THE RELATION OF NUTRITION TO THE HEALTH OF PLANTS.

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INTRODUCTION.

The writer will not attempt in this paper to do more than present a general outline of some of the most important problems of nutrition in relation to the health of plants and to suggest lines of research likely to prove of value to agriculture. Some of the most difficult, and therefore still unsolved, problems are to be found in plant and animal nutrition. Their study requires the most careful technical research, and every truth learned or process explained is of great practical value. The study and careful description of the symptoms of the various kinds of starvation and malnutrition have been greatly neglected by plant physiologists and pathologists. Similar symptoms may develop in the plants from the most diverse causes. It then becomes very difficult in many cases to diagnose troubles unless all of the conditions of environment and often also the hereditary tendencies are known.

OUTLINE OF RELATION OF NUTRITION TO HEALTH OF PLANTS.

Nutrition is a fundamental condition of life, both animal and vegetable. It is the process by which living organisms obtain and organize into living tissue the simple elements (carbon, hydrogen, oxygen, nitrogen, potassium, calcium, magnesium, phosphorus, etc.) of which they are made up, and which constitute what are called their food elements; or, briefly, it is the process by which living substance is organized out of nonliving substance.

All plants and animals may be resolved into the same primary elements, but in the processes of organization these elements enter into multitudinous combinations and relations to each other, making up the various organic materials and tissues. Each living cell has a tendency to organize its simple elements as the cell itself is organized, and there results more or less well-defined fixity of organization which has come to be accepted as a natural course in the reproduction of all individuals,
and which is designated as species or variety. It is evident, however, that the necessary elements must be available and the conditions for organization must be essentially the same as those under which the cell itself was organized if the same end is to be reached. Variation in these conditions of environment and food will produce variation in the plant. The kind and quantity of food available to plants is a prolific source of variation. For example, a plant grown on a rather poor soil compared with a plant of the same species grown on a very rich soil might not at first be recognized as the same. While at first there may be no essential difference except in size, in a few generations a distinct variation usually appears in the more highly nourished plants, which are in a state of great physiological activity, and become, therefore, much more sensitive to the conditions surrounding them. Closely correlated with food supply are temperature and light conditions, both of which exert a powerful influence on nutrition and growth.\(^1\)

Every plant must have certain elements in order to live and complete its growth, and these elements must be in combinations available to the plant. In the vegetable kingdom, as a whole, there is great diversity in the power of plants to obtain their food elements from different substances, but with the ordinary agricultural plants there is not so much difference in this respect. While they all absorb the free oxygen of the air through roots, stems, and leaves, and obtain their nitrogen from nitrates, ammonia, and other simple compositions in soils mainly by absorption through the roots, none of the agricultural plants are able to absorb nitrogen directly from the air. The indirect absorption of free nitrogen will be discussed later. Carbon is obtained by plants mainly from the carbon dioxide of the air absorbed through the leaves and other green parts. Water and the various salts of calcium, magnesium, potassium, sulphur, phosphorus, etc., in solution are absorbed mainly through the roots from the soil. The relative amount of these different substances entering into the structure of plants may be roughly represented by the following analysis made by Johnson of the dry leaves and stems of clover:

\[\text{Analysis of the clover plant.}\]

<table>
<thead>
<tr>
<th></th>
<th>Per cent.</th>
<th>Per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>47.4</td>
<td>Sulphur</td>
</tr>
<tr>
<td>Oxygen</td>
<td>37.8</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5.0</td>
<td>Remaining ash</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2.1</td>
<td></td>
</tr>
</tbody>
</table>

From 70 to 90 per cent of the weight of living plants is water.

\(^1\) For a discussion of variation due to food and the various conditions of environment, see article by Webber in Yearbook for 1896, pp. 89-106.
In the ash of an oat plant the relative abundance of atoms of the various elements is well represented in the following:

Various elements in ash of oat plant.

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage of composition</th>
<th>Relative number of atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>CaO = 12.1</td>
<td>216</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P₂O₅ = 8.8</td>
<td>124</td>
</tr>
<tr>
<td>Potassium</td>
<td>K₂O = 45.9</td>
<td>971</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl = 6.1</td>
<td>173</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na₂O = 2.32</td>
<td>60</td>
</tr>
<tr>
<td>Magnesium</td>
<td>MgO = 4.12</td>
<td>114</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe₂O₃ = 0.51</td>
<td>6</td>
</tr>
<tr>
<td>Silicon</td>
<td>SiO₂ = 17.2</td>
<td>287</td>
</tr>
<tr>
<td>Sulphur</td>
<td>SO₂ = 2.86</td>
<td>86</td>
</tr>
</tbody>
</table>

These analyses, however, give only the barest suggestion of the relative importance of the various food elements. It has been shown in the analyses by Wolff and other investigators that the quantitative composition of the ash of the same kind of plants varies according to the soil on which they are grown. Every plant, as Loew expresses it, "absolutely requires a certain minimum of each mineral nutrient, and in most cases, besides this minimum, it takes up not only an excess of these various compounds, but also substances which are perhaps useful, but not absolutely necessary for plant functions, such as sodium and silica." If a plant fails to obtain any of the elements mentioned, except, perhaps, silicon and sodium, it can not develop, and must finally perish. A decrease below the amount required for normal growth will retard growth and finally result in disease or death. On the other hand, an excessive amount, as in alkali soils, may be quite as injurious. It thus becomes a very important matter to know the chemical composition of soils as well as their structure and texture. It is difficult, however, to draw correct conclusions from such analysis unless all of the conditions influencing the growth of the plant are considered together. With the increase of the knowledge of the physiological importance and relationship to the plant of the various elements which it absorbs from the air and soil, the grower will be enabled to more and more control the growth of crops by modifying these conditions.

EFFECT OF SOIL CONDITIONS ON PLANT GROWTH.

The effect of soil conditions upon the growth and development of plants is well recognized. As already shown, if the water that plants contain is counted, the largest percentage of their substance, in fact

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everything except carbon and oxygen, comes to them through the soil by way of the roots, and the texture and structure of the soil affects decidedly the availability to the plant of the soil foods with air and water. Many agricultural plants have been more or less adapted to soils of a certain texture. If an attempt is made to grow a crop on a soil not well adapted to it the crop is likely to suffer, unless the skill of the cultivator is able to modify the conditions of growth to meet the requirements of the crop. Most of the ordinary field and greenhouse crops require abundant and readily available food for the maximum production and vigorous growth, but this food must not be in too strong a solution in the soil water, and the water itself must be readily available, though the soil, as a rule, must not be so wet as to exclude the air. It is more difficult to maintain these conditions in light, sandy soils than in soils containing more or less clay. It is also more difficult to manage a sandy, clay soil poor in humus and fibrous matter than one comparatively rich in fiber and humus. A light clay soil with humus and fiber derived from decaying roots and plant tissues, or manure if the soil is properly drained, will not easily become too wet or dry out too quickly. A great deal of soluble food can be absorbed by such a soil without danger to the roots of plants growing in it, and air is easily admitted to the roots. The mechanical condition of such a soil, apart from these other factors, also favors a strong development of roots.

