The Origins of Horticultural Technology and Science

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Abstract

Horticulture is an ancient pursuit. Beginning some 10,000 years ago, our brilliant forebears discovered the horticultural craft secrets that are the basis of our profession. They initiated a revolution that changed forever the destiny of humans from scavenging, collecting, and hunting to agriculture. We all are the heirs and beneficiaries of this legacy from the past. Our roots derive from prehistoric gatherers, Sumerian, Egyptian, Chinese, and Korean farmers, Hellenic root diggers, medieval peasants, and gardeners everywhere who devised practical solutions to problems of plant growing for food, ornament, medicine, fiber, and shelter. The accumulated successes and improvements passed orally from parent to child, from artisan to apprentice, and became embedded in human consciousness via legend, craft secrets, and folk wisdom. It was stored in tales, almanacs, herbals, and histories and has become part of our common culture. More than practices and skills were involved as improved germplasm was selected and preserved via seed and graft from harvest to harvest and generation to generation. Practically all of our cultivated crops were selected and improved by prehistoric farmers. An array of technological approaches from primitive tools fashioned during the Bronze and Iron Ages through the development of the horticultural arts – irrigation, propagation, cultivation, pruning and training, drying, and fermentation – were devised to accommodate the needs and desires of humankind. The sum total of these technologies makes up the traditional lore of horticulture. It represents a monumental achievement of our forebears, unknown and unsung. Horticultural technology has been continuous over the millennia but in the last 100 years dramatic changes have occurred that have transformed horticulture from a craft to a science, and these changes will be displayed in the present Congress. However, all these advances are based solidly on the foundation of ancient techniques.

HISTORY OF HORTICULTURE

Horticulture: The First 10,000 Years

Horticulture is truly an ancient pursuit. Some 10,000 years ago, our brilliant forebears discovered the horticultural craft secrets that are the basis of our profession. They initiated a revolution that changed forever the destiny of humans from scavenging, collection, and hunting to agriculture. We all are the heirs and beneficiaries of this legacy from the past. Our roots derive from prehistoric herders and collectors, Sumerian, Egyptian, Chinese, and Korean farmers, Hellenic root diggers, medieval peasants, and gardeners everywhere to obtain practical solutions to problems of plant growing and the use of these plant materials as food, medicine, fiber, and shelter. The accumulated successes and improvements passed orally from parent to child, from artisan to apprentice, and became embedded in human consciousness via legend, craft secrets, and folk wisdom. It was stored in tales, almanacs, herbals, and histories and has become part of our common culture. More than practices and skills were involved as improved germplasm was selected and preserved via seed and graft from harvest to harvest and generation to generation. Tremendous shifts in horticultural techniques, from primitive tools fashioned during the Bronze and Iron Ages through the development of the horticultural arts – irrigation, propagation, cultivation, drying and fermentation – an array of technological approaches to making horticultural crops fit the needs and desires of humankind. Many of these technologies can be followed in the artistic record (see the article *Art as a Source of Information on Horticultural Technology* in the current volume). The sum total of these technologies make up the traditional lore of horticulture. It represents the monumental achievement of our forebears, unknown and unsung. Horticultural technology has been continuous over the millennia but in the last 100 years dramatic changes have occurred that have transformed horticulture from a craft to a science, and these changes will be displayed in the present Congress. However, all these advances are based solidly on the foundation of ancient techniques.

The scientific tradition of horticulture is not as old but is ancient nevertheless. Its beginnings derive from attempts systematically to discover rational explanations for nature. Science, from the Greek "to know" is in reality a method for accumulating new information about our universe. The driving imperative is the desire to understand. If necessity is the mother of invention, curiosity is the mother of science. The scientific method involves experimentation, systematic rationality, inductive reasoning, and constant reformulation of hypotheses to incorporate new facts. When new explanations of natural phenomena are accepted, they nevertheless must be considered not as dogma but as tentative approaches to the truth and subject to change. The process is cumulative and science is alive only when it grows. When any society claims to know the complete truth such that further question is heresy, science dies.

Horticultural knowledge accumulation has always been in a state of tension between the mundane empiricism of the gardening arts discovered by generations of sophisticated but uneducated ordinary people in contrast to information generated by scientists, often academics, sometimes indifferent to the uses of their discoveries and often obsessed by the irrelevant. In the 1900s, horticultural science was considered an oxymoron. A century later, horticulturists reject this taunt and have demonstrated that horticultural science is a truly humanistic plant science, concerned with all information relevant to the interaction of humans and the plants that serve them. Our goal is the betterment of humankind.

This paper, with emphasis on the American experience, will review a number of significant advancements in technology and science that have been made by horticulturists and later applied to agriculture and other fields (see Janick, 1989a; Janick and Goldman, 2003). For example, Gregor Mendel's groundbreaking discovery of the principles of heredity in the monastery garden led to what might be considered the most important scientific revolution in modern times: the flow of genetic information from generation to generation. Photoperiodic effects on plant growth were first reported by W.W. Garner and H.A. Allard on a number of horticultural crops in 1920 and set the stage for our understanding of the relationship between crop production, light, and temperature. Field-level photosynthetic rates were first measured by horticulturists A.J. Heinicke and N.F. Childers in the 1930s using an apple tree model. These concepts were later applied to many agricultural and ecological situations to evaluate carbon dioxide fixation and photosynthetic rates. Horticulturists L.R. Jones and J.C. Walker developed the concept of genetic control of plant disease resistance in their work with cabbage, leading to widespread efforts to use breeding techniques to obtain host plant resistance. Horticulturists H.A. Jones and A.E. Clarke discovered the cytoplasmic-genic system of hybrid seed production in onion, which led to the revolution in F_1 hybrid crops during the 20th century. Particle acceleration technology, in which DNA is blasted into plant tissue in order to produce transgenic plant cells, was invented by the horticulturist John Sanford in the 1980s.

Few scientific fields have captured the imagination as has horticulture, perhaps because of its centrality to the development of human culture. Biblical and other religious texts are filled with horticultural metaphors, such as the placement of Adam and Eve in the Garden of Eden near the Tree of Knowledge, the olive branch as a symbol for peace, and Noah's cultivation of a vineyard as his first act after the flood. We speak of a renaissance in events as a “flowering” and the end of innocence as a “de-flowering.” The education of our youth involves, appropriately, a garden of children, or kindergarten. We “cultivate” relationships and speak of our hard work “bearing fruit,” certain people as “late bloomers,” or others as “wall flowers,” or worse, “gone-to-seed.” Moving to a different location marks us as “transplants,” but staying put means we are “putting down roots.” Many of our best thinkers have communicated complex concepts with such horticultural metaphors. Charles Darwin, in describing the process of evolution in nature, used the branching tree. In his vision the branches represent phylogenetic patterns of lineage, and the dropped branches and twigs represent extinction. This tree metaphor for descent with modification has completely permeated biological science and popular culture. Horticulture and its practices are woven into our consciousness and have become part of the fabric of our language and thought.

Nineteenth Century Horticulture

The horticultural information and lore that was available at the beginning of the 20th century was prodigious although its application seems primitive by today’s standards. Practically all of the horticultural crops – fruits, vegetables, ornamentals – we now use were known through generations of explorers, missionaries, plant hunters, and immigrants who exchanged germplasm from all over the world. It is indeed remarkable how few of our horticultural commodities are native to any one continent, and how much horticulture itself was dependent on international trade, exploration, and immigration. The ancient horticultural arts including cultivation and irrigation, pruning and training, thinning and girdling, seed and vegetative propagation, storage and marketing were part of a thriving industry but there were tremendous problems with losses at all levels of the production chain due to diseases, pests, and unknown maladies and problems of quality, low yields, and inability to provide product uniformly with problems of seasonal gluts and shortages. There were many unanswered problems: why cultivars seem to run out, why some plants failed to flower, why some fruits did not store well. Despite an active seed and nursery industry there was no rationality or predictability in crop improvement.

