

## CHAPTER 1

### CONTROLLED ENVIRONMENT AGRICULTURE AND HYDROPONICS: PAST, PRESENT AND FUTURE

#### DEFINITIONS:

**Protected Agriculture:** mulches, row covers, shade structures, greenhouses, etc.

Any type of method or structure used to extend the “growing season”.

**Controlled Environment Agriculture (CEA)** includes greenhouses, growth chambers, or any totally enclosed structure providing control of the aerial environment: temperature, relative humidity, carbon dioxide (CO<sub>2</sub>) around the leaves & light (for photosynthesis) and oxygen (O<sub>2</sub>) around the roots and shoots (for respiration).

**Hydroponics** growing plants without soil & controlling the root zone conditions  
(water, nutrients, oxygen, temperature)  
using a complete nutrient solution with every watering  
(water + mineral nutrients)  
with or without an aggregate medium to support the roots  
(aggregates include sand, gravel, perlite, rockwool, coco coir, etc.)

**THE ANCIENT PAST:** Discoveries in agriculture from 600B.C. to 300 A.D.

\*600-500 B.C. – The “Hanging Gardens of Babylon” One of the seven wonders of the ancient world. Possibly one of the first examples of protected agriculture. Built by King Nebuchadnezzar II on the east bank of the Euphrates River in the middle of the desert for one of his wives. Renditions suggest a series of terraced growing areas in which water is supplied by a “chain pump” lift system from the river below.

\*Several hundred years B.C. – Egyptian hieroglyphs tell of the people growing plants in water culture, possibly papyrus (for paper) and lotus.

\*372-287 B.C. Theophrastus – One of the greatest early Greek philosophers and called the “father of botany”. He performed experiments in crop nutrition; noted that rotting manure (compost) warms & ripens the soil increasing growth; worked with potted plants.

\*92 B.C. Sergius Orata of Rome – Invented a combusted gas heating system in which the warm air passed through flues in the floor. Bath water was also warmed by his system.

\*14-37 A.D. – Cucumbers were grown off-season for the Roman Emperor Tiberius using a structure covered with “transparent rock” (presumably mica). First known use of controlled environment agriculture. Other such structures described during 1<sup>st</sup> century.

\*23-79 A.D. – Pliny “The Elder” (Gaius Plinius Secundus) wrote Naturalis Historia, a series of 37 books. Books 12-27 covered botany, agriculture, horticulture and pharmacology. He talked about the use of “straw caps” (mulch) to protect young plants.

\*~300 A.D. Rome – Roses were forced to flower early by the addition of warm water into the irrigation ditches twice a day. This would warm the roots and stimulate growth.

**THEREFORE, up to ~300 A.D.**, the ancients had perfected protected agriculture (terraced growing areas, mulches and compost heating), greenhouses, hot air and hot water heating systems and had experimented with plant nutrition, water culture and more.

**THEN:** The Great Library in Alexandria Egypt was burned. Rome fell. Enter the Dark Ages! What was learned before was forgotten... When people forget their “history” they are doomed or, in this case, required to repeat it!

**1300’s 1400’s 1500’s – European Renaissance: revival of art, literature & learning.**

#### **DEVELOPMENT OF PROTECTED AGRICULTURE AND GREENHOUSES:**

People want to “grow out of season” (i.e., have tomatoes in Winter) or grow plants where they don’t normally grow (i.e., lettuce, a cold weather crop, in Tucson in the Summer!). Therefore, move the plant from the natural environment to an artificial one... using protected agriculture and/or greenhouses. Modify or control the temperature, relative humidity, CO<sub>2</sub>, light, etc., to provide optimum conditions to grow any crop any time anywhere! What discoveries had to be made in order to develop the modern greenhouse?

\*1385 – The French built “glass pavilions” oriented toward the south to grow flowers (though mainly for the wealthy to enjoy!).

\*1500’s and 1600’s – The expanding glass industry in Italy probably prompted Italians, English, Germans and French to experiment with glass for plant growing: reports of glass bells to cover plants, greenhouses used to grow flowers in the winter using solar heating, the building of “orangeries” for growing oranges and other citrus (to help guard against scurvy during the winter) and the first greenhouse or conservatory to be built at a botanical garden was constructed at Padua, Italy, in 1550.

