# Lecture 31
# Agricultural Scientific Revolution: Chemical

## Crop Nutrition

Interest in materials that would increase crop growth dates to antiquity. The early Greek philosophers proposed the strikingly modern concept that plants are derived from a combination of chemicals. Democritus of Abdera (ca 460–360 BCE) proposed what could be considered as akin to the atomic theory:

> *Mother earth when fructified by rain gives birth to crops for the nourishment of man and beast. But that which come from earth must return to earth and that which came from air to air. Death however, does not destroy matter but only breaks up the union of is elements which are then recombined into other forms.*

In contrast, Aristotle (384–322) believed all material constituents were derived from the mutual convertibility of the four elements: earth, water, fire, and air, a concept that was upheld to the medieval period and beyond. Aristotle assumed that plants assimilated organic matter from the roots, the beginning of what has been known as the *humus theory of plant nutrition*. The incorrect assumption that plants take up organic matter is understandable in light of the ancient observations that organic matter, particularly manure and plant residues, benefit plant growth. In the Chou dynasty of China (about 1100 BCE) Tsi gave the following advice:

> *They (green manure) are broadcast in the fifth or sixth month and plowed under in the seventh or eighth month… Their fertilizing value is as good as silkworm excrement and well-rotted farm manure"*

Similarly early Roman agricultural writers recognize the beneficial affects of manure and crop rotation especially with leguminous crops (green manure). Pliny writes:

> *It is universally agreed by all writers that there is nothing more beneficial than to turn up a crop of lupines, before they have podded, either with the plough or the fork, or else to cut them and bury them in heaps at the roots of trees and vines.*

While the use of manure continued in medieval times, there were no theoretical contributions to plant nutrition until the Renaissance. Bernard Palissy (1510–1589), considered the founder of agricultural chemistry, states the modern concept that the purpose of manuring was to replace substances lost by crop removal:

> *Manure is carried to the field for the purpose of restoring to the latter a part of what had been removed… Proceeding thus you will restore to the soil the same substances that have been removed by previous crops and which following crops will regain to their advantage.*

In an infamous 5 year experiment with willow by Jan Baptista van Helmont (1577–1644), plant growth was attributed to water (!) based on the fact that soil lost only 2 ounces while the willow gained 169 pounds. However, 80 years later, John Woodward (1665–17628) was able to demonstrate that spearmint grew better in water containing soil than merely in rainwater. The beginnings of true understanding of the relation of chemistry to plant nutrition can be traced two 17th century chemists, Johan Glauber (1604–1655) and Gabriel Plattes (1600–1655) from analysis of "salts" such as wood ash, limestone, and saltpeter (potassium nitrate) on plant growth. To compensate for lack of manure brought about by the Thirty Year War, Galuber invented a chemical fertilizer called "philosophic dung" or "fattening salt."

Despite these observations on the value of salts, the belief that humus (organic material) was the "food" of plants was upheld well into the 19th century and was supported by such renowned chemists as Theodore de Saussure (1767–1845) and Sir Humphrey Davy (1778–1829). The source and function of the inorganic elements in plant ash was unknown. A prize was offered in Germany to resolve the question of whether the inorganic elements, found in the ashes of plants, are constituents produced by plants or must be absorbed and what was their role. The prize was awarded to A.F. Wiegmann and L. Polstroff based on experiments using synthetic soil vs. sand alone. In the 19th century Justus von Liebig (1803–1873), dominant figure in plant nutrition, demonstrated that carbon was supplied by the air and not by humus (although he believed it was absorbed by roots). Liebig assumed most N was absorbed from the air (he was unaware of N fixation by bacteria) and not from humus (incorrect) but did agree that the quantity was insufficient for agriculture.

The contribution of plant nutrition as a science bloomed in the 20th century. Some important contributions included:

1. The concept of essential elements.
2. The contribution of air as a source of carbon via $CO_2$ and nitrogen (indirectly through N-fixing micro-organisms.
3. The creation of inorganic fertilizers
4. The importance of trace elements
5. The respective roles of nitrate and ammonia nitrogen in plant nutrition
6. The concept of cation exchange and soil fertility
7. The classification of soil and its relation to plant nutrition.
8. The importance of soil tilth, pH.
9. The problems of nutrient balance.
10. Use of foliar application
11. Soil testing and leaf analysis
12. The production of nitrogen from the Huber process and the development of the fertilizer industry.