In many cases it requires very careful watching to prevent starvation and stunting in light soils. These conditions, however, favor some crops, like sweet potato and peach. On the other hand, in very heavy soils there is danger from overwatering, except, of course, for crops like rice, which require wet soils. There is also danger from poor drainage and lack of air, causing a weakened development of roots and making them subject to root rot and other diseases. Sorauer has described the ideal condition of a soil for ordinary field and greenhouse crops as "one in which it resembles a sponge and in which it will retain the greatest amount of nutritive substances and water without losing its capacity of absorbing air." Speaking of forcing-house soils, Bailey says:

They should not only be rich in available plant food, but they should be of a mealy and friable texture, so that water soaks through them uniformly, leaving them dryish and loose on top. A soil with much clay tends to run together, or to cement itself, especially if watered from a hose, and the plants tend to make a spindling and unwilling growth. On the other hand, a soil with very much manure or litter is so loose as not to hold sufficient water to keep the plant in health; or if it does hold the requisite moisture, it tends to produce a robust and overwilling growth at the expense of the fruit. Yet, despite all this, the skill of the gardener is much more important than the character of the soil, for a skilled man will handle even hard clay soils in such a manner as to give good results. The chief single factor of manipulation in determining the productivity of a soil in forcing houses is the water.

1 Physiology of Plants, p. 56.  
2 The Forcing Book, p. 50.
A Healthy Branch and Diseased Branches of Norton Grapevines.

[1. Healthy branch; 2, 3, and 4. Diseased branches, showing short, compact growth due to unfavorable soil conditions.]
Fig. 1.—A Diseased Norton Grape.
[From vineyard near Charlottesville, Va. This view shows how the leaves fall from the new growth as a result of unfavorable soil conditions.]

Fig. 2.—Tobacco from Sand Cultures: Upper Plants, Excess of Magnesia; Lower Plants, Excess of Lime.
Sorauer\(^1\) says:

The practical experience of gardeners teaches us that a root can never have too much air, but often has too little. * * * As soon as we are able to satisfy the wants of roots with regard to water and nutritive substances, we may choose beads of glass or crumbled quartz instead of ordinary soil. Indeed, by timely changes of the nutritive solution and by constantly renewing the supply of oxygen, we can cultivate plants for years in water itself.

It is not profitable, however, to employ soils that require such close and constant attention, even when conditions are largely under control, as they are under glass. It is the aim of economical production to select a soil for a given crop that, with a minimum of labor expended on the part of the cultivator, will produce the desired results, and this is true in culture under glass as well as in field culture.

**INJURIES TO PLANTS FROM LACK OF OXYGEN.**

The greatest dangers due to unsuitable mechanical conditions of soils are poor drainage and consequent excess of water and lack of oxygen, bringing on asphyxiation, weakening, and even death of the roots of plants growing in such soils. Crops growing in heavy clay soils, especially where there is an impervious subsoil or hardpan, will often have many of their feeding roots killed by suffocation during extended wet periods, especially in spring or early summer. Roots forming in a moist or dryish soil are often killed in two or three days if the soil becomes saturated with water. The vitality of the whole plant is weakened, not only by the loss of its feeding roots, but by the development of injurious products, such as alcohols, in the cells of the roots that are not killed.

A peculiar disease of grapes that appeared a few years ago in Virginia was found by the writer to be probably due to asphyxiation of the feeding roots of the vines in "gumbo" soils. These soils occurred in spots through the vineyard, and during protracted wet weather remained saturated. In dry weather they became dry and hard, thus further excluding the air and injuring and preventing the normal and healthy development of roots. The leaves of the vines in these spots became small and yellowish, matured early, and fell off. The stems were shortened and were inclined to break at the nodes, and the fruit fell off before maturing. The vines struggled on a few years and then died. No parasitic fungus or insect could be found constantly associated with the disease. Everything indicated that it was due to the unfavorable soil conditions as described. Pl. II shows healthy and diseased branches and leaves of vines from this vineyard. Pl. III, fig. 1, shows a diseased vine, the new growth having shed its leaves.

Plants, especially trees, growing where the surface soil becomes caked and packed, are likely to suffer for want of oxygen for the roots.

\(^1\) Physiology of Plants, p. 71.
The trouble is especially apparent along paved streets, where the open space of a few feet left around the trunk of the tree is often packed as hard as the pavement. In some cases the space is so small that, even if it were properly cultivated, not enough air could reach the roots after the tree reaches the age of ten or fifteen years. Under these conditions there is also often a lack of proper food and water, as well as a lack of air. The feeding roots slowly die and the vitality of the whole tree is weakened; the leaves turn brown along the edges early in the summer, and fall prematurely. The annual growth is shortened and here and there limbs die back. In this weakened condition the tree is likely to become the prey of insects and fungi, which attack roots, trunk, branches, and leaves, and death comes slowly or quickly, as the case may be. The only remedy in all cases of this kind is to loosen up the soil and let the air down to the roots, working in deeply some good manure to stimulate the new growth of feeding roots. All of the diseased and dead limbs should be thoroughly pruned out of the top, and if the tree has not been too greatly weakened its recovery may be effected. In the case of ordinary crops growing in soils that have caked on the top, careful cultivation is, of course, the remedy. Soils that behave in this way are universally benefited by stable or other similar organic manures, and in many parts of the country by liming.

Where the standing of water in the soil is the cause of the lack of aeration, drainage is, of course, the remedy. Crops and trees are often greatly injured by overirrigation or by excessive rains. This is especially likely to occur in very fine sands, which are at best poorly aerated.

It should be clearly understood that roots of all plants must have oxygen. If they do not get it they will die of suffocation. The plant will be poisoned by its own decomposition products, and will starve or become the prey of parasitic enemies, which it is too weak to resist.

Soil foods necessary to plant growth.

