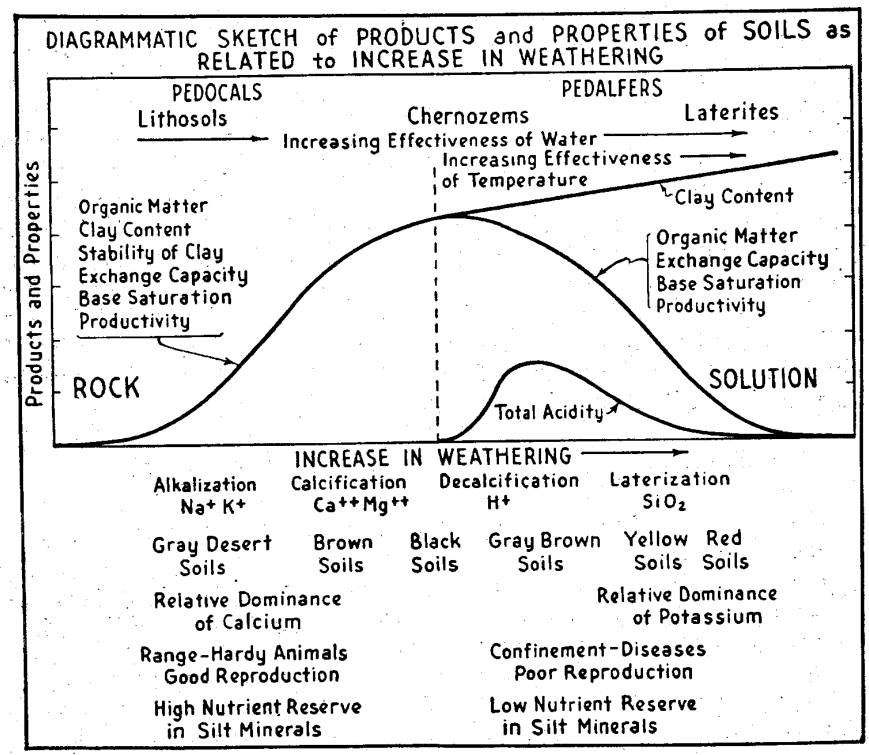

FIGURE 9. Soils differ according to the degree to which the rocks have moved toward solution under the influence of weathering. Vegetation and animals differ according to the fertility differences resulting.

in some areas or destruction in others, and as they control life in terms of the differences in soil fertility offered for nutrition. Lesser rainfalls, or those below 30 inches, in western United States, for example, break down the rock but do not leach away their products. Nor do they produce much clay. This process is then mainly soil construction with little destruction. More rainfall and especially when made more effective by higher temperatures carries the clay production and the nutrient removal much further. This is dominantly soil destruction. Much more of the elements of life-sustaining value is moved to the sea. Wet tropical climates produce soils exhausted to the point of serious deficiency for life forms. Northern frigid soils lack sufficient construction to support life extensively. In the United States, it is in the "chernozem" belt with its 20-30 inches of rainfall that the rocks have moved to about the maximum in soil construction and the minimum of soil destruction. It is east of that line that there is much that is soil destruction in terms of the fertility supply and good nourishment for animal life by way of the vegetation.

Many illustrations of plants and their differences in chemical composition fit into the general rainfall pattern and therefore into the soil fertility picture of the United States. Alfalfa grows readily without soil treatment in western Kansas, Nebraska, Colorado, and in other states with their less leached soils. It is in the states east of these that oats and corn are common crops. Corn moves well eastward into the regions of heavier rainfall with dark soils. Cotton is the crop of the more red, more highly weathered soils of the South, and rubber of the much more weathered soils of the tropics. The real causal force producing this crop series—seemingly exemplifying nice agreement with increasing rainfall as possible cause—is the difference in fertility offered by the soil. It is these different levels of plant nutrients that bring about correspondingly different chemical compositions of the crop and move them from the category of animal forage feed in the case of the alfalfa to that of no feed value in case of the cotton fiber or the rubber crop.

