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VITAMIN-LIKE SUBSTANCES IN PLANT NUTRITION

By

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VITAMIN-LIKE SUBSTANCES IN PLANT NUTRITION

By J. F. Breazeale

INTRODUCTION

It has been shown by many investigators, that certain organic compounds stimulate the growth of plants. Particular attention is called to the classic researches of Dr. W. B. Bottomley, of King's College, London, upon peat. These results were published in several British journals during the years 1915 to 1922 inclusive, and were abstracted in the Experiment Station Records of these dates.*

In working with both untreated and inocculated, or "bacterized" peat, Dr. Bottomley discovered compounds which he termed "auximones," that, in their effect upon plants, were analogous to vitamins in their effects upon animals.

In presenting this bulletin it may be stated that no effort was made to identify any of the compounds that are associated with plant nutrition. The author is more concerned with the reasons for the reactions, than with the substances which produce them. The aim of this bulletin, therefore is to give a reason, why plants behave as they do, when placed in contact with certain forms of decomposed vegetable matter. As with practically all phenomena of plant nutrition, the stimulating effect of organic compounds appears to be a phenomenon of adaptation.

THE STIMULATING EFFECT OF DECOMPOSED ORGANIC MATTER

The decomposed remains of most plants possess the peculiar property of stimulating the growth of other plants. The stimulating effect obtained in the application of stable manure to farm lands, in green manuring, and in crop rotation is probably of the same nature. This stimulating property is characteristic of all the legumes with which the author has worked, but it is not confined to this plant family. Certain other plants, such as mustard and tobacco, as will be shown later, when decomposed, possess this peculiar property.

The particular organic compounds that stimulate the growth of plants are probably products of bacterial action or decomposition. While fermenting, nearly all forms of vegetable matter are toxic. This is true even with manure. It is not until after active fermentation is over that

*W. B. Bottomley, Ann. Bot. (London) 1920—No. 135, Exp. Sta. Rec. 45—1921 p. 220—etc.

the organic matter becomes effective. There is, however, a possibility that the stimulant exists in the undecomposed plant, and that its property is liberated by the process of decomposition. It is well known that no crop should be planted upon land immediately after an application of fresh manure or after plowing under a heavy growth of green vegetable manure. Sufficient time, ordinarily 2 or 3 weeks, should be given for the vegetable matter to decompose. Manure should first "go through a heating process," and when once decomposed it becomes active as to its effect upon plants.

It is almost impossible to imitate the full effect of either vegetable or animal manure with mineral fertilizers. In certain forms of intensive agriculture, such as growing garden crops in greenhouses, mineral fertilizers are seldom used. In such cases, well-rotted manure is the only economical fertilizer. While it is true that much benefit is derived from the use of inorganic fertilizers upon field crops, and that most plants will make a better growth when fertilized than when unfertilized, yet there is "an appearance" to a plant growing in a soil that has been manured, that is different from that of a plant growing in a soil that has not been so treated. The general appearance of a plant growing in soil treated with manure is good, that is, it is likely to be a healthy plant.

There is often a great difference between a soil that has been manured or intelligently rotated and properly tilled, and a soil that has not been so treated. One can often detect the difference between good soil and poor soil merely by walking over them. Manured soils contain earthworms, bacteria, and other organisms, and they are usually productive. Surely there is something characteristic about manure or green manuring that puts life and fertility into a soil, and every one who has had any practical experience in agriculture has observed this.

The beneficial effect of organic matter in soils is shown under natural conditions. In the Southwest our desert soils, when properly handled, are usually productive. However, except in the lowlands where there has been an accumulation of active organic matter, it is often difficult to bring these soils under cultivation for certain crops, without first planting them to alfalfa or some other legume, and turning this crop under. These soils have been lying exposed to the sun for ages, with but a scanty vegetative cover. They contain very little organic matter, and often none of that stimulating principle that is so characteristic of manure. The effect of green manuring upon desert soils may be seen for several years after plowing under the crop.