Important as the mechanical condition of a soil may be in its relation to the growth of crops, the chemical condition is not less important. As already stated, there are certain elements that are absolutely necessary to plant growth. Every soil must have these in an available form and of proper concentration. If there is too little of any one or all of the necessary elements, the crops growing in such soils will starve, and if there is too great an excess of soluble salts the roots will be injured. It is often a difficult matter to determine by the behavior of the plant what the trouble may be. Take, for example, the disease known as “chlorosis,” or the production of yellow foliage, instead of the normal green leaves. The most common cause of this condition is the lack of available iron—either its absence altogether from a soil, or the failure of the roots to dissolve and absorb
such compounds as may be present. Sometimes, in the presence of an excess of lime, the roots are unable to dissolve the iron compounds and absorb them; and occasionally from a lack of oxygen, or the presence of parasites killing the root hairs and feeding roots, the plant is also prevented from absorbing the iron or any of the other difficultly soluble materials. Wherever the trouble is due to a lack of the iron, the addition of a soluble iron salt, such as iron sulphate, to the soil, or even spraying it on the yellow leaves, will usually cause them to turn green again. The lack of magnesium, lime, phosphoric acid, or nitrogen will also produce yellowing of many crops, and occasionally an excess of these substances will have the same effect, as will also the lack of water or excess of water, lack of light or excess of light. The different kinds of yellowing can be more or less easily distinguished by other pathological conditions occurring at the same time. Of course, the addition of iron in the latter cases of yellowing would have no effect, and the lacking nutrient must be supplied or the unfavorable condition corrected.

INFLUENCE OF MAGNESIUM AND LIME ON PLANT GROWTH.

The combination and ratio to each other of the various food elements which exist in soils have a marked influence on growth. It has been recently shown that magnesium is a poison to many plants unless accompanied by a readily available calcium compound. Plants become stunted when they have too much magnesium and not enough lime. As it will not be possible to go into this subject in detail here, it may be stated that Dr. Loew¹ has shown the physiological importance of magnesium and the part it plays in connection with lime in the nutrition of the plant. Plate III, fig. 2, reproduced from Dr. Loew's bulletin, shows the effect of too much magnesium on tobacco. The lack of fertility in many soils is undoubtedly due to an insufficient amount of available lime as compared with magnesium. Such soils are benefited by liming with a lime free from magnesium and are injured by a magnesium lime. On the other hand, soils poor in magnesium are benefited by a magnesium lime and injured by a lime free from magnesium.

While magnesium in the absence of lime acts as a poison, it is nevertheless absolutely necessary to plant growth. It is especially important in the formation of seeds, and the want of it is often not felt in the plant until this period of development is reached. A comparatively small amount is often sufficient to meet the requirements of growth up to the period of flowering or fruiting, but at this time, if a sufficient supply is not available, the plants fail to flower or set fruit, the flower buds not forming at all or withering before maturing. If

the absence of this element is still more marked, normal vegetation soon ceases, the stem becomes shortened, the leaves grow crowded together—small, distorted, and yellow. All of these symptoms, however, may also be produced by other causes, and the probability of these must always be taken into consideration in diagnosing cases of this kind. No other substance can fully take the place of magnesium in plant growth. It occurs in soils, from disintegrating rocks, chiefly as magnesium carbonate and sulphate. In soils where the magnesium content is already too high, or where it exceeds by weight \( \frac{1}{7} \) parts of magnesium to 7 parts of lime, magnesium limestones should not be used for lime. Care is to be taken also in applying fertilizers containing magnesium, as in the crude potash salts. If the soils do not contain a large excess of lime it is necessary to add lime at the time fertilizers containing magnesium are added.

**FUNCTION OF CALCIUM, OR LIME, IN THE SOIL.**

Lack of calcium, or lime, in plant development is first indicated by stunting and the production of small, yellowish leaves. Chlorophyll (leaf-green) bodies do not develop normally, and the starch which they make is with difficulty changed into sugar, possibly owing to the failure of the nucleus of the cell to manufacture diastase, the ferment necessary for transforming starch to sugar in plant nutrition. It used to be thought that the main purpose of calcium was to neutralize free acids developing in the nutrition of the cell, and while it undoubtedly serves this purpose to a large extent, it owes its greatest importance to the fact that it is a necessary constituent of the compounds entering directly into the composition of the nucleus and of chlorophyll bodies, and it can not be replaced for this purpose by any other substance. In the soil lime performs many important mechanical and chemical functions. One of the most important of the latter is the part which it plays in combining acids set free by decompositions in soils. These are brought about through the action of roots and other organisms upon the soil particles, and also by strictly chemical decompositions. If these free acids were not neutralized they would act injuriously to the roots of crops. The presence of lime also favors nitrification in soils. This point will be discussed more in detail farther on.

**IMPORTANCE OF POTASSIUM AS A PLANT FOOD.**

Potassium, the essential ingredient of potash, is well known to be one of the most important and indispensable of all plant foods. Large quantities of it are required by all crops. Loew estimates that the amount required annually per hectare \( (2 \frac{1}{4} \text{ acres}) \) of pine forest is 7\( \frac{1}{4} \) kilos (15.34 pounds); for the same area of wheat field, 37\( \frac{1}{4} \) kilos (76.74 pounds); clover field, 102 kilos (208.69 pounds); potato field, 125 kilos.

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(255.75 pounds). A considerable part of the ash of most plants consists of this material, and though closely related to sodium in its chemical properties, the latter can not replace it in the plant. Plants growing in soils containing more sodium than potassium will nevertheless absorb much more of the potash. One of the first signs of a lack of potash is a decided cessation in growth without other apparent cause of trouble. The plants often have their normal green color, but make very little starch or sugar and almost no protein or nitrogenous matter. Potash plays an important part in the formation of starches and sugars, but its greatest importance is in connection with protein formation, in which it is apparently indispensable. When it is remembered that proteins or the related nitrogenous compounds are the main source of food for the young growing cells, the importance of potassium will be appreciated.

Recent investigations also indicate that potassium is necessary to turgescence, or water pressure, in the cells. This condition is one of the most important physical requirements of growth. The fact that potassium increases water pressure in cells would also indicate that it increases the water-absorbing power of the plant as a whole, thereby increasing its ability to hold more effectually, in times of drought, the water which it has absorbed. It also increases the water-holding power of soils for the same reason, and is, therefore, valuable from this standpoint on droughty soils. On the other hand, it must be avoided on soils naturally heavy and wet for the same reason. It enables herbaceous plants, like tobacco, to resist light frost, probably by increasing the water-holding power of the cells, as above described, thus preventing the excessive withdrawal of water from them by the formation of ice in the intercellular spaces to such an extent as to result in injury. The importance of increasing the water-holding power of the cell exposed to cold will be appreciated when it is understood that in many cases the effects of freezing are the same as those of drought, namely, the water is withdrawn from the cells by the ice forming in the intercellular spaces. This may go on to such an extent that the protoplasm of the cell becomes almost dry. The cell collapses, and when the ice in the intercellular spaces melts, the cells are unable to absorb the water again, not because they were injured by the cold, but simply as the result of becoming too dry. Protoplasm may, on the other hand, be killed outright by cold at a temperature varying with different species of plants, and even with individuals.