Rainfall in its distribution pattern has too often been mistaken for the reciprocally varying soil fertility as cause of the plant pattern. It is the soil fertility pattern, rather than the climatic pattern, that is reflected as the cause in the pattern of animal nourishment that is at a high level under low rainfall but falls to low levels as the rainfall and temperature increase. Vegetation and correspondingly the animals and the human beings subsisting on the soil respond more sensitively to the pattern of the supply of soil nutrients to feed them than they do to any pattern picturing how wet or how warm they are.

FERTILE SOILS MAKE "GROW" FOODS OF HIGHER NUTRITIVE CONTENTS

Should we make chemical analyses of the vegetation in these regions of soils differing according to the climatic pattern, there is a relation between the nutrient ash content in the vegetation and the degree of the soil development. As the soils are more highly developed by more rainfall and higher temperatures, the nutrient ash contents decline. It is significant to note too that while there is less of nutrients in the ash, silicon, a nonnutrient, increases to make up a larger share of the total ash. Calcareous soils in what might be called the *midlands of the United States,* produce vegetation that is low in silicon but high in mineral nutrients. The less calcareous soils, conversely, give an ash that is higher in silicon. It is essential that we consider the ash in terms of its nutrient, or fertility, contents rather than the ash in total—as we relate the vegetation on the basis of this criterion of soil fertility to the mineral content it carries.

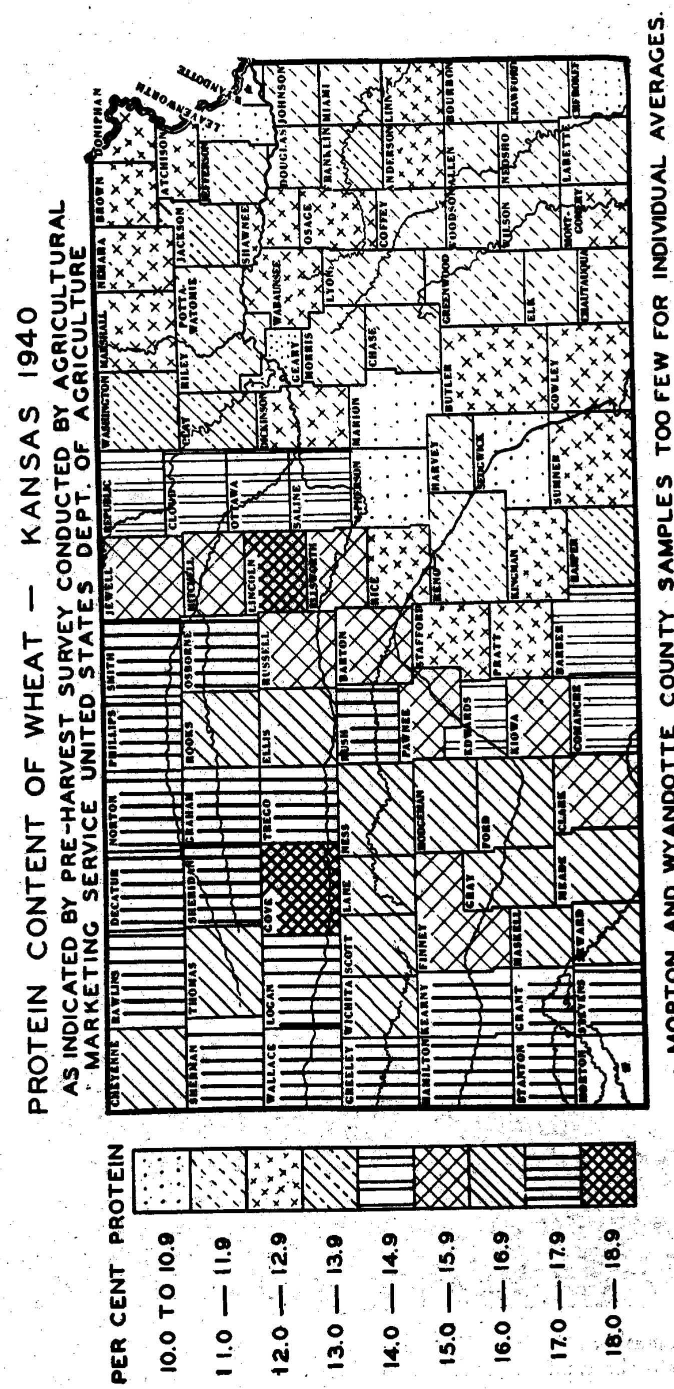

FIGURE 7. Increasing protein content of wheat from East to West in Kansas results from the increasing soil fertility with decreasing rainfall.