On the other hand the "new grounds" of the South and East, or those lands that have been heavily timbered and newly cleared, are very productive, but they usually lose their fertility in part, in the course of a few years, when grown continuously to one crop, as for example, cotton which requires clean cultivation. Almost invariably, when the leaf mold disappears from the soils, the virgin fertility disappears with it. It is practically impossible to restore such lands to their original fertility by the use of mineral fertilizers.

CROP ROTATION AND GREEN MANURING

An adequate supply of stable manure seldom can be obtained upon the farm, and it is not always economical to devote a full season's growth to a crop that can be used only for green manuring. For these reasons, in practically all systems of agriculture, and with nearly all cultivated crops, some form of rotation is necessary. With most plants, rotation is the order of nature. Natural rotation may be very slow, as with the great trees of the forest, or it may be very rapid as with many annuals. Even when the major forest growth appears to be permanent, there is often a rotation going on in the underbrush. When the virgin or hardwood forests of the South are cleared, they nearly always "come up" in pine timber. Few plants are so constituted that they will grow to advantage in a soil that has been continuously cropped with their own species. There are some exceptions, but it may be said safely, that most agricultural crops are benefited by a rotation, and that for certain crops a rotation is almost a necessity.

The application of stable manure, the growing of "catch" crops, intercropping with cover crops, green manuring, and rotation, all accomplish the same beneficial results, all bring organic matter into the soil. In green manuring the organic matter is grown upon the land and plowed under, while in the application of stable manure the organic matter may be grown elsewhere, passed through an animal, and then applied to the land. In either case the fertility of the soil may be maintained.

It must be understood that manuring and rotation benefit the soil in other ways than by furnishing active organic matter, but these other effects are not now being considered.

SOIL FERTILITY AND PLANT NUTRITION

The whole problem of crop production or the maintenance of soil fertility centers upon plant nutrition. A soil is good only because it has the ability to produce a good crop. A soil may contain plant food in abundance and yet not be a good soil, or a soil may be in excellent physical condition and yet not produce a good crop. The maintenance of fertility, therefore, involves factors other than the supply of plant food or the mechanical condition of the soil.

A great amount of work has been done already, and much more remains to be done upon the subject of soil fertility. We know that one soil is good and another soil is poor but, strange to say, no one has told us all the reasons why this is true. The lack of positive results suggests the possibility that, in our investigations, we have not maintained close enough contact with the plant, we have probably depended too much upon chemical and physical measurements, and have not studied the likes and dislikes of the plant itself. A plant will often react to a change in soil conditions that cannot be detected by chemical or physical means.

VITAMINS IN PLANT NUTRITION

The term, vitamin, as applied to plant nutrition, must not be misunderstood. By this term is meant certain organic compounds, not ordinarily considered as plant foods, that are required by plants, and that are effective in exceedingly small amounts.

During the last few decades our views upon dietetics and animal nutrition have been undergoing a radical change. Now we no longer think of the value of an article of food solely in terms of its coefficient of digestibility, its percentage of carbohydrates, hydrocarbons, and protein, or in terms of the calories of heat that it contains. These are important, but there are other factors that are necessary in the food of animals before it becomes capable of sustaining life. These factors are called vitamins.

It has been only in recent years that the nature, distribution, and properties of vitamins have been studied, but the necessity for a varied diet in human foods has been recognized from time immemorial. This is true of nearly all newly discovered facts or observed phenomena. Their applications have probably been known for ages.

During the past 25 years, the writer has grown, handled, and watched critically many hundreds of thousands of seedlings of different plants in an effort to find out something of their likes and dislikes and of their food requirements, and during this time many phenomena have been observed that cannot be explained by the usually accepted plant-food theories. Much fragmentary evidence is at hand that teaches that plants require certain organic compounds, which may be called vitamins, and that these are just as necessary in plant life as are other vitamins in animal life.

THE PLANT, A PRODUCT OF ENVIRONMENT

When placed under certain conditions, especially very favorable conditions, almost all seedling plants are likely to show certain peculiarities, or likes and dislikes. The study of the likes and dislikes of seedling plants is one of the most interesting lines of investigation, and one that offers, from a research standpoint, almost unlimited possibilities.