A ready supply of potassium also hastens and perfects the maturing of plants, especially the ripening of the wood of fruit and other trees, thus enabling them to better withstand winter cold. A lack of potash is said by Webber to cause in the orange "an excessive growth of

1 This refers especially to certain salts of potassium.
2 Yearbook of the Department of Agriculture for 1894.
weak, immature wood, which does not harden up as winter approaches, and is liable to be injured by frost.” Webber also calls attention to the fact that many growers believe that potash, at least in the form of sulphate or when derived from tobacco stems, causes the production of excessively sour fruit. It would be important to determine if this is really true. There are good physiological reasons which lead us to expect such a result, not only in the orange, but in plants in general. However, an increase of starch or sugar would also be expected at the same time. The acid juices of plants are, as a rule, disliked by insects and fungi. This may explain why muriate of potash prevents to some extent the ravages of the rust mite on the orange and the injurious action of the rust mite on cotton.

It is possible that potash salts might in this way have an influence also on the intensity of color in flowers and fruits, especially where the intensity depends on the amount of acid present in the cell sap. The importance of varying tones of color is well understood by florists, and the ability to slightly change a shade by the use of fertilizers would be valuable not only to florists, but to fruit growers and other horticulturists. The whole question should receive careful investigation in view of its possible economic bearing on these minor but important matters. Clay soils, especially clay loams, usually contain from 0.5 to 0.8 per cent of potash, lighter loams about 0.3 per cent, and deep sandy soils less than 0.1 per cent, but even this small amount is equivalent to 3,500 pounds to the acre, assuming that an acre of land 1 foot deep weighs 3,500,000 pounds. As a rule, therefore, it is only upon the lighter sandy soils that a lack of potash may be expected. In the use of potassic fertilizers careful attention should be given to their composition. Muriate, or chloride, of potash and the sulphate are examples of common potash fertilizers in use. The former is as a rule cheaper, and for some crops just as good as the sulphate, and should therefore in these cases be used. The sulphate is preferable for certain crops, and when doubt exists is much safer and more satisfactory. This is especially true in the case of tobacco, which requires a proportion in the leaf of about 6 parts of potash to 1 part of chlorine to produce a leaf of good burning quality. Night soil, kainit, and other manures rich in chlorine should not be used for tobacco. The quality of sugar beets and potatoes is also said to be injuriously affected by fertilizers rich in chlorine. Sugar made from beets rich in this element is said not to crystallize readily. However, it is doubtful if it seriously interferes with the more modern methods of sugar purification. Potatoes, when rich in chlorine, are likely to be pasty or soggy. While these conditions are not pathological, and may be quite the reverse, as far as the health of the plant is concerned, still these instances are instructive in showing how the substances absorbed by the roots may affect the commercial value of crops, entirely apart from
the ordinary consideration of yield. There is a rich field open for a careful study of the effect of such elements as chlorine, sodium, and silicon (usually not strictly required in plant nutrition) on the commercial value of plants. While chlorine may be undesirable, and in fact injurious in some cases, on the other hand it improves celery and apparently makes it more resistant to Cercospora (leaf spot), and its value on asparagus and similar crops is well known. It has long been known that common salt is of great value when applied to light soils too rich in nitrogen. In such cases it reduces the excessive vegetative growth of crops, especially wheat, oats, and barley, thus permitting the formation of more grain in proportion to straw and preventing the lodging due to rank growth. English farmers use it on very light lands, especially for wheat, at the rate of 2 to 3 hundredweight per acre, applied usually before the land is plowed. It is said to prevent rank growth, especially in wet seasons, to retain moisture in the soil in seasons of drought, to strengthen and whiten the straw, and to brighten the appearance of the grain. Salt, however, should not be used on soils poor in nitrogen. Storer suggests that the use of salt may be valuable on some of the rich bottom lands of the West. He says:

On the so-called American Bottom in Illinois, for example, the growth of stalks and straw is said to be enormous in proportion to the yield of grain. Corn stalks grow 10 to 12 feet high, and are sometimes 5 inches in circumference. While at about the height of a man's head they bear a single ear of corn. For all the rank growth of stalks the harvest is hardly 50 bushels of Indian corn or 25 bushels of wheat to the acre. It would be an interesting experiment to try whether salt or any other chlorine compound would in this case bring the stalk production into fit relations with a proper crop of grain.

Storer also calls attention to the experiments of Nessler and others, showing that salt toughens and makes more elastic the leaves of tobacco, flax, and hemp, greatly improving the length and quality of the fiber of the latter. As already pointed out, however, it injures the "burn" of tobacco and can not be used on this crop for that reason. He also quotes from one of the most successful planters of the South, who says that he has used salt on his cotton lands for fifteen years, and that 300 pounds of salt to 200 pounds of plaster are almost a total preventive of rust, making the cotton bear longer in the season, stand drought better, increasing quantity and improving quality of the product. It is doubtless, in part, this beneficial effect of common salt that makes kainit such a popular form of potash on many crops in the South. This observer finds also that it acts equally well on corn, oats, and other grains, and toughens wheat straw so that there is less waste from the ears breaking off when the crop is cut. These observations lead us to think that salt might be valuable on some of the rich nitrogenous lands of the Northwest in preventing the shattering of cereals.

1Agriculture, p. 586.
IS CHLORINE A FOOD?

While it appears that in some cases plants can be grown to maturity without chlorine, a small amount of this element is, as a rule, necessary for even moderately vigorous growth. Besides the relation to growth already suggested, it promotes the solution and movement of starch and the formation of cellulose or fiber. Buckwheat was found by Nobbe to thrive normally in culture solutions without chlorides until the first flowers were formed. Soon after this the tips of the stalks died off, the upper part of the stalk thickened and developed ring-like swellings, the epidermis burst vertically, and the dark-green leaves became brittle, spotted, puffy, and rolled in. No fruit was produced, and the stems were gorged with starch. This observation has been confirmed by other investigators. Where it is desirable to use a fertilizer containing chlorine, chloride (muriate) of potash would probably, in most cases, prove more valuable than common salt (chloride of soda). Many of the valuable qualities of common salt, however, may be due to the sodium rather than the chlorine. The subject needs further investigation, keeping in view changes in the crops, which, though slight, might be of great practical value.¹

FUNCTION OF PHOSPHORIC ACID IN PLANT GROWTH.

