The Early Development of the Fundamental Concepts of Plant Nutrition. (600 BC—1804 AD)

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The nutrition of plants has long interested mankind as a fit subject for philosophical conjectures and for experimental investigation in more recent years. According to Julius von Sachs, the great German botanist of the 19th century, several questions have been presented for consideration. Briefly stated, they are: What is the nature of the food substances taken up by plants? In what way do these substances find their way into the plant? How are they distributed within the plant body? What is the nature of the forces employed?

The Early Greeks

As early as the 6th century before Christ, the Greek philosopher Thales, one of the Seven Sages, emphasized the importance of water in the nutrition of plants. According to him, water was the all important and essential food of plants. He supposed that plants derived all of their food and all of their substance from water alone. This early belief in water as the one essential food of plants was, strangely enough, echoed by van Helmont over 2,000 years later as the major conclusion of the first recorded experiment in plant physiology.

In the fourth century B.C., the renowned Greek teacher, Aristotle gave an entirely different answer to the question of what food substances are taken up by plants. Plants were compared to animals and the conclusion drawn that plants like animals could feed upon materials of like nature with themselves, but not upon materials of unlike nature. Hence the important food of plants consisted of the decaying animal and vegetable matter, the "humus" component of the soil. Since plants produce no excrement, as do animals, Aristotle believed that plants were able to select from the soil only those substances required for their structure. This food material was accordingly elaborated in the earth for the plants use, much as the food utilized by higher animals is elaborated in their stomachs. Therefore, the role of plants was considered to be passive in the work of nutrition, since the food which they absorbed was already prepared in the soil. Growth in plants was thus looked upon largely as a process of accretion, unaccompanied by chemical change.

The following rather cryptic statements of Aristotle serve to indicate some of his ideas upon this subject.

"Everything feeds on that of which it consists, and everything feeds on more than one thing; whatever appears to feed on only one thing, as the plant on water, feeds on more than one thing, for earth

in the case of the plant is mixed with water, therefore the country people water plants with mixtures of things.

"As many savours as there are the rinds of fruits, so many it is plain prevail also in the earth. Therefore also many of the old philosophers said that the water is of as many kinds as the ground through which it runs."

The Sixteenth Century

Leaving Aristotle, a long leap over some 19 centuries brings us to the great French potter Palissy (Bernard Palissy—1509-89 A.D.) who was also concerned with the question of plant foods. He observed that the growth of crop plants was markedly increased when manures and the ash of plants were applied to the soil on which crops were growing. Let us give this observation of Palissy in his own words rendered into English. "You will admit that when you bring dung into a field, it is to return to the soil something that has been taken away. . . . When a plant is burned, it is reduced to a salty ash called alcaly by apothecaries and philosophers. . . . Every sort of plant without exception contains some kind of salt. Have you not seen certain laborers when sowing a field with wheat for the second year in succession, burn the unused straw which had been taken from the field? In the ashes will be found the salt that the straw took out of the soil; if this is put back, the soil is improved. Being burnt on the ground, it serves as a manure because it returns to the soil those substances that had been taken away."

In considering the uptake of nutritive materials by plants, Andrea Cesalpino, a contemporary of Palissy, invoked the physics of his day for an explanation of how plants remove liquids from the soil. He stated that it was not the "ratio similitudinis, that is, the force which draws iron to the magnet, which causes the attraction of the juice by the roots, because then the smaller would be drawn to the larger, or the juice from the plant would be drawn out by the moisture of the earth. Neither is the movement due to the "ratio vacui," for the plant is not filled with air but with juice even though the soil contains both air and liquid. Cesalpino suggests, however, that since many dry objects such as sponges, linen and powder absorb moisture because they have more in common with water than with air; it appears that the absorbing organs of plants must be of this nature. These organs he considered fibroid, like nerves, so that suction (biblia natura) conveys the moisture to the place of internal heat, in a fashion similar to the movement of oil in the wick of a lighted lantern. Cesalpino further suggested that the pith, with its surrounding cylinder of wood, was the seat of internal heat in plants, and likened it to the spinal cord of animals with its enclosing vertebral column.

The Seventeenth Century

While agreeing with Aristotle's view of the selective property of roots, Joachim Jung (German mathematician and naturalist) took a different stand regarding the question of plant excreta. Jung believed

plants like animals also have their excreta, which in the case of plants are exhaled through the leaves, flowers, and fruits. He included resins and other exuded liquids as plant excreta and stated that a large portion of plant juices escapes from the plant surfaces by imperceptible evaporation, as with the case of animals. Jung further opposed Aristotles views by regarding the plant not as passively absorbing elaborated food from the soil, but as assisting in its nourishment by chemical activity.