Liberty Hyde Bailey’s *Cyclopedia of Horticulture* in 1914 was a massive work that is a repository of late 19th century information. We still read it and marvel at the extent of what was known. Horticultural science in the last 100 years did not start from ground zero but at a firm foundation of when we now call the Old Horticulture.

Bailey’s opus describes the tremendous wealth of information that had been generated during the early years of the so-called traditional agricultural revolution. The period from 1840-1940 in the U.S. has been called the “Agricultural Revolution” by more than one agricultural historian (Edwards, 1940). While this is certainly true for agriculture, it is perhaps most true for the entire economic development of the U.S. during this period. In just over five decades during this period (from 1860-1914), the population of the U.S. grew from 31.3 million to 91.9 million, including 21 million immigrants. During this same period, the number of workers grew by 700%, the rate of production by 2000%, and investment capital by 4,000%. Thus, the U.S. was poised for a major economic change that had implications for many sectors including agriculture. The transformation of the agricultural landscape was depicted by Schmidt (1930):

> *Agriculture was transformed from a simple, pioneer, and largely self-sufficing occupation into a modern business organized on a scientific, capitalistic, and commercial basis; industry definitely underwent the change from hand labor in the home to machine production in the factory. And the local market was transformed into the world market. This threefold revolution in agriculture, industry, and commerce is the key to the study of the recent history of the United States.*

The primary forces behind the “Agricultural Revolution” in the United States between 1840 and 1940 were: (1) the transition from public to private ownership of land,

(2) the expansive westward settlement of the U.S., (3) the invention and popularization of farm machinery, (4) the development of transportation facilities for agricultural products, (5) the transition of the industrial sector from the farm to the factory, (6) the significant expansion of foreign and domestic markets for agricultural products, and (7) the establishment of public agencies for agricultural research and scientific advances relevant to agriculture. While each of these forces has obvious antecedents in the agriculture of today, the continued scientific and technological advances and societies that fuel agricultural development are the primary subject of this review.

In 1900 the farm population of the United States was 29 million (as compared to about 300 million in 2006) that constituted 39% of the population. Nonfarm families spent 25% of their income for food. Horticulture was a strong force in American agriculture, with millions of home gardens, and hundreds of thousands of small market gardens. The US was coming out of the farm depression of 1898 but things were looking up. This feeling of progress was based on the tremendous technological changes taking place in communications, transportation, and in a series of inventions such as the electric light, the motor car, the telegraph, and coast-to-coast railroads changed the way ordinary people lived. However while the Industrial Revolution had transformed America it had relatively little effect on Agriculture. The Agricultural Revolution was to be truly a 20th century phenomenon (Paarlberg and Paarlberg, 2000).

Yet, a farmer from biblical times miraculously transported to an American farm in the year 1900, would have recognized and had the skill to use most of the tools he saw: the hoe, the plow, the harrow, the rake with horse and mule power fueled by oats and hay. Most of horticulture was an adjunct of the family farm but the beginnings of large horticultural operations were beginning in the West. Produce was seasonable and storage facilities were primitive. The family farm was one of unending toil. Production was low and losses due to diseases and pests were severe.

The 20th century breakthroughs in agriculture that were to have explosive consequences had many causes including advances in science in general. Of particular significance to horticultural science in the U.S. was the establishment of the U.S. Department of Agriculture in 1862, announced in President Lincoln's first communication with Congress. Beset by many administrative problems in the early years, the Department of Agriculture made significant headway in scientific advances in agriculture during the latter part of the 19th century. Beginning with a division of chemistry, they expanded to soils and fertilizers, analyses of the relative compositions of plants raised on the various soils of the U.S., investigation of food and drug adulteration, and the manufacture of sugar. Later, an entomology branch was added, and in 1882 the U.S. Congress made its first appropriation for agricultural research in the form of a $20,000 annual grant for investigating insects injurious to agriculture.

The lubricant and hatchery for the 20th century revolution in agriculture was to be found in the establishment of people's university known as the Land Grant colleges (Kerr, 1987). This occurred as a result of the Morrill Act signed by President Abraham Lincoln in 1862, emphasizing but not restricted to agriculture and the mechanical arts. This proved to be one of the greatest pieces of legislation enacted. When the land grant colleges were established there was little national coordination among their agricultural programs. To serve this need, agriculture experiment stations were formed. Their purpose was to link the work of the state colleges with national priorities. The first was established in Connecticut in 1875, and by 1880 there were many such stations at land grant colleges.

The Hatch Act of 1887 institutionalized the federal and state experiment station systems with state administration in the land grant colleges, a system that continues to this day. The Smith-Lever act of 1914 established a national system for extension that developed into a state-supported cooperative extension program. The trinity of research, teaching, and extension carried out by land grant colleges were to have a profound effect on agriculture including horticulture. Most important it transformed agriculture of which horticulture was a significant part, into an academic discipline. Academic horticulture in the United States strove to break away from the empiricism of the past and to devise explanations for the horticulture lore in order to solve the enormous problems that were faced in growing and distributing horticultural products. From the beginning it was inclusive, drawing little distinction between food for the body and food for the soul including ornamentals and landscape plants, medicinal and aromatic plants, crops considered commodities and foods of health and delight. Changes were not additive but multiplicative and from the beginning of the 1920s crops yields were to increase exponentially. Yields per hectare of maize and processing tomato are a dramatic example of agricultural progress that were attributed to the scientific approach to agriculture.

The beginnings of horticulture as a science can be traced to founding of the Horticultural Society of London in England in 1806 subsequently the Royal Horticultural Society (Fletcher, 1989). In the early years the society was led by Thomas Andrew Knight (1759-1838) and later by John Lindley (1799-1865), author of a book presciently entitled *The Theory of Horticulture* (1840). In the United States, state horticulture societies were formed and flourished, and the American Pomological Society established in 1848 was the leading national fruit organization. There were a great number of horticultural books devoted to fruit growing and the culture of individual crops written by practitioners. Characteristic of these state level activities was a focus on fruit and vegetable crops, rather than on the more ornamental aspects of horticulture. This was due to the desire to provide adequate food for the settlers and test the limits of the new climate with respect to crop production.

Despite all of this activity at the local level in many states, and a thriving horticultural industry, there was no national society devoted to all of horticulture much less horticultural science. In fact horticulture and agriculture were not considered scientific at all, and the haughty botanists disdained the Mother of Science. Into this swirling maelstrom of ideas, Spencer Ambrose Beech, a pomology professor in Geneva made the decision to found a Horticulture Society devoted to Science which was later to become the American Society for Horticultural Science. Liberty Hyde Bailey, the father of horticultural science in America, was the first president serving from 1903 to 1907 (Janick, 2003). The International Society for Horticultural Science (ISHS) derives from a series of International Congresses devoted to horticulture beginning in 1864 in Brussels and the present International Horticultural Congress held in Seoul Korea is, in fact, the 27th of such quadrennial horticultural meetings. The concept of an international society devoted to horticultural science was formally proposed in 1955 and became a reality in 1959.

A CENTURY OF HORTICULTURAL SCIENCE

Horticulture has undergone cataclysmic changes in the last 100 years. Recent progress will be discussed in terms of commodities and disciplines in the other papers presented in this Congress. Here we discuss the changes in the broad terms of three revolutions: mechanical, chemical, and biological. The dramatic changes in these technologies were to spawn enormous changes in horticulture and horticultural science.

The Mechanical Revolution

Mechanical devices inherent in agriculture from its very beginnings facilitated animal traction, cultivated crops, and lifted and transported water for irrigation. Although these devices underwent continual improvement over the millennia, they remained essentially similar in concept. The life of a farmer was one of drudgery and toil. In the early 19th century, mechanical advances such as McCormick's reaper and Eli Whitney's cotton gin were to profoundly affect US agriculture. Steam-powered threshers and tractors were developed but the engines were costly to operate, required tenders for water and coal. They were dangerous to operate and fire hazards to fields and farmstead. It was the gasoline engine that was to transform agriculture in the 20th century.