By their habits of growth and nutrition, seedling plants reflect the conditions under which they grew wild in their native habitats, before man interfered. They reflect the soil, the climate, the rainfall, the bugs and animals and other enemies with which they had to contend, and such other things as made them what they are today. We call this their "age of adaptation."

Every plant that is now growing in its native habitat, and every plant when first removed from its native environment, is in equilibrium with the forces of nature. If only one of these forces or factors is changed or suddenly eliminated, it may mean the extermination of a whole plant species. This fact should be borne in mind when a plant is removed from its native habitat and grown under unnatural conditions.

The era of adaptation ends with the present; a plant may therefore be defined as an up-to-date product of environment. But time is long and the span that man can devote to the work of adapting a plant to new conditions is insignificant, when compared with the ages during which the plant was growing wild in its native habitat. Most of the conditions that a plant is likely to reflect in its habits of growth and nutrition at the present time are those to which it became adapted probably tens of thousands of years ago.

As products of environment, plants and animals do not differ greatly. Most animals have the advantage of plants, inasmuch as they are able to move around freely and thus modify their conditions. There is one similarity between plants and animals that is very pronounced. The young of every species, whether plant or animal, reflect more of the past than do the adults. The young of animals, for example, show more primitive traits than do the mature animals, and a seedling reflects more of the past than does a full-grown plant. Much information, therefore, may be gained by observing the habits of seedlings, that might not be obtained from older plants.

THE VALUE OF MANURE AS DETERMINED BY THE FOOD OF THE ANIMAL

Several years ago John W. McLane and the writer fermented many kinds of plants and other vegetable matter, in an effort to produce manure without passing the organic matter through the animal. Large earthenware jars were placed in the open air, and samples of alfalfa, leaves of different kinds of trees, desert sedges, sawdust, etc., were chopped fine, placed in these jars, and moistened with as little water as would thoroughly wet the samples. The jars were then allowed to stand until the organic matter was decomposed.

In warm weather, such plants as alfalfa and clover will ferment and reach a manurial stage in 10 or 20 days. The manure thus produced can scarcely be distinguished from the product of the stable, and when used upon plants, it has all the properties of the natural product. When organic matter such as the sedges, or other non-leguminous vegetation is fermented, it decomposes also, but very slowly, and it apparently never reaches a true manurial stage. Such fermentation is likely to be acidic and such manure, when applied to a soil, aside from improving its mechanical condition, has little value.*

The manure from an animal that has been fed straw or non-leguminous plants or that has grazed such feed upon the range is, from our experience, of little value from a fertilizer standpoint. The fact that the beneficial effect of manure depends largely upon the character of the food of the animal is not usually considered when placing a money value upon manure. The character of the plant, however, is usually considered in planning a rotation. Some kind of legume is nearly always included in the rotation, because of its beneficial after effects, while many weeds and grasses are carefully excluded from the rotation, for the reason that they yield a form of organic matter that may be actually detrimental to the succeeding crop.

When an animal at equilibrium is fed vegetable matter, practically all of the fertilizing elements may be recovered in the solid and liquid manure. This is not true with an animal that is gaining weight, nor with an animal that is giving milk. An animal neither adds to nor removes anything of fertilizing value from alfalfa hay. For example, the hay may be more thoroughly pulverized by passing it through an animal; such a process breaks down the starches and sugars and may cause the hay to decompose more rapidly, and it may be more valuable on this account, but the manure will contain all, and no more, of the fertilizer materials that were in the original hay. Plowing under organic matter in the form of green manure, represents an application of manure equal in dry weight to the manure that might have been obtained by feeding the entire crop to an animal at equilibrium, and returning the manure, urine, and gases of decomposition back to the land.

THE VALUABLE COMPONENTS OF MANURE ARE SOLUBLE IN WATER

Whether obtained from the stable or by fermenting the proper kinds of vegetable matter, all good manure possesses the peculiar power of stimulating the growth of plants. This property of manure lies in that part of it that is soluble in water.

*Much work has been done at Rothamsted in the production of synthetic manure, by treating straw and such material with ammonium sulphate and allowing the mixture to ferment. The effect of th s synthetic manure on plants is similar to natural farmyard manure. Hutchinson and Richards, Jour. Min. Agr. 1921, Vol. XXVIII, p. 398.