Leaving the purely observational method of plant study and speculation, we turn now to the experimental method as introduced by the Dutch alchemist van Helmont. Johann Baptist van Helmont (1577-1644) performed what is considered to be the first recorded experiment of plant physiology in an attempt to determine the true nature of the nutritive materials used by plants. This experiment may best be described in a translation of his own words. "I took an earthen vessel in which I put 200 pounds of soil dried in an oven, then I moistened with rain water and pressed hard into it a willow shoot weighing five pounds. After exactly five years the tree that had grown up weighed 169 pounds and about three ounces. But the vessel had never received anything but rain water or distilled water to moisten the soil when this was necessary, and it remained full of soil, which was still tightly packed, and, lest any dust from outside should get into the soil, it was covered with a sheet of iron coated with tin but perforated with many holes. I did not take the weight of the leaves that fell in the autumn. In the end I dried the soil once more and got the same 200 pounds that I started with, less about two ounces. Therefore the 169 pounds of wood, bark, and root rose from the water alone."

Here we are back again to the early view of Thales that water constitutes the sole material from which plants are built. It is evident that van Helmont regarded the 2 ounce discrepancy in his soil weights as "experimental error". Also, the fact that he overlooked the atmosphere as a source of nutritive substance is undoubtedly due to the ignorance of the day regarding the true nature of air.

In contrast to van Helmont's neglect of the essential nutrient materials which the soil is now known to provide, we have the efforts of the German chemist Glauber (1650) in searching for the substances in manures which are responsible for the increased growth of plants, as pointed out by Palissy a hundred years earlier. Glauber was successful in isolating salt-peter from soil on which cow manure had been lying. He also found that application of this chemical to the soil was followed by greatly increased plant growth. Since the salt-peter from the dunged soil came from the urine and feces of animals, it seemed evident that this salt must have been present in the plant materials which constituted the food of these animals. This work of Glauber is considered to be the first definite connection of chemical substances with the nutrition of plants.

Viewing the subject of plant nutrition from a different approach, let us note the concepts which the Italian physician and plant anatomist, Malpighi, held as the result of his studies. Malpighi considered that the fibrous elements of the wood serve as the organs of sap conduction

from the roots, and that the wood vessels, which he called tracheae after the tracheae of insects, act as air passages. He believed that air was taken in by the roots rather than by the leaves. He did consider the leaves, however, as the seat of the changes which the crude juices of the plant undergo to fit them for maintaining growth. This belief was based upon experimentation with cotyledons (seed leaves) of the gourd which he considered true leaves. He found that the plumule would not grow if the cotyledons were removed. From this he reasoned that the liquid absorbed from the soil by the roots and conducted up the stem by the wood fibers, must be first elaborated into food in the leaves before being fed to the growing shoot. If the leaves were removed, as was the case with the cotyledonous leaves, the plant failed to grow because it lacked elaborated food. In this point, Malpighi came very close to the truth, although we now recognize the cotyledons to be food-storage organs primarily.

A contemporary of Malpighi was Edme Mariotte, a French ecclesiastic interested in the scientific learning of his day. Mariotte presented his views concerning the chemistry of plant nutrition in a letter dated 1679. In this document he discussed 3 hypotheses concerning the "elements" or principles of plants.

In his first hypothesis, he stated that there exists in plants many immediate "principles" such as water, sulfur, oil, salt, nitre, etc., which are made up of 3 or 4 simpler principles united into one body, as for example, Nitre=phlegma (tasteless water), "spiritus", fixed salts, etc. These simpler principles also are compounds of differing parts. He considered the union of these constituents the result of a natural disposition to move together and to unite upon touching.

In his second hypothesis he suggested that the possible sources of the several principles contained in plants come from the earth. Lightning burns the small particles of the air which are then carried downward by rain into the earth and absorbed by plants. Dry distillation of plants produces water, acids and ammonia. An ash results from burning; this ash contains salts which differ from one another according as they are mixed with more or less ammoniacal spirits, or other unknown principles.

In this third hypothesis, Mariotee maintained that the salts, earths, oils, etc., yielded by different plants are always the same, and that the differences in plants are due entirely to the way in which these principles and their simpler parts are combined. He stated a problem designed to demonstrate that plants do not draw their elaborated substance directly from the earth, but produce it themselves by chemical processes. The problem is as follows: A pot containing 7 or 8 pounds of soil will grow any of 3,000 or 4,000 different kinds of plants from the principles contained in the soil when watered with rain water. If different elaborated foods were required from the soil for each kind of plant (as held by Aristotle), 500 pounds of soil would be required for the three or four thousand plants on the basis of a dram of fixed salt and 2 drams of earth per plant. Thus some 70 times the soil quantity actually required would seem to be needed if Aristotle's contention were true.

To John Woodward (1665-1728) we owe the inception of the method of water cultures in the study of the nutrition of plants. Woodward grew spearmint plants in rain water, Thames river water, sewage water from the Hyde Park conduit, and sewage water plus an addition of garden soil. After 77 days of growth the following results were obtained:

Rain water	17½ grains
Thames water	26 grains
Sewage water	139 grains
Sewage soil	284 grains

From this experiment Woodward drew the following conclusion: "Vegetables are not formed of water but of a certain peculiar terrestrial matter. It has been shown that there is a considerable quantity of this matter contained in rain, spring, and river water, that the greatest part of the fluid mass that ascends up into plants does not settle there but passes through their pores and exhales up into the atmosphere; that a great part of the terrestrial matter, mixed with water, passes up into the plant along with it, and that the plant is more or less augmented in proportion as the water contains a greater or less quantity of that matter; from all of which we may reasonably infer, that earth and not water is the matter that constitutes vegetables".