1. The Gasoline Engine. In 1892, John Froelich built the first successfully operating gasoline tractor, concurrent with the gasoline-powered automobile. The iron beast took over and there were soon scores of companies developing them. In 1923, the Farmall, a tricycle type row-crop machine produced by International Harvester marked the agricultural transition form horse to machine. In the 1930s, the invention of the power take off permitted the tractor to be the basic farm machine able to power a score of other operations. In the US, farm horses for traction peaked in 1919 (26 million) and dropped to 4 million in 1955, many of which were for recreational uses. For 1940 to 1950 tractors increased form 1.6 to 3.4 million. In the next 50 years the gasoline engine, the tractor, and a thousand modifications were to become increasingly complex, augering in present developments dubbed precision agriculture, a combination of mechanical devices with electronic analytical instrumentation, including global positioning systems, to adjust application geared to each plant and location.

2. Controlled Environment Horticulture. Attempts to control the crop environment have precedents that date to antiquity. Pliny in the first century CE, discusses a greenhouse (specularia) using "transparent stone" (mica) to force cucumbers beloved by the emperor Tiberius. In the 18th century, gall cold frames were developed to force seedlings using heat generated from rotting manure. The glass greenhouse, based on an iron super-structure and heated by steam, was developed in the 19th century. Elaborate conservatories were built on the estates of the wealthy and in botanical gardens. By the beginning of the 20th century, a prosperous industry developed for the production of cut flowers, bedding plants, and a few vegetables. In the first half of the 20th century, improvements included improved construction, metal replacing wood glazing, better heating, a shift to oil and gas, and fan and pad cooling, but little essential change. However, research in Kentucky by horticulturist E.M. Emmert in the 1950s with polyethylene plastic film had a profound effect on world horticulture. The new technology dubbed plasticulture was used for greenhouse coves, soil mulch, and various crop tunnels. The greatest development first occurred in Europe where the plastic greenhouse found a place for winter production in subtropical climates, especially Spain and Israel. Recently the plastic greenhouse has a great effect in China and at present there are over 1 million hectares of plastic greenhouses for vegetable production.

Artificial lighting in horticultural environments also transformed horticultural science and crop production. The antecedents of this technological innovation can be found in Liberty Hyde Bailey's 1891 publication in the Cornell University Agricultural Experiment Station Bulletin series entitled "Some preliminary studies on the influence of the electric arc lamp upon greenhouse plants." This paper recounts work conducted on the feasibility of using electric lights in greenhouse environments for vegetable production. Bailey was the first U.S. scientist to conduct research on horticultural crop production using electric lights (Wilcox-Lee, 1989). Although there were European precedents for this kind of work, they were primarily concerned with physiological effects of light. Bailey's focus was pragmatic, and it also attempted to answer the question of whether electric lights were injurious to plants, as was believed at the time. Bailey concluded that light caused more rapid maturation in some plants and suggested that it might be useful one day in crop production. He also noted that light affected crop species differentially, causing undesirable bolting in some. The mysterious effects of photoperiodism remained unknown until Garner and Allard's pioneering work some 30 years later (Wilcox-Lee, 1989).

Once the effects of light were understood at a practical level, horticulturists began to manipulate the kinds and amounts of light in order to influence crop production. One horticultural triumph in this area was the discovery that light exclusion and a resulting shortened daylength could hasten flowering in ornamental plants. This discovery resulted in the birth of the international chrysanthemum industry. The seminal work in this area was reported by Kenneth Post in 1934, in the New York State Experiment Station Bulletin in a paper titled "Production of early blooms of chrysanthemums by the use of black cloth to reduce the length of day" (Langhans, 1989). Post was aware that chrysanthemum was a plant that flowered in response to specific daylengths, but he struggled with how to exclude light in order to promote flowering. Post experimented with different types of cloth, finally settling on sateen, a tightly woven cloth that satisfactorily excluded light. He demonstrated the value of covering the plants beginning at 6 p.m. and not uncovering them until 9 a.m. This in turn allowed for the production of a flower crop on a year-round basis using relatively inexpensive and simple materials. Known as a "gem of applied horticulture," this work was the beginning of a multi-million dollar horticultural industry.

Automatic controls of the greenhouse environment became common in the last 25 years, and greenhouse design has undergone a redesign as they increasingly resemble automatic plant factories and incorporate climatic control similar to phototrons, the *sine plus ultra* of environmental control. Artificial lighting and automatic covers for daylength modification, automatic temperature and humidity control, automatic flat and pot filling and movement are now found in many modern greenhouses but power costs and capital requirements are the main issue. The emergence of the tomato and cucumber industry in Ontario is an example of progress achieved with the combination of horticultural science combined with energy subsidization.

3. Irrigation. Irrigation technology has always been a basic part of horticulture. In the 19^{th} century, irrigation in the western states was still based on furrow systems and gravity flow from canals, much as it had been since antiquity. Irrigation technology was to be transformed with the development of fixed sprinkler irrigation systems and then completely transformed in the more humid areas of the country with the development of light-weight portable aluminum pipe. In addition to moveable pipe, the development of center-pivot irrigation systems was to have a large and significant impact on vegetable and fruit crop production in the western U.S. and in many other parts of the country where large scale crop production was under development. These systems make use of a stationary pivot point for an irrigation system comprised of a 360° rotating sprinkler arm on wheels.

A new technology, called drip or trickle irrigation which had its antecedents in techniques used in the U.S. and Australia with perforated pipe that was buried beneath the soil, as well as the Chapin system to water individual pots in greenhouses via individual plastic tubes, was developed for semi arid areas in Israel. This was destined to completely transform irrigation for horticultural crops in all climates. In the early 1960s, work by S.D. Goldberg and M. Shmueli in the Arava desert in southern Israel demonstrated that a trickle irrigation system installed on the soil surface worked exceptionally well in producing vegetable crops, even with saline water (Elfving, 1989). The system, responsible for the greening of a formerly unproductive environment, relied on light-weight plastic materials developed during and after World War II. These materials, often called "spaghetti tubes" had been in use in greenhouse production by the 1950s.

The use of irrigation for frost control was to have a major impact on fruit production and out-of-season vegetable production. Attempts to control ice formation on fruit and vegetable crops received widespread public attention with the development of a genetically engineered bacterium known as "ice-minus" in the 1980s. The idea was to engineer the ice-nucleating bacterium *Pseudomonas syringe* to prevent its ability to initiate ice crystals. Because it was one of the first products of the new biotechnology industry, public scrutiny was at an all-time high, particularly when scientists in what appeared to be outfits suitable for a lunar landing were pictured spraying genetically engineered bacteria in strawberry fields in northern California. Although a fascinating scientific discovery, the deployment of non ice nucleating bacteria into the environment did not develop into a productive strategy for crop production.

Horticultural crops are often differentiated from agronomic crops by their high moisture content. Indeed, horticulture is fundamentally about water, and thus its availability and economics will in large part dictate the success of horticultural practices and industries. The determination of precise water needs for certain horticultural crops has been developed in an effort to conserve water and improve crop quality. Salinization has become a world problem and the issues of water use, water quality, and water efficient plants will clearly be the focus of irrigation research in the next hundred years as agriculture is confronted with expanding industrial and urban demands.

4. Mechanical Harvesting. Mechanical harvesting started with grain crops and soon expanded to horticultural crops, particularly root crops such as potato, sweet potato, and onions and later to peas and beans. However, it was difficult to mechanically harvest many fruit crops because of the problem of sequential harvest, selectivity, and bruising. A breakthrough was made in the 1950s with the development of the tomato harvester and it did not take long for the harvester to completely change the processing tomato industry. Mechanical harvesting was to have a profound effect on cultural practices and was accompanied by high plant populations, breeding for concentrated ripening and production and processing yield and quality, and the use of growth regulators to ripen fruit on schedule. It had unintended consequences. It resulted in almost the entire processing industry moving to California. The industry continues to adjust and at the present time the industry has moved from northern to southern California because the occasional rains during harvest caused quality problems. Mechanical harvest soon moved to fruits destined for processing such as blueberry, raspberry, tart cherry, and grape. However, mechanical harvesting has not yet become the norm for fresh market produce because of the bruising problem as well as social considerations to protect higher paying jobs for migrant laborers. In such cases, harvesting has been accomplished by a combination of hand harvest and mechanical aids. The mechanical revolution also affected ordinary cultivation practices including transplanting, orchard establishment, and pruning.

