Introduction to Controlled Environment Agriculture and Hydroponics

by

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CHAPTER 1

CONTROLLED ENVIRONMENT AGRICULTURE AND HYDROPONICS: PAST, PRESENT AND FUTURE

CONTROLLED ENVIRONMENT AGRICULTURE =
Also "Protected Agriculture".
Control of both the root zone and aerial environmental factors (temperature, humidity, gas composition including carbon dioxide around the leaves for photosynthesis and oxygen around roots and shoots for respiration, light, water, growing medium, and mineral nutrition)
usually in a greenhouse or totally enclosed structure.

HYDROPONICS = A technology for growing plants (without soil)
using a complete nutrient solution (water + mineral nutrients)
with or without the use of an aggregate medium (e.g., sand, gravel, perlite, rockwool, etc.) to provide mechanical support for the roots.

THE PAST:

*Several hundred years B.C. – The Babylonians had hanging water culture gardens considered one of the seven wonders of the ancient world.

*Several hundred years B.C. – Egyptian hieroglyphs tell of the people growing plants in water culture.

*Theophrastus (372-287 B.C.) – A Greek philosopher, performed experiments in crop nutrition.

*During the 1st century A.D. – cucumbers were grown off-season for the Roman Emperor Tiberius using a "transparent rock" (presumably mica) covered structure (first known use of Controlled Environment Agriculture (CEA)).

*1200's and 1300's (as described by the Venetian traveler, Marco Polo) - Floating gardens of the Chinese.

*1400's – The Aztecs, who settled near Lake Tenochititlan (near the site of present day Mexico City), created gardens on floating rafts called "chinampas".

NOTE: During the past 400 years plant culture techniques were developed to study the mineral nutrition requirements of plants. These techniques, known as "water culture", were the beginnings of what later became "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.

*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.

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

*1851 – The French chemist, Jean Boussingault, verified de Saussure's proposal when he grew plants in insoluble artificial media such as 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 contain nitrogen and other mineral nutrients.

*1860 & 1861 – Two German scientists, Julius von Sachs and another by the name of Knop, used "nutriculture". Today this is called water culture, a type of hydroponics. The 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 minerals were needed in large amounts by the plant, hence the term "macronutrients". Both scientists devised nutrient solution recipes.

NOTE:
*From the 1860's to the 1940's several other scientists studied plant mineral nutrition using water culture and identified other minerals 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).

*During this time several plant nutrition scientists also developed nutrient recipes for optimum plant growth, including Hoagland (U.C. Berkley, 1919), Hoagland and Arnon (U.C. Berkley, 1938 – "The water-culture method for growing plants without soil") and Robbins (Rutgers U. 1946). D.R. Hoagland became so well known for his work in plant nutrient formulas that today it is common to refer to a 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 and pests. Small-scale laboratory techniques were modified to accommodate large-scale commercial crop production.

1930’s – W.F. Gericke (U.C. Berkley) experimented with nutriculture on a large scale and coined the term “hydroponics”, which is derived 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 in the Pacific. After the war the U.S. Army built a 22 hectare hydroponic operation at Chofu, Japan.

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

1970’s – With the advent of plastics an interest in hydroponics was renewed. Plastics began to be used as greenhouse covers, growing bed liners and in irrigation systems. However, two new problems arose: Escalating oil prices in 1973 substantially increased heating and cooling costs AND there were few chemicals registered for pest control in greenhouses. Increases in root pathogens (which when inadvertently introduced into a recirculating hydroponic system could spread to all the plants in the greenhouse), and an increase in aerial pests (which found a perfect environment to multiply in the climate controlled greenhouses) caused many operations to fail.

1990 – There is a renewed interest in hydroponics.

THE PRESENT:

Hydroponics is now used by researchers, commercial growers, teachers, hobbyists and horticultural therapists to name just a few.

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 revegetation 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) when grown in warm temperatures.

Commercial Growers – Large-scale production of vegetable and flower crops, house plants and medicinals for sale.

In Arizona and surrounding "high light" states vegetable growers include:
- Bonita Nurseries, Willcox, AZ – 120 acres/tomatoes
- Suntastic, Snowflake, AZ – 20 acres/tomatoes
- Sunco, Ltd., North Las Vegas, NV – 12 acres/tomatoes
- Willcox Greenhouse, Willcox, AZ – 8 acres/tomatoes
- Sunizona, Willcox, AZ – 2 acres/cucumbers

Commercial facilities are also prominent in
- "lower winter light" countries such as Holland, Belgium, England and Canada (total about 500 ha – NOTE 2.5 acres/hectare)
- "higher winter light" countries such as Spain, Southern France, Israel and Mexico (total about 600 ha)

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).

Teachers – for use in schools 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 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
*writing and oral communication skills

Hobbyists – for use by home gardeners to provide healthy, tasty produce for personal consumption. A variety of unit styles (home-made and commercially produced) 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 gardens of 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 systems made of leftover PVC pipe for the growing of tomatoes, lettuce, strawberries and other fruits and vegetables at the scientific research station in McMurdo, Antarctica. A well lit "growth chamber" was constructed that provided more than fresh fruits and vegetable. It also provided a place for researchers to go to experience humidity, green and the smells of growing things: a needed mental break in the most bleak and driest desert on Earth. (A hammock was even hung amongst the plants!)

THE FUTURE:

Besides the groups and uses listed above, hydroponics has the potential for uses in:

- *The military – Highly specialized culture in atomic submarines 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.
- *Hydroponic systems and facilities could be used in small countries where the main industry is tourism. Hydroponic facilities can be located on non-arable land to feed both the indigenous population and the tourists.

LEADING GREENHOUSE TOMATO STATES IN THE U.S.A. (hectares):

Arizona	59.2	Tennessee	8.0
Texas	43.2	New Mexico	8.0
Colorado	37.6	Mississippi	6.8
California	20.0	New Jersey	6.0
Virginia	17.2	Florida	4.8
Pennsylvania	16.0	Nevada	4.8
New York	14.0	North Carolina	4.0
Ohio	8.0		

Total = 257.6 hectares

(NOTE: 2.5 acres = 1 hectare)

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CHAPTER 2

THE PLANT

INTRODUCTION

*Not all crops are appropriate for HYDROPONICS or CONTROLLED ENVIRONMENT AGRICULTURE (CEA). The reason: ECONOMICS

*Both hydroponics and CEA (e.g., shade and greenhouses, etc.) cost money. Therefore, the crops chosen must yield a high enough monetary return to justify the expense.

*In North America the typical crops that are grown using hydroponics include:
- TOMATOES (mainly beefsteaks and TOV's – tomatoes on the vine)
- COLORED BELL PEPPERS (mainly yellows or goldens, also oranges, reds)
- LONG CUCUMBERS (also known as English, European, Seedless or Burpless)
- LETTUCE (several crops can be grown per year in hydroponics/CEA)
- SPECIALTY SALAD GREENS
- MEDICINALS (especially root crops grown using "aeroponics" where the roots can be harvested without destroying the whole plant – mainly in research)

*Other crops that are grown using some form of CEA or protected agriculture include:
- FOLIAGE PLANTS (usually require shade and humidity – as in the jungles from which they come)
- FLORAL CROPS (including cut flowers, i.e., mums or carnations, and potted plants i.e., roses, etc.)
- CERTAIN "ROW" CROPS (can be planted outside in colder climates using plastic tunnels (row covers) for protection against the cold)

*This chapter will concentrate on tomatoes with brief discussions of other crops (mainly vegetables) grown in hydroponics.

SOME BASIC PLANT ANATOMY

*Flowering plants are composed of TWO MAJOR SYSTEMS: SHOOTS AND ROOTS.
*THE SHOOTS:
- *Grow up in response to gravity AND will grow toward a light source.
- *Bear the leaves, flowers and fruit.
- *The leaves usually contain pigments and are the sites of photosynthesis.
- *The leaves also contain stomata, pores in the leaf through which water exits and through which gas exchange occurs (carbon dioxide in and oxygen out).
- *Leaves attach to the stem = NODE; the stem in between nodes = INTERNODE
- *Flowers or clusters of flowers are usually produced at regular intervals.

*THE ROOTS:

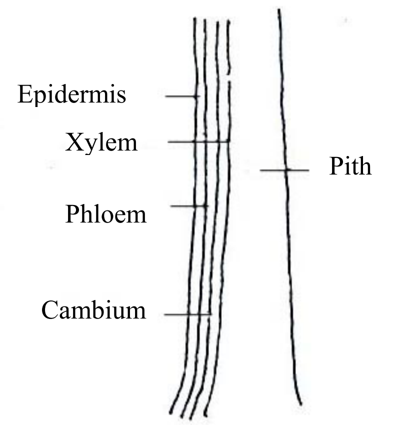
*Grow down in response to gravity.
*Act to ANCHOR the plant in the growing medium.
*Absorb water, mineral nutrients and oxygen.
*Classified as tap or fibrous. Submerged roots may not develop root hairs.
*Storage organs (carbohydrates, etc.); site of synthesis alkaloids, hormones, etc.)

*SHOOTS AND ROOTS: CONNECTED BY VASCULAR TISSUE

The XYLEM carries water and mineral nutrients from the roots to the leaves, flowers and fruits.

The PHLOEM mainly carries photosynthates, the products of photosynthesis, from the leaves (the "source" of photosynthesis) to various "sinks" (apical meristem, fruit, roots, etc.)

The CAMBIUM separates the xylem and phloem. It is the growing layer that produces new xylem to the inside and new phloem to the outside of the stem.



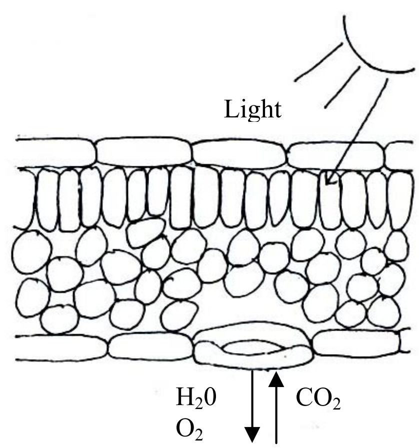
*THE LEAVES: THE PRIMARY SITE OF PHOTOSYNTHESIS (though any green tissue is usually photosynthetic).

A typical leaf is covered on both sides by the EPIDERMIS. The epidermis is covered by a waxy CUTICLE.

Interior to the epidermis on the upper side are the PALISADE PARENCHYMA cells. These are where photosynthesis takes place.

Interior to the epidermis on the lower side are the SPONGY MESOPHYLL cells. These create an air space for gas exchange.

Mainly on the lower leaf surface are pairs of cells, called GUARD CELLS, that form openings, STOMATA, through which gas exchange takes place.



SOME BASIC PLANT PHYSIOLOGY

*WATER MOVEMENT (TRANSLOCATION) THROUGH THE PLANT:

*Water is crucial and used in almost every metabolic process. Plants use water to move mineral nutrients up from the soil, and to move the products of photosynthesis from the leaves (SOURCE) to the fruit, roots, etc. (SINKS)

*Water translocation into and through plants is believed to be passive – requiring no metabolic energy.

*BULK FLOW: Movement of water due to an external force (gravity, pressure)
Ex: Water movement upward through the xylem due to "root pressure".

*DIFFUSION: Movement of molecules from high to low concentration.
Ex: Movement of perfume molecules from an open bottle outward.
Ex: Movement of water molecules out of the stomates (transpiration).

*OSMOSIS: Movement of water molecules through a semi-permeable membrane from high to low concentration.

Ex: Plants maintain high salt levels in the cells of their roots that make the relative concentration of water lower inside and therefore water tends to move IN from high (outside) to low (inside) concentration.

Problem: If too many salts are added to the solution around the roots, the resulting lowered concentration of water outside will tend to draw the water out of the roots, which will lead to wilting and ultimate death of the plant. Therefore, it is imperative to have the proper concentrations of nutrients in the nutrient solution (see Chapter 8).

*NOTE: Just inside the outer most cell layers of the root is a specialized layer of cells, the ENDODERMIS. The radial and transverse walls of these cells are impregnated with hydrophobic suberin (Casparian band) which does not allow water (and the mineral nutrients or other solutes dissolved in it) to pass freely. At this point the water (and solutes) must pass through the membranes and protoplast of the endodermal cells. Water will move via osmosis according to concentration gradients. The solutes (including mineral nutrients) can move passively according to concentration gradients via simple diffusion or by facilitated diffusion (requires channel or carrier proteins) or they can be moved actively through carriers which require metabolic energy => active transport.

*TRANSPIRATION: The evaporation of water from plants primarily through the stomata (but also through the cuticle or structures usually in woody plant bark called lenticels). Transpiration occurs via the passive process of DIFFUSION.

*Transpiration is used to move water through the plant but also used to cool the plant: As water evaporates off the leaf surface (liquid to gas) the water gains energy (heats up) and the leaf surface looses energy (cools down).

*Plants are 80-95% water and can transpire up to 98% of the water they absorb.

*PHOTOSYNTHESIS: From the Greek = to synthesize using light.

*Plants contain PIGMENTS that trap light energy – The LIGHT REACTIONS.

CHLOROPHYLLS are the primary pigments (CHL a and CHL b). They are found in the CHLOROPLASTS (organelles in the palisade parenchyma cells). They absorb blue and red light and reflect green and yellow light.

CAROTENOIDS are accessory pigments. They absorb violet and blue light and reflect green, yellow orange and red light. There are two kinds:

CAROTENES are pure "hydrocarbons".

XANTHOPHYLLS contain oxygen.

*These pigments all reflect green, which is what gives the plant its green color.

*The energy absorbed from light is used to drive The DARK REACTIONS.

CARBON DIOXIDE moves from the air into the plant through the stomata and into the chloroplasts within the palisade parenchyma cells.

Energy from light absorption is used to FIX CARBON DIOXIDE into SUGARS.

WATER is required for the reaction. The splitting of water yields OXYGEN.
OXYGEN is then released from the plant through the stomata.
The SUGARS produced are used to produce all of the other molecules needed for life (simple and complex carbohydrates, proteins and fats).