When well-decomposed manure is leached with water, a black solution, or manure extract is obtained. Such an extract will usually go through a fermentation process, but when this is over it may be kept in this condition almost indefinitely. When this black solution is added to a soil or to water cultures in reasonable amounts, it causes plants to grow in a characteristic way. After the soluble components have been removed from manure by leaching, the coarser material or residue, will be found to have lost the greater part of its fertilizer value. Evidently the most valuable components of manure are soluble in water. The coarser materials, when applied to a soil, may affect its mechanical condition and its water-holding capacity, but until they are decomposed they add little that is of direct value as plant food. For this reason manure should be protected from the weather and should never be allowed to become leached before being applied to the land.

A black manure extract was made by leaching well-decomposed manure with water, and this extract was analyzed for those elements that are ordinarily considered plant foods, namely, nitrogen, potassium, and phosphorus. A nutrient solution, the concentration of which corresponded exactly to the manure extract in these fertilizer elements, was then prepared from chemically pure salts from the laboratory. Wheat seedlings grown in the manure extract and in the nutrient solution were compared with others that were grown in distilled water. The nutrient solution produced plants that were better than were those grown in distilled water, but it did not produce plants as good as were those that were grown in the manure extract, judging by their size, color, vigor, and weight. There seemed to be something radically different in the manure extract that distinguished it from the nutrient solution. The difference in the plants was especially marked in the color of the foliage and in root development. It seemed impossible to produce a solution from pure salts that had all the properties of the manure extract.

Several liters of the manure extract were evaporated to dryness and a quantity of black residue was obtained, which was ground into a fine powder. A sample of this powder was put into a Soxhlet digesting apparatus and leached with 80 percent alcohol for about 10 days. The black organic matter of the manure extract is practically insoluble in 80 percent alcohol, while much of the available plant food goes into solution readily. The Soxhlet apparatus was so arranged that the alcohol, when placed in a flask and connected with a condenser that contained the sample of manure, distilled off, condensed in the chamber above, dripped through the tube containing the soluble manure extract, and returned to the flask with all the elements that it was capable of dissolving.

After 10 days digestion the extraction was assumed to be complete and the manure extract had been separated into two parts, one of which contained most of the soluble plant food without the black organic matter, and the other, the black organic matter without the soluble plant food. The separation was, of course, not as complete as are some other chemical separations, since some of the plant foods are not dissolved in alcohol. The readily available nitrates are soluble, but the nitrogen in organic combination is not soluble. The organic forms of nitrogen, however, are usually not directly available to plants, and in an experiment like this, when the readily available plant foods alone are of any consideration, this was not thought to be a serious error. The soluble potassium compounds were nearly all removed, as were the phosphates that were readily soluble.

At the end of the digestion, the two separates were emptied into porcelain dishes, the alcohol that remained was evaporated, and the residue was dissolved again in water and made up to a volume that was represented by the original manure extract. Instead of one, there were now two aqueous solutions, one very black containing the organic matter with but little of the nutrient elements, and the other solution a light straw color, containing most of the nutrient elements and but little organic matter.

Five sets of wheat seedlings were put into solutions, as follows:

1. Control, seedlings grown in distilled water.
2. Seedlings grown in "alcohol soluble" manure extract, or in the extract that contained the plant food.
3. Seedlings grown in the "alcohol insoluble" manure extract, or in the extract that contained the black, organic matter.
4. Seedlings grown in a mixture of 2 and 3.
5. Seedlings grown in untreated manure extract as a control.

After two weeks the difference in growth of the seedlings was very striking. The seedlings in No. 2, or in the solution that contained the plant food that had been extracted from the manure, grew better than did those in distilled water, but they did not in any way equal the growth of seedlings in the black, organic solution, No. 3, that is, the solution that contained very little plant food. The difference was especially marked in the root development. The plants in No. 3 were about as good as were those grown in the original manure extract, No. 5. A mixture of the two solutions that contained the manure separates, No. 4, gave plants equally as good as did the untreated manure extract, showing that apparently no change had been made in the constituents during the extracting process.*

*The writer wishes to acknowledge the helpful suggestions of Dr. O. Schreiner in the above experiment.