Mechanization had a great impact on postharvest horticulture, as the backbreaking job of lugging crates was taken over by forklifts to move larger and larger pallets. The packing house underwent an increasing sophisticated transformation as sorting and grading and packing was largely taken over by electronically assisted, seemingly intelligent machines. Today, electronic color sorters have been employed in many ways in horticultural production, from fruit and vegetable processing factory lines to seed purity operations, although the human eye has continued to find a place on the sorting line.

5. Instrumentation. In the last half of the 20th century, advances in instrumentation greatly affected horticultural research, especially in plant physiology and plant biochemistry. The tedious parts of chemical analysis such as the cumbersome kjehldahl apparatus for nitrogen determination in soils developed into inductively coupled plasma (ICP) spectroscopy. Soil and foliar analysis were completely altered with sequential analysis using chromatographic techniques (first paper, then thin layer, and now gas chromatography combined with mass spectroscopy) that completely changed qualitative and quantitative analysis. Analytical procedures for complex secondary compounds in horticultural plants, such as vitamins and vitamin precursors, pigments, flavors, and defense compounds were developed using techniques such as high-pressure liquid chromatography (HPLC) and gas chromatography. Modern instrumentation allows for temperature and light control and auto-sampling capability, thereby eliminating much of the tedium and time associated with the measurement of such compounds.

This is particularly true in the area of photosynthesis research, where measurements of carbon fixation have changed dramatically during the 20th century. In the 1930s, plant physiologists recognized that carbon dioxide concentration was important for photosynthetic activity, however much of the work was conducted on individual leaves from plants growing in pots. Horticulturists became very interested in examining the impact of carbon dioxide concentration on photosynthesis of plants growing in horticultural production environments. The methods currently in place to evaluate the amount of atmospheric carbon dioxide included gasometric, volumetric, electrometric, and gravimetric techniques, none of which were very promising (Faust, 1989). The desire to understand the photosynthetic rate in a real horticultural environment led to the seminal work of Heinicke and Childers, reported in 1937 in Cornell University Experiment Station Memoir 201, of the daily rate of photosynthesis of a single apple tree during the 1935 growing season (Faust, 1989). Their paper was a marvel of both endurance and scientific accomplishment. Childers measured the level of irradiation, leaf area, transpiration, and carbon assimilation for the entire season using a tree growing in a glass-enclosed box in an experimental apple orchard. This pioneering study led to evaluations of field-level photosynthetic rates in agronomic crops and the design of field cages to evaluate photosynthesis in a range of other environments. Today, photosynthetic rates can be evaluated using highly sophisticated, portable, lightweight instrumentation developed for individual plant tissues, organs, or plants. The equipment can measure light interception, transpiration, photosynthetic efficiency, and a range of other parameters in an instant, thereby greatly improving the speed, accuracy, and efficiency of whole-plant and field level horticultural research.

The fields of genetics and molecular biology have perhaps seen the greatest benefits from the instrumentation revolution. The polymerase chain reaction (PCR), and the instrumentation designed to perform routine PCR amplification in a matter of hours, has completely revolutionized genetic analysis in horticulture. By virtue that millions of copies of DNA fragments can be made in a short time, genes and DNA polymorphisms can be studied and used as diagnostic markers for a range of applications, from genetic engineering to assessments of seed purity to characterizing phylogenetic relationships. The new chemico-mechanical revolution reached unprecedented speed and accuracy in the field of genomics where nucleotide sequencing is performed on speeds unimaginable ten, much less 100 years ago, and a new word "throughput" has been coined to represent the automation of data collection at very high speed.

Statistical analysis became an integral part of agricultural research in the first half of the 20th century. The monotonous and time-consuming job of data analysis was first carried out by hand, and then by hand-cranked, later electrified, calculators, and finally transformed by computers and computer programs that completely changed the way data are handled. Advances in numerical analysis turned out to be essential components of the genomic revolution. The presentation of data also underwent a remarkable transformation. Computer graphic technology drafting equipment for charts and graphs have made the LeRoy lettering sets as obsolete as the slide rule. The scientific talk was transformed from excruciating boring presentations where scientific papers were simply read (much as is inexplicably still the case in the humanities), to real theatre with improvements of visual presentation techniques evolving from lantern slides, to overheads, the carousel slide projector, and, now, computer-generated Power Point® presentation.

The Chemical Revolution

1. Plant Nutrition. Interest in materials that would increase crop growth date to antiquity. Democratus of Abdera an early Greek philosopher proposed the strikingly modern concept that plants are derived from a combination of chemicals. Early Roman agriculturists and writers recognized the beneficial effects of animal manure, plant residues from leguminous crops, and crop rotation. Despite this knowledge, there was no real understanding of the theory of plant nutrition and the contribution of organic matter and inorganic material were confused up to the 19th century. It remained for Justus von Liebig (1802-1873) to demonstrate that carbon was supplied by the air and not by humus, although he believed roots absorbed it. Liebig assumed that most N was absorbed by the air but was unaware of N fixation by bacteria.

There was a strong sense among the leaders of the U.S. that European scientific developments could play a role in our agricultural development. Nowhere was this sense stronger than in the political stronghold of the U.S., New England. The sad fact that rocky New England soils were nutrient-poor was, inadvertently, the impetus to search for scientific solutions to agricultural problems. In particular, a significant effort was made to find chemical solutions to agricultural production issues. This was particularly true during the late 18th and early 19th centuries, when agricultural chemistry was synonymous with agricultural science. The primary promise of agricultural chemistry was to improve agricultural productivity through soil fertility, and the place this was needed most was in the newly-settled region of New England.

As agriculture in the U.S. began to develop during the late 18th century, farmers began to realize that the rocky soils in New England could benefit greatly from fertility amendments. The work of European soil chemists, in particular Justus von Liebig, was held in very high regard during this period. Methods were developed to analyze soil composition and recommend practices to improve their fertility. During this period, agricultural societies such as the Massachusetts Society for Promoting Agriculture (MSPA) began to encourage scientific practices in agriculture as well as stimulate research that would benefit farming (Anon., 1871). One of Liebig's students, Samuel Johnson, was responsible for starting the Connecticut Agricultural Experiment Station (CAES) in 1875, the first of its kind in the U.S. State agricultural experiment stations would not be in widespread development until the end of the 19th century, with the passage of the Hatch Act in 1887. The CAES had a focus on soil fertility and was one of the first proponents of chemical research in agriculture in the U.S.

The contribution of plant nutrition as a science bloomed in the 20th century. The important contributions were air as a source of carbon and nitrogen, the production of N from the Haber process, the concept of cation exchange and soil fertility, the development of the fertilizer industry, the concept of essential elements, importance of trace elements, respective role of nitrate and ammonia nitrogen in plant nutrition, soil classification, recognition of the importance of soil tilth and pH, the problems of nutrient balance, the role of calcium in fruit disorders, and the use of foliar application, soil testing and leaf analysis.

Special advances in nutrition were involved in the development of synthetic soils which led to the increase in container production of ornamentals, hydroponics, and tissue culture technology. Out of these developments grew such innovations as plug technology, expansion of agriculture to sandy soils, muck solids, and micropropagation.

In the last quarter of the 20th century, concerns over the environment and the growth of the organic movement have led to reappraisal of plant nutrition with the realization that excess amounts of fertilizers could lead to environmental problems and some questioned the sustainability of relying too heavily on inorganic nutrition. Yet at the same time it has now been conclusively demonstrated that poor production in many parts of the tropical world is directly related to the technology of fertilization of problem soils and plant nutrition is once again becoming considered as a critical component of food production and the alleviation of world hunger and world poverty. The 2002 World Food Prize, announced at the 2002 International Horticultural Congress was presented to Pedro Sanchez for his work in South America and Africa arising from his efforts at improving the productivity of tropical soils and for developing the connection between soil fertility, soil management, and poverty reduction.