Phosphorus is one of the most important of the mineral food elements. It occurs in all organisms, both plant and animal, as phosphoric-acid compounds. It enters largely into the nutrition of the nucleus of cells; and it should be remembered that the nucleus is the most highly specialized portion of every living cell, and is its controlling center. In the absence of phosphoric acid the nucleus can neither grow nor divide for the production of new cells, and the growth of the plant is therefore at a standstill. Phosphoric acid is also an important constituent of the chlorophyll bodies, or chloroplasts, as they are commonly called, and of the chlorophyll that stains the chloroplasts green. The formation of sugar and starch from the carbon dioxide of the air can be accomplished by plants only when the chloroplasts are present in a cell and are colored by the chlorophyll. The reduction of phosphoric acid below the required amount, besides preventing growth, causes a yellowing of the chlorophyll, as in the case of the lack of iron, lime, or magnesium, thus preventing the manufacture of sugar and starch. In the case of tobacco, the older or lower leaves of the plant are, as a rule, the first to show yellowing as a result of scarcity of phosphoric acid. Even the partly matured leaves may be involved, while the tuft of young leaves at the end of the stems may be of normal color, though of slow growth. Some orange growers, according

¹For a fuller treatment of this subject, see Storer's Agriculture, from which many of these observations are selected.
to Webber, claim to be able to recognize phosphorus starvation by the appearance of the young leaves. "If these, when they first push out, or while they are still young and tender, present a slightly variegated appearance, mottled with light and dark green, it is claimed that they are suffering from a lack of phosphorus, and that if a liberal application of soluble phosphate is applied this appearance may be checked." A similar mottling or frenching of the young leaves of tobacco, however, can not be cured by the addition of phosphoric acid, and is known to occur in many plants where there is no lack of this element. A decided lack of magnesium, like a lack of phosphoric acid, causes a yellowing, usually involving first the older leaves. Yellowing due, on the other hand, to lack of iron usually shows first in the young leaves, while the older leaves may retain for a long time their normal green color. A lack of nitrogen is usually manifested by much the same symptoms as are produced by lack of phosphoric acid. Chemical investigation has shown that as a plant nears its flowering and fruiting period, phosphoric acid, magnesium, proteins, and carbohydrates pass rapidly into the younger parts of the plant, preparatory to being stored in the seeds or fruits to meet the requirements of rapid growth at these periods. Young plants, and the young parts of plants, may, therefore, live for some time on this reserve supply before they draw to any extent upon the soil. These materials, if scarce in the plant, are even forcibly withdrawn from the lower leaves and the roots when the reserves are used up. The living substance of cells in the lower leaves is dissolved and absorbed after the carbohydrates, the fats, and other reserve foods are gone. The chlorophyll disappears, then the chloroplasts, the nucleus, and the rest of the valuable constituents of the cells are absorbed by the younger parts. The phosphoric acid, proteins, carbohydrates, potash, etc., thus obtained serve to feed the tuft of young leaves for a considerable time.

A similar transfer of valuable food constituents takes place before the fall of leaves in autumn in practically all deciduous trees.

NITROGEN AS A CONSTITUENT OF PLANT FOOD.

Nitrogen is an important constituent both of plant and animal food. It is essential to the formation of albumin and of various constituents of the protoplasm or living substance of the plant. It is absorbed from the soil by the plant largely as nitrates or ammonia. The latter, when very dilute (3 parts by weight in 10,000 parts of air), can in some cases be directly absorbed by foliage. It has been used to some extent in this way by placing carbonate of ammonia on steam pipes in conservatories. If there is more ammonia in the air, however, than the plants can convert into proteins, the protoplasm will be coagulated and growth almost completely checked, or in case of a great excess, the leaves may be killed. • An amount not greater than 3 to 4
parts in 10,000 greatly stimulates the development of foliage, thus retarding flowering or fruiting. Ordinarily, the amount of ammonia in the air is too small to be of any importance either as a direct food of plants or as a source of nitrogen for the roots by accumulating in the soil. By far the most important source of nitrogen for most agricultural crops is the nitrates of the soil. The main source of nitrogen in the soil, besides the decay of organic matter, is the fixation of the nitrogen of the atmosphere through the agency of microorganisms. Though about 75 per cent of the volume of the air is nitrogen, it does not become available to ordinary crops, except as it is absorbed by these microorganisms and converted into nitrates or some other higher nitrogen compound. Many varieties of bacteria and fungi have been found which can absorb free nitrogen if they are furnished with carbohydrate food. This is usually derived from decomposing vegetable matter or from living roots or cells. In some cases bacteria and algae are associated in the process and in others bacteria live on, or in, the roots of more highly developed plants, forming swellings or tubercles on them, as in the Leguminosae, or clover family. The great importance of this to agriculture is at once apparent, and the study of the conditions favoring the growth of these beneficial microorganisms is of the highest practical value.