*THE OVERALL REACTION - PHOTOSYNTHESIS:

$$6CO_2 \quad + \quad 6\,H_2O \quad + \quad \text{Light} \quad \rightarrow \quad C_6H_{12}O_6 \quad + \quad 6O_2$$

(carbon dioxide) (water) (sugars) (oxygen)

*RESPIRATION: A set of oxidation-reduction reactions producing energy.
Carbon containing COMPOUNDS are OXIDIZED to CARBON DIOXIDE.
Compounds available to be oxidized include starch, fructans, sucrose or other sugars, fats, organic acids, and even proteins.
OXYGEN (absorbed through the stomata) is REDUCED to form WATER.
NOTE: Oxygen also needs to be absorbed into the roots for respiration.

*THE OVERALL REACTION – RESPIRATION (specific for the sugar glucose):

$$C_6H_{12}O_6 \quad + \quad 6\,O_2 \quad \rightarrow \quad 6\,CO_2 \quad + \quad 6\,H_2O \quad + \quad \text{Energy}$$

(glucose) (oxygen) (carbon dioxide) (water)

TOMATOES

*The classification system devised by the Swedish botanist Carolus Linnaeus (1707-78):
Kingdom Division Class Order Family Genus Species

*Current taxonomic research, based on genetic markers instead of subjective evaluation of morphological traits, is leading to a major restructuring of long established classifications. Suffice it to say…

*Tomatoes belong to the
FAMILY = SOLANACEAE
This family also includes peppers, potatoes, eggplant, tobacco, belladonna (deadly nightshade), datura (jimson weed), mandrake (a medicinal) and petunias.

GENUS = LYCOPERSICON
This genus is thought to have originated in the coastal strip of western South America which includes the countries of Ecuador, Peru and the northern portion of Chile.

SPECIES = ESCULENTUM (written: *Lycopersicon esculentum*)

This species contains plants with large fruit that grow wild or in cultivation as annuals (usually live only one year) or perennials (usually live two or more years).

VARIETY = several including Trust, Quest, Blitz, Rapsodie, Mariachi, etc.

*Cultivated tomatoes are divided into two types based on growth habit:

INDETERMINANT (typically used in greenhouse cultivation)

Vining types with an apical (top) meristem (growing point) that continues to produce a main stem, leaves and flower clusters.

Normally trained to a single stem (side shoots or suckers removed).

These plants are usually suspended from high wires in the greenhouse better utilizing the vertical space that the grower has paid for by building the greenhouse.

Theoretically, all indeterminant plants are perennials.

DETERMINANT (typically used in field cultivation)

Bush types where the plant terminates in a flower cluster.

The side shoots (or suckers) of these plants are left on.

Theoretically, all determinant plants are annuals or may be grown as annuals.

*Start with the seed:

*The oldest way to improve tomatoes is to save the seeds from plants with desirable traits. Varieties with desirable traits, that have been maintained from generation to generation, are called “HEIRLOOM” varieties.

A grower can plant these seeds, grow the plants, harvest the tomatoes and use the seeds found in these fruits to plant a new crop, with the same traits, the next year.

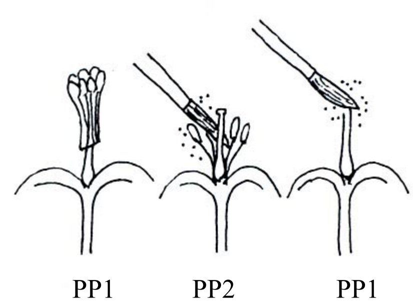
*In recent years breeding techniques have been employed to create “F_1 Hybrids”.

The male parts (ANTHERS) from parent plant one are removed leaving the female parts.

Pollen from parent plant two is transferred to the female portion (STIGMA) of parent plant one.

The flower on parent plant one, now pollinated, will develop into a fruit which will contain the F_1 seeds.

These seeds are collected, dried, packaged and sold to the growers.



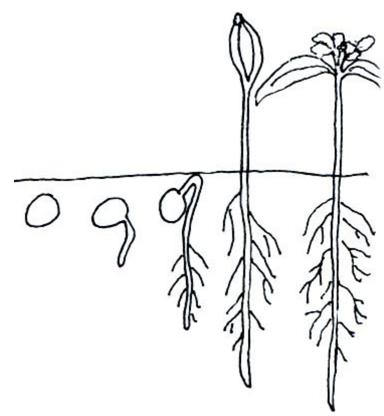
A grower will then plant these seeds, grow the plants and harvest the fruits from these plants. If seeds from these fruits are planted they WILL NOT produce the same type of plant as was obtained from the initial cross.

*Another recent, but more controversial, technique = GENETIC ENGINEERING
Genetic material from one plant, organism, etc., is transferred to another plant, organism, etc. in order to confer a specific trait or characteristic. Examples include:

1) Conferring long shelf life to tomato fruit.
2) Conferring insect resistance to field crops such as corn, cotton and potatoes by introducing the gene for an insect toxin found in the bacteria Bacillus thuringiensis.
3) Conferring herbicide (Round Up, 2-4-D, etc.) resistance to field crops such as soybeans, corn or wheat. This allows the field to be planted and then, when the protected crop emerges, along with the unprotected and unwanted weeds, the herbicide will kill the weeds but not the crop.

NOTE: The seed is a little more expensive. However, time dealing with the crop and overhead expenses are reduced (the farmer does not have to spend time or fuel cultivating or weeding).

*Tomato seed germination:



*Seeds = 3-5 mm (millimeters), good viability (90% germination after 10 years when stored cool & dry).
*The small white root (RADICLE) emerges and pushes down (due to gravity) into the growing media.
*The initial stem (HYPOCOTYL) emerges and grows upward (toward the light) in a whitish hook-like form (PLUMULAR HOOK).
*When the plumular hook reaches the media surface (and light) it straightens and turns green.
*The first seed leaves (COTYLEDONS) are pulled out of the seed coat (TESTA), expand and turn green.

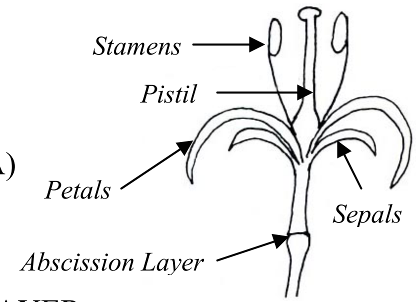
*The tomato plant:

*ROOT SYSTEM = A well-defined TAP ROOT with lateral fibrous roots.
NOTE: Tomatoes readily form ADVENTITIOUS ROOTS = aerial roots on the stem.

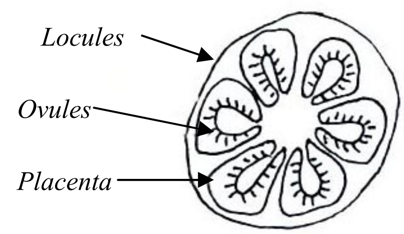
*SHOOT SYSTEM =
Above the two cotyledons (which are opposite on the stem), appear the first TRUE LEAVES (alternate along the stem).
The true leaves are classified as COMPOUND.
After the first 7-12 leaves the stem forms a FLOWER CLUSTER.
Thereafter, there are 2-4 leaves between flower clusters.
Side shoots (SUCKERS) can grow from the axils of each leaf.
These are usually removed (pruned) to maintain a single stem.

*FLOWER = COMPLETE, with both male (STAMENS) and female (PISTIL).
Typically it contains
5 green SEPALS
5 yellow PETALS
A ring of STAMENS (made up of a FILAMENT
and ANTHERS (contain the POLLEN)
A PISTIL (made up of the OVARY, STYLE and STIGMA)

One to many flowers are borne on the stem of the TRUSS
or PEDUNCLE.
Each flower is attached to the truss by an ABSCISSION LAYER.
If the plant is stressed, excess flowers may be aborted at this point.



*FRUIT = The tomato fruit is classified as a BERRY.
The first fruit on a cluster is the KING FRUIT.
It contains two or more LOCULES (chambers)
with fertilized OVULES (the seeds)
which are embedded in a gelatin placenta.



OTHER CROPS GROWN USING CEA AND/OR HYDROPONICS:

1. PEPPERS

*A member of the Solanaceae family (like tomatoes).
*Scientific name: *Capsicum annuum*.
*"Capsicum" comes from the Greek "kapto" meaning "to bite" referring to the pungency of many of the varieties (especially small fruited varieties).
*This species originates in South America.
*This species includes most of the commonly grown pepper varieties including sweet or red peppers, chilies and bells (greens, reds, oranges, yellows).
*NOTE: The Tabasco pepper from Mexico is a separate species: *C. frutescens.*
*Seed germination is similar to that of tomato (but with a shorter shelf life).
*The plant grows as a single stem producing perhaps 7 leaves. Then it branches.
*At the first branch point 1-2 flowers are produced. First fruit = CROWN FRUIT.
These should be removed to promote stronger fruit set higher on the plant.
*The plant is trained to 2 or 3 stems and supported with vine twine to the wires.
*At each node the stem branches and, if the plant is vigorous, forms a flower.
*Flowers are complete with white petals.
*Depending on light, plant vigor, temperature, fruit load, etc., every other flower may be removed to maintain proper set/development of remaining fruit.
*Fruit takes about 6 weeks to reach the mature size (the skin is glossy – "MATURE GREEN").
Colored peppers (yellows, oranges and reds) will require another 3-6 weeks to turn color.
*Peppers prefer warmer temperatures than tomatoes.
*Yellow peppers, in particular, require shading, especially in summer.

2. CUCUMBERS

*A member of the Cucurbitaceae family which also includes melons, squashes and loofah gourd.

*Scientific name: *Cucumis sativus*.

*This species most likely originated in India or Burma. It has been cultivated for 3000 years.

*Seeds are large (1 cm long) and remain viable for about 4 years. If sealed in air-tight containers with carbon dioxide, viability can be extended for several years.

*The main stem grows like a vine, with laterals and tendrils.

If the plant is trained to a single stem, the laterals are removed.

If the plant is trained to an "umbrella", laterals are removed until the apical meristem reaches the support wire. The meristem is then removed and two laterals are allowed to grow out and down.

NOTE: There are several methods of training cucumber plants including single stem, "umbrella", "Vertical-Cordon" and "Guernsey Arch" .

*At each successive node a flower is usually formed.

*Up to a height of 80-100 cm (2.6-3.3 feet) the flowers/fruit are removed to reduce plant stress and encourage full root development.

*Cucumbers are fast growers – up to 15 cm (about 6 inches) per day.

*Cucumber plants prefer warmer temperatures than most tomatoes.

*The cucumber flower can display several "sex types":

PERFECT (bisexual or hermaphroditic): A flower with both male (stamens) and female (pistil) organs (but may not have the green sepals or colored petals).

MALE (STAMINATE): A flower lacking a pistil.

FEMALE (PISTILATE): A flower lacking the stamens.

*The cucumber plant itself can display several "sex types":

MONOECIOUS: A plant with both male and female flowers.

DIOECIOUS: Male flowers on one plant and female flowers on another.

ANDROECIOUS: A plant with only male flowers.

ANDROMONOECIOUS: A plant with some perfect and some male flowers.

GYNOECIOUS: A plant with only female flowers.

GYNOMONOECIOUS: A plant with some perfect and some female flowers.

PREDOMINANTLY FEMALE: A plant with mostly female but also some male flowers.

PARTHENOCARPY: Reproduction without fertilization –
In cucumbers it is the production of seedless fruit without pollination.

NOTE: Most greenhouse varieties are usually GYNOECIOUS or, rarely, PREDOMINANTLY FEMALE.

*The cucumber fruit is considered a false berry or "PEPO".
It varies in size, shape and color depending on cultivar.
The young fruit is covered with "hairs", as is the rest of the plant.
These hairs may get stuck on another part of the plant and cause "CROOKING" (bending) of the fruit – these should be removed.
Greenhouse varieties have smooth, thin-skinned fruit. These tend to loose moisture quickly after picking and must be wrapped in plastic.
The skin is not bitter (as in field cucumbers) and need not be peeled.
Greenhouse varieties are long and thin – 25 to 50 cm.
Greenhouse varieties are now called "LONG CUCUMBERS" but have also been called "European Cucumbers", "English Cucumbers", "Seedless Cucumbers" or "Burpless Cucumbers".

3. LETTUCE

*A member of the Asteraceae (Compositae) family which also contains sunflower, purple coneflower (Echinacea), guayule, zinnia, marigold, flea bane, yarrow, chrysanthemum, edelweiss, gazania, burdock, artichoke, Transvaal daisy and dandelion.
*Scientific name: *Lactuca sativa*.
*This species probably originated in Europe and Asia. It was first cultivated 2500 years ago and was used for food and as a medicinal.
*Lettuce seeds are small, ~1000 seeds/gram. Good viability if kept refrigerated.
*The lettuce plant is an annual with milky sap and alternate leaves on a short stem that forms a rosette.
*Though lettuce is usually not "high cash value", a hydroponic/CEA grower can produce many crops per year as opposed to 1or 2 crops in the field.
*Depending on the variety the leaves can be green or colored, smooth or ruffled, glossy or dull.
*Several types of lettuce are grown: NOTE: If you look at 10 different seed catalogs you get 10 different ways to categorize lettuce!

HEAD:
- "CRISPHEAD" – Leaves well wrapped; firm head; crispy texture. Iceberg, Great Lakes, Ithaca, Mesa, Mission
- "BUTTERHEAD" – Outer leaves are loose; heart leaves are wrapped; and not crispy: Buttercrunch, Bibb, Boston

LEAF: Great for home hydroponics. Leaves can be harvested singly. Leaves can be green or red, variable texture and usually higher in nutrients than Iceberg: Blackseeded Simpson, Grand Rapids, Oakleaf, Red Sails, Salad Bowl, Ibis.

COS (or Romaine): Taller than all others (8-10"); upright outer leaves with inner head: Parris Island Cos, Olga, Green Towers, Little Gem (dwarf: 5-6")

*Lettuce prefers cooler temperatures than tomatoes and is suitable for winter growing in Arizona.
*High temperatures cause TIPBURN, BITTERNESS and BOLTING.

4. SPECIALTY GREENS

*A mix of many kinds of young, tender leaves but can also contain flowers

*Started in and around Nice in southern France as MESCLUN (French for "mix") and includes tender early sprouts of arugula, dandelion greens, lettuces, watercress and chervil.

*Most mixes today combine 8-16 different kinds of leaves and/or flowers.