2. Pest Control. The search for chemicals for pest control has an ancient tradition but the great variety of nostrums had little value. The first examples of successful pest control occurred in the 19th century with the use of lime sulfur, originally sprayed on grapes to discourage pilfering, when it was observed that it reduced several fungal diseases, particularly powdery mildew. In the early 20th century this material was basically the only weapons to control many fungal diseases of crops (apple scab for instance) while a number of truly dangerous materials were used such as lead arsenic for coddling moth control and mercury compounds for seed borne diseases.

The development of pesticides received a major boost during World War II with the discovery that DDT could control insects at very low concentrations. However DDT, despite its positive insect control effects, was easily concentrated in the food chain, and was found to adversely affect birds through a reduction in eggshell thickness. The publication of *Silent Spring* by Rachel Carson in 1962 initiated the environmental movement. Although the development of chemical pesticides had led consumers to expect and demand blemish-free horticultural products, the indiscriminate use of pesticides was responsible for a backlash. This led to attempts to reduce the use of chemicals in agriculture and to strive for environmentally friendly materials. As a sign of the times, Joni Mitchell sang in *Big Yellow Taxi*

Hey hey farmer
Put away that DDT now
Give me spots on my apples
But leave me the birds and the bees, please!

The reduction of pesticides by employing many avenues of control including chemical, biological and cultural techniques is known as integrated pest management (IPM). This is the current mantra of most horticultural scientists. Most horticulturists feel that while it is inconceivable that chemical pesticides can be completely eliminated, it is clear that more environmentally friendly materials can be found, and that alternate technology can further reduce usage. It is also clear that horticultural marketers and consumers are interested in crops produced with more environmentally-friendly practices. The phenomenal growth of the organic food market in the U.S. and E.U., as well as the appearance of new eco-friendly brands of certain horticultural products, suggests an expansion of efforts designed to deliver horticultural products produced with lower amounts of synthetic pesticides. The ultimate control will include biological through gene action, but the technology of moving resistance genes into organisms is controversial.

3. Growth Regulation. One of the main contributions of the 20th century was the regulation of plant growth by specific chemical substances (Looney, 1997). 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. 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 horticultural science, but this bandwagon had staying power and were to have a profound effect on agriculture. The singular event was the development of 2,4-dichlorophenoxyacetic acid (also known as 2,4-D), a chemical similar to auxin. Herbicides have become essential to modern production of agronomic and horticultural crops. The hoe, after 7000 years, had finally become obsolete.

A number of scientific papers published during the 1940s indicated that certain plant growth regulators (discussed in more detail in the following section) could act as herbicides if used at specific doses. One such class of promising compounds were phenoxy and benzoic acids, which had been discovered earlier by P.W. Zimmerman and A.E. Hitchcock. One of these acids, 2,4-D, seemed to serve as a very promising selective herbicide, killing broadleaf weeds but not the grasses that grew alongside them. In addition, it was more than one-thousand fold as effective as other inorganic compounds.

Classic work by Marth and Mitchell published in 1944 (Weller and Frank, 1989) described the value of this selective herbicide in crop production. This in turn opened up a new avenue for controlling weeds in cereal and turf production, and today 2,4-D is still used widely in these applications.

There were other dramatic economic effects of growth regulation, especially in horticulture. These include rooting stimulation, flower induction, fruit setting and thinning, abscission control, growth inhibition, and fruit ripening accelerators and inhibitors. 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.

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 pyrethrums, compounds from *Chrysanthemum* species, were acceptable but not the modified compounds called pyrethrins. Spores of *Bacillus thuringienis* 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 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 an ever decreasing cost of the percentage of family expenditures. The larger problem at issue is the interrelationship of biological systems and the problem of sustained agricultural productivity. The challenge to horticultural science will be to steer a course between the scylla of environmental chaos and the charybdis of world hunger.

THE BIOLOGICAL REVOLUTION

The biological revolution emerged from the work of Charles Darwin and Gregor Mendel, both horticulturists in their own right. Darwin was to investigate the myriad of changes introduced by horticulturists in selecting garden plants which led him to formulate his theories of evolution, a theory that was to unify biology and shock the world. His work on plant movements were to pressage the beginnings of phytohormones. Gregor Mendel was a cleric from Brunn who unraveled the laws of inheritance from studies of the garden pea and in a sense created the science of genetics. The same decade that Mendel reported on his famous work on inheritance in the garden pea (1865), Johann Friedrich Miescher described a substance called nuclein derived from pus extracted from surgical bandages and later found in fish sperm. Nuclein was later shown to consist of protein and nucleic acid. The research of Mendel and Miescher were the origin of investigations that that would culminate in the unraveling of the genetic code in the 20^{th} century.

1. Inheritance. The similarities and dissimilarities between parents and offspring have been commented on from the beginning of the written record. The aphorism "like begets like" is the basis of genetic wisdom. Knowledge of the genetic connection between parents and offspring is implicit in the biblical prohibitions against adultery, which results in ambiguity regarding inheritance and paternity. Similarly, insight into the function of sex in plants dates to Mesopotamia with clear knowledge of pollination in date palms. Theophrastus was aware of these ancient concepts, but this information became virtually lost until the Dutch botanist Jacob Camerarius (1670) experimentally proved the sexual nature of plants. Despite the clear relation between parent and offspring there was not a basic way to predict performance. Hereditary theories were murky and the best analysis was a blending of blood although it was understood that some characters could reappear and that certain traits could be sought and maintained in certain lineages.

In the 19th century, the first experimental research began to confront the problem of inheritance. Thomas Andrew Knight demonstrated segregation of seed characters of the garden pea but offered no explanation. The great Charles Darwin was the first to demonstrate and explain a mechanism of evolutionary change that could account for the highly-branched lineages that nature represents. He called this mechanism natural selection. Darwin collected a vast amount of information and carried out a review of experimental studies but failed to arrive at a satisfactory theory of inheritance. His concept of pangenesis involved a persistent hereditary unit, but he assumed incorrectly that units were replenished by input (gummulea) from somatic tissue. The difficulties of a genetic theory were compounded by a lack of understanding of variation both continuous and discontinuous, the interaction with environment, and of complications introduced by dominance, inbreeding, outbreeding, apomixis, and mutation. Despite his inability to account for the mechanism of inheritance, Darwin's view on evolution was to become the unifying, dominant force of biology in the 20th century.

Yet all confusion was swept away by the obscure monk, Gregor Mendel, in a backwater town of the Austro-Hungarian Empire. In a series of brilliant experiments with the garden pea, Mendel was able to perform precisely the correct experiment with precisely the correct interpretation. His evidence was presented in a scientific paper that is a model of order and lucidity (Janick, 1989b). More astonishing, the hypothesis was formulated in a pre-cytological era. Mendel essentially demonstrated that characters were controlled by entities or factors that we now call genes. These genes interact to form a phenotype and segregate unaltered from one generation to the next. He demonstrated that in peas 2 forms of the gene (we now call them alleles) can interact in the formation of a visible trait (phenotype). When the alleles vary in function, one could dominate the other. Furthermore, the recessive allele although hidden, passes unaltered from generation to generation, and reappears in predictable ratios.

2. Genetics. The immediate impact of Mendel's paper, presented in 1866, was nil. It was fairly widely distributed but either ignored or brushed off until its "rediscovery" in 1900. Yet the period from 1866 to 1900, the classical period of cytology, the study of cells, was to establish the basic part of structural cell biology that put Mendel's theoretical discovery of inferred genes (*anlage*) into structures contained in each living cell. In 1866, Haeckel published his conclusion that the cell nucleus was responsible for heredity. Soon thereafter, the chromosomes, the physical framework for inheritance became the focus of attention in mitosis, meiosis, and fertilization with speculation on its relation to heredity. The issue was cloudy because the details of the meiotic process were not well understood.