**EFFECT OF NITROGEN ON GROWTH.**

The lack of nitrogen is usually manifested by reduced leaf and stem growth and the tendency to the production of flowers and fruit at a very early period, though the amount of fruit produced is correspondingly small. In this respect the effect of a lack of nitrogen is similar to that of a lack of water. On the other hand, an excess of nitrogen acts like an excess of water, stimulating the production of vegetative growth at the expense of flowers and fruit. In Pl. IV, 1 and 2, are shown two flowers, some of the petals of which have turned to foliage leaves as a result of too rapid vegetative growth at the time of the development of the flower buds. Such flowers are common, especially in roses and violets. This growth is rich in nitrogenous matter and water, and is very easily injured by unfavorable conditions. It is a well-known fact, for example, that wheat and other cereals have not only soft leaves and weak stems under such conditions, but the plants are more subject to rust and mildew, and various other parasitic diseases. This is true not only of cereals, but practically of all ordinary plants. In culture under glass these conditions can be controlled and remedied, but in the field it is more difficult. The use of salt on soils overrich in nitrogen has already been discussed. Drainage and methods of cultivation also in a measure afford means of check to rapid and succulent growth in wet seasons. Besides these general effects of the lack or excess of nitrogen on growth, attention should be directed to some
FIGS. 1 AND 2, "GREEN FLOWERS" OR "BULLHEADS" OF VIOLET (VODORATA VAR. CAMPBELL), CAUSED BY STIMULATING VEGETATIVE GROWTH AT TIME OF FORMATION OF FLOWER BUDS. FIGS. 3 AND 4, LEAVES OF SAME VARIETY SUFFERING AS SHOWN IN YELLOW MARGIN BY OVERFEEDING WITH WOOD ASHES.
obscure diseases where nitrogen assimilation appears to be involved. Among these may be mentioned mosaic disease of tobacco, winter blight of tomatoes, peach yellows, “die back” of the orange, California vine disease, and mulberry disease of Japan. As already stated, plants obtain most of their nitrogen through the absorption of nitrates by the roots. The dilute solutions pass up through the stem to the leaves, where, through the aid of the chlorophyll, the nitric acid unites with sugars to form the more highly organized nitrogen compounds, amids, and proteids, which serve as food for the growing cells. The young cells can not use the original soil nitrates any more than animals can, so that if anything interferes with the process of proteid organization nitrogen starvation will follow, even in the presence of large quantities of nitrates. For the organization of proteids sugars are required, and sugar can not be produced unless the chloroplasts are in good working order and exposed to light and heat of the proper intensity. The proper mineral nutrients, lime, potash, phosphoric acid, magnesium, iron, etc., must always be present. With insufficient light or heat there is no proteid formation from nitrates, neither is there any in albino leaves or those devoid of chlorophyll. In both of these cases, therefore, nitrates accumulate in the plant. With the renewal of the activity of the chloroplasts the accumulation of nitrates is gradually worked up into proteids, except, of course, in albino leaves, where the chloroplasts may have permanently lost their functional activity. In such cases the cells usually remain comparatively rich in nitrates. It is known from experimental investigation that a large excess in nitrates may in themselves cause a yellowing in the chloroplasts, and thus serve directly to prevent further nitrate assimilation. At first, plants overfed with nitrate of soda or other strong nitrogenous fertilizer become brighter green and grow rapidly, but as the nitrate accumulates in the cells faster than it is used, the leaves begin to turn yellow on the edges and along the vascular bundles, and growth is checked and the plant dies back. This is especially likely to happen in violets and other crops that are not gross feeders. Yellowing and death of the edges of leaves (though not following a stimulated growth) is caused by an overapplication of almost any quickly soluble salt (potash, sodium chloride, etc.). Pl. IV, 3 and 4, shows the results of overfeeding violets with wood ashes. In the case of the orange, Webber has observed that the disease known as “die back,” appears to be greatly favored, if not caused, by excessive fertilization with organic manures rich in nitrogen. It is not known whether nitrogen from mineral fertilizers has the same effect. Webber also observes that on the poor sandy soils of Florida sulphate of ammonia and nitrate of soda stimulate not only vegetative growth of the orange, but the

production of fruit as well, while organic manures are more likely to stimulate vegetative growth at the expense of fruit, the fruit produced with organic nitrogen being coarser, thicker skinned, and of poorer quality than when mineral fertilizers are used. Muck acts in this respect like the organic manures, as might be expected. The latter material often contains iron pyrite, which, when exposed to air, oxidizes to iron sulphate or copperas. The sourness of muck or peat is often due to this. Free sulphuric acid often forms in such cases, especially in the presence of decaying organic matters. The injurious action of muck on plants is often due to these causes rather than to any peculiarity of their nitrogen. Thorough composting with lime is a remedy for these conditions.

Mr. M. B. Waite has observed that the peach is very sensitive to overfeeding with nitrogen. Trees grown near barnyards shoot out very vigorously at first, but the tissues seem to degenerate rapidly, forming gum pockets and exuding large quantities of gum. The trees suffer from winterkilling, and in extreme cases are often killed outright. An application of nitrate of soda at the rate of 300 pounds per acre in one case changed the ripening time of peaches two weeks. Peaches regularly ripen on the poor knolls and hilltops earlier than in adjacent valleys or pockets a few feet away, where seepage nitrogen affects them. The latter are also more subject to the Monilia fungus. The proximity of an old stable was in one case the cause of the fruit being belated, and while the trees and fruit were larger, the latter was inferior in color and quality. The fruit on the trees moderately supplied with nitrogen was brighter in color, sweeter and finer in texture, and only slightly smaller. In fact, the peach is healthiest and yields the best fruit in soils which for most other crops would be considered deficient in nitrogen. The plum in this respect behaves very much like the peach, especially the Japanese varieties. Two plum trees were given 6 pounds of nitrate soda, strewn in a circle around the trees about equal to the spread of the branches. It was applied in spring, after the growth had started, and while growth was moderately stimulated during the season and they appeared to be all right in the fall, they were killed, root and branch, the following winter, though adjacent trees were entirely unharmed. On account of this sensitiveness to nitrogen, skillful peach and plum growers are always very cautious in the use of nitrogenous fertilizers, especially stable manure.

Nitrates are moderately strong oxidizing agents, that is, they yield up their oxygen readily to substances having a strong affinity for it. It is a curious fact that in many cases an increase of nitrates in a cell, under conditions not favorable to their organization into the higher nitrogen compounds, proteids, etc., is accompanied by an increase of a ferment or enzym, which is also an active oxidizing agent, or rather

\[^{1}\text{Storer, Agriculture, Vol. II, p. 198.}\]
DISTORTION OF TOBACCO FOLIAGE BY MOSAIC DISEASE,
CAUSED BY CUTTING BACK, WHICH BRINGS ON MALNUTRITION.
Leaves from plant shown in Plate V.
Some of the leaves are so starved that only the midrib developed.
RELATION OF NUTRITION TO THE HEALTH OF PLANTS. 171

a promoter of oxidation processes. The excessive oxidation not only destroys the easily oxidized nitrogen compounds, but also the chlorophyll and the diastase, or starch-dissolving enzym. The normal nutrition of the cell is therefore interfered with, and we thus find starvation in the presence of an excess of food, because the nature of the food compounds present forbids their use directly by the growing cells. When a plant once gets into this diseased condition it is difficult to cure it. Its vitality is weakened, and it becomes the prey of insects and fungi, or may completely starve to death through a kind of indigestion and rapid oxidation. (See Pls. V and VI.) It is impossible to go into a full discussion of this intricate subject here. It will be treated more at length in a special bulletin by the writer on the so-called mosaic disease of tobacco. Much more work needs to be done, however, before the exact explanation of some of these peculiar phenomena can be given. In the use of organic nitrogen, especially fresh organic manures, there is a possible danger of the production of nitrites during decay and fermentation in the absence of a ready supply of oxygen. The acid juice of the roots of plants would convert nitrites into nitrous acid, which would, of course, quickly kill the feeding roots. This may be one reason why fresh manures often act injuriously on crops, especially in soils not well aerated.