\*1597 – France: first accounts of the reinvention of mulches (mats, cloth, straw, etc.) to protect plants in beds during periods of cold (but probably used prior to this).

\*1600’s – Widespread use of glass greenhouses of different designs (including those with removable tops for Summer) to “force” bulbs and to grow flowers, citrus and other trees and shrubs in England, France, Germany, Sweden, The Netherlands, Spain and China.

\*1600’s – Heating systems “rediscovered”: steam/hot water, “bark” stoves (moist heat), manure as a heat source and charcoal heaters (though, high sulfur coal was found to be phytotoxic). Greenhouses were built with flues in the floor for below-ground heating. Note: Since greenhouses started in northern Europe, heating was emphasized.

\*1700’s – Greenhouse designs continue to improve in Europe and then in the USA, including multi-span structures. The first greenhouses with glass on all sides were built in Boston (1720, later in Chicago). Growers in The Netherlands found that glass cleaning along with greenhouse orientation (perpendicular to radiation source) are important for light penetration, especially in northern latitudes. They also used cloth, reeds or hair on their greenhouses during cold nights as insulation. George Washington built a glass conservatory with below-ground heating at his home at Mount Vernon in the 1780’s.

\*1800's – USA: The first commercial greenhouse (1820). Articles in Boston gardening mags. on forcing of vegetables in greenhouses (1836). By 1894 Boston was the center of greenhouse vegetable production in the USA growing lettuces (1860's), radishes and cucumbers (1870's) and tomatoes (1883). By 1899 total greenhouse crops in the USA (mainly flowers, but some vegetables) covered 2,200 acres and brought in \$2.25 million.

\*1824 – Ridge and furrow (gutter-connected) greenhouse was proposed and in 1842 one was built in England (forerunner of modern gutter-connected greenhouses).

\*1840's – Hot water heating systems for greenhouses were used extensively in England and by 1869 hot water & steam were being used in the USA (note emphasis on heating).

\*Late 1800's – Commercial greenhouses expand in England, The Netherlands and the USA (primarily northeast and Midwest). Experiments were conducted on arc (England) and incandescent (USA) lamps for use in greenhouses (light needed in northern areas).

\*1904 – New thought: Greenhouse = Factory: Beverly T. Galloway, "...the time has come when the construction of glasshouses and the production of plants under glass are regarded much in the same light as the development of manufacturing interests in a large factory; in other words, a modern greenhouse establishment is so handled at the present time that in many respects it is a factory, utilizing nature's forces in a way to reverse the seasons for the purpose of converting into wealth the products of the soil."

\*1900's – The advent of electricity brings the prospect for automation in greenhouses. Early in the century: proposals for electric motors to pump water, open vents, etc.

\*1920's – Sweden and Germany: first uses of carbon dioxide enrichment in greenhouses. USA: soil is steamed for the first time to kill pathogens. Up until then greenhouse soils were replaced annually! The use of I-beams allows greenhouse spans to increase to 15.5 m (over 50 feet). And 3980 acres of greenhouses reported with 1285 acres in vegetables.

\*1930's – Europe & USA: development of the hose for watering! Note: fire hoses were developed much earlier & out of animal intestine). Hoses replace watering cans for irrigation. The Netherlands: the first "Venlo" style greenhouse is built.

\*1948 – USA: first proposal to use cellophane and plastics for greenhouse glazings.

\*1950's – USA: First use of sub-irrigation, evaporative cooling and aluminum framing.

\*1960's – Denmark: the development of a "tube" watering system. USA: van Wingerden builds a double-layer polyethylene covered, ridge and furrow Quanset style greenhouse.

\*1970's – Plastics were used as glazings, growing bed liners and in irrigation systems. The Netherlands: first use of computer-assisted environmental control systems. However, escalating oil prices in 1973 substantially increase heating and cooling costs and many greenhouse operations faltered or failed.