Lettuces: sweet, mild, tender and crunchy:

Butterheads like Bibb or Perella Red

Loose leaf reds and greens like Lollo Rosso, Oakleaf and Tango

Romaines like Little Gem (a dwarf)

"Greens" add spicy flavors, firmer textures and various colors and shapes:

Arugula, dandelion greens, frisee (fine curly endive), Belgian endive (inner leaves), Swiss chard, kale (red and green), mizuna, radicchio, red mustard, shiso, totsoi, watercress (anchocress, upland broadleaf cress, curled cress), purslane and chervil (as a green and an herb with a cool licorice flavor).

Flowers: the entire flower or petals may be added for color and flavor:

Bachelor's buttons, calendulas, nasturtiums (and their leaves), marigolds, borage, lavender, pansies and violas

*Can be grown in CEA/Hydroponics, however, thousands of "soil" acres are now in production. Some growers have farms in coastal areas for Spring and Summer growing and farms in the deserts of California and Arizona for Fall and Winter growing.

5. HERBS

*All herbs may be grown in hydroponics and are a favorite of home gardeners including anise, basil, borage, caraway, catnip, chervil, chives, coriander, chamomile, dandelion, dill, fennel, marjoram, oregano, lavender, peppermint, rosemary, rue, sage, spearmint, savory and thyme.

*Commercial production:

Most herbs are grown in soil, though some growers are doing "organic".

BASIL is one herb that has been grown widely in hydroponics.

MINTS are grown on a much smaller scale in hydroponics.

GINGER is being grown in Hawaii using sand culture hydroponics.

The roots retain a lighter color and are favored over the darker roots obtained when grown in soil.

MITSUBA is grown in Japan in hydroponics. It has a distinctive aromatic flavor like celery or parsley. Used in soups or eaten raw in salads.

*Herbs are perfect for the classroom.

Each student can have their own plant.

Plants grow quickly in hydroponics - the life cycle may be observed in one semester.

Plants may be sold fresh or dried to raise money for school activities.

6. MEDICINALS

*Plants with medicinal value have been harvested from the wild for thousands of years by herbalists and village shamans.

NOTE: Archeologists have noted that some medicinals have been harvested to extinction. Example: A plant in Roman times that was highly sought after as a means of birth control.

NOTE: The root medicinal, Goldenseal, was almost harvested to extinction in the wild and may now, by law, only be harvested from cultivated stands for medicinal use.

*Herbalists and shamans , through trial and error, have learned that medicinals have their highest potency when harvested from certain soils or locations, during specific times of the year, or in association with specific environmental conditions. Researchers are now studying these practices to define optimum conditions for growing medicinals.

*With hydroponics and CEA we can control these factors and provide an optimum environment. Example: The root medicinal Echinacea usually takes 2-3 years to grow in soil. However, it only takes 9 months in the greenhouse using aeroponics (see below for definition).

*Root medicinals are of particular interest. The roots could be grown using AEROPONICS where the roots hang down into an enclosed box and are sprayed with a complete nutrient solution. A portion of the roots could be harvested on a regular basis without destruction of the plant itself (as is the case with soil grown plants).

*Aeroponics for root medicinals offers several advantages over soil culture:

- The plants have faster growth rates (as mentioned above for Echinacea).
- The roots are easily accessible and can be sampled whenever needed.
- The roots are "unadulterated", i.e., they are pure medicinal crop roots without weed species roots being mixed in as found in soil crops.
- They can be grown in higher densities than in the soil.

*Root medicinals with potential for use in hydroponics/aeroponics (note the sale price per pound) include:

BURDOCK – used as a blood purifier (from USA: $18.55/lb)
VALERIAN – a sedative in sleeping disorders (from Hungary: $27.95/lb)
ECHINACEA – immune enhancer (Cert. Organic from USA: $116.05/lb)
GOLDENSEAL – rhizome; dries out mucous membranes/colds ($230/lb)
GINSENG – an overall tonic (6yr old root from China: $224.05/lb)
BLACK COHOSH – a menopausal herb that evens out hot flashes, etc.
(Information provided by Dr. Anita Hayden, Native American Botanics.)

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CHAPTER 3

GENERAL CULTURAL PRACTICES

INTRODUCTION

*General cultural practices include all information, techniques and skills required to successfully produce a crop and optimize yields – the main goal of any grower!

*This chapter will concentrate on tomatoes with reference to other crops to illustrate the variability in cultural practices between crops.

CROP AND CULTIVAR SELECTION

*This is one of the most important decisions a grower will make and depends on:
MARKET… LOCATION… EXPERIENCE

MARKET:**

*Research the region. Know if there are other growers in the area = competition. If there are too many tomato growers… try cucumbers, peppers, basil, etc.

*Know the market. Brokerage houses, grocery vs specialty stores, farmer's markets, restaurants, etc.

*Hydroponics/greenhouse culture is expensive. Therefore, a high cash-value crop must be chosen. These include:

Tomatoes: Indeterminant (vining) varieties to take advantage of the vertical space in the greenhouse that has been paid for!
- **Beefsteak:** large fruit, harvested individually.
  Ex: Trust, Blitz, Quest, Rapsodie, Mariachi.
- **Cluster, truss or TOV (tomato on the vine):** medium to large fruit, harvested as an entire truss.
  Ex: Tradiro, Balance, Cronos.
- **Cherry:** small fruit, harvested individually or as an entire truss.
  Ex: Micro-Tom, Favorita, Conchita.

Peppers: Colored bells only, primarily yellows – require sun protection.
Ex: Kelvin, Samanta, Cubico, Paramo, TriStar.

Cucumbers: Long (European, seedless, parthenocarpic, burpless).
They are thin-skinned and must be wrapped in plastic after harvest.
Ex: Corona, Discover, Marillo, Millagon, Thor, Odin.

Lettuce: Head, leaf or cos; specialty or bred for hydroponics/CEA.
Ex: Ostinata, Salina, Grand Rapids, Oakleaf, Tango, Summer Bibb or "Limestone" lettuce.

Specialty Greens, Herbs and Medicinals: Several types and varieties.

NOTE: Consult seed companies for suitable crops/varieties.

LOCATION:

*The selection of a crop will dictate the best location for the operation… and visa versa.

Example: If a grower chooses tomatoes in Arizona, the optimum elevation is between 4,000 and 5,000 feet. Any lower and it is usually too hot to grow in the Summers. Any higher and it is too cold to grow in the Winters…UNLESS SIGNIFICANT EXPENSE ($$) IS PUT TOWARD COOLING OR HEATING!

Example: If a grower has land at about 2500 feet in elevation in Arizona, a crop that can tolerate warmer temperatures than tomatoes, such as cucumbers could be selected… Or grow different crops in Summer and Winter.

*The selection of a "cultivar" or "variety" is also important when choosing a location.

Seed companies are always coming out with new cultivars (or varieties) to suit different climates and tastes.

With the move of many growing operations to higher light regions of the world … remember photosynthesis… (Southwest USA, Mexico, Spain, Israel) AND the demand for good quality, good tasting tomatoes year around, many seed companies are introducing more HEAT TOLERANT varieties.

The first tomato variety used by Bonita Nurseries (Eurofresh) in Willcox, AZ about 10 years ago was "MATCH", then they went to "TRUST".

TRUST: a Dutch variety (DeRuiter Seed); optimum day temperature = 72 F. The first 10 acres (and next 30) of greenhouses were passively cooled (no fan and pad/evaporative cooling). They were not able to grow in the Summer and therefore started with transplants (1 month old seedlings started in Canada) in August and removed the crop the following July.

PROBLEM for Bonita:

From June until the following October, when the operation was not producing tomatoes, they would loose their "shelf space" in the markets. This shelf space became increasingly difficult to regain.

SOLUTION for Bonita:

Build evaporatively cooled (fan and pad) greenhouses AND
Do variety trials to determine the best tomato variety for their conditions.

EXPERIENCE:

*If a grower has experience with a particular crop… stick with it.

Example: A family with experience in growing long cucumbers in British Columbia, Canada, moved south of Willcox, AZ and is growing cucumbers… not tomatoes.

*If a grower does not have experience with a particular crop…

Work for someone who is successful with that crop to gain experience.
Hire someone who is experienced… an expert!

CROP SCHEDULING

*Plan ahead… When do you want to market your product for the best monetary return?
Arizona hydroponic tomato growers get a better price in Winter –
no field competition and little from greenhouses in northern latitudes.
Alternative: grow year around to maintain stable, consistent market/shelf space.

*Tomatoes: 2 examples of crop scheduling from Bonita Nurseries, Willcox, AZ.

Example 1: Passively cooled greenhouses (vents): No Summer harvesting.
Seed first crop in early July in 1” (or 1.5”) Rockwool cubes.
Transplant in mid-July into 3” (or 4” with 2 holes) Rockwool blocks.
Plant 1-month-old seedlings onto Rockwool slabs in August.
Harvest from October until March – Top the plants in February, remove when second crop begins producing in March.
Seed a second crop in early December as above.
Transplant in mid-December as above.
Interplant new 1 month old seedlings onto Rockwool slabs in January.
Harvest from this new crop from March until July. Remove plants. Clean.

Example 2: Actively cooled greenhouses (fan and pad): Year around harvesting.
Seed, transplant and plant first and second crops as above, removing first crop as above in March.
Continue second crop, harvesting from March until the next October.
Seed, transplant and plant the third crop, as the first, in July/August.
When third crop is ready to harvest in October, remove second crop.
Continue the process for up to 5 years.

NOTE: Bonita Nurseries does not grow their own transplants. They concentrate on the production end (growing the plants, harvesting, marketing, etc.) and purchase 1 month old seedlings from a TRANSPLANT GROWER.
NOTE: Why 2 crops/year? Fruit size and quality go down over time.

GREENHOUSE PREPARATION

*Select a site for the greenhouse that is appropriate for the operation (see Chapter 10).
*Select a greenhouse structure that is appropriate for the operation (see Chapter 11).
*Make sure all equipment is cleaned, serviced and working at optimum efficiency.
*For any crop, incl. tomatoes, the following items must be considered prior to planting:

Good light transmission: Choose the proper greenhouse covering and structure.
If year-around production is planned, shading must be used in Summer.
Adequate cooling: Either passive (vents), active (fan and pad), or both.
Heating is necessary in Winter: NATURAL GAS is the most economical way.
(Other, more expensive, methods of heating: propane, oil, electric, solar.)
Carbon dioxide generation: This is especially important for Winter mornings.
The sun rises, but it’s cold. So if fans come on, it’s only for a short time.
Plants begin to photosynthesize, using up the ambient carbon dioxide to the point where photosynthesis is effected and even reduced..
If photosynthesis is reduced, fruit set is reduced – and that’s $$!

Ground cover: Usually white plastic or a white woven material is put down first.
Reflects light back up into the crop increasing photosynthesis.
Provides a barrier between the plants and pathogens in the soil.
Helps to control weeds.
Allows for ease of cleaning: CLEANLINESS IS PARAMOUNT!
Trash, leaf litter, etc. is a perfect habitat for bugs/disease.
Irrigation system: (see Chapter 8 for details and diagram) This inlcudes:
Timer/controller to regulate the "fertigation" (water + fertilizer) schedule.
This will be hard-wired to solenoid valves that open for watering.
Reservoirs to contain the nutrient solution (full strength or concentrate).
Injectors (if concentrates are used) to dilute the nutrient solution.
Distribution tubing/emitters/drainage and/or recycling system.
Possibly integrated pH (acid/base) and EC (electrical conductivity) probes.
Overhead support wires: These need to be strong enough to support the crop and high enough (8-14 feet) to make use of the vertical space provided.

ENVIRONMENTAL CONDITIONS REQUIRED (see also Chapter 12)
***Light:** Two factors are important and can be affected by greenhouse structures and coverings (see Chapter 11). NOTE: Both of these vary with plant species.
Quality: Refers to wavelengths of light. (Remember in physics: light spectrum)
Visible light = 390-760 nm: blue at the low end, red at the high end.
PAR (photosynthetically active radiation) = between 400 and 700 nm
(blue, yellow, orange and red… but not green – see Chapter 2)
NOTE: This varies slightly for each plant species.
Quantity: Is affected by both day length and sun angle (changes with season):
Day Length: In Tucson, AZ day length on June 21 is 14 hours 15 min.
On December 21 day length, however, is only about 10 hours.
Sun Angle: Tucson AZ is located approximately 32.5^{o} North, 111^{o} West.
In June the angle is high = 81^{o} from the horizon (almost overhead).
In December the angle is low = 34^{o} from the horizon.
**The quantity (amount) of light reaching the Earth's surface is therefore higher in Summer than it is in Winter.
**For tomatoes in the desert southwest or other high light areas:
During the Winter or times of low light the quantity of light available is enough to support 3 – 4 fruit/cluster.
During Spring/Summer/Fall the quantity of light may be too high and shading may be needed. 4 – 5 fruit/cluster is typical.
(See below for physiological disorders related to sun.)
***Temperature:** The optimum growing temperatures (day and night) vary for different plant species and different varieties within a species.
For TRUST tomatoes (used initially by Bonita Nurseries):
Germination and post-emergence temperatures = 23-25 C (74-77 F)
Production optimum temperatures = 22 C (72 F) day/20C (68 F) night.
Tucson is nearly 2000 feet lower than Bonita and Summer temperatures are higher. Therefore, different varieties need to be tested for suitability.

***Relative humidity (RH):** The amount of water in the air compared to the total amount of water that the air can hold at a given temperature.

$$\%RH = \frac{\text{Amount of water in the air}}{\text{Amount of water possible at a given temp.}} \times 100$$

As the temperature increases the amount of water that the air can hold increases.

When the air is saturated water molecules condense. This causes clouds when at altitude or fog when near the ground.

How does this relate to tomato plants growing in a greenhouse?

*As the RH increases around the leaf (concentration of water molecules outside increases) it makes it more difficult for the water molecules inside the leaf to move out (transpiration) via diffusion (the passive movement of a substance from high to low concentration – see Chapter 2).

*Therefore, as the RH increases, transpiration decreases, water and therefore nutrient movement decrease, and nutrient deficiencies can result.

*ALSO, as RH increases and transpiration decreases, leaf temperatures often increase, since transpiration is the plant's way of cooling itself.

Optimum RH range for tomatoes (and most plants) = 55% - 95%

In Arizona during hot, dry weather, fan and pad cooling adds moisture to the air.