**Pest Control**

The search for chemicals for pest control has an ancient tradition (see **Readings** 18-1 and 31-1). In the 19th century, one of the first examples of successful pest control was the use of lime sulfur. This material was sprayed on grapes to discourage pilfering when it was observed that it reduced several fungal diseases, particularly powdery mildew. In the early 20th century a number of materials were used to control insects, many of which turned out to be truly dangerous. These included arsenic (particularly lead arsenic) and mercury compounds. The development of pesticides received a major boost with the discovery that DDT could control insects at very low concentrations. However, DDT was shown to be dangerous because despite its effects at low concentrations, the material was very stable and would accumulate in the food chain. For example, it directly affected the fertility of birds through a reduction in egg shell thickness. The publication of *Silent Spring* by Rachel Carson in 1962 initiated the environmental movement (see **Reading** 31-2). A list of important pesticides (bactericides, fungicides, nematocides, insecticides, acaricides, and herbicides) is presented in Table 1.

**Growth Regulation**

One of the main contributions of the 20th century was the regulation of plant growth by specific chemical substances. The seminal work in this field traces to a classic experiment on phototropism, the bending of plants toward light, carried out by Charles Darwin and his son Francis Darwin. They were able to demonstrate in a simple but brilliant experiment involving oat seedlings and a razor blade that the ability of seedlings to respond to light was due to the tip of the plant. Julius Sachs, a German physiologist in 1880, introduced the concept of causality to organ development and assumed the existence of root-forming, flower-forming, and other substances that moved in different directions in the plant. In 1911 and 1913, Boysen-Jensen demonstrated by grafting, that the phototropic stimulus was "chemical' in nature. The term "*hormone*" introduced into animal physiology to denote a substance produced in one part of the organism and transferred to another to influence a specific physiological process was transferred to plant biology as early as 1910. Went and Thimann in 1937 in the Boyce Thompson Institute later demonstrated that the hormone concept was applicable to plants, and the term *phytohormone* was coined.

The modern age of phytohormones began in the 1920s when Fritz W. Went (1929) demonstrated that a substance from the excised tip of the oat coleoptile (seedling shoot) could be absorbed by agar. Furthermore, the infused agar block when placed on the cut surface of the coleoptile produced the effect achieved by the excised tip alone. The active substance from the coleoptile tip was later shown to be **indoleacetic acid** (IAA) or **auxin**, the natural growth substance that affects cell elongation and other processes. In their book, *Hormones and Horticulture*, Avery and Johnson (1947) confidently stated that:

> *A chemical revolution is sweeping through the agricultural world. It is unrivalled by any of the previous great advances in agriculture and, perhaps, by most advances in the biological field. For the first time man can change the pattern of growth and development of plants; can retard growth here and speed it there. The growth-controlling hormones...now in use are but crude beginnings."*

This was the first of many research bandwagons that were to sweep agriculture.

Growth regulators were to have a profound effect on agriculture. The greatest effect was the development of 2,4-D, a chemical similar to auxin. This compound, at very low concentrations, killed certain plants initiating the era of chemical weed control. Furthermore, some chemical plants could distinguish between crop and weed, the principle of **selectivity**. Herbicides have become essential to modern production of agronomic and horticultural crops. The hoe, after 7000 years, had finally become obsolete.

There were other dramatic economic effects of growth regulation, especially in horticulture. These include rooting stimulators, fruit setting compounds, abscission control, fruit ripening, and induction of flowering. The influence of growth regulators also coincided with an increase in pesticides.

The increase in growth regulators and pesticides in general was responsible for a backlash. Concern with the effects of these substances on the environment gave birth to the **environmental movement**. This led to attempts to reduce the use of chemicals in agriculture and to strive for environmentally friendly materials. The reduction of pesticides by employing many avenues of control including chemical, biological, and cultural avenues is known as **Integrated Pest Management (IPM)**. However, most agriculturists feel that while it is inconceivable that these materials can be completely eliminated, it is clear that safer, more environmentally friendly materials can be found, and that technology can be used to reduce usage.

An outpouring of concern for the environment was the catalyst of the **organic movement** which had its birth in elimination of inorganic fertilizers. The organic movement grew to become a philosophical reaction to technology, and strives to eliminate all "chemicals" except those that are "natural" or "organic." Thus, rock phosphate was considered acceptable, as was lime, as soil amendments but superphosphate was not. Similarly pyrethrum, compounds from *Chrysanthemum* species, were acceptable but not the modified compounds called pyrethrins. Spores of *Bacillus thuringenis* were acceptable but the use of the gene introduced to the plant via transgene technology (genetic engineering) was considered an anathema. The organic concept found a willing advocate in the home gardener but had little effect on commercial agriculture until recently.

The organic movement is now causing a fundamental change in attitude in growers and consumers. It is has increased awareness of the possibility of a more ecological approach to agriculture but is up against the need to increase production of food in the underdeveloped world. The developed world, as a result of the advances in scientific agriculture, is awash with surpluses. In fact, the major problem in European and North American agriculture has been the result of ruinous prices to growers due to overproduction and the cost to the taxpayer of subsidies which can account for almost half of agricultural receipts. However, in the developing world, food prices still account for ever decreasing percentage cotst. The larger problem at issue is the interrelationship of biological systems and the problem of sustained agricultural productivity.