As a general principle, it may be said that any vegetation is mainly carbonaceous. Carbon constitutes about 40 to 50 per cent of any plant material. However, whether there is put into the carbonaceous vegetation a significant amount of protein and other food compounds by means of the plant's own synthetic activities depends on how much this is prompted through the delivery of fertility by the soil. Vegetative production seems prevalent on almost any soil where rainfall and temperature permit. The quality of this vegetation in terms of animal and human nutrition, however, is a matter of the soil fertility. In general, then, any crop is carbonaceous, but crops are also proteinaceous and of nutritive value only when the soils have not lost their fertility through leaching. This fertility store is commonly indicated by the presence of calcareous materials in the soil which, if present, are indications that other fertility elements are also present. It is on these premises that we can say that the calcareous soils serve to represent proteinaceous and mineral-rich crops, while leached soils represent carbonaceous crops. In terms of animals and their nutrition the former are the regions of growth or of "grow" foods, the latter are the regions of energy or "go" foods.

CROP COMPOSITION CAN BE CONTROLLED EXPERIMENTALLY BY MEANS OF SOIL FERTILITY

This principle that locates either proteinaceous or carbonaceous forage according to the soil fertility has been demonstrated experimentally by Dr. E. R. Graham and by Dr. Carl E. Ferguson of the University of Missouri, in their researches with soybeans. By increasing the potassium in relation to the calcium offered, the crop yield was increased. The crop composition was so changed, however, as to give it proteinaceous characters when the calcium was high in relation to the potassium, and contrarily carbonaceous properties when the calcium was low in comparison. These changes occurred even when the yield was or was not increased. The yield was no indication of the particular chemical composition. This was contrary to the accepted belief that the crop must be a better feed in consequence of higher yields. Here then a single species of plant, even a legume, is of decidedly different nutritional value on different soils if its chemical composition, according to common methods of feed analysis, can be considered a guide. It is this feature, namely, the change in composition of the plant and in its nutritive value without change in its pedigree, that points to the plant's value according to the soil, rather than according to other plant properties that are more commonly accepted as indexes.

Vegetable crops are no exceptions to the rule, if some work with spinach by Dr. R. A. Schroeder of the University of Missouri, is an indication. Here the acidity of the soil was beneficial rather than detrimental in mobilizing the soil fertility into the crop to make it richer in calcium and magnesium and to reduce the detrimental effect of its oxalate content. He grew spinach in two series of soils, each series offering increasing calcium contents, but constant supplies of other nutrients. One of these series was kept acid while the other was neutral at the outset. Growth was of good appearance and the yields satisfactory in all cases.

When the crop was analyzed for its calcium content, this element in the crop increased as more calcium was added to the soils which were acid, but failed to do so in the spinach grown on the originally neutral soil. On the acid soils, the oxalate content was not so high but that the crop's contents of calcium and magnesium were more than ample to make the oxalate insoluble. There was a surplus of calcium and magnesium to make this crop a provider of these nutrient elements in available form in the diet in spite of the oxalate. In the case of the spinach on the neutral soils, this crop contained more oxalate than could be precipitated by the calcium and the magnesium within it. It was a provider of so much oxalate as to make unavailable not only its own calcium but also that from other sources, if such should be put with spinach into a digestive mix. Soil acidity, too, brings soil fertility into significance in vegetable crops, and more directly into significance in human nutrition.