On hot, humid days, fan and pad cooling adds moisture but does not cool as well.

During cool, damp weather, RH inside the greenhouse can approach 95%.

***Carbon dioxide:** As mentioned earlier, carbon dioxide is critical for photosynthesis and enrichment is most important during the Winter on cold mornings.

Outside ambient levels are around 330 ppm, part per million, (higher in cities due to industrial exhaust products). Enrichment = 800 to 1000 ppm.

***Air circulation:**

This avoids pockets of high or low temperature, humidity or carbon dioxide.

This also reduces the BOUNDARY LAYER (the physical "still air" layer around the leaf) so that proper gas exchange and transpiration can occur.

When cooling fans are off use HAF (horizontal air flow) fans in the upper part of the greenhouse.

***Oxygen:** All parts of the plant require oxygen for respiration (see Chapter 2).

There is usually no problem supplying the top part of the plant with enough.

But waterlogging and high temps. will inhibit oxygen movement to the roots.

PLANT SPACING AND CROP LAYOUT

*Plant spacing is determined by two main factors:

The availability of light to the canopy. Plants must be far enough apart so that a maximum amount of light reaches the leaves for optimum photosynthesis.

The availability of water and nutrients to the roots. Plants must be far enough apart so that all plants have an optimum supply of these items.

*Plant spacing in "vining" greenhouse crops, including tomatoes, is much closer than for field crops.

Example: Field (bush) tomatoes = 4000 – 5000 plants/acre.
Hydroponic greenhouse tomatoes = 10,000 – 11,000 plants/acre.

*Why? A vine has a much smaller diameter than a bush, so they can be closer together and the leaves will still obtain optimum light for photosynthesis.

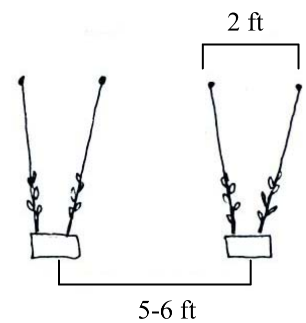
The roots of a plant growing in hydroponics receives all the water and nutrients it requires – They are "spoon-fed" and do not have to grow large systems.

The roots of a field grown plant will be more spread out as they search for water and nutrients in the soil matrix. Therefore, field grown plants must be positioned far enough apart to avoid competition of neighboring plants for water or nutrients. NOTE: Drip irrigation allows for closer spacing.

*Typical hydroponic plant spacing: Tomatoes = 2.5 – 3 plants per square meter
Peppers = 2.5 – 4 plants per square meter
Cucumbers = 1.25 – 3 plants per square meter

*The typical layout of the greenhouse for vining vegetable crops is in rows tending approximately north and south.

This is important because during the day the sun moves from east to west and if the rows were also set up east to west the southern most rows (in the northern hemisphere) would shade the rows behind them.



*Typically, tomatoes are also grown in "double rows".

These double rows are usually 5-6 feet apart.

With 3 plants per Rockwool slab (1 meter long each) or perlite bag (about 36"), sets of 2 slabs/bags are placed side by side.

With 6 plants per slab/bag a single row of slabs/bags is used.

Overhead support wires are set at least 2 feet apart.

TRAINING AND PRUNING

*In general greenhouse crops (tomatoes, peppers and cucumbers) are indeterminant (vining) types to take advantage of the vertical volume of the greenhouse.

*The plant vines are supported on vine twine by vine clips. The twine is wrapped around some sort of device from which it can be unwound (tomahook, bobbin, etc.).

Plants are trained up the twine to the wires forming a "V" shape (see diagram).

As the plants grow up to the overhead support wire, the twine is unwound, the plants lowered and shifted one space – "LEANED AND LOWERED".

Tomato vines should not be lowered more than 2 feet at a time OR another good way to tell, DO NOT lower the vine such that an 80 or higher degree bend is created in the vine near the floor. High angles promote stem cracking.

*Plants are trained to 1-3 stems by removing (pruning) side shoots or "suckers".

Tomatoes are trained to 1 stem (or 2 stems to replace a topped or broken neighbor or during a season of high light, i.e., Spring or early Summer).

Peppers are usually trained to 2 or 3 stems. Their stems are much more brittle than tomatoes and tend to snap if they are leaned and lowered.

Cucumbers have traditionally been trained using such methods as the "V-cordon" or "umbrella". However, they can also be trained to 1 stem like tomatoes.

*Side shoots or suckers are so named because they suck nutrients from the main plant.
The process of removing suckers = "sucker pruning" or "suckering".

*NEVER PRUNE SIDE SHOOTS WITHIN 2 INCHES OF THE TOP!
It is too easy to remove the APICAL MERISTEM, the top growing point.
If the apical meristem is removed or damaged (the plant is "topped"), a lower side shoot or even a sucker from a neighboring plant will need to be allowed to grow and take over as the apical meristem.
This will take time and this plant will now be behind the others.
Therefore, STUDY the top of the plant carefully, DETERMINE the location of the apical meristem, MOVE 2 inches down, THEN begin pruning!

*Extra growths may also occur on fruit clusters. These should be removed.

*Leaves: As the plants grow old leaves furthest from the apical meristem will begin to age or senesce = yellow spots appear due to the loss of chlorophyll.
These leaves are no longer contributing as much to photosynthesis.
These leaves should be removed – usually 3 leaves once a week. This is about the usual number of leaves that appear at the meristem per week.
The first three leaves will be removed when the plants reach 4-6 feet.
Leaves should be removed in the morning when the plants are "turgid" (full of water) so that they break off crisply.
Leaves should be removed at the stem-petiole abscission zone – the bulbous point of attachment of the leaf petiole to the main stem.
This abscission zone forms a clean break and seals quickly. If the leaf is "ripped" off, the damaged tissue could provide a point of entry for pathogens.
NOTE: Removing old, lower leaves also allows for air movement around the lower part of the plant. This reduces humidity that can promote disease.
Also, certain insect pests tend to reproduce on lower leaves. Pruning reduces their overall populations. (Ex: white fly – see Chapter 4)

FRUIT PRUNING
*The plant has a finite amount of mineral nutrients and photosynthates.
Removing defective/extra fruits keeps the plant from wasting precious resources.
*Any fruit that shows defects should be removed. For tomatoes these include blossom end rot (a leathery patch at the blossom end – see Chapter 7), cat facing (hole in the fruit exposing seeds – see Chapter 6), sunscald or green shoulder (a white area caused by overexposure to direct sun – see below), boats (elongation of the fruit – see below) and insect or disease damaged fruit (see Chapter 4).
*Tomatoes can also set huge clusters – up to 14 fruit or more! Since there is a finite amount of nutrients in the plant, if large clusters are allowed to stay, individual fruit size will usually be smaller within that cluster and clusters higher up on the plant may not receive enough resources resulting in few fruit or no fruit set at all.
*Recommend: for high light = 4-5 fruit/cluster; for low light = 3-4 fruit per cluster.

FACTORS CONTROLLING PLANT ARCHITECTURE

*Plant growth can be divided into 2 types:

1. **Vegetative growth:** Includes growth of the roots, stem and leaves.
2. **Reproductive growth:** Includes growth of the flowers and fruit.
   (Sometimes referred to as "Generative")

*The plant goes through 3 main stages of growth:

1. **Purely vegetative:** the production of roots, shoot and leaves only.
   In tomatoes this stage is about 3 weeks long.
   If the grower also seeds and grows the seedlings, environmental and feeding conditions are easily controlled and known.
   If the grower obtains the seedlings from a transplant grower, the environmental and feeding conditions may be significantly different from the conditions in the growing greenhouse.
   This may cause "transplant shock" and require an adjustment period.
2. **Before maximum fruit load:** vegetative parts continue to be produced but plants also begin to produce flowers and set fruit.
   In tomatoes this stage is between 3 weeks and 3 months long.
   During this stage the plants will produce between 4-7 trusses. However, this is still considered a "vegetative phase" since the flowers and fruit are a relatively small "sink" for the products of photosynthesis as compared to the vegetative parts of the plant.
3. **Maximum fruit load:** vegetative parts and flowers/fruit continue to be produced, and fruit is also now being harvested.
   In tomatoes this phase lasts for 3 to 9 months or more.

*There needs to be a balance between vegetative and reproductive growth:

Vegetative growth is needed for a strong structure (roots and shoot) as well as for good leaf coverage – the sites of photosynthesis.

Reproductive growth is important since this is the reason the grower is raising the tomato (or other fruit bearing) plants in the first place ($$)!

*Characteristics of vegetative versus reproductive growth in the tomato:

Characteristic	Reproductive Growth	Vegetative Growth
Leaves	Flat and open, light green, soft	Curled, thick, dark green
Flowering	Close to the top of the plant Flowers open fast and uniform Rapid flowering within truss	Further from the top of the plant Flowers open poorly; sepals stick Poor uniform flowering within truss
Flower Color	Dark yellow	Pale, light yellow
Truss Stem	Thick, sturdy, short and curved	Thin, long and sticking upwards
Fruit	Large, many, good shape and fast development	Small, few, poor shape and slow development

Modified from: DeRuiter Seeds, Inc. Newsletter, Cultural Information, 11/03/97.

*Various environmental or nutritional factors and also different cultural practices can affect the growth habit of the plant. This is known as “Steering plant growth”.

Factor/Practice	Steer towards reproductive	Steer towards vegetative
Difference between day and night temperature	Larger difference	Smaller difference
Day to night cooling rate	Quickly	Slowly or not at all
Position of grow pipe (metal or plastic pipe filled with circulating water running horizontally through the crop)	Three trusses under the top flowering truss	At the level of the truss to be harvested, or turn off
Temperature of grow pipe (0-80 C)	Raise	Lower
Relative humidity	Lower (make dryer)	Raise (make more humid)
Ventilate (where outside temp. is above 10 C)	More ventilation	Less ventilation
Carbon dioxide	Increase (800-1000 ppm)	Decrease
Irrigation: electrical conductivity (salt level) in the drip or input going onto the plants (2.5 - 4 mS/cm)	Higher (or very low) Stress the plant with very low or very high EC (1-1.5 or 3-4)	Lower Moderate EC (2-2.5)
Irrigation: how often and how long	Less frequent but longer duration	More frequent but shorter duration
Irrigation: start time	Later	Earlier
Irrigation: end time	Earlier	Later
Truss pruning	Less (leave more fruit on)	More (remove more fruit)
Leaf pruning	More (remove more leaves)	Less (leave more leaves on)

Modified from DeRuiter Seeds, Inc. Newsletter, Cultural Information, 11/03/97.

NOTE: To keep these factors straight remember that “vegetative growth” is like foliage plants that evolved in the “jungle” under conditions of high humidity, high temperature, no difference between day and night temperatures and more frequent watering.

PHYSIOLOGICAL DISORDERS

*NOTE: Disorders resulting from diseases and insect pests or from nutritional problems will be covered in Chapters 4 and 7, respectively.

*Physiological disorders include noninfectious or abiotic disorders caused by extremes in light, temperature, or soil or root zone moisture, a lack of oxygen, high air pollution, toxicity to pesticides or improper cultural practices.

***Tomatoes:**

Boats = elongated fruit/blossom scar due to improper temperatures (too high or too low) resulting in flower fusion and improper pollination/fertilization.

Cat Facing = breaks in the fruit skin with unfertilized seeds exposed due to abnormally cold temperatures during flowering, high nitrogen levels in the root zone or any mechanical disturbance to the flower during anthesis.

Cracking = concentric rings around or radial cracks from the calyx due to slow-then-fast fruit expansion resulting from wide differences in day/night temperatures, rapid water uptake early in the morning due to high root pressure, or (less likely in hp) a dry period followed by a rain/irrigation.

Flower Drop = flowers may spontaneously fall off due to temperatures over 90 F or below 50 F, drought (not usually seen in hydroponics unless the irrigation system fails), excess nitrogen (not usually seen in hydroponics unless irrigation system malfunctions), low light or too heavy a fruit set.

Gold Fleck = gold spotting due to high temperatures or rapid fruit/plant growth.

Microcracking or Russetting = small fractures in the skin. During the night all plant surfaces cool off. When the air temperature is increased quickly from night to day (a rise of 4-10 degrees) the thin leaves heat up quickly but the fruit stays cool. Like a soda being removed from the refrigerator and set on the counter, the cool fruit acts as a moisture condenser. The condensed water on the skin then causes the microcracking.

Stick Truss = thin, vertical truss with 2-3 fruit at most caused by excessive heat.

Sunscald or Green Shoulder = white, shiny, leathery area caused by sudden exposure to sunlight (due to leaf overpruning, disease, etc.).

***Peppers:**

Cracking (around shoulder; calyx end) = widely fluctuating temperatures.

Flower Drop = too much fruit set or other stresses (temperature, nutrient, etc.).

Glassy Patches = excessive root pressure forces water up bursting cell walls under the fruit skin. Excessive root pressure can result if the air temperature drops significantly faster than the root zone temperature and the roots stay active and force water up through the plant. Also, can occur as a result of THRIPS damage (see Chapter 4).

Sunburn or Sunscald = necrotic (dead) areas, primarily in yellow/gold varieties, caused by direct exposure of the fruit to high light. Allow the crop to develop a denser foliage or use shade cloth/whitewash on the greenhouse.

***Cucumbers:**

Crooking = excessive fruit curvature caused by one or a combination of:

mechanical interference with the growth of the young fruit,
insect damage (i.e., thrips)
adverse temperatures,
high root zone moisture,
poor nutrition or
air pollution (carbon monoxide, ethylene, NO_X gases, i.e., nitrous oxide)

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4. **Hydroponic Food Production.** 2001. H.M. Resh. Woodbridge Press Publishing Company, P.O. Box 209, Santa Barbara, CA 93160. ISBN 0-88007-222-9.
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CHAPTER 4

PLANT PROTECTION

INTRODUCTION

***Plants need to be protected against several things:**

Animals… of all sorts, including

Birds that steal fruit from trees, shrubs, vines, etc.
Herbivores that browse your favorite fruits and flowers
Harvester ants that denude your shrubs of leaves to feed to their fungus
Errant children who want your tomatoes, peppers, etc.

NOTE: Most of these problems can be solved by erecting some form of physical barrier between the perpetrator and your prized plants. Barriers might include a fence or wall, bird netting, "tangle foot" or even a locked greenhouse.