The striking feature of this experiment was that the peculiar effect of the manure extract seemed to depend largely upon the presence of the black organic matter, and not upon the amount of plant-food ingredients that it contained. An analysis of the manure for the plant foods, nitrogen, potassium, and phosphorous, will, therefore, give but a vague idea of its real value.

The experiment just described was repeated, but instead of using a Soxhlet apparatus, the solid black manure extract was dissolved in water, placed in a membrane, and the plant food dialized out with alcohol, as completely as possible. The residues after the dialysis, were prepared like those that have just been described and the solutions were then made

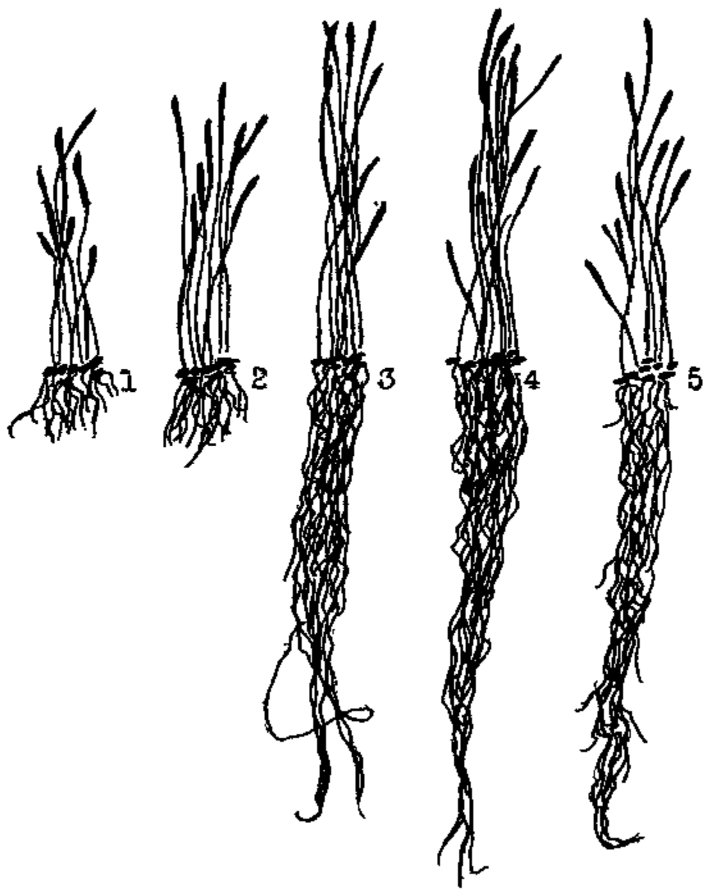

Fig 1.—Effect of dialyzed manure extract upon wheat seedlings.

up to the original volume, plants were grown in these solutions as they were in the former experiment and almost the identical results were obtained. The black organic matter and not the plant food appears to be the valuable constituent of manure. Some representative plants from these experiments were photographed, and a line drawing of one of these photographs is shown in figure 1.

EXPERIMENT WITH TOBACCO STEMS

In the South tobacco stems are extensively used in commercial fertilizer mixtures, presumably on account of the potash they contain. They often run as high as 7 percent or over, of K_2O and their value as a commercial fertilizer, based upon the units of K_2O alone, is of considerable importance. A sample of tobacco stems was secured, ground finely, leached with water, and this leaching made into an extract. This extract stimulated the growth of wheat seedlings very much as a manure extract does. Some of this tobacco extract was evaporated to dryness and the plant foods dialized out with alcohol in the manner described above. When these residues were made up to their original volumes, the extract containing the organic matter was of a brownish yellow instead of black, so in the final solutions, a clear solution containing the plant food, largely potash, and a brownish-yellow solution, containing the organic matter, was obtained. Plants were now grown in these two solutions in much the same way as in the manure extract, and they developed characters very much like those shown in figure 1. The solutions containing the plant food that had been dialized out, produced a slight increase in growth over the control, very much like that which might have been expected had an equivalent amount of pure chemicals been weighed out and used in the nutrient solution, but the plant food did not give the characteristic effects that were noticed when the organic matter appeared in the solution. The value of tobacco stems in a commercial fertilizer mixture does not rest entirely upon the amount of potash which they contain, but probably to a much greater degree, upon their content of active organic matter.