The Eighteenth Century

Stephen Hales, English clergyman and "father of Plant Physiology" contributed to the subject of nutrition in 1727 by emphasizing his belief that air cooperates in the construction of the plant body in the formation of its solid substance, and that neither water nor the materials derived from the soil alone supply the substance of what plants consist. He concluded from dry distillation experiments that plant substance is made of sulfur, volatile salts, water and earth, and that all of these principles are endowed with mutual power of attraction. The leaves were considered important in the nutrition of the plant, since they draw up substance from the earth. He further believed that they also remove excess water by evaporation, retaining its nutritious parts, in addition to absorbing salt, nitre, dew, and rain. In considering light, which he supposed to be a substance, he asks: "May not light, which makes its way into the outer surfaces of leaves, and flowers, contribute much to the refining of the substances of the plant?"

The work of Joseph Priestley, another English clergyman and scientist, greatly stimulated interest in the effect which plants may exert upon the surrounding air. Priestly found that plants could purify air in which animals had been kept so that it could again sustain animal life. He stated his findings in 1771 as follows: "Plants instead of affecting the air in the same manner with animal respiration, reverse the effects of breathing, and tend to keep the atmosphere pure and wholesome, when it is become obnoxious in consequence of animals, either living, or breathing, or dying and putrifying in it." After his discovery of oxygen in 1774, Priestley attempted to advance his work but was not able

to obtain consistent results with his experiments since in some cases purification of air was obtained, while in other cases the plants appeared to contaminate the air as did animals.

The difficulty encountered by Priestley was explained a few years later by the Dutch scientist, Ingenhousz who is said to be one of the most brilliant investigators of the 18th century. Ingenhousz in 1779 was able to show that it is only in light that plants are able to purify the air, since in darkness they contaminate the air in the same manner as animals. He also demonstrated that it was the aerial parts of plants—the leaves and stems—that were active in this respect, while flowers and fruits did not possess this power.

After the work of the French chemist Lavoisier had shown the nature of the gases of the air and explained the process of combustion, Ingenhousz expanded his ideas on the inner nature of the process. He stated in 1795 that all vegetables continually give out carbon dioxide but that green leaves and shoots only release oxygen in sunlight or clear daylight. Moreover he considered that the carbon dioxide of the air was the main if not the only source of carbon dioxide to plants. The following statement of Ingenhousz indicates his conclusion concerning this phenomenon; "plants changing in the dark more respirable air into carbonic acid than they can digest, they throw out a large quantity of it, and thus render the air in contact with them as respirable, and that in the day they absorb with the atmospheric air so much matter of heat and light, or caloric furnished by the sun, that they cannot all digest it and therefore throw it out as superfluous, combined with the oxygen, which has thus acquired the nature of vital air."

Early Nineteenth Century

In closing this discussion, there is yet one more worker who must not be neglected. Theodore De Saussure (1767-1845), a brilliant Swiss scientist, published work of extreme importance regarding the nutrition of plants. De Saussure demonstrated by careful quantitative studies of the gas exchange of plants that not only was carbon fixed in plants, but also the hydrogen and oxygen derived from water. This process he found was essential to the life of the plant. He was also able to demonstrate that there is no normal nutrition of plants without the utilization of nitrates and of mineral matter supplied in dilute solution by the soil. Even though the amount of mineral material required for the growth of plants was small, yet a certain amount of ash materials was essential for their growth.

Conclusion

In retrospect, let us briefly recall certain concepts in the evolution of our early knowledge of the nutrition of plants. First, the nature of the materials required by plants: Aristotle and his followers down through the centuries believed that plants require complex, elaborated foods. Second, Aristotle, Palissy, and Woodward emphasized the soil as the all important source of required materials. Third, Hales, Priestley,

and Ingenhousz called attention to the air as an important source of materials employed in the nutrition of plants. And fourth, the importance of water in the building of plant substance was emphasized beginning long ago with Thales, and many centuries later by van Helmont, and still later by the careful quantitative studies of De Saussure.

Chronology

640 - 546 BC	Thales	Plants are made of water.
384 - 322 BC	Aristotle	Elaborated food is taken from the soil.
1563 AD	Palissy	Soil salts occur in plants.
1583	Cesalpino	Physical explanation of absorption attempted.
1587, 1657	Jung	Active absorption of plants emphasized.
1577, 1644	van Helmont	All plant substance comes from water.
1650	Glauber	Salt peter promotes growth.
1671	Malpighi	Leaves are essential for growth.
1679	Mariotte	Plants synthesize their own foods.
1699	Woodward	Plants are formed from soil substances.
1727	Hales	Leaves use light and air in food synthesis.
1771	Priestley	Plants purify the atmosphere.
1779, 1796	Ingenhousz	Illuminated leaves absorb carbon dioxide and produce oxygen.
1804	De Saussure	Both carbon dioxide and water are fixed quantitatively in plants.

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