RESULTS OF OVERFEEDING PLANTS.

Some of the results of overfeeding with certain elements of plant food have already been mentioned. Attention has also been called to the unbalanced plant foods and their effect on growth; for example, the improper ratio of lime and magnesia, chlorine and potash, etc. There is still to be discussed the question of excess of food in solution. There are certain physical relations between the solutions in the cells of the roots and the soil solution around the roots which must be maintained in order to secure a healthy, vigorous growth. It is sufficient to say here that if the solid matter in solution in a soil exceeds 1 part in 500 parts of water it is nearing a limit beyond which many plants are likely to suffer; the leaves turn yellow on the edges, become spotted, and drop off (Pl. IV, 3 and 4), or growth is checked, shortened, and compacted; the leaves often become puckered and twisted, owing to the weakened development of the vascular tissue ("veins") as compared with the soft cells of the leaf. The roots and root hairs are also shortened, thickened, and deformed. This refers, of course, to conditions where concentration is not sufficient to kill the roots outright. Sorauer¹ says:

We must not forget that the kind of soil and manure which is best for a certain species of plant may be much too strong for another one and cause it to sicken.

¹ Physiology of Plants.
Ericaceae, Myrtaceae, and many Leguminosae require a comparatively weak solution of nutritive matter, while highly concentrated solutions are beneficial to Cruciferae (especially our vegetables), Resedaceae, Cucurbitaceae, Chenopodiaceae, etc.

If we seek for sound guidance from the aspect of the plant as to the amount of concentration which it requires, we may take it as a general rule that plants with leathery leaves, with hard and narrow leaves, and with hard wood require more dilute solutions than those with large, soft, and expanded leaves. The period at which manure is added is also of considerable importance. During the period of leaf formation all plants can do with the greatest amount of nutritive matter.

Plants adapted to alkali soils are in some cases able to live in solutions of alkali salts of high concentration. They are exceptional, however, and one of the great problems of agriculture in the alkali areas of the West and Southwest is on the one hand to determine how to reduce the injurious action of the various alkalis or remove them from the soil, and on the other hand how to increase the natural resistance to alkali of crops for these areas.

Probably the greatest danger of overfeeding is in the culture of plants under glass and in the intensive work of the market gardener and truck grower. The desire to push growth rapidly and secure maximum crops often leads to an overapplication of stimulating fertilizers, usually with disastrous results.

WATER AS A FACTOR IN PLANT GROWTH.

Water as a factor in the growth of plants was discussed in a paper in the Yearbook for 1894, and can here be touched upon only briefly. When water is artificially supplied, as in irrigation or under glass, it can be given in accordance with the needs of the crop. A lack of sufficient water causes a hard, stunted growth, while an excess of water may cause a soft, watery growth, subject to the attacks of various plant and animal parasites and easily injured by subsequent drought. An excess of water in the soil causes the exclusion of air and asphyxiation of the roots, as before described. The periods of greatest water requirements, for most annual plants at least, are during the rapid development of new shoots and leaves, and again at the period of development of flowers and fruit: During the dormant or resting period, which most plants require at some stage of their development, very little water is required, as well as very little food of any kind. Many evergreen plants, if watered during the resting period, drop their leaves, after which, unless the soil is promptly brought to the proper degree of dryness, the feeding roots decay and the plant may die. In the case of bulbous and tuberous plants the natural ripening and resting periods of the bulbs or tubers must be regarded or the bulbs will either rot or

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1 Ericaceae, heath family; Myrtaceae, myrtle family; Leguminosae, clover family; Cruciferae, mustard family; Resedaceae, mignonette family; Cucurbitaceae, gourd and melon family; Chenopodiaceae, beet family.
Fig. 1.—Seventeen healthy and 8 diseased plants, from 25 mature and rested bulbs of Lilium harrisii.

Fig. 2.—Nine healthy and 16 diseased plants, from 25 immature unrested bulbs of Lilium harrisii.
A young plant of Lilium harrisiII suffering from the Bermuda Lily Disease. Plant grown from an immature, unrested bulb.
produce plants of very low vitality. The so-called Bermuda lily disease was found by the writer to be caused in part by digging the bulbs for shipment before they were ripened and rested and in using unripened and unrested bulbs for stock. By this careless method and disregard of the natural requirements of the plant the lily in Bermuda has become so weakened that only the strictest selection and careful culture can bring it back to a vigorous, healthy condition. Pl. VII, fig. 1, shows the plants raised from 25 mature and rested bulbs and Pl. VII, fig. 2, shows plants from 25 bulbs not fully matured and rested. The original plants from which the bulbs were obtained were carefully selected from the best field that could be found in Bermuda, and were apparently perfectly healthy to start with. Twenty-five of the bulbs were dug before the stems had matured and were kept packed in sawdust in a cool place, as in ordinary storage; the other lot of 25 was allowed to remain in the ground until the stems were fully matured and dried up. They were then dug and shipped to Washington and stored for two weeks, when both lots were planted under the same conditions in the usual way. Both lots of bulbs were perfectly plump and apparently sound when planted, but the unrested bulbs produced 64 per cent diseased and 36 per cent healthy plants, averaging four flowers per plant, while the rested bulbs gave 32 per cent diseased and 68 per cent healthy plants, averaging seven flowers per plant. Pl. VIII shows how the leaves of such weakened plants, as described, die in spots, especially as the result of insect punctures.

Immediately following the period of active vegetative growth and fruit production, most plants store up their reserve food. In perennials it is stored in the roots and stems, and in bulbous and tuberous plants in the bulbs and tubers. Here it undergoes slow changes, varying for different species, preparatory to a renewed period of growth. Many seeds also have to go through a similar resting period in which these nutritive materials become available for further growth. In some cases these changes, during the dormant period, require freezing temperature for normal progress, as in the apple and some other trees, and in some bulbs, like the Lily of the Valley. This is probably owing to the fact that in Northern plants the dormant period is during cold weather, while in tropical plants the dormant period is in dry and hot weather. While plants, bulbs, and seeds may often be forced to grow without their period of rest, it is evident from what has been said that the reserve foods may not be in the right form to properly nourish the early stages of growth, and a weak, diseased plant is the result. No amount of nutritive salts or fertilizers applied to the roots of such plants can help them out. They will eventually starve to death in the presence of an excess of food. The pathological conditions in the cells are the same as described under the head of nitrogen.
ASSIMILATION OF CARBON A CONDITION OF PLANT NUTRITION.