EXPERIMENTS WITH CITRUS SEEDLINGS

Attention has been called to the fact that although our desert soils often contain an abundance of plant food, it is difficult to bring them into production without first cropping them to alfalfa or some other legume. Most cultivated crops grow better on soil that has been given this treatment, but all plants do not respond equally well to such treatment. Certain plants probably will not respond at all. It is reasonable to assume that many desert plants, such as cactus and creosote bush, that have been growing for ages in a soil almost devoid of organic matter, will not profit by an application of manure, as will those plants that have been growing in a leaf mold or that have become adapted to a soil with a high percentage of vegetable matter.

Under field conditions, the effect of either green manure, or animal manure is very pronounced upon all kinds of cultivated citrus, and the habits of growth of citrus seedlings in pot cultures indicate this. The little seedlings reflect in a very striking way the conditions to which they have become adapted during their era of development, and their behavior will be cited as an illustration.

When citrus seeds are planted in the spring, first, they may lie dormant from 2 to 4 weeks before they begin to sprout; second, they require a comparatively high degree of heat in the seedbed to cause them to germinate; third, when they come up out of the seedbed and unfold their primary leaves, they will be killed by the sun unless partly shaded; fourth, when the root systems develop, the laterals move outward from the taproot, and grow upward toward the surface of the soil and if organic matter, such as leaf mold or manure, is spread upon the surface and kept moist, the roots will grow and mat into the organic matter; and fifth, the seedlings will absorb large amounts of calcium, and will do much better if limestone is present in the soil or subsoil in addition to the organic matter, than if it is absent.

In the opinion of the writer, the above-mentioned characters indicate that, first, in its age of adaptation, the citrus grew in a humid and not in a desert country, therefore, it did not develop the ability to withstand desiccation, in order to protect itself from long droughts; neither did it develop the ability to germinate rapidly as does the palo verde, in order to catch the fleeting moisture of a sudden shower; second, it grew in a climate as warm if not warmer than that of southern Arizona or southern California; third, it grew as an underbrush or in a thicket, probably under the shade of large tropical trees, so that the sprouting seeds were not exposed to the direct rays of the sun; fourth, as an underbrush, in the shade of other trees, it fed upon the leaf mold provided by the trees; and fifth, in its native habitat it had calcium carbonate or limestone within easy reach, probably in the subsoil.

Many times has the writer planted healthy citrus seedlings, and given them restricted food ration, consisting of nitrogen, phosphorus, and potash, but no organic matter. Symptoms of malnutrition are almost sure to appear. Usually the seedlings may be restored to a healthy, normal condition by the addition of organic matter, sometimes in exceedingly small amounts. A thimbleful of peat or leaf mold, or a small amount of bog water, when sprinkled upon the top of a pot containing unhealthy citrus seedlings, will often cause the seedlings to turn green and start out

Fig. 2.—Effect of a small amount of organic matter upon the growth of citrus seedlings

anew with a vigorous growth. In many experiments when solutions of peat, or bog water were used, the amount of plant food in the application will be represented, in gram weights, by a figure in the second or third decimal place. Such marked effects cannot be explained upon the basis of the plant food that is contained in the peat.

When citrus seedlings are grown in pots of sand that contain a high percentage of calcium carbonate, 2 percent or more, but no organic matter, symptoms of malnutrition often develop more rapidly than they do in plants that have been grown in pure sand. The plants usually grow a few inches high, then stop growing, turn yellow, and remain in this condition for a long time. The roots that grow to a limited extent into the calcareous sand seem to cutinize, or "cork over" at the tips, and ordinarily one does not find a healthy, transparent growing root-tip in a hundred plants. A set of such dormant plants that were nearly a year old, and mottled and yellow, was selected for experiment. One-half of the pots were set aside as control, and in each of the other a small hole, about 4 inches deep, was made in the sand with a lead pencil, near the outer edge of the pots. Into this hole about a thimbleful of leaf mold was sprinkled, and the sand was again packed down into the hole. Care was taken to give these plants no organic matter from any other source.