Wild Animal Choices and Eating Habits Reflect Delicate Differences in Soil Fertility

That the soil fertility is reflected in the nutritive quality of the vegetation is suggested by animal eating habits and animal choices. They point out not only the different crops but also the differences in the same forage crop or even grain. Wild animals that are free to roam demonstrate this particularly well. The squirrel of the forest is not considered as carnivorous. But it carries bones during pregnancy, as reported by Dr. Carlson, and the prevalence in the abandoned nests of bones well-gnawed points to the attention this animal, that lives on highly weathered soils, gives to its needs for calcium and phosphorus during pregnancy where soils are apt to be deficient in these respects. Antlers that disappear so rapidly in the forests are similar evidence to help explain the scant animal population of forests in the temperate zone, to say nothing of the much more scant wildlife in the tropical forests. Turkeys for the Pilgrim Fathers on the New England coast, but bisons by the hoards for the Forty-niners are only small samples of how the wildlife population locates itself so that it can feed according to the soil fertility.

Wild animal choices, seemingly uncanny as they are, demonstrate an unusual ability to recognize differences not detected even by chemical assays. When southern pine seedlings in the native Missouri forests do not serve as deer browse and go untouched, yet this same tree species transplanted from the fertilized soil in the forest nursery to the newly made highways is taken completely by the deer, we must accept the animal's discrimination as a delicate measure of vegetation differences associated with soil differences.

The Animal Distribution Fits the Soil Fertility Pattern

The distribution of our domestic animals gives a picture that is more readily superimposed on that of the soil fertility. The location of the horse in Europe furnishes an interesting illustration. Within small ranges of latitude and longitude reaching no great distances out from the British Isles as the center, and all within the influence of the Gulf Stream, one can go from the smallest to the largest of the horses. The Shetland pony, or the midget horse, is at home on the more rocky, less developed soils of the Islands at 60° north latitude. The Irish pony and the Welsh pony, larger but still in the pony class, are on the granitic and slaty soils respectively at 55° north. Of about corresponding size are the Russian horses on the gravelly, glacier-deposited soils of North Russia, and the Norwegian horses in the rockbound fjords at not much different latitudes.

One needs only to go into Scotland with the greater clay content of its soils to find such active and stylish hulks of horseflesh as the Clydesdales, or east from Wales and its slates into England with its clay soils to go from ponies to the massive Shires and Suffolks. South, a bit farther, there are the heavy, closely-coupled Belgians. Nearby in Normandy of France on soils similar to those of England where heavy clays, heavy plows, and heavy horses all go together, we find the original Normans or the Percherons of tremendous body, surplus power, and excellent disposition.

Through this small area—all within the region where woolens are the common wear—the climate is not so widely different. Yet the soils include a great variety because the different rocks in similar climate mean different minerals. Therefore the soils made from them are different. Different soils make different feeds. Different feeds mean horses differing in size, speed, conformation and disposition.

Donkeys too (if they be declared domesticated) demonstrate their need for more calcareous soils. They have always been native to drier climates, or have been most "natural" when feeding on mineral-rich vegetation. The "Jack" farm in Missouri that rose to fame did so under the combination of the able management by Mr. Monsees and the lime-laden herbage produced on "The Limestone Valley Farm" as Mr. Monsees named it. Mules have attained their fame on soils more leached than those required by the donkey, one of the parents of this hybrid, but even this mule-raising fame rose highest only in Arkansas, Missouri, Kentucky, and Tennessee with their soils largely of limestone origin. Liberal supplies of soil fertility with calcium in dominance connect the soil pattern with these fineboned, but surefooted beasts.

Sheep fit themselves likewise into the soil picture when they, like cattle, tolerate the severe weather conditions of the open range, yet seem to be subject to "disease" so common in their sheltered management in the areas of the eastern United States. Hogs too with their carcasses mainly of fat are located in the cornbelt where carbohydrate crops rather than proteinaceous forages are of common occurrence. But even hogs declare their need for soil minerals as they root up the very earth for them in spring and then cease to root once they have had spring grazing to supply them.