Reference has already been made to the fact that the assimilation of carbon through the absorption of carbon dioxide from the air is one of the fundamental conditions of nutrition. This element forms about half (44 to 60 per cent) of the dry organic matter of both plants and animals. Though the amount in the air is very small, viz, only 0.03 per cent (or 3 volumes in 10,000 volumes of air), the air is the direct source of supply.

The transformation of carbon dioxide into carbohydrates (starch, sugar, etc.) takes place only in cells containing chlorophyll, and these are located, of course, mainly in the leaves. Anything which interferes with the normal development of the chlorophyll bodies in the leaves or the development of their green color (chlorophyll) will of course interfere indirectly with carbon assimilation.

Attention has already been called to various nutritive conditions which do interfere in this way; for example, lack of iron, or the lack or excess of various other salts or nutritive materials, including water.

HEAT AND LIGHT REQUIREMENTS.—It hardly needs to be said that light and heat are also extremely important factors, and that different species of plants vary in regard to their heat and light requirements. In cultivating plants under glass the requirements in regard to intensity of light are controlled by shading or coating the glass with whitewash, clay, or some similar material. The main purpose of this, however, for ordinary crops is not to reduce assimilation, but to prevent too rapid transpiration or evaporation of water from the foliage and too high a temperature of the house, thus preventing wilting. Some plants require less light normally and must be shaded. When leaves are even slightly wilted the stomata, or breathing pores, through which the principal interchange of gases (carbon dioxide, oxygen, etc.) between the leaf and the air takes place, close in order to prevent the further loss of water. In this wilted condition carbon dioxide enters the leaf with difficulty and the sugar production is greatly reduced or altogether prevented.

When leaves are exposed to sunlight, as the writer has determined by experiment, their internal temperature becomes several degrees warmer than the surrounding air. If the external air temperature is very high, tender leaves may get so hot as to be actually scalded. Plants growing in hot deserts and places exposed to powerful sun are, as a rule, covered with a dense coating of hair or scales. This prevents the excessive heating of the tissues and consequent excessive evaporation. It has been observed by some investigators, and confirmed by the writer, that spraying foliage with Bordeaux mixture or lime reduces evaporation. There can hardly be any doubt that these applications act like a covering of hairs or scales in this respect. It is possible that a part of the beneficial influence of Bordeaux mixture in promoting
assimilation, apart from its fungicidal value, is in preventing excessive absorption of heat and light rays by the leaves during hot, dry periods. This would suggest also the use of similar spraying mixtures during droughty hot years for the purpose of reducing the internal tissue temperatures and evaporation from the leaves. Crops so protected might be able to withstand a dry, hot period that would otherwise greatly injure them. It also suggests the inadvisability of spraying heat-loving plants during the cool weather of early spring.

Even when the light intensity is not so great as to cause such extreme injury as just described, it may nevertheless be so strong as to interfere with normal development.

It is as necessary to study the light requirements of crops, especially of plants grown under glass, as it is to study their heat and water requirements. When plants are exposed to too strong light the fact can usually be determined by the effort on the part of the suffering plant to place the surface of its leaves more or less parallel to the light rays, thus reducing absorption. When more light is required, the leaves present their upper surface as nearly as possible at right angles to the light rays, thus increasing light absorption. In very strong light the chloroplasts move to the side walls and turn their edges to the light, and the leaves thus have a lighter green color and less light and heat are absorbed. On the other hand, when the light is weaker, the chloroplasts present their largest surface and the same leaf becomes a darker green and more light is absorbed. If the light is too weak, however, the plant finally becomes yellowish and starved, and various other pathological conditions may develop.

RESERVE FOOD OF PLANTS.

Although it would be of interest to take up in detail the more important elaborated foods, such as starch, sugar, nitrogen compounds, etc., as they are organized by the plant, only a brief general statement can be given here. It is these compounds that the cells draw upon directly for food, as has been already pointed out.

It is well known, of course, that a mature seed of any plant contains not only the embryo plant, but more or less reserve food—starch, sugar, oils, and protein materials. In some cases these materials are directly available to the germinating seedling, even before the complete maturity of the seed. In other cases, after the seed is mature, it has to go through a "resting" period, in which internal changes take place preparatory to germination. Ferments are formed ready to cause the solution of the reserve food during the process of germination. If germination is forced before these changes are complete, a weak and poorly nourished growth is the result. Often these preparatory resting period changes take place only when the seeds are exposed to certain natural conditions of environment, such as heat or cold,
moisture or dryness, etc. These requirements should always be as carefully considered for seeds as for bulbs, tubers, and the resting periods of perennial plants.

During the early stages of growth of herbaceous plants, after the reserve food in seeds or tubers has been used up, the young plant must manufacture its own supply. For this reason the first leaves must begin work early in cases where the reserve food in the cotyledons or other storage tissues is small, and they should therefore be carefully protected against injury. Tobacco is a good example of a plant that has very little reserve food in its seed and has to begin almost at once to look out for itself. This is probably in part the reason why tobacco seedlings grow so slowly at first, and after the production of the second or third minute leaves apparently wait to organize a sufficient amount of reserve food to start off successfully the subsequent rapid development. The young seedlings should therefore not be pushed too rapidly during this early stage of development.

In most plants we have first a root development requiring a warm, moist soil and cool air, then a development of stem and leaves. This is true of seedlings as well as of bulbs and tubers. If during the first stage of development conditions favor leaf instead of root growth, the young plants soon suffer for water and soil food, and even if not killed, may never fully recover from the setback thus received.

The writer has observed that the disease already described as the mosaic disease of tobacco can be induced by stimulating growth in the absence of a sufficient supply of available organized nitrogen compounds (proteins). While the young tobacco plant is making rapid growth after the production of the fourth or fifth leaf, it in many cases contains almost no proteid or sugar reserve. If the roots of such a plant are severely injured, a sufficient supply of nutritive salts and water can not be absorbed to meet the demands of growth, and any existing reserve is quickly used in the formation of new roots.

That many other plants besides tobacco are weakened by similar unfavorable conditions of growth has been observed by the writer and confirmed by other investigators. The amount and nature of reserve food should always be considered in the various operations of propagating and pruning if the health, vigor, and productiveness of the plants operated on are to be kept up to a high standard.

The problem of what fertilizers to use for different crops under varying conditions is a matter of great importance, and would require a special paper for its adequate treatment.