In a short time after the application of the leaf mold, the plants in these pots began to grow. After a few months' time some plants were removed from the pots and photographed. A drawing from this photograph is shown in figure 2.

As illustrated in the drawing, a few roots had grown into the ball of leaf mold and had made a mat of it. These roots had clear, healthy, growing tips, and what was more surprising, the other roots of the plant, growing on the opposite side of the pot, also had healthy, growing tips. These roots had not been in direct contact with the organic matter, yet they were responding to such an application to the other root at some distance away. Apparently the citrus plant requires a certain amount of active, organic matter, but it is not necessary to have this organic matter in actual contact with all of the roots.

This observation has an economic bearing on citrus culture. Many of our best growers, when manuring citrus orchards, apply the manure in trenches, or holes, at some distance from the tree. It often does not seem economical to scatter the manure broadcast over the surface of the soil. If the manure is placed in a trench near the trees and kept in bulk, and if the soil and manure are kept moist, the roots of the trees will be almost certain to find the manure and to be benefited by it.

This experiment with citrus, like many others, illustrates the fact that a little active organic matter, even when applied in exceedingly small amounts, possesses the peculiar property of stimulating the growth of certain plants.

WHY VITAMINS ARE NECESSARY IN ANIMAL NUTRITION

For several years the writer has been watching others carry on nutrition work with animals. When rats, for example, are fed an unnatural diet, such as bolted, white corn meal, they soon sicken and die However, if this diet is reinforced by some other food in very small amounts, such as the juices of vegetables, or the seeds of plants, the rats will live and fatten upon the corn-meal diet. The rat, in its era of adaptation, did not live upon corn meal alone. He lived upon a variety of seeds and plants, and now he, the product of these ages of environment, demands those things that have made him what he is today. They are as necessary in his nutrition as the oxygen of the air is necessary to his respiration, and for the same reasons he is accustomed to and is adapted to them. Had the rat been developed upon a diet of corn meal alone, we probably should have to use some other animal for our nutrition experiments, as he would not be affected by the presence or absence of vitamins. If, in the same way, the rat had been developed in an atmosphere that was free from oxygen that gas might be poison to him.

The coral polyp, as it builds up islands in the southern seas, may not be concerned with specific vitamins that have been isolated. It is concerned with the chemical composition of the sea water, and it will not thrive in an artificial salt solution unless the exact chemical balance of the sea water is imitated. The same phenomenon is true of many other forms of sea life. The polyp and the sea urchin probably require their vitamins, but these may or may not be vitamin A or vitamin B.

UNNATURAL FOODS AND UNNATURAL CONDITIONS

It is similar with all plant and animal life. Unnatural foods bring about unnatural conditions. The necessity for the presence of vitamins in the food of animals is probably purely accidental. The vitamins are essential only because the animals have become physiologically adapted to them. Had vitamin A, B, or C been absent from the food of our forefathers, they would not now be necessary for us. Had rats been developed upon a pure corn-meal ration, they probably would not now be the same kind of an organism that they are, and in all probability, they would not now demand cheese, potatoes, tomato juice, or grass seed in their diet. The corn-meal worm waxes fat upon a restricted diet.

PLANT VERSUS ANIMAL VITAMINS

In their effects upon living organisms, plant and animal vitamins are very much alike. Both plants and animals are products of environment, and in their nutrition, neither have very wide powers of accommodation. Both demand natural foods. Adapting a plant or an animal to new climatic conditions is a relatively easy task, but in matters of nutrition, adaptation is an extremely slow process. After the orange tree had spent perhaps a million years in adjusting its physiology and anatomy to the presence of certain compounds in its foods, it is a difficult matter to make it change suddenly its likes and dislikes. They have become definitely fixed.

The act of removing a certain vitamin from the food of an animal, for example the polishing of rice, changes the food from a natural to an unnatural product, and if fed upon polished rice alone an animal will suffer. In like manner, an attempt to grow certain agricultural crops on a soil that is deficient in one of its natural components, active organic matter, will most likely induce some nutritional disease, for which there is only one remedy, namely adding the organic matter.