The pieces of the puzzle however quickly fit together only after the independent verification of Mendel's result by Hugo de Vries, Carl Correns (a student of Nägli, the professor, who, while sent Mendel's paper, refused to understand it), and Erich von Tschermak. None of them completely understood Mendel's paper although Correns came close. It remained for W.S. Sutton to recognize, in a 1902 paper, that the association of paternal and maternal chromosomes in pairs and their subsequent separation during meiosis constituted the physical basis of Mendelian genetics. Sutton wrote two of the most important papers in cytology but never received his PhD; he left science for surgery. Sutton was a student of E.B. Wilson whose famous work *The Cell* (1896) described chromosome behavior and speculated on their role in heredity.

The genetic revolution had a rapid impact on plant and animal improvement. Although breeders had unconsciously been using many appropriate procedures via crossing and selection in the 19th century, the emerging science of genetics and, especially, the fusion of Mendelism and quantitative genetics, put plant and animal breeding on a firm theoretical basis in the 20th century.

The relation between genetics and post-Mendelian plant breeding is best exemplified by two routine breeding protocols. One is the extraction and recombination of inbreds combined with selection to produce heterozygous but homogeneous hybrids, a procedure analogous to reforming Rubic's cube, whereby combinations are first disturbed to complete the final order. The other is backcross breeding, in which individual genes can be extracted and inserted with precision and predictability into new genetic backgrounds. The combination of backcross breeding to improve inbreds and hybrid breeding to capture heterosis is the basis of the present day strategy known as the inbred-hybrid method. The elucidation of the genetics of male sterility in onions by horticulturists H.A. Jones and A.E. Clarke solved a horticultural problem of hybrid seed production and brought attention to non-nuclear genetic factors (Gabelman, 1989).

The success of the new science of plant breeding had a substantial impact on agriculture and horticulture. Dramatic successes quickly followed: examples include hybrids and disease resistant crops. The spectacular example of plant breeding prowess was the development of short-stemmed photoperiod-insensitive wheat and rice, the forerunners of the Green Revolution for which Norman Borlaug, a plant breeder with the Center for the Improvement of Maize and Wheat (CIMMYT) was to receive the Nobel Prize for Peace in 1970, other advances include the creation of a new crop species, triticale, from hybrids of wheat and rye (an accomplishment in which Borlaug also played a part), a host of disease resistant crops, and seedless watermelon from the production of triploids produced from intercrossing tetraploids (plants having twice the number of chromosomes) and diploids (Eigsti, 1989).

Of particular significance in the history of horticulture is the understanding that genetics can control disease reaction in plants and that host plant resistance can be an object of selection. Beginning with L.R. Jones in the early part of the 20th century, research in horticulture and the newly developing field of plant pathology led to the idea that breeding could be used to develop disease resistant cabbage. This work was picked up by J.C. Walker, who used experiments in controlled-temperature tanks to demonstrate the genetic control of resistance to cabbage yellows, the first such demonstration for a plant disease (Coyne, 1989). This ushered in an era of breeding for disease resistance in many agricultural species.

Yields of horticultural crops have increased significantly during the past 100 years (Warren, 1998; Tiefenthaler et al., 2003) due to a mix of genetic and cultural improvements. The average yield of processing tomato and potato have increased faster than that of field maize. In the case of tomato, the improvements were due to a combination of genetic and cultural factors; in potato, higher yields were mainly due to superior management practices such as nitrogen fertilization, which became widespread in the 1940s. Interestingly, a substantial portion of U.S. potato production remains dependent on a single cultivar: 'Russet Burbank'. There was a doubling of yield for onion beginning in the 1920s, table beet and snap bean in the 1930s, and carrot beginning in the 1950s. Part of the reason for the large difference between yield gains in most vegetable crops vs. maize is because vegetables breeders must routinely select for many characteristics, such as flavor, color, shape, and texture of high-moisture in immature organs, a challenging and daunting task.

During the 20th century horticultural crop breeders succeeded in making great improvements in quality factors in both ornamental and edible crops. The startling array of colors, shapes, and forms currently available in many ornamental species represents the tremendous success of both the hobbyist-breeder and the professional geneticist. The use of related species to improve the visual, adaptive, and pest-resistant qualities of ornamental species serves as an outstanding example of the utilization of plant genetic resources. Tremendous improvements in nutritional quality have been achieved by vegetable crop breeders, including enhancing the pro-Vitamin A value of carrots and the modification of carotenoid profiles in a variety of species including tomato and many cultivated members of the Cucurbitaceae. Because horticulturists are often experts in the domain of plant-human interaction, they have chosen to play a critical role in the development of unique pigments, flavors, and nutritionally-relevant secondary compounds in ornamental and edible crops. This area of horticultural science will likely expand significantly during the 21st century as knowledge of the specific health contributions of horticultural crops emerges and astute consumers exert demand for unique horticultural products. Many of the efforts described above involve the manipulation of secondary metabolites through physiological genetic strategies. These projects represent some of the most unique and promising areas of horticultural research today. For example, genetic approaches to reducing antinutritional factors such as oxalic and phytic acid, or manipulating mineral uptake mechanisms to enhance phytoremediation efforts may lead to new horticultural crops and industries, in addition to improving human and environmental health.

3. Biotechnology. Dramatic advances in biology augur a third agricultural revolution involving biotechnology, a catch-all term that includes both cell and DNA manipulation. A conventional baseline for the biotechnological revolution is 1953, the date of the brilliant paper by James Watson and Francis Crick on the structure of DNA, 50 years after the discovery of Mendel's paper. However, the biotechnological revolution has no precise beginning, because science is cumulative. One pathway developed from a series of investigations into gene function and structure and another from the culture and physiology of cells using microbial techniques.

One of the most powerful engines driving basic research in plant biology is the ability to target particular genes and gene products in key biochemical pathways and modify them using the tools of molecular biology. Photosynthesis research, for example, has benefited tremendously from the cloning and sequencing of genes coding for key proteins in the photosynthetic machinery. Cloned genes are also used to develop deletion mutants that are deficient in particular pieces or subunits of the protein, and whose function can be restored following transformation with complementary pieces of DNA. Plant physiology has made major strides forward by utilizing information from molecular genetics to dissect pathways and understand the regulation of important plant processes. Horticulturists have played a part in the biotechnological revolution. The gene gun, an innovative way to introduce genes was developed by J.C. Sanford, a small fruit breeder at Cornell University, at Geneva, New York.

In another corner of biology, plant and animal physiologists far removed from genetics were attempting to culture cells and tissues in a fully defined medium. In 1902 pioneering studies of in vitro culture of plant organs and tissues by G. Haberlandt who predicted that the notion of producing plants from cultured cells would provide final confirmation of the cell theory (see Janick, 1989a). In 1922, procedures were introduced by W.J. Robbins for the culture of roots and L. Knudson developed the aseptic germination of the embryo-like seed of orchids (Arditti, 1989). The breakthrough in plant cell and tissue culture arose from a series of physiological investigations, principally by Folke Skoog and his coworkers. They developed media with growth-regulating substances, including vitamins, hormones (particularly auxin and cytokinins), and organic complexes such as liquid coconut endosperm, and from the development of generalized tissue culture media by P.R. White in the 1930s and 1940s, and most successfully by horticulturist Toshio Murashige and Folke Skoog in 1962. The demonstration of asexual embryos initiated in the cultures of carrot root cells in 1958 by J. Reinert and by F.C. Steward and K. Mears (an event analogous to producing human babies from skin cells) was a confirmation of the concept of cell totipotency: that each living cell contained all the genetic information.

Plant cell and tissue culture was quickly utilized in horticulture for rapid propagation, first for orchids by G.M. Morel in 1960, and then for a number of ornamental plants. Extensive investigation continues to explore the potential of cell and tissue culture as an adjunct to crop improvement. Techniques include embryo rescue, freeing plants from virus and other pathogens, haploid induction, cryogenic storage of cells and meristems for germplasm preservation, the creation of new nuclear and cytoplasmic hybrids via protoplast fusion, and the exploitation of changes, dubbed somaclonal variation, induced by cell and tissue culture. It was recognized that cell and tissue culture technology would be required as an intermediary for recombinant DNA technology.