NOTE: The above animals do not usually pose a significant problem in CEA and will therefore not be considered further here.

Insect and mite pests: Whiteflies, aphids, thrips, spider mites and other pests do pose a significant threat, particularly to crops growing in greenhouses.

Insects and mites can cause different types of damage:

Direct physical damage: chewing, sucking, etc.
Injection of toxins into the plant during feeding that effect growth or quality of the plant and/or fruit.
Transmission of bacterial, fungal or viral diseases.

Disease-causing organisms: In order for a pathogen to be considered "disease causing" it must meet 4 criteria, **"Koch's Rules"** (from Plant Pathology by Agrios, 1988):

1. The pathogen must be found associated with the disease in all the diseased plants examined.
2. The pathogen must be isolated and grown in pure culture on nutrient media, and its characteristics described (non-obligate parasites), or on a susceptible host plant (obligate parasites), and its appearance and effects recorded.
3. The pathogen from pure culture must be inoculated on healthy plants of the same species or variety on which the disease appears, and it must produce the same disease on the inoculated plants.
4. The pathogen must be isolated in pure culture again, and its characteristics must be exactly like those observed in step 2.

A. Disease-causing organisms that are major problems in CEA/hydroponics:

Fungi: Kingdom Mycetae

They usually produce hyphae on or within the plant.

Several types of fungi can infect every part of the plant (stems, leaves, fruit and roots) with "zoosporic" root fungi (that have a motile swimming spore stage) being a significant problem in recirculating hydroponic systems.

Fungi can cause rots, spots, wilts, blights, molds and mildews.

Prokaryotes (bacteria): Kingdom Prokaryote

Single celled organisms that (in tomatoes) usually infect the upper portions of the plant resulting in necrotic (dead) spots on various portions of the stem, leaves and fruit, as well as causing whole plant wilts.

NOTE: Another type of prokaryote, mycoplasmas, have not been seen in CEA/hydroponics.

Viruses: Kingdom Vira

Viruses are particles of infectious single or double stranded DNA or RNA surrounded by a protein coat.

NOTE: Viruses require a "**vector**" to be transmitted to a plant. Insects are common vectors, but viruses can also be transmitted mechanically (hands, pruning shears, etc.).

NOTE: Viroids (infectious, circular, single stranded RNA that lacks a protein coat) have not seen in CEA/hydroponics.

B. Disease-causing organisms that are not significant problems in CEA/hydroponics (These will not be considered further here.):

Parasitic higher plants: These plants grow into the host plant and obtain water and nutrients from the host. They include dodder, witchweed, mistletoe and broomrape. Greenhouse hydroponics excludes parasitic plants.

Nematodes: Microscopic animals that are worm-like in appearance but different, taxonomically, from true worms. They are free-living in fresh or salt water or in the soil and feed on microscopic plants and animals. In greenhouse hydroponics, where soil is not used, avenues for nematode infection would be from a contaminated water supply or from soil brought in on shoes, equipment, etc.

INSECT AND MITE PESTS

*As noted above, insects and mites can cause physical damage to plants, or transmit toxins, bacteria, fungi or viruses from plant to plant.

*CEA can help exclude many insects and mites from the greenhouse environment. The closed nature of the greenhouse in conjunction with **insect screening** on vents and air intakes can create an effective barrier.
However, the greenhouse environment coupled with the typical monoculture that is grown there can create a perfect breeding ground for insects and mites that do manage to get in and population explosions can occur quickly.

*Traditional insecticides CANNOT BE USED since most hydroponic greenhouse operations (especially tomatoes and peppers) use bees for pollination and insecticides would also kill the bees. Therefore, control measures listed here include predatory or parasitic insects or mites, infectious fungi and bacteria or soap solutions and dusting sulfur that can be spot sprayed onto pests.

*Many insects and mites harm plants. However, several groups are of major concern in CEA/hydroponics. If not monitored closely and controlled immediately, populations of pests can explode quickly and devastate a crop.

1. **Aphids (several genera):**
   *Appearance: 6 legs/insect, round body, several colors (white, green, tan, black).
   *Life cycle: Complicated: reproduce asexually in summer, sexually in winter.
      Young born complete (miniature adults) and molt 4 times.
      White "cast skins" indicate the presence of molting young.
      Can be wingless or winged if populations high or when changing hosts.
      Mainly produce females (except in winter for sexual reproduction).
      High growth rate: 40-100 larvae/aphid (3-10/day over a few weeks).
   *Damage:
      Young and adults suck plant sap (high in sugar); plant growth is reduced, and leaves curl upward.
      Excess sugar is excreted as honeydew that drops onto lower leaves; sooty molds colonize the honeydew and reduce photosynthesis.
      Toxic substances can be injected.
      Pathogens (esp. viruses) can be transmitted (mainly by winged adults).
   *Control/Natural enemies:
      Gall-midge (*Aphidoletes aphidimyza*): same family as flies, mosquitoes. Gall-midge larvae inject poison that paralyzes and liquefies the aphid's insides which can then be drained.
      Parasitic wasps (Ex. *Aphidius matricariae*): The wasp lays an egg on the aphid which then swells and hardens ("mummy"). After growth, the adult wasp leaves the mummy through a circular hole.
      Verticillium lecanii: A fungus that parasitizes and ultimately kills aphids.
      Ladybird Beetles or lady bugs (*Hippodamia convergens*) and Lacewings (*Chrysoperla carnea*) also provide control of aphids.

2. **Red spider mites (*Tetranychus urticae* and *T. cinnabarinus*):**
   *Appearance: 8 legs (spider family); ovoid bodies; variable color (green, yellow, orange and black but reddish brown when feeding on tomatoes).
   *Life cycle: 5 stages: egg, larva, first nymphal (6 legs), second nymphal, adult.
      Time in each stage depends on temperature (~30C/86F is optimal).
      The population = 75% females, 25% males.
   *Damage:
      Larvae, nymphs and adults pierce plant cells and suck out the contents usually from the under side of leaves.
      Chlorophyll is destroyed leaving yellow patches and photosynthesis decreases. These patches are a major problem on ornamentals.
      Nymphs and adults produce webbing which are swarming with mites and give the leaf a reddish hue.
   *Control/Natural enemies:
      Dusting sulfur is an effect miticide. DO NOT dust beneficial mites or bees
      The predatory mite (*Phytoseiulus persimillis*): Belongs to the same order as the red spider mite – Acarina. Nymphs and adults eat spider mites. Feeding depends on populations, temperature and humidity.

3. **Thrips (*Thrips tabaci*, *T. fuscipennis* and *Frankliniella occidentalis*):**
   *Appearance: 6 legs (smallest of the winged insects); long and narrow; tan.
   *Life cycle: 6 stages:
      Egg - laid inside the leaf surface, flower petals or soft stems – causes small warts on sweet pepper leaves.
      2 larval stages – these are very active and feed on all aerial parts of the plant. After these stages they drop to the ground and pupate.
      2 pupal stages – these stages do not feed. Wing stumps begin to form.
      Adult – has two pairs of wings.
   *Damage:
      Larvae pierce and suck out cell contents; cells die and turn silvery gray. Loss of chlorophyll; decreased photosynthesis; brittle leaves.
      Black spots appear – these are the excrement of the thrips.
      Also damage to fruit (tomatoes, cucumbers, peppers) and flowers.
      Tomato Spotted Wilt Virus: is acquired by the larvae during feeding on infected plants but TSWV is transmitted exclusively by the adults.
   *Control/Natural enemies:
      Predatory mites (*Amblyseius barkeri* and *A.cucumeris*) eat thrips. They are shipped in "sachets" with "grain mites" (plant/fungus feeders and food for the beneficials to eat during shipping). Hang sachets in the crop for a max. of 2 weeks and then removed to avoid grain mite infestation on the plants. (Grain mites: see *Eriophyid* mites below)
      Predatory bugs of the genus *Orius* with flattened bodies and protruding mouth parts for sucking the juices from the thrips body.
      Verticillium lecanii: a fungus that parasitizes and ultimately kills thrips. This fungus does not harm other natural enemies of the thrips.

4. Whitefly

Trialeurodes vaporariorum (Greenhouse whitefly)
Bemisia tabaci (Genn.) (Sweet Potato whitefly)

*Appearance: (Insect) Both are white in color. *Trialeurodes* holds its wings out giving it more of a triangular shape, whereas *Bemisia* appears more linear.

*Life cycle: Essentially 7 stages:
- Egg: on a stalk on the leaf underside, sometimes with several in a circle.
- 4 larval stages: initially with legs, but lose their legs after they pierce the leaf tissue and begin to feed.
- Pupal (or false pupa) stage: sedentary stage; adult red eye color appears.
- Adult: emerges from the pupa. This stage also feeds.

*Damage:
- Larvae and adults pierce and suck juices from plant cells causing reduced photosynthesis and growth, leaf drop and reduced harvest.
- Larvae and adults excrete honeydew onto leaves and fruit. Molds colonize the honeydew reducing photosynthesis and transpiration on leaves and leaving sticky, "dirty" deposits on fruit (unmarketable).
- Both whiteflies have been shown to transmit viruses (see Viruses below).

*Control/Natural enemies:
- Parasitic wasps: An egg is laid in the whitefly larvae (3rd or young 4th stages preferred). The egg hatches and the wasp larvae devours the whitefly larvae, then uses the host's shell to develop to adult which emerges through a small round hole in the host's shell.
  - The wasp *Encarsia formosa* prefers the whitefly *Trialeurodes*. Upon entry the wasp larvae turns the w.f. pupa black.
  - The wasp *Eretmocerus eremicus* prefers the whitefly *Bemisia*. Upon entry the wasp larvae turns the w.f. pupa golden.
- *Verticillium lecanii*: A fungus that parasitizes and ultimately kills whitefly.

5. Butterflies and Moths (Order *Lepidoptera* , 5 species in the family *Noctuidae* and one in the family *Tortricidae* are important in greenhouse culture.)

*Appearance: 6 legs (winged insects); varying sizes with 2 pairs of wings.

*Life cycle: 4 stages:
- Egg – laid on leaves or even glass or greenhouse structures.
- Larva – a caterpillar: well developed head with strong jaws; 3 pairs of real legs on the front, 5 pairs of false legs on the rear. Molt 3-9 times.
- Pupa – a resting stage during which the larva is transformed.
- Adult – winged butterfly or moth.

*Damage:
- The larval stage or caterpillar causes immense damage. They feed on the undersides of leaves though larger ones will eat holes through the leaves. Certain types will bore into the stems, flowers, fruits and growing points. Their excrement can contaminate the crop.

*Control/Natural enemies:
- *Bacillus thuringiensis* var. *kurstaki*: this bacterium kills larvae when eaten.

6. **Eriophyid mites (*Eriophyes sp.)* Also gall, rust, russet, bud and blister mites.**
   Appearance: (Spider family) Invisible to the unaided eye; 4 legs; worm, spindle or tear drop shaped; usually clear bodies with 2 parts – a mouth and a body.
   Life cycle: Egg; larva; nymph; adult. Unlike other mites, they have only 4 legs.
   Damage: Each species has a narrow range of host plants.
   Tomato stems and leaf petioles take on a reddish (russet) appearance.
   Leaflets will show chlorosis then necrosis from the petiole base outward.
   May be capable of transmitting viruses during feeding and moving fungi or other plant diseases during their movement from plant to plant.
   Control/Natural enemies:
   There are no known beneficial enemies of this group of mites.
   Dusting sulfur is effective but it must be applied evenly not only on the reddish areas (where mites have been), but above/below where mites are now feeding but are invisible to the unaided eye.

***Some insects may not cause significant direct harm to plants but may, as those listed above, act as vectors for devastating diseases.**

1. **Shore flies:**
   *Appearance: Look like miniature houseflies.
   *Life cycle:
   Eggs are laid in moist, algae infested areas.
   Larvae burrow down and feed on organic matter including plant roots.
   Pupal stage is in the root zone.
   Adults are black, usually only fly when disturbed and can be found on tops of Rockwool blocks or other moist places where algae grows.
   *Damage: Shore flies have been shown to transmit pathogenic fungi including *Pythium* and *Phytophthora*. They eat the fungal spores, that remain intact in the gut, fly to an uninfected plant and deposit the spores. The new plant can then become infected. Shore flies can also carry viruses.
   *Control:
   The bacteria *Bacillus thuringiensis* (Gnatrol) attacks the larval stage.
   A soap solution (Safer Soap) can be sprayed onto the adults, plugging their breathing tubes along their sides and suffocating them.
   Preventative: Silica sand can be put on the surface of the Rockwool blocks which will inhibit algae growth and subsequent fly habitat.

2. **Fungus gnats (or Sciarid flies):**
   *Appearance: Look like miniature mosquitoes.
   *Life cycle:
   Eggs are laid in moist, algae infested areas.
   Larvae are legless maggots with black heads that feed on organic matter.
   Pupal stage is in the root zone.
   Adults are grayish black with long antennae. They are very “nervous” fliers and are found near moist areas where algae grows (as above).

*Damage:
Fungus gnats, like Shore flies, can transmit fungal and viral pathogens.
*Control:
The bacteria *Bacillus thuringiensis* (Gnatrol) attacks the larval stage.
A soap solution (Safer Soap) can be sprayed onto the adults, plugging their breathing tubes along their sides and suffocating them.
Preventative: Silica sand can be put on the surface of the Rockwool blocks which will inhibit algae growth and subsequent fly habitat.
Parasitic nematodes (*Steinernema feltiae, S. carpocapsae*): The 3rd larval stage is infectious. Optimum conditions for the nematodes include a temperature of 15C/59F (a little cool for tomatoes, peppers and cucumbers) as well as high humidity.

DISEASES
*Many organisms (bacteria, fungi and viruses) cause disease in plants.
*Because of the closed nature of the greenhouse and the fact that soil (source of many diseases) is not used, many diseases are not seen in greenhouse hydroponics.
*The diseases that are seen can become catastrophic if not recognized and dealt with. Knowledge of plant diseases typical to greenhouses and hydroponics is essential.