\*1980's – First use of acrylic and polycarbonate panels as greenhouse glazings. Since then, the development of modern greenhouses = galvanized steel structure, glass or plastic glazing, computer systems for temperature, light, humidity, CO<sub>2</sub>, nutrients, etc.

## **THE DEVELOPMENT OF HYDROPONICS:**

### **Early reports of hydroponics:**

\*1200's and 1300's in China – Marco Polo, who traveled with his father and uncle along the “Silk Road” to China, described “floating gardens” used to grow food. This type of garden had presumably been used for centuries by the Chinese.

\*1300 & 1400's – The Aztecs, who built Tenochtitlan on an island in the shallow lake, Texcoco (near present day Mexico City), created artificial islands (floating gardens) called “chinampas”. This was necessary since there was little dry/level land for farming.

**Why use hydroponics?** In early greenhouses, plants were still grown in the soil. BUT the soil soon became infested with insects, mites and diseases. So, if you want to get rid of the soil, you need to...

- 1) discover what plants obtain from the soil (water, nutrients, oxygen)
- 2) build an artificial system that provides those things.

### **What discoveries had to be made to develop modern hydroponics?**

\*1600 – A Belgian, Jan Van Helmont, performed the earliest known experiments to determine the constituents of plants. A 5 lb willow shoot planted in 200 lbs of soil was covered to keep dust out and watered with rain water for 5 years. The willow increased its weight to 160 lbs., but the soil lost only 2 oz. His conclusion: plants obtain substances from the water needed for growth (these “substances” were “elements” (not yet known)). But he failed to realize that plants also require carbon dioxide and oxygen from the air.

\*1699 – An Englishman, John Woodward, used various types of soil to grow plants. He found that the greatest growth occurred in water which contained the most soil. His conclusion: plant growth results from substances in the water derived from the soil, rather than from the water itself. As with Van Helmont, the elements were not yet fully known.

\*1669 to 1808 – European chemists discovered a majority of the elements (except carbon, sulfur, iron and copper, which were discovered in ancient times) including those elements necessary for plant growth.

\*1804 – N.T. de Saussure made the first quantitative measurements of photosynthesis and proposed that plants are composed of chemical elements from soil, water, and air.

\*1851 – The French chemist, Jean Boussingault, verified de Saussure's proposal when he grew plants in insoluble artificial media (sand, quartz and sugar charcoal) plus solutions of known chemical composition. His conclusions: plants require water and obtain hydrogen from it; plant dry matter contains hydrogen plus carbon and oxygen which comes from the air; plants also contain nitrogen and other elements.

\*1860 & 1861 – Two German scientists, Julius von Sachs and another by the name of Knop, used “nutriculture” (today called water culture, a type of hydroponics) to study plant nutrition. Plant roots were immersed in water that contained “salts” of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulfur (S) and calcium (Ca). It was shown that these elements were needed in large amounts by the plant, hence the term “macronutrients”. Both scientists also devised nutrient solution recipes.

\*1860’s – 1940’s – several other scientists studied plant mineral nutrition using water culture (hydroponics) and identified other elements needed by plants in much smaller amounts. These are called “micronutrients” and include iron (Fe), chlorine (Cl), manganese (Mn), boron (B), zinc (Zn), copper (Cu) and molybdenum (Mo).

\*First half of the 20<sup>th</sup> Century: several plant nutrition scientists developed recipes for optimum plant growth: Dennis R. Hoagland (U.C. Berkley, 1919), D.R. Hoagland & Daniel I. Arnon (U.C. Berkley, 1938) “The water-culture method for growing plants without soil” and Robbins (Rutgers U. 1946).

**Dennis R. Hoagland became so well known** for his work in plant nutrient formulas that today it is common to refer to a hydroponic nutrient solution recipe as a  
**“MODIFIED HOAGLAND’S SOLUTION”**

\*1925 - 1935 – The greenhouse industry expressed an interest in using “nutriculture” instead of conventional soil culture because, over time, greenhouse soils would have problems with soil structure, fertility, diseases and pests. Several researchers in the

1930’s began modifying small-scale laboratory techniques for liquid culture (hydroponics) to accommodate large-scale commercial crop production, including...