Recombinant DNA technology has raised great expectations for agriculture. The discovery of enzymes which cleave DNA at specific sequences and subsequently ligate to extra-chromosomal DNAs of bacteria, permit gene replication in a bacterial host, a process known as gene cloning. The commercial production of human insulin by bacteria, the first commercial achievement of gene cloning, stimulated a new industry for producing gene products for therapeutic uses such as blood clotting factors and growth hormones. The technology to describe cloned genes in terms of nucleotide sequence is available and thus manufactured genes are theoretically feasible. Finally, DNA can be inserted into the DNA of higher plants by various techniques including the gene gun. The most promising vector for dicotyledonous plants has been the tumor-inducing plasmid of *Agrobacterium tumefaciens*, a bacterium that normally incorporates its DNA in the host as part of the infection process. Even genetic engineering is not new!

The story beyond this point although spectacular is still somewhat speculative because agriculturally-useful genes are not in surplus and their expression with foreign genomes is still completely unresolved, although many positive results have been achieved. The ability to move new genes into old plants has led to imaginative flights of fancy: a new range of disease and stress-resistant plants, nitrogen fixation of non-legumes, and amino acid-balanced plant protein. As a result, much venture capital has been absorbed by aspiring firms, large and small. However, the concept of improving agriculture in the traditional sense by recombinant DNA technology became a reality with three dramatic discoveries: the creation of a slow-ripening tomato ('Flavr Savr'), the creation of glyphosate-resistant soybeans, and the creation of pest resistant maize and cotton by insertion of the insecticidal gene *Bt*, from the bacterium *Bacillus thuringiensis.*

The slow-ripening tomato was a scientific success but not a commercial one for a number of interesting reasons. The lessons from this story bear re-telling, because ironically it was horticultural barriers themselves (and the failure to appreciate their importance) that limited the success of this unique product.

The development of 'Flavr Savr' was conducted by scientists at a California company known as Calgene, an upstart in the rapidly-expanding world of plant bio-technology in the early 1980s. Calgene had significant financial support from Procter and Gamble and a number of patents on herbicide-resistant plants. Calgene's idea, to use a transgenic approach to limit the activity of the enzyme polygalacturonase (PG) and thereby inhibit tomato ripening, was visionary for the time. By introducing the sequence of PG in a reverse orientation, company scientists were successful in shutting down the activity of this enzyme and thus tomato fruit stayed red for many weeks without shriveling or rotting. Of course, this was a signal to many that fruits could be harvested ripe instead of green, and transported to grocery stores where consumers could actually purchase ripe, good-tasting tomatoes in winter. Investors voted with their wallets on Calgene's idea, and soon the company was spending millions of dollars to market the 'Flavr Savr' tomato to the general public.

Interestingly, Calgene pushed for regulatory approval of its 'Flavr Savr' tomato through the Food and Drug Administration (FDA), wanting to prove to consumers that the tomato was safe to eat. This effort took considerable time and money in the form of animal testing and political wrangling, but in the end the FDA did rule that the 'Flavr Savr' was not significantly different than any other tomato on the market. Thus, the first genetically-engineered food product available anywhere in the world became a classic horticultural product modified to improve consumer food angst. Unlike many of today's successful transgenic crops, the 'Flavr Savr' was a horticultural product developed to appeal *directly to the consumer, rather than the farmer.* Many have speculated on whether transgenic technologies would have fared better in today's marketplace had the 'Flavr Savr' been successful. This is because consumers could clearly see a benefit to an improved tomato, whereas the potential ecological benefits of herbicide resistant corn and soybeans may not be as widely appreciated by the non-farming public.

Despite all of this promise, the 'Flavr Savr' tomato failed. Unfortunately, Calgene mis-calculated the importance of horticultural science in the web of modern plant biotechnology. Despite the fact that the 'Flavr Savr' actually did what they said it did, Calgene had only introgressed the antisense PG construct into a single tomato cultivar, one that would not be able to grow well in the wide array of environments necessary for consistent tomato production year-round in and around the U.S. In addition, they failed to appreciate the complexity of the postharvest environment: shipping ripe tomatoes was significantly more challenging than shipping unripe green tomatoes across the country in the middle of winter. Calgene was confronted with problems familiar to many horticultural scientists, but was unable to solve them in time to be successful in the marketplace. Writing in *Lords of the Harvest*, Dan Charles (2001) quotes produce magnate Bob Meyer on the horticultural issues surrounding the 'Flavr Savr':

> *They were doing their genetic engineering. They were all Ph.D.'s But put a molecular biologist out on a farm, and he'd starve to death. They had no concept of what agriculture was like. There was no one like myself. I'm the bottom of the bucket, you might say. I'm a dirt farmer. I'm the guy that puts the plant in and gets the fruit out and gets it shipped.*
>
> *They thought it was simple. You get a tomato plant and plant the damn thing. But you don't just get a seed and plant it. I work in the Salinas Valley, and that requires two different varieties as the weather changes; and the San Joaquin Valley, that requires two or three different varieties. At the southern end we have lots of sun; we need lots of leaves, and where we have rain we need a plant that doesn't have so many leaves, so the rain won't destroy it.*
>
> *They had no concept of how many varieties it would take. They said: "So you mean we'll have to put this gene in more than one variety? So I actually gave them a list of all the tomato varieties that I thought we should use, in the United States and Mexico. And it was a large list. They were….surprised. I was going to use another word. I'll be nice and say surprised.*

The creation of "Roundup-Ready" soybeans was to have an extremely rapid rate of adoption, unsurpassed in agriculture. *Bt* cotton was also rapidly adopted and *Bt* maize somewhat less because the cost benefit ratio was not as high as the corn root worm incidence varied with location. By 2002, herbicide resistant soybean accounted for 75% of the crop area, *Bt* and herbicide-resistant cotton 71%, and *Bt* maize 22% in the United States (Agricultural Statistics Board, NASS, USDA, March 2003). At the present time, the widely heralded "blue rose" has been claimed but has not appeared commercially. The reasons progress has been slower than expected were perhaps too much early hype, which created unrealistic expectations; a lack of appreciation for the complexities involved, such as the need for specific promoters; unavailability of really useful genes; technical difficulties of gene transformation; and patent problems. However, the greatest roadblock was fear by the consumer, a backlash encouraged by a new class of reforming "*Luddites*," as they were derisively termed by the *technocrats*, after a band of workman who in 1811-1816 prevented labor-saving machines in the looming industries of England. Fear of genetic manipulation as "unnatural" emerged and restrictions imposed on research may slow advances by reducing commercial interest. Consumer resistance in Europe was intense where transgenic crops have been derisively termed "*Frankenfoods*" by their detractors, and production is essentially banned. The issue of "natural" vs. "unnatural" is in a sense the conflict between nature and science (Janick, 1994b) and many still are uncomfortable with those who "tamper with nature." Shakespeare in an extraordinary passage explains that the art of changing and improving nature (by plant breeding) is itself part of nature and cites grafting as an example:

Yet Nature is made better by no mean
But Nature makes that mean; so over that art
Which you say adds to Nature, is an art
That Nature makes. You see, sweet maid, we marry
A gentler scion to the widest stock,
And make conceive a bark of baser king
By bud of nobler race. This is an art
Which does mend Nature – change it rather; but
The art itself is Nature
The Winter's Tale (IV, iv, 81-103)

The short-term future of genetically modified (GM) foods in horticulture is cloudy, but the long-term future is positive. GM food is unlikely to be a problem in Asia in view of the high need for increased production and acceptance of biotechnology by China and several countries in South America, including Argentina and Brazil.

Despite this current backlash, tremendous advances in biotechnology continue to sweep the biological sciences involving: (1) mapping the genome (the complete set of genetic information on the chromosomes), (2) determining gene function, and (3) developing an understanding of the DNA sequence homology among divergent genes in both related and disparate organisms. A new word, genomics, was coined for this technology. By 2001, the DNA of a number of organisms had been completely mapped including bacteriophage, bacteria, yeast, nematode, *Arabidopsis* (mouse-ear cress), a rapid cycling miniature plant of the mustard family, and finally humans (!!) and this is now being greatly expanded in horticultural families such as the Rosaceae. Analysis of gene function indicates that all living organisms hold genes in common, and Darwin's principle of common ancestry was vindicated. Soon all our major crop plants will be mapped. The name of the next emerging field has already been coined, proteomics, which will unravel the protein changes involved with gene function and development. We live in very exciting times.