***Selected diseases of tomato** also found in greenhouse hydroponics:

1. **Fungi:**
   *The fungi listed here consist of a plant-like vegetative body (**mycelium**) made up of individual filaments (**hyphae**), each surrounded by a cell wall.
   *They can be divided into two groups depending on whether or not they produce a zoospore (a motile, flagellate spore that lacks a cell wall):

   Non-zoosporic fungi:

   a) ***Botrytis cinerea*** **(botrytis or gray mold):**
      *Has a wide host range and is a good saprophyte (lives on dead matter).
      *Spores can be disseminated by air, water or by infested plant or greenhouse materials (clippers, gloves, etc.).
      *Can infect all above-ground parts of the plant, usually through wounds.
      *Gray fungal masses will form on the stem (girdling it), the leaves (forming a "V" shape), the calyx end of the fruit, or, if it spreads to the fruit but is then exposed to sun/high temperatures, "ghost spots" (white to pale yellow or green) will remain.
      *Optimum conditions: cool, humid and overcast. Also, too close of plant spacing and poor ventilation can promote infection.
      *CONTROL:
      Adequate ventilation of the greenhouse to reduce humidity.
      Increased ventilation around stems by pruning lower leaves.
      Fungicides may be applied to pruning wounds or used in severe cases. (Ex: Mancozeb: bis-di-thio-carbamate + Mn & Zn)

b) *Fusarium* species (Fusarium Wilt, Fusarium Crown and Root Rot):

*Caused by several species and "pathovars" of the fungus.

*Spread by spores in the air, water, infected transplants, workers or infested greenhouse materials or equipment.

*Infection takes place through feeder roots and wounds caused by secondary root formation.

*Optimum conditions: moist, moderate temp. (20C/68F) in the root zone.

*General symptoms: leaf yellowing, vascular discoloration, wilting and plant death. In high humidity, the white mycelium may be visible.

*CONTROL:

Use resistant varieties.

c) *Verticillium dahliae* (Verticillium Wilt):

*Has a wide host range and can survive in soil for several years.

*Infection takes place through root wounds caused by secondary root formation (or cultivation or nematode feeding in soil culture).

*Optimum conditions: cooler temperatures (21-25C or 70-77F).

*General symptoms include plant stunting, a light tan discoloration in the vascular tissue, yellowing then browning in a "V" pattern on the leaflets with wilting, yellowing and finally dying of older leaves.

*CONTROL:

Use resistant varieties.

Zoosporic Fungi:

a) *Phytophthora* species:

*Different species of the fungus attack different hosts.

*Infection can be at the roots or on the leaves/stems/fruit depending on species. Note that the leaf/stem/fruit infections (Ex., Late Blight) is not usually seen in CEA/hydroponics.

*Optimum conditions: Most species prefer cooler (15-30C or 59-86F), humid conditions.

*General symptoms of root rots include stunting of the plants and/or a collapse of the entire plant. Plants can also become weakened and susceptible to attack by other pathogens. Attack on seedlings is known as "damping off" and causes death.

*The disease is spread by motile zoospores that swim through the nutrient solution. This is especially dangerous in recirculating systems.

*CONTROL: Sanitation is very important. Mats with disinfectant can be positioned at entry ways to remove soil from shoes. Tools, hands, gloves, etc. must also be cleaned between uses. Leaf, sucker and other prunings should be removed from the greenhouse. Since the motile zoospores do not have a cell wall, their naked membranes are easily dissolved by soaps or surfactants. These can be placed in the nutrient solution (use low concentrations only, 5-20 ppm, as higher concentrations will cause phytotoxicity).

b) *Pythium* species:

*Usually non-host-specific, though some have host specificity.
*Infection is most often at the roots or crowns but can also be on the fruit.
*Optimum conditions: Most species prefer warmth (20-40C or 68-104F)
*General symptoms on roots include stunting or plant collapse; plants using the same water source will die simultaneously due to rapid spread by zoospores. "Damping off" = attack/death of seedlings.
*The disease is spread by motile zoospores that swim through the nutrient solution. This is especially dangerous in recirculating systems.
*CONTROL: Sanitation is very important, including disinfectant mats, tool/hand/glove cleaning, and pruning removal. Surfactants in the nutrient solution have given 100% control over spread of disease.

2. Prokaryotes/Bacteria:

*Bacteria are single-celled microorganisms with a cell membrane and cell wall surrounding the cytoplasm that contains "naked DNA" (no nucleus). They often have one or more flagella (whip-like appendages that propel them through the water).

a) Bacterial Canker (*Clavibacter michiganensis subs. Michiganensis*)

*Has been shown to infect tomato in greenhouse hydroponics.
*Gram positive, non-sporing, non-motile, obligate aerobic rod. Survives up to 5 years in soil, on infected plant material, on weeds, volunteer tomato plants and seeds. Infection occurs via wounds but also through the roots or leaf stomata.
*Optimum conditions: moderate temperatures (18-24C or 65-75F) and greater than 80% relative humidity. Other conditions that promote the disease include optimum root zone moisture for plant growth, low light and high nutrient concentrations (especially nitrogen).
*General symptoms: Downward turning and wilting of lower leaves which remain attached to the stem. Streaking along leaf midribs, petioles and/or stems can break open forming cankers. Can show vascular discoloration with the pith becoming mealy or hollow. Diagnosis: place fresh cut stem in water – yellow stream of bacteria will exude from the end (bacterial streaming). Fruit will show small white lesions that develop into brown, scabby lesions surrounded by a "halo" (bird's eye).
*Spread by splashing water and contaminated equipment and/or tools.
*CONTROL: Use disease-free seed and/or transplants. Sterilize tools and equipment. In soil systems: rotate to a non-host crop for at least 3 years (not practical in greenhouse hydroponics!).

b) Bacterial Wilt (*Burkholderia solanacearum* or *Pseudomonas solanacearum*)

*Can infect over 200 species of plants, including tomato.

*Gram negative, aerobic, motile rod.

Survives in the soil where it attacks the roots through natural wounds caused by secondary root formation, or wounds caused by transplanting, cultivation or nematode feeding.

It can also be transmitted via chewing insects.

*Optimum conditions: Warm temperatures (29-35C or 84-95F) and high root zone moisture favor development.

*General symptoms: Drooping of the lower leaves followed by wilting of the entire plant (no leaf yellowing). A longitudinal section of the stem shows yellow to light brown vascular discoloration (later turning dark and/or hollow).

Diagnosis: place fresh cut stem in water – milky stream of bacteria will exude from the cut end (bacterial streaming).

*The disease is spread in irrigation water, from soil on shoes, equipment, etc., and from diseased transplants.

*CONTROL: Use disease-free transplants and/or tolerant varieties.

In soil systems: soil fumigation, weed control, crop rotation and grafting to resistant root stocks can minimize losses.

3. Viruses:

*Definition:

"Nucleoprotein" (single or double stranded RNA or DNA surrounded by a protein coat).

Very small. Need an electron microscope.

Multiplies only in living cells.

Has the ability to cause disease.

*Many viruses infect tomatoes, however, only a few have been seen in greenhouse hydroponics.

a) Tomato Mosaic Virus (or Tobacco Mosaic Virus): ToMV or TMV

*These two viruses are nearly identical and can both infect tomato.

*Single-stranded RNA, rod shaped.

Can survive on plant debris, tools or worker's hands…

NOTE: If you smoke, wash hands before entering greenhouse!

Chewing insects can transmit the virus, but rarely.

*General symptoms: Leaves show light green to yellow or dark green mottling, necrosis and upward leaf rolling. Stems will show streaking depending on strain. The entire plant can be stunted. With cool temperatures leaves may appear "fernlike". Fruit can show uneven ripening or a browning of the fruit wall. If resistant varieties are used necrotic streaks or spots on the stem, petioles, leaves and fruit may develop.

*CONTROL: Use TMV resistant varieties. Steam sterilize all equipment and tools before use.
NOTE…NOTE: All workers should wash their hands with soap and water… ESPECIALLY SMOKERS… before entering the greenhouse or handling plants, tools, equipment, etc.

b) Family = Geminiviruses, Genus = Begomovirus

*At least 15 different viruses infect many plant species, including tomato.
*Small, paired, isometric virus, each virus pair containing one circular single-stranded DNA.
*These viruses are specifically transmitted by whiteflies. Examples:
Tomato Mottle Virus transmitted by *Bemisia tabaci*
Tomato Yellow Leaf Curl Virus transmitted by *Bemisia tabaci*
Tomato Infectious Chlorosis Virus by *Trialeurodes vaporariorum*
*General symptoms: Most geminiviruses cause leaf mottling and/or chlorosis (yellowing) in various patterns as well as leaf curl. With chlorosis comes reduced photosynthesis and growth resulting in stunting of plants and reduced yields.
*CONTROL: Since these viruses are specifically transmitted by whiteflies, control of the whitefly population in the greenhouse is the best control measure.
Use insect screening specific for whitefly.
Use biological control (parasitic wasps – see insects above).
Use whitefly free transplants.
Remove old crop and allow greenhouse to heat up (sterilize).

c) Tomato Spotted Wilt Virus (Tospovirus or TSWV)

*Has a large host range including tomato, tobacco, dahlia and pineapple.
*Fairly large uniquely spherical particles surrounded by a membrane, containing a single strand of RNA.
*Spread by thrips (onion and western flower). Initially acquired by the larval stage, but only transmitted by the adult thrips
*General symptoms: In tomatoes older leaves show orange-yellow flecks which develop into dark circular spots giving a bronzing appearance. Leaves may show irregular or one-sided growth. Stem and petioles may show dark, shiny streaks. Plants become stunted with yellowing, drooping foliage (appears wilted). Fruit can have green, yellow and red bumpy concentric rings.
*CONTROL: Use resistant varieties, and virus-free transplants.
Control thrips using insect screening and, when necessary, predatory insects or parasitic fungi as noted above).
Also, remove nearby virus host weeds.

***Selected diseases of other crops** grown in greenhouse hydroponics:

1. Fungus: *Didymella* or *Mycosphaerella* (Gummy Stem Blight):

*A non-zoosporic fungus that can be host-specific or attack different hosts depending on the fungal species. The greenhouse cucumber is particularly susceptible (another species of the fungus attacks tomatoes but is more common in Europe, the Middle East and North Africa).

*Infection usually occurs on the stem at or above the soil line.

*Optimum conditions: Prefers high moisture and humidity. Optimum temperatures range from 20-25C/68-77F

*General symptoms include initial tan spots then necrotic (dead) spots on the leaves, stem lesions and fruit rot, usually at the flower end. Black "dots" that appear from these spots, lesions and rots are spores oozing out.

*The fungus is spread by aerial spores, by workers who handle infected plants or plant material, by splashing or dripping water, through infected transplants or via infested greenhouse materials or tools.

*CONTROL:

Use clean transplants.

Reduce greenhouse humidity by not using mist cooling.

Remove infected plants and plant material. Workers should wash hands with soap and water after handling infected material.

Can use fungicides (but not usually used in greenhouse hydroponics).

2. Fungus: *Olpidium brassicae*:

*A zoosporic fungus that has been shown to infect roots of hydroponic lettuce. Main problem: this fungus is a carrier for **Lettuce Big Vein Virus** and several other viruses, as well.

*Optimum conditions for the fungus: Moisture; temperatures less than 16C/61F.

*General symptoms: The fungus does not produce any real symptoms, whereas Lettuce Big Vein Virus causes swollen leaf veins and bitter tasting leaves.

*The fungus is spread by motile zoospores as well as on infected plant parts or on contaminated plants and soil.

* CONTROL: Remove all contaminated plant material.

Surfactants can be used to halt the spread of fungal zoospores.

Some fungicides are effective but are prohibitively expensive and are not usually used in hydroponics.

3. Fungus: Powdery Mildews:

*Non-zoosporic fungi where species in 3 different genera cause infections on specific hosts including peppers, cucumbers, lettuce and tomatoes.

NOTE: The fungus on tomatoes moves fairly slowly and can be effectively controlled by removal of the contaminated leaves.

*Optimum conditions: Prefers warm and dry conditions, which makes it a significant problem in the desert southwest USA. Needs some moisture for spore germination, so it does well in humid greenhouse conditions.

*General symptoms: The fungus usually attacks the leaves forming yellow lesions or white powdery areas. Severe infections cause reduced photosynthesis and growth and sometimes leaf drop.

*These fungi are obligate parasites (can not be cultured) that are spread by aerial spores and by workers.

*CONTROL: Use resistant varieties (particularly peppers and cucumbers).
Fungicides can be used but resistance tends to develop easily.
Dusting with sulfur has provided excellent control of powdery mildews.
At present various biofungicides are being tested for efficacy.

BIOLOGICAL CONTROL AND INTEGRATED PEST MANAGEMENT

Biological Control: The use of one organism (beneficial) to control another (pest).

*Often used to refer to beneficial insects such as wasps, bugs or mites that are used to control such pests as white flies, thrips or aphids (see above).

*This term can also apply to parasitic bacteria, fungi and nematodes (see above).

*Note that there are at least 72 species of predators/parasites for 60 pest species.

***History**: By the late 1930's biological control (i.e., use of the parasitic wasp *Encarsia Formosa*, originally discovered in a greenhouse in England in 1926, to control the white fly) was common in commercial greenhouses in England and Australia.
In the 1940's, with the introduction of the insecticide DDT, the use of biological control ceased. Other chemical pesticides were also developed.
In the later part of the 20th Century many growers, especially greenhouse hydroponic growers, began returning to biological control due to

- the development of pesticide resistant pest populations
- the high cost of pesticides
- the difficulty in observing "harvest restrictions", the delay time between application of pesticide and harvest
- the reduction in yields due to phytotoxicity of the pesticides
- the fact that DDT and other chemical pesticides were persistent in the environment and affected other species than those intended (i.e., DDT which caused thinning and brittleness of the eggs of the California Condor, death of the chicks, and decreased populations almost to the point of extinction)
- the increased concern with exposure of greenhouse workers to pesticides and, for the consumer, of exposure to pesticide residues on the produce
- the use of bumble bees in the greenhouse to pollinate the crop, especially tomatoes and peppers (see Chapter 6). Pesticides would not only kill the pest but the bees as well!
- the fact that vegetables produced "pesticide free" command a higher price at the market!

*__Biological control is an extremely "knowledge intensive" technique__.

Example: If white flies are discovered on tomatoes, the grower could spray… and that would be that.