\*1930’s – W.F. Gericke (U.C. Berkley): introduced “soilless” culture (1929), grew tomato plants in nutriculture and experimented with nutriculture on a large scale for commercial purposes. He coined the term “hydroponics” (1937), from two Greek words: “hydro” meaning “water” and “ponos” meaning “work”. Literally = “water working”.

\*1940’s (WWII) – The United States military used hydroponics to supply the troops stationed on isolated, non-arable islands and coral atolls in the Pacific. After the war the U.S. Army built a 22 hectare hydroponic operation at Chofu, Japan.

\* Late 1940’s – Robert & Alice Withrow, Purdue University, develop a flood & drain hydroponic system.

\*1950’s – Commercial hydroponic operations appeared throughout the world in France, England, Germany, Israel, Italy, Spain, Sweden, the USA and the USSR. However, hydroponics was not yet widely accepted since some of the techniques used incorporated concrete growing beds which were expensive to construct.

\*1960's – There was increased interest in hydroponics in England, The Netherlands and other northern European countries during this time. The nutrient film technique (NFT), which did away with concrete growing beds, was developed in England.

\*1970's – Many operations failed during this time due to gas & oil prices but also due to soil diseases and insect pests.

Soil pathogens can be inadvertently introduced into recirculating hydroponic systems (which were just beginning to be used) and spread to all the plants in the greenhouse. Research in The Netherlands and Scandinavia during the late 70's led to the development of the chemically inert, pathogen free root substrate Rockwool. Other substrates were developed later (RW first used as insulation, 1937, Denmark & Sweden).

Insect pests can multiply quickly in the climate controlled environment of the greenhouse, and there were few chemicals registered for greenhouse pest control. Again, research in The Netherlands led to the development of the beneficial insect industry. Farmers had known about “beneficials”, but these companies learned to grow, package and ship insects, mites and other beneficials to growers for use in their greenhouses.

\*1980's to present – There is a renewed interest in hydroponics.

Greenhouse hydroponics grew in The Netherlands (from 5 ha in 1976 to 4100 ha in 1996), and other parts of the world including the United States, Canada and Mexico.

New hydroponic growing substrates are developed including perlite, vermiculite, peat lite mixes, polyurethane foam, expanded clay, coco coir, sawdust, sand, gravel and various types of volcanic rock.

Recirculating hydroponic systems were developed that included sterilization units (ozone, ultra violet light, etc.) to eliminate the threat of diseases circulating to the plants.

Biological control & integrated pest mng't reduced the use of chemical pesticides.

**THE PRESENT:** Hydroponics and CEA are now used by many people and groups:

**\*Researchers –**

Certain experiments require specific root zone environments:

Mineral nutrition: can vary one nutrient at a time and note the symptoms.

Salt stress: can study the reactions to varying amounts of salt.

Heavy metal contamination: can study responses and also screen for tolerant species for re-vegetation of old mining sites.

Variations in root temperature: Ex – if the roots of lettuce (a cold weather crop) are chilled, the heads do not “bolt” (go to flower) as when grown in warm temperatures (chilling increases oxygen in the water!).

Effects of different types of lighting, including LED's

Testing new varieties of various crops, including tomatoes, with disease resistance or environmental adaptability.

Studying greenhouse designs that incorporate new sustainable technologies.

**\*Commercial Growers** – vegetables, flowers, houseplants and medicinals.

Examples of vegetable growers, hydroponic/CEA: SW USA - high light states:

Nature Sweet, Willcox, AZ – 265 acres/various tomatoes

Nature Sweet, Snowflake, AZ – 44 acres/tomatoes

Originally EuroFresh; aquired by Nature Sweet, San Antonio TX,  
in 2013; original facilities in Mexico – grape & cherry tomatoes

Willcox Greenhouse, Willcox, AZ – 8 acres/tomatoes

Sunizona, Willcox, AZ – over 2 acres/tomatoes, greens (certified organic)

Also hoop houses, raised beds and field crops

Wholesum Harvest, Amado AZ – 12 acres / organic cherry & TOV

Village Farms, 5 sites in TX – 232 acres/tomatoes, cucumbers, peppers

Houweling Nurseries, Camarillo CA – 125 acres/tomatoes and cucumbers

Grimmway Farms, Tehachapi CA – 10 acres/organic tomatoes

Flowers/Houseplants: Use greenhouses, shade structures or other protected ag

Commercial facilities are also prominent in

“lower winter light” countries such as Belgium, England, Canada and The  
Netherlands – many have switched to flowers.