In the Southwest, nearly all forms of agriculture are being carried on under unnatural conditions, and nearly all of our cultivated plants are out of their natural environment. Practically all of the forces of nature are continually at work tending to cause our reclaimed areas to revert to natural desert conditions. Unnatural conditions in agriculture bring about mysterious nutritional diseases that baffle the skill of the plant physiologist and pathologist. We often prune, spray, plow deep, or add commercial fertilizers without getting any response from the plant, for the reason that the plant is probably suffering from the absence among other things of a certain vitamin and that it will respond only to the application of some form of organic matter that contains this vitamin. It should be the aim of the farmer especially under arid or semi-arid conditions, whenever possible, to work in harmony with nature, that is, to imitate natural conditions. Whenever man tries to oppose nature, in the end nature is sure to win.

If the behavior of seedlings were studied much more would be known about the likes and dislikes of the mature plant, and more would be known of the natural conditions that the plant requires.

VITAMINS AND SOIL CONDITIONS

Future investigations with vitamins may develop facts that will prove that the compounds stimulating the growth of plants are closely associated with similar compounds that stimulate the growth of animals. The nutritive value of a cereal, for example, may depend to a large extent upon the conditions of the soil that produced the cereal. It may be possible even to grow a cereal for several generations in pure sand that has been fertilized with mineral plant foods only, or in a soil that is deficient in organic matter, and to produce a crop that is deficient in vitamins, or a cereal with a low nutritive value.

A few years ago some investigational work upon this subject was begun by Colonel Robert McCarrison,* a surgeon in the British Medical Service of India, but the work was discontinued after one season, due to the lack of funds.

Dr. McCarrison, while studying the nutritive value of different foods, observed that rice from different paddies varied considerably in its nutri-

*Reported in an address by Col. Robert McCarrison before the Royal Society of Arts. Jour. Roy. Soc. of Arts. January 2, 1925.

tive value, and that these differences were not indicated by its chemical composition. In coöperation with Dr. Norris, Agricultural Chemist to the Madras Government, nine plots at the Agricultural Farm at Coimbatore, that had each received a different fertilizer treatment for 15 years were planted to millet. One of these plots had never received any fertilizer, organic or inorganic, and was non-productive or "exhausted." Another plot had received annual applications of nitrates, another plot phosphate, another potash, and other plots mixtures of mineral fertilizers. Plot No. 9 had been manured for 15 years with the manure of cattle. The nutritive value of the grain that was produced upon these plots was tested by feeding it to animals.

It was found that the millet grown on the manured plot was more nutritious and contained more vitamins than did that grown on any other plot, and that the millet that was grown on the exhausted soil plot was of the lowest value in this respect.

It is a well-established fact that, if a cow is fed upon foods that contain no vitamins, the milk that she produces will be lacking in these essential elements. Vitamins are not synthesized within the body of the animal but are taken in through the food.

This work by the British surgeons can be considered as merely preliminary, but the indications are that there may be an analogy between the animal and the plant, that the nutritive value of cereals may depend to a certain extent upon the manurial conditions of their growth. The soil either contains the essential vitamins and these are transmitted to the growing plant, or the plant requires a natural condition for its growth, that is, it requires the presence of organic matter in the soil, in order to function normally and to produce these vitamins.

CONCLUSIONS

1. Certain plants, upon decomposing, develop compounds that stimulate the growth of other plants.
2. Manure may be produced without passing the vegetable matter through an animal.
3. The stimulating property of manure rests largely in the black, water-soluble, organic matter, and not in the plant foods, nitrogen, phosphorus, or potassium that it contains.
4. From observations upon seedlings, it appears that many plants, in order to develop normally, require certain organic compounds in the soil, that are not usually considered as plant foods. These compounds are effective in exceedingly small amounts, and they are necessary in plant nutrition because they are one of the factors that have made the plant what it is today.
5. The beneficial effects of manuring and crop rotation are due, in large part, to the fact that vegetable matter is thus added to the soil, and that, in decomposing, this vegetable matter develops or sets free certain organic compounds that are essential to the growth of plants.