However, if biological control is used, the grower must first identify the type of white fly (*Trialeurodes* verses *Bemisia*) then order the appropriate beneficial wasp, then place the wasps in the proper locations in the crop…

*__Introduce the beneficial(s) BEFORE the pest organism is present.__

If the grower waits until the pest is noticed, populations are already rising and the lag time between noticing-ordering-introduction may be up to 2 weeks – plenty of time for a pest to get out of control! This is commonly done with white fly parasitic wasps.

*__There are natural "swings" in both the beneficial and pest populations.__

As the pest population rises there will be more food/hosts for the beneficial (predator/parasite) population which will begin rising.
As the beneficial population rises and eats/parasitizes the pests, the pest population will decrease resulting in less food/hosts for the beneficials.
As the beneficial population decreases the pest population rises again, etc.

*__There are 3 ways to introduce "beneficials" to a crop:__

1. **Conservation:** Attraction and preservation of naturally occurring beneficial organisms in the crop (best for field crops).
2. **Inoculation:** Periodic releases of small numbers of "beneficials" starting early in the season. Used in greenhouse hydroponics.
3. **Inundation:** Mass introductions of "beneficials" aimed at eliminating pests immediately, especially when pest populations are high.

Integrated Pest Management (IPM): The prevention and control of pests and diseases using all existing crop protection techniques and strategies.

*__Techniques and strategies that prevent pests and diseases:__

1. **Hygienic measures:**
   *Start with clean seed and/or transplants.
   *Remove old plant material (source of disease inoculum and refuge for insects) from greenhouse and dispose of.
   *Solarization: increase the temperature set point in the greenhouse after the last crop is removed. This can kill harmful organisms on gravel, walls, tubing, etc.
   *Remove weeds inside and outside the greenhouse (these can be hosts for insects and diseases for present and future crops).
   *Prevent transmission of pests/disease by humans/machines/tools. ("Hygiene coats" for guests; disinfect shoes/hands/tools.) Note: Skimmed milk can encapsulate viruses on tools!
   *Prevent transmission of pests/diseases in the irrigation water by filtering, UV radiation or ozone treatment.

2. **Mechanical measures:**
    *Use insect netting (several sizes specific to different insects) over air intakes or vents to prevent entry.
    *Use a plastic or woven floor covering to isolate the plants from insect pests and diseases in the soil below.

3. **Cultural practices:**
    *Optimize plant growth: a healthy plant is a more resistant plant.
    *Avoid plant damage (creates easy entry for disease).
    *Plant workers should move from clean to infested areas.
    *Although greenhouse hydroponic crops are planted at higher densities than field crops (see Chapter 3, General Cultural Practices), too high of planting densities can result in thin, weak plants that are more susceptible to pests/diseases.
    *Maintain a regular harvest schedule – plants allowed to get over or under-loaded with fruit may become weakened.
    *Can use "crop rotation" – alternating host and non-host crops. This is not usually done in greenhouse hydroponics.

4. **Genetic/transgenic/other control:**
    *Use "resistant" or "tolerant" varieties. If growing "susceptible" varieties, grow during times of low infestations.
    *Note: There may be a trade-off between growing resistant or tolerant species/varieties and maintaining maximum yields.
    *Can use plant material from tissue culture – disease free.

***Techniques and strategies that control, reduce or eliminate pests and diseases that have already become established:**

1. **Mechanical measures:**
    *Check the crop regularly for the presence of pests and diseases.
    *Capture insects (best for winged/flying insects)
        Sticky traps: plastic or other non-porous surface covered with a sticky substance and of a certain color (white flies prefer yellow, thrips prefer blue, etc.).
        Trap plants or pheromone traps (both attract insects and can then be removed from the greenhouse).
    *High temperature treatment
        Not appropriate for mature tomatoes, peppers, etc.
        Hot water or air on seeds/bulbs/tubers/cuttings can remove mites, nematodes, bacteria and some viruses.

2. **Biological control:** (See above for definition) Pay attention to:
   *The directions for use (application, time of day, location in crop).
   *The directions for storage (temperature and "use-by" date).
   *The quality of material (supplier guarantees quality and quantity).
   *The "biology of the beneficials".
   *The reduction of beneficial insects by the removal of lower leaves or other prunings where they might be developing.
   Useful practice: pile prunings at one end of the house for a day or two to let beneficials migrate back into crop.
   Opposite practice: if pest population has soared, prunings can be removed immediately to cut pest numbers.
   *The possible use of "banker plants" – plants that attract pests and can also be hosts for beneficials.

3. **Natural control:** The control of pests and diseases by spontaneously occurring natural enemies. Ex: Stimulate colonization of beneficials by creating optimal conditions for them.
   Not usually done in greenhouse hydroponics. (Too "iffy"!)

4. **Chemical control:** Only used as a "last ditch" corrective measure.
   *Start with "natural pesticides":
   Soaps/surfactants: they plug insect breathing tubes
   Neem oil: Neem tree/India: interrupts insect metamorphosis
   Sulfur: effective mitacide but also kills insects and bees
   *Use selective pesticides (do not kill or harm beneficials or plants).
   *Use selective application techniques.
   *Use pesticides with short persistence times.
   *Check the compatibility of all pesticides with beneficials (i.e., Koppert Side Effect List – see Ref. 3 below).

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CHAPTER 5

BASIC PRINCIPLES OF HYDROPONICS

ADVANTAGES OF USING HYDROPONICS OVER SOIL CULTURE

1. **Crops can be produced on non-arable land including land with poor soils and/or high salinity levels.**
   *The grower doesn't have to have good soil since the systems, bags, etc. are placed on top of the ground.

2. **Isolation from diseases or insect pests usually found in the soil**.
   *The plant roots are contained in systems, bags, etc. and do not grow through soil that might contain diseases or other pests such as insects and nematodes.
   *Additionally, white fabric ground covers can be placed on the greenhouse floor to further isolate the systems and plants from soil-borne pests.
   NOTE: The white fabric also reflects light back up into the canopy enhancing photosynthesis, allows for ease of cleaning and helps control humidity and weeds.

3. **Direct and immediate control over the rhizosphere**.
   *Since the roots are either growing in water or growing through an inert medium, whatever is in the nutrient solution is bathing the roots. Therefore, nutrient concentrations and pH can be adjusted quickly.

4. **Higher yields are possible.**
   *For field grown tomatoes yields are 10-40 tons per acre compared with around 300 tons per acre for tomatoes grown using greenhouse hydroponics.
   *Yields are greater due to better control over water, nutrition, EC, pH and diseases (plus control over environmental conditions – see below).
   *Yields are also higher due to the use of certain varieties bred for hydroponics that are also indeterminant ("vining" – see below).

5. **High density planting = minimum use of land area**.
   *For tomatoes in the field a typical planting density is 4000 to 5000 plants per acre. Greenhouse hydroponic tomatoes can be 10,000 to 11,000 plants per acre!
   *Plants can be grown closer together because of the use of indeterminant ("vining") varieties that take up less cross-sectional area than do bush varieties usually used for field cropping. This also takes advantage of the greenhouse volume, so that production is on a "cubic volume basis".

6. **Efficient use of water and nutrients.**
   *In soil culture water may be lost in wetting the soil beyond the reach of the plant roots or from the surface through evaporation.

*In hydroponic culture, since the nutrient solution is enclosed in a bag, tube, etc., there is no loss AND little or no water stress in the plant.
NOTE: When comparing monetary return for water use – for every gallon of water used to irrigate cotton the grower gets 1/10th of a cent. For every gallon of water used to irrigate hydroponic tomatoes, the grower gets over 30 cents!
*Nutrients (which equate to $money$) are also not lost to the soil but retained in the root zone and in closed systems are replenished and recycled.

7. **Ease of cleaning the systems.**
*The aggregate growing media can be steam sterilized, or simply replaced.
*Whole systems, including the drip irrigation system, can be quickly sterilized using 10% bleach and cleaned of salt build-ups using a mild acid (rinse well).

8. **No weeding or cultivation is needed**.

9. **Transplanting of seedlings is easy – No transplant shock.**
* In soil culture the root mass can be easily disturbed during transplanting causing root breakage, plant stress and stunted growth for up to a week.
*In hydroponic culture seeds are started in Rockwool cubes or plugs, then transplanted into larger cubes with holes made for that purpose (see Chapter 9 Seed Germination and Transplanting). There is no disturbance of the root mass, little or no root breakage and therefore minimal plant stress and transplant shock.

10. **Fruit of hydroponically grown plants is usually tastier.**
*Hydroponically grown tomatoes, for example, are picked after they have begun to ripen, which includes the typical red color formation of the fruit (lycopene), the formation of gel within the locules and the characteristic taste. The grower can also raise the EC (electrical conductivity measuring salt levels) in the root zone that tends to enhance flavor.
*Tomatoes from field grown plants (in many areas) are picked "green", then "gassed" with ethylene which induces lycopene formation but does not enhance the flavor. Therefore, you get nicely colored fruit with little or no taste.

ADVANTAGES OF GREENHOUSE CULTURE

1. **Virtual indifference to the seasons.**
*In the desert southwest crops can be grown year around including in the winter when field crops are not being produced and prices are higher.

2. **Control over the aerial (upper) portions of the plant.**
*The air temperature and, to some extent, the relative humidity can be regulated to suit the crop under cultivation in the greenhouse environment.
*Higher than normal (~330 ppm) levels of carbon dioxide (up to 1000 to 1500 ppm) can be reached using a carbon dioxide generator (burning natural gas) in order to enhance photosynthesis.

3. **The greenhouse environment is suitable for mechanization.**
   *Includes personnel carts for plant maintenance and picking as well as future designs for automated harvesting “robots” (will require changes in plant structure).

DISADVANTAGES OF GREENHOUSE HYDROPONICS

1. **Requires a large capital ($money$) input and energy input.**
   *Any size commercial operation (including injector irrigation systems, computer controls, etc.) will cost about $600,000 per acre with the land itself costing $1000 - $2000 per acre (depending on location).
   *Energy costs can be high and can include those for heating (usually burn natural gas), cooling (usually use evaporative – fan and pad – cooling), electricity to run various types of equipment (some injectors, computer controls, motors, sorting/packing/storage equipment, etc.).

2. **The grower needs a high degree of competence in plant science, engineering, computer control systems and marketing.**
   *Or experts in these fields needs to be hired. This is an intensive form of agriculture where a small problem can escalate to a major disaster very quickly.

3. **The technology is limited to crops of high economic value.**
   *Since the initial cost of a large commercial facility is so high it would not be profitable to grow anything but crops of high economic value including tomatoes, colored bell peppers, cucumbers and even lettuce which, in a hydroponic greenhouse, can yield multiple crops per year.

4. **Plant diseases and insect pests may be more difficult to control.**
   *Root pathogens that produce water-borne spores (e.g., zoospores of such fungi as *Pythium* or *Phytophthora*) can be devastating to plants growing in a “closed” system where the nutrient solution is recirculated since infected solution will circulate to all plants. NOTE: For treatments see Chapter 4: Plant Protection.
   *The greenhouse, with its controlled environment, is a perfect habitat for many types of insects, including those considered “pests” on plants such as white flies, aphids, thrips, spider mites, shore flies and fungus gnats. These pests may cause direct damage to the plants or may transmit viruses to the plants.
   NOTE: Beneficial insects that can be released. See Chapter 4: Plant Protection.
   *$0.80 – $1.00 per plant can be spent for insect pest control. That adds up!

REVIEW OF PLANT NEEDS

This is critical for understanding how to build hydroponic systems.

1. **Water** – Critical for metabolic processes, for transport of substances throughout the plant body (phloem and xylem) and for transpirational cooling.
2. **Light** – Critical for photosynthesis. (Where you put your system is important.)
3. **Inorganic mineral nutrients** – at the correct concentrations (EC) and pH levels.
4. **Carbon dioxide** – Critical for photosynthesis (needed at the leaf surface).
5. **Oxygen** – Critical for respiration (needed by all parts of the plant including the roots, therefore aeration of the nutrient solution may be required).
6. **The proper temperature and relative humidity** (specific to type of plant).
7. **Support systems** for the roots and shoots. For plants where the roots hang directly into the nutrient solution and do not provide any support for the plant, mechanical support may be needed. For an indeterminant tomato plant, support for the stem will be needed in the form of twine and vine clips.

TYPES OF HYDROPONIC SYSTEMS

Systems categorized by where the roots are located:

1. **Liquid Culture**: The roots are hanging into the nutrient solution which can be either in the form of a liquid or a mist.
2. **Aggregate Culture**: The roots grow into an inert medium such as sand, gravel, Rockwool, perlite, vermiculite, peat moss, foam, coconut coir, etc. and are then irrigated with a complete nutrient solution.

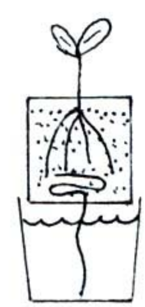
Systems categorized by what happens to the nutrient solution:

1. **Open:** The nutrient solution is distributed from a reservoir to the plants and is then "drained to waste" (i.e., not used again).
2. **Closed:** The nutrient solution is distributed from a reservoir to the plants. After passing through the root zone it is collected and reused. In large systems the solution may be analyzed, then modified by the additions of water, acid/base, and/or various inorganic elements to return the solution to the appropriate inorganic mineral composition (and EC) and pH. The solution may also be sterilized (UV light, ozone treatment, etc.) so that any plant pathogens, picked up in the solution from perhaps one or a few infected plants, are not subsequently spread to all of the plants.

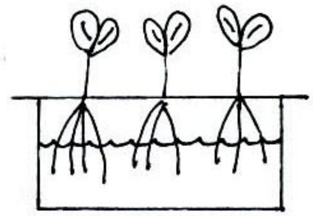
SYSTEM DESIGNS

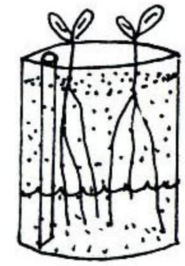
1. **The basic wick:** The roots grow down through an aggregate medium. A wick (absorbent material) is laced through the medium and hangs down into a reservoir and draws the nutrient solution up into the root zone.