“higher winter light” countries such as Spain, France, Turkey, Israel and  
Mexico (growing quickly) – largely fruit/vegetable production.

Commercial facilities have also been constructed in desert areas and/or near  
oceans where sea water is used for cooling and is desalinated and used for  
irrigation (Examples: Mexico and the Middle East).

\* **“Local/Urban/Metropolitan” Agriculture** – Is inner city or roof top farming in the  
soil or CEA/hydroponics for personal, community or commercial purposes. This type of  
production is growing in such urban areas as the Bronx NY (see Gotham Greens), Seattle  
WA, Los Angeles & San Francisco CA. Several groups are revitalizing Detroit MI with  
urban agriculture (i.e., MI Urban Farming Initiative). People are concerned about where  
their food comes from and how it’s grown (pesticides, etc.). Also, much of the increase  
in food prices comes from transportation costs – food now travels an average of 1500  
miles from farm to fork! CEA/hydroponics can be set up anywhere (in or close to cities,  
cutting transportation costs), uses little, if any, pesticides and because access to  
greenhouses can be monitored/controlled, food safety and security is enhanced.

\***Teachers** – used as a teaching tool. Systems can include small desk-top units, outdoor  
units, or scaled-down commercial style units in greenhouses.

Subjects that can be covered during a study of greenhouse hydroponics include

\*plant production, care, nutrition, seeding and transplanting

\*chemistry and math and the calculation of nutrient recipes

\*engineering (greenhouse and system construction and structures)

\*computers (sensors, heating and cooling systems, irrigation controllers)

\*marketing, business skills and economics (school store to sell produce!)

\*writing and oral communication skills

\***Hobbyists** – home gardeners can provide healthy, tasty produce for personal use. Many types of systems, home-made and commercial, are available to suit any location or crop.

\***Horticultural Therapy** – for use in nursing homes or other situations where patients may not be able to work in a “traditional” garden but where gardening is suggested to exercise mental and physical faculties. For example, the elderly who may no longer be able to easily work in a soil garden or patients in wheel chairs can easily access their hydroponic systems with lettuce, herbs, or tomatoes which can be placed on tables or on a concrete floor.

\***Hydroponics at the South Pole** – One unusual adaptation of this is the use of hydroponic systems for the growing of tomatoes, lettuce, strawberries, etc., at the scientific research stations in Antarctica. Well lit “growth chambers” have been constructed at several Antarctic stations that provided not only fresh fruits and vegetables, but also a place for workers to experience humidity, green and the smells of growing things: a needed mental break in the most bleak and driest desert on Earth.

#### **NOW & INTO THE FUTURE:**

Besides the typical groups and uses listed above, hydroponics is also being used in some rather interesting and unusual places and has the potential for growth in many others:

\*The military – Highly specialized cultural systems are being used in atomic submarines that can provide vegetables for the crew.

\*NASA/space program – NASA has been working with hydroponics for years for use on long duration space missions and on non-terrestrial bases.

\*Low-tech hydroponic systems can be used in developing countries to provide intensive food production using limited acreage and resources.

\*Hydroponic systems and facilities can be used in small countries where the main industry is tourism. Example: The Cuisinart Resort & Spa on the Caribbean island of Anguilla for the production of fruits, vegetables & herbs.

\*Hydroponic facilities can be located anywhere – on an island, a ship, a space station, an offshore oil rig or on non-arable or isolated land such as Antarctica.

Examples: UA/CEAC food growth chamber at the South Pole;  
UA/CEAC Lunar Greenhouse Demonstration Unit.

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