Beef cattle in the United States are grown where they multiply most efficiently with the minimum of attention. It is on the plains of Texas, Kansas, Oklahoma, and other areas of the soils with proteinaceous and mineral-rich vegetation that there is the efficient feed for them regardless of the low tonnage yield per acre. The cattle are fattened on our carbonaceous feeds on soils separated widely from the place of their origin. The same picture prevails in Argentina where grass-fed cattle are grown in one grass region of lower rainfall and fattened in another grass region of higher rainfall. Here the differences in the rainfall are commonly given credit for the differences which are in reality soil fertility differences associated with the rainfall variation.

By Courtesy W. M. Landess, TVA

FIGURE 10. Irregularities in growths of herbage in pastures result from animal choices of plants according as their chemical compositions fit the animal needs.

DOMESTIC ANIMALS SERVE TO ASSAY FEEDS ACCORDING TO SOIL FERTILITY

Domestic animals, too, by their habits and feed choices are pointing to the soils and the soil fertility as basic to their nutrition. Cattle select varieties of plants from mixed herbage and graze some out more completely while others remain. The same kind of plant fertilized differently is chosen more or less readily according to the different soil treatments. Grass grown unusually green through urine droppings in the pasture is disregarded and allowed to grow taller while grass around it is grazed shorter. While this unbalanced fertilizer effect through excessive nitrogen on the grass is detected and refused by the cow, mineral fertilizer additions including lime, phosphate, and potassium are often preferred. Soil treatments as surface application of fertilizers and lime on the virgin prairie in Missouri have been the cause of haystack selection by cattle annually since 1936, the year when the treatments were applied. Animal selections are giving us hints that we should look to the soil fertility to balance their rations not only in carbohydrates, proteins, and minerals, but possibly with respect to some of the less prominent micro-nutrients and catalytic agents that only animal assays can detect.

Animal diseases, like plant diseases, are also correlating themselves with nutrition in terms of soil fertility. Those animal ailments that are more prevalent in late winter and early spring are especially suggestive. Pregnancy diseases of sheep, acetonemia and milk fever in dairy cattle,

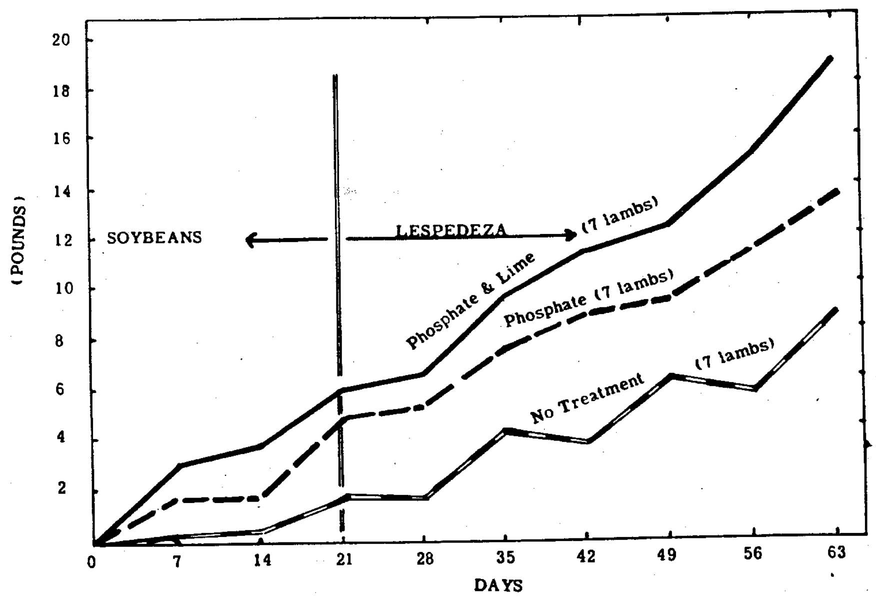

FIGURE 11. Gains by lambs reflect the different values in the hay according to soil treatment when amounts of hay and grain consumed were constant.

various forms of paralysis and lamenesses in the hind legs of cattle, sheep, hogs, and many other troubles labeled as "bad luck" are common in the animal's struggle to carry the reproductive load across from the dry carbonaceous feeds of winter to the soil fertility-laden grass of early spring. Hay made after the plant has exhausted from the clay the readily usable supply of fertility and after ample sunshine has pushed the plant carbohydrate synthesis to the maximum rate, must necessarily be low in the soil-given growth substances and high in energy and woodiness. Such forages on which animals struggle through the winter are still evaluated by the tons per acre rather than by the soil fertility that gives them internal value in terms of the plant's performances and particularly in terms of the animal struggles in reproduction.