HORTICULTURE IN THE NEW MILLENNIUM

In the beginning of the 21st century we find horticultural production industries still organized by crop production groups: fruit, vegetables, floriculture, ornamental horticulture, herbs, medicinal, and spices. However, increased sophistication of production in the developed world has resulted in enormous increases in yield and efficiency reducing the number of growers and increasing the size of operations. In the United States, California and Florida have become the major horticultural states but with globalization, horticultural imports are becoming increasingly important. Horticulture is increasingly important in Asia and at present the main producer of horticultural crops is China. Increasingly horticulture is seen as a route to development. One thing is sure, horticulture is in a constant state of change.

Postharvest horticulture has become increasingly important, as horticultural products are shipped from coast to coast and continent to continent. In the United States and Europe dining habits have been altered such that half of our meals are consumed away from home, and the consumption of ready-made meals and ready-made dishes has increased dramatically. Advances in food technology have increased the consumption of packaged, fresh-cut vegetables and fruits, and processed food. In some cases, the increased diversity of ethnicities in the U.S. and Europe has resulted in new crop introductions and new opportunities for horticulture. The re-discovery that increased consumption of horticultural products such as fruits and vegetables can defer disease risk is regularly re-emphasized in the popular media. However, with the arrival of the field of "food functionality," exaggerated and untested benefits have been ascribed to many natural products. While scientists strive to sort out these conflicting claims for the medicinal value of horticultural products, the consuming public is naturally confused about the value of their food choices. Despite the fact that a number of fruit and vegetable crops were domesticated with medicinal benefits in mind, and that their consumption reduces the chance of disease onset, it is unlikely that any of these products can live up to the snake oil-like claims that modern marketers suggest.

Many forces have influenced these changes that have occurred. Horticultural science has expanded to the private sector and now in advanced economies that arena carries out more than 50% of research expenditures. However, it is fair to say that horticultural scientist and horticultural progress still remain centered in our universities, where they are trained, and where progress is archived in our society publications. Scientific societies must continue to play a role but this role is changing as society and horticulture change. Throughout this period we follow the beat of different drummers. Consider the buzzwords that have affected us in the last 100 years: plant breeding, colchicine, cryobiology, statistics, international programs, biotechnology, energy efficiency, genomics, organic agriculture, sustainability, integrated management and so forth. Despite these changes of focus, horticulture goes on to provide food for body and soul, to enrich the lives of all, and to glorify the human condition. We here today can agree certainly that our lives depend on horticulture.

I find myself "loath to close" this historical review without reflection about horticulture, horticultural science, and the future of our profession. We are still growing horticultural crops and we are still growing as a profession. However, growth must be viewed in the future in qualitative rather than quantitative terms. We must be growing better, stronger, and more relevant to the problems we face, adapting to our future, just as our founders responded to their future. They succeeded brilliantly making horticultural science a dynamic part of both agriculture and science. We must continue to carry this torch because we have a responsibility to make sure that our science is both cutting edge and relevant to the needs of humanity. We must continue not only to find explanations for plant growth, development, and heredity but also be sure that the progress that is made in the scientific arena is translated to the betterment of producer, consumer, and all humankind.

Literature Cited

Arditti, J. 1989. Introduction to "Lewis Knudson. 1922. Nonsymbiotic germination of orchid seeds. Botanical Gazette 73:1-25." p.14-18. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.

Avery, G.S. Jr. and Johnston, E.B. 1947. Hormones and horticulture: The use of special chemicals in plant growth. McGraw-Hill, New York.

Charles, D. 2001. Lords of the harvest: Biotech, big money, and the future of food. Perseus Publ., Cambridge, MA.

Coyne, D. 1989. Introduction to "J.C. Walker and Rose Smith. 1930. Effect of environmental factors upon the resistance of cabbage to yellows. J. Agr. Res 41(1):1-15." p.526-528. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.

Edwards, E.E. 1940. American agriculture – The first 300 years. p.171-276. In: The Yearbook of Agriculture, 1940. United States Department of Agriculture, United States Government Printing Office, Washington, D.C.

Eigsti, O.J. 1989. Introduction to "H. Kihara. 1951. Triploid watermelons. Proc. Amer. Soc. Hort. Sci. 58:217-230." p.554-556. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.

Elfving, D.E. 1989. Introduction to "S.D. Goldberg and M. Shmueli. 1970. Drip irrigation: A method used under arid and desert condition of high water and soil salinity. Trans. Amer. Soc. Agr. Eng. 13(1):38-41." p.392-395. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.

Faust, M. 1989. Introduction to "Arthur J. Heinicke and Norman F. Childers. 1937. The daily rate of photosynthesis during the growing season of 1935, of a young apple tree of bearing age. Cornell Univ. Expt. Sta. Mem. 201." p.276-278. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.'

Fletcher, H.H. 1969. Story of the Royal Horticultural Society (1804-1969). Oxford Univ. Publ. for RHS, Oxford.
Gabelman, W.J. 1989. Introduction to "H.A. Jones and A.E. Clarke. 1942. Inheritance of male sterility in the onion and the production of hybrid seed. Proc. Amer. Soc. Hort. Sci. 4:189-194." p.544-547. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.
Janick, J. 1989a. Classic papers in horticultural science. Prentice Hall, Englewood Cliffs, N.J.
Janick, J. 1989b. Introduction to "Gregor Mendel. 1865. Experiments on plant hybrids (Versuche uber Pflanzen-Hybriden). Verhandlungen des Naturforschenden den Verlienes in Brunn 4:33-47." p.406-412. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.
Janick, J. 1994b. On tampering with nature. HortScience 29:1402-1403.
Janick, J. 2003. Presidential addresses 1903-2003. American Society for Horticultural Science, Alexandria, VA.
Janick, J. and Goldman, I.L. 2003. Horticulture, horticultural science, and 100 years of ASHS. HortScience 38:487-504.
Kerr, N.A. 1987. The legacy: A centennial history of the state agricultural experiment stations, 1887-1987. Missouri Agr. Expt. Sta. Univ. Missouri-Columbia.
Korcak, R.F. 1992. Early roots of the organic movement: A plant nutrition perspective. HortTechnology 2:263-267.
Langhans, R.W. 1989. Introduction to "Kenneth Post. 1934. Production of early blooms of chrysanthemums by the use of black cloth to reduce the length of day. N.Y. State. Expt. Sta. Bul 594." p.241-244. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.
Looney, N.F. 1997. Hormones and horticulture. HortScience 32:1014-1018.
Paarlberg, D. and Paarlberg, P. 2000. The agricultural revolution of the 20th century. Iowa State Univ. Press, Ames.
Schmidt, L.B. 1930. The agricultural revolution in the United States, 1860-1930. Science 72:585-594.
Tiefenthaler, A.E., Goldman, I.L. and Tracy, W.F. 2003. Corn and vegetable yield trends, 1900–present. HortScience 38:1080-1082.
Warren, G.F. 1998. Increase in crop yield in the United States in the 20th century. Weed Technol. 12:752-760.
Weller, S.C. and Frank, J.R. 1989. Introduction to "Paul C. Marth and John W. Mitchell. 1944. 2,4-dichlorophenoxyacetic acid as a differential herbicide. Bot. Gaz. 106:224-232." p.324-336. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.
Wilcox-Lee, D. 1989. Introduction to "L.H. Bailey. 1891. Some preliminary studies on the influence of the electric arc lamp upon greenhouse plants. Cornell Univ. Agr. Expt. Sta. Bul. 30." p.114-140. In: J. Janick (ed.), Classic papers in horticultural science, Prentice-Hall, Englewood Cliffs, N.J.