In experimental studies using animal growths to test the significance of soil treatments for their nutritional value delivered in the crop, the rates and amounts of animal growth—to say nothing of the other physiological manifestations—emphasized pronouncedly the effects of soil fertility that are reaching up through the plant and to the animal. These nutritional effects are readily transmitted from the soil through the forage. They are also transmitted through the grains consumed by the animal. A single fertility element applied on the soil may in some cases be beneficial, while in some cases it may be an excess. It may even reduce the nutritive value as measured by animal gains. It has been experimentally demonstrated that liberal applications of nitrogen only as a fertilizer on grass may be an excess to make this forage of less service than that which had no soil treatment. Calcium has been widely beneficial in terms of animal growth measures. Superphosphate has given similar beneficial demonstrations. Potassium has served in other cases. In general, the well-balanced soil treatment that exaggerates no single shortage seems to be the ideal desired. Animal assays bid fair to give measures of new values of soil treatments not generally anticipated.

Human Population Can Be Pictured According to the Pattern of Soil Fertility

The picture of the distribution of human population, and much that is considered disease, can also be superimposed on the picture of soil fertility. Concentration of humans in the temperate zone rather than in the tropics is a matter of the clay and mineral properties of the soil that represent a *reserve* and *delivery* of fertility to support both animal and human life. It is not so much a matter of the jungle mass of carbonaceous vegetation. The red or lateritic clays of the tropics still deliver potassium to provide carbohydrates by photosynthesis, but soils with such low exchange capacities do not retain and deliver sufficient additional fertility for any other than merely carbonaceous crops. Even these crops survive only when the fertility elaborated into vegetative matter is dropped back to the soil and decayed rapidly to keep this small amount of soil fertility in a continuous cycle of growth into the plant and decay back to the soil.

Life in the tropics is always hanging by a very slender thread of soil fertility. Life there usually centers about the seacoast where fish as food serve to bring fertility back from the sea. Ceremonial rites, customs, traditions, and many practices by the primitives—so lightly considered by us—have contributed to their survival in most instances because they contribute through soil fertility management. Great areas of the tropics are still unpopulated. Migrations into their interiors will become possible only when the fuller significance of soil fertility in human nutrition on such soils is appreciated.

National Nutrition Rests on Soil Fertility

Problems of national nutrition need to be viewed in terms of the larger picture of soil fertility that is at the basis of agriculture and consequently is the basis of food production. That it is the soil fertility that gives an

East and a West, or that divides our East into a North and a South is little recognized. To date such natural divisions have been ascribed to personal differences, political affiliations if not to differences less significant. Fertilizer use in the southern states on their quartz sand base is a matter of survival for agriculture. In the midwest, fertilizer use is a supplement to soils with a natural reserve of diversified fertility in its original minerals. It is from such differences in soils that one can readily expect the conservatism of New England, the adherence to tradition in the South, and the boldness and the bombast of the midwest or other traits of character not apt to be premised on nutrition and the soil. We are learning to believe that *we are as we eat in spirit and behavior as well as in body form and stature.*

Policies for agriculture, practices in soil conservation, programs of agricultural adjustment, and other far-flung national activities dealing with society cannot be blanket orders emanating from the nation's capitol as duplicate copies of single state experiences applied to other states on the national scale. Basic to our life is our food. Food is the product of agriculture in the form of fabricated soil fertility. Our life is therefore built on the soil and our future life as it is to be readjusted in global dimensions dare scarcely disregard our soils in terms of their differences in fertility.