   Type of system = Aggregate/Closed



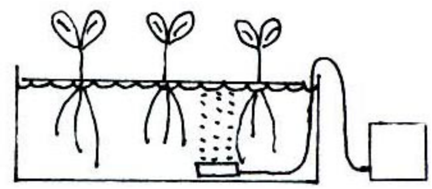
2. **The non-recirculating ("air-gap") system:** The roots hang into a nutrient solution reservoir, with the upper part of the root mass suspended in air (air roots to take up needed oxygen) and the lower part of the root mass in direct contact with the nutrient solution (water and nutrient roots).
   Type of system = Liquid/Closed
   Option: Aggregate/Closed



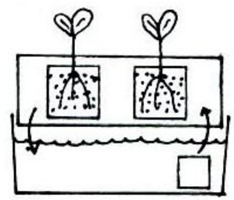


Aggregrate Option

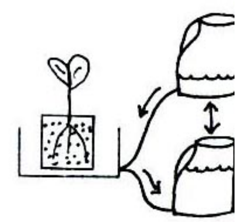
3. **The raft, float or deep flow system:** Plants are suspended through styrofoam boards which float on the surface of the nutrient solution. Oxygen must be supplied to the roots using an aquarium pump and air stones or a "venturi" system.
   Type of system = Liquid/Closed



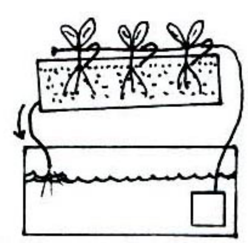
4. **The flood and drain (or ebb and flow) system:** The roots grow down through an aggregate. The nutrient solution is pumped into the aggregate medium, floods the root zone for a short time, and is then allowed to drain back into the reservoir.
   Type of system = Aggregate/Closed

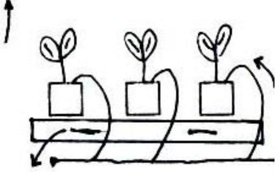


Manual Option

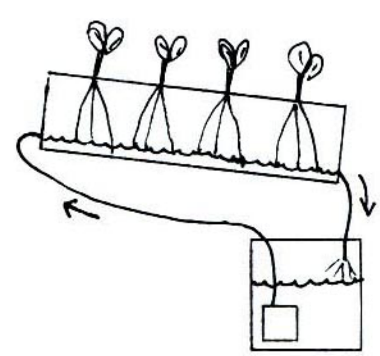


5. **The top feeder system:** The roots grow down through an aggregate. The nutrient solution is delivered to the top of the aggregate medium, percolates through and then either drains to waste or is recirculated into a reservoir.
   Type of system = Aggregate/Closed or Open

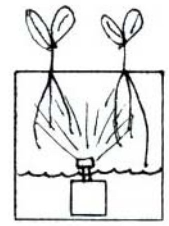




6. **Nutrient film (flow) technique (NFT):** The roots may be growing from Rockwool blocks or through cups filled with an aggregate for support but ultimately hang into a slightly slanted tube or trough. The nutrient solution is pumped to the higher end, flows past the hanging roots and then back to the reservoir.
   Type of system = Liquid-Aggregate/Closed



7. **Aeroponics:** The roots are suspended in an enclosed space and, at regular intervals, sprayed with the complete nutrient solution.
   Type of system = Liquid/Closed or Open



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CHAPTER 6

POLLINATION, FERTILIZATION AND BEE MANAGEMENT

INTRODUCTION

* **Types of crops chosen for greenhouse hydroponics** include tomatoes, colored peppers (especially yellows or golds), long cucumbers (also called "English", "European", seedless or burpless cucumbers), lettuce of various types and other "greens" used in specialty salads, and medicinals (of which many are root crops).

***For leafy crops or root crops** flowering is unwanted and suppressed. For example, most lettuces are cool weather crops and can be kept in the "vegetative state" (leaves, stems and roots only) if lower air and especially solution temperatures are used. High temperatures will cause "bolting" – an elongation of the main stem and subsequent flowering. This will also cause the leaves to become bitter and unpalatable. For more information on these crops see Chapter 2.

***Tomatoes and peppers** require pollination and fertilization for fruit development.

***Long cucumber fruit** develop the characteristic slender, smooth appearance because they are not pollinated. If the flowers are allowed to be pollinated the resulting cucumber fruit will be shorter, bulbous and irregular.

PLANT DEVELOPMENT

***Plant seeds germinate when moistened.**

*A "white root" or radicle emerges growing downward in response to gravity. Tomatoes, peppers and cucumbers all have a "tap root" type root system.

*A yellowish "plumular hook" grows upward. When it encounters light the hook straightens and the first seed leaves or cotyledons open and turn green. Tomatoes, peppers and cucumbers are all considered "dicotyledonous" plants. Dicots have two (di-) cotyledons or first "seed leaves".

***Tomatoes:** Leaves are compound and develop at each node.

7-12 leaves from the cotyledons, the apical meristem produces a flower cluster or "truss". After this there are usually 3 leaves between trusses.

The truss has a stout stem or peduncle which branches and ends in flowers.

There are usually 4-6 flowers per truss, but 1-2 or as many as 10 or more are seen.

In order to maintain an even fruit load and consistent harvest, clusters should be pruned to 3 to 5 fruit depending on environmental conditions.

The first fruit on each truss is called the "king" fruit.

***Peppers:** Leaves are simple and develop at each node.
7-12 leaves from the cotyledons, the growing point branches producing 1 – 2 flowers.
After this the plant branches at each node producing 0 – 2 flowers depending on various factors including nutrition, health of the plant, etc.
Each flower/fruit is borne on its own stem attached to the main stem of the plant at the branch point.
In order to maintain an even fruit load and consistent harvest, some fruit pruning may be required depending on environmental conditions, health of the plant, etc.
The fruit that develops at the first branch point is called the "crown" fruit.

***Cucumbers:** Leaves are simple and develop at each node.
Depending on variety, environmental conditions, etc., flowers may begin developing at the first few nodes.
In order to maintain an even fruit load and consistent harvest prune to 1 fruit/node. In northern or low light areas all initial flowers/fruit should be removed up to a height of 80 – 100 centimeters (2.6 – 3.3 feet) to encourage root growth that will later support fruit production. In high light more initial flowers/fruit may be left.
Each flower/fruit is borne on its own stem attached to the main stem at a node.

***For all plants:** The green leaves are "sources" of "photosynthate" (carbohydrates formed during photosynthesis) while the roots, growing tips and fruit are all "sinks" (where the photosynthate will be used for new growth and tissue metabolism).

*Note that if any plant is under stress (temperature, water, nutrient, etc.) or has too much fruit load, it will drop flowers and/or fruit to compensate.

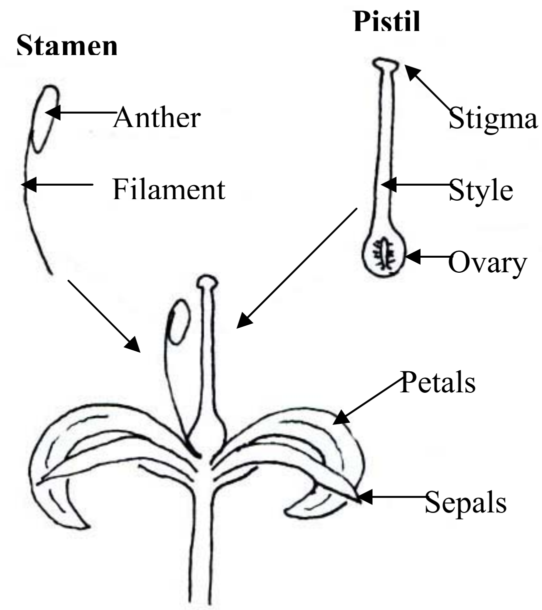
*Environmental stresses can be dealt with in the controlled environment of the greenhouse. However, fruit load needs to be controlled by the grower in the form of "fruit pruning" to maintain a balance between vegetative (leaf and stem) growth and reproductive (flowers and fruit) growth.

THE FLOWER

Tomatoes and Peppers:

*Flowers of these plants are "complete" (having 5 sepals, 5 petals, stamens and pistil).

- *Sepals = green leaf like structure (calyx)
- *Petals = bright yellow in tomatoes, white in peppers (corolla)
- *Stamens = male organ composed of the filament and anther (they surround the pistil)
- *Pistil = female organ composed of the ovary, style and stigma



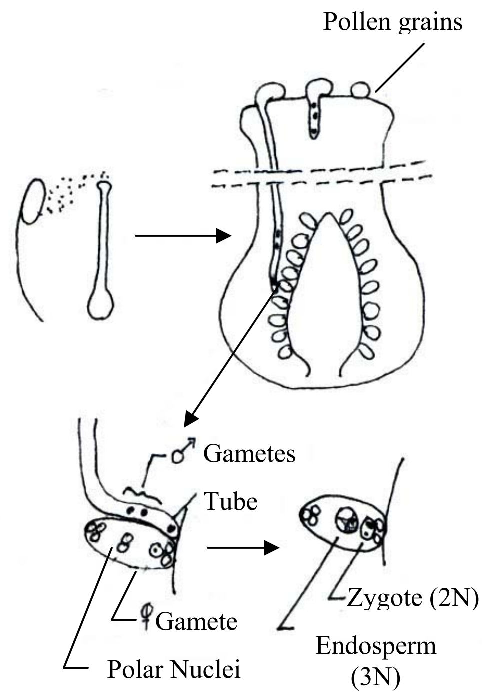
***Two processes must be completed in order to initiate fruit development:**

***Pollination** = transfer of the pollen from the male anther to the female stigma.
The pollen grains germinate.
The pollen tubes grow down the style to the ovary.

***Fertilization** = a two part process:

1. The union of one of the male gametes with the female gamete (ovule) = zygote (2N)

2. The union of the second male gamete with the 2 polar nuclei = endosperm (3N)



Cucumbers:

*Cucumber flowers are "imperfect" having only male or female flowers. Both male and female flowers are yellow with 5 petals.

*Male and female flowers are borne at nodes on the main stem; 3-5 per node for male flowers, 1-3 for female flowers.

*Male flowers have no pistils but 3 stamens, two with two anthers each and one with one anther.

*Female flowers have reduced and nonfunctional stamens but well developed pistils with three bilobed stigmas, a style and a three-chambered ovary.

*There are several different "sex types" in cucumber flowers and in cucumber plants (see Chapter 2, The Plant, for detailed descriptions).

*Since pollination/fertilization of flowers in long cucumbers is not wanted and will cause abnormally lumpy growth, most growers choose either a
"gynoecious" plant (with only female flowers), or a
"predominantly female" plant (with mostly female but some male flowers)

ENVIRONMENTAL CONDITIONS NEEDED FOR GOOD POLLINATION

*__Proper temperature and relative humidity__ are crucial for good pollination of tomato and pepper plants. Note that pollination is unwanted in long cucumbers, as described above. They will not be discussed here.

***Optimum conditions** will vary with crop chosen and with variety used.

*__Temperature:__ Overall, tomatoes will prefer cooler temperatures than peppers.
- *Above the optimum temperature range for a particular crop/variety
  - the pollen grains can be damaged and may not germinate or have enough energy for pollen tube growth.
- *Below the optimum temperature range
  - the growth of the pollen tube will be slowed and the pollen grain may run out of energy before reaching the ovary.

*__Relative Humidity:__ A typical optimum range for many crops is 60 – 80 %.
- *Above the optimum RH range
  - the pollen may be too sticky to release properly from the anthers, or
  - the pollen grains may clump on the surface of the stigma resulting in uneven pollination and fertilization.
- *Below the optimum RH range
  - the pollen grains may become desiccated, or
  - the stigma surface may be too dry for the pollen grains to stick to it.

*__Light:__ Several days of cloudy weather can slow the development and germination of the pollen which can cause poor fruit set.

*__Example: Tomato__

Optimum temperature range for "Trust" tomatoes:	60 – 85F
Optimum relative humidity range for "Trust" tomatoes:	60 – 80%
Optimum light levels:	Sunny

ABOUT POLLINATION

*Pollination must be done when the flowers are "receptive".
In tomatoes the petals are curled back, in peppers the flowers are fully open.

*Tomato flowers are usually receptive for two days, therefore pollination should take place at least every other day.

*Flowers outside are normally pollinated by wind, bees, etc. In the greenhouse they must be pollinated by other means including flicking or tapping the flowers by hand or by using a vibrator such as an electric toothbrush or a hand-held battery-operated pollinator. However, in a large commercial facility, bees are used (see below).

*Problems with pollination and/or fertilization can cause fruit disorders such as:

Cat facing: the pollen is not evenly distributed on the stigma such that a section of ovules does not get fertilized. Since hormone secretion from the developing seeds is what causes fruit development, sections of the fruit do not develop resulting in "holes" in the fruit with unfertilized ovules visible.

POLLINATORS FOR GREENHOUSE VEGETABLE PRODUCTION

***Bumble bees** are used routinely for pollination of tomatoes, peppers, blueberries, strawberries and other small fruit and orchard crops.

NOTE: Research has recently been proposed to test the effectiveness of native Southwestern carpenter bees as pollinators for greenhouse vegetable crops.

The species *Bombus impatients (native to the Eastern United States) is available from several companies but are reared by the Dutch company "Koppert Biological Systems, Inc." (28465 Beverly Rd., Romulus, MI 48103 1-800-928-8827).

***The hives** contain 50 – 100 worker bees to pollinate the crop, a laying queen and a developing brood. They are called "NATUPOL" hives for "Natural Pollinators".

***There are two standard sizes of hives**:

Class "B" hive: Used in greenhouses of 5,000 to 15,000 sq.ft.
These last 6 – 10 weeks before needing replacement.

Class "A" hive: Used in greenhouses of 15,000 sq.ft. to half an acre.
These last 8 – 12 weeks before needing replacement.

***Ship bees** "next day air" and keep them between 60 and 80 F until they are placed in the greenhouse (greenhouse temperatures should be suitable for them).

***DO NOT TAP ON THE BOX!** This disturbs the bees. Remove the box top to view the bees through the plastic top. There is cotton insulation covering the comb.

***Placing the hive:**

*Place the hive on a stable, horizontal stand or bench between the plants at the beginning of an aisle.
*Shade from direct, bright sunlight, especially if greenhouse temp. is above 85F.
*Do not put hive near fans. Use a minimum of ¼" mesh screen to protect bees.
*Direct hive entrance away from where people gather to avoid "conflicts".
*Keep hive away from carbon dioxide sources. High levels reduces bee activity.
*Ants can be attracted to the hive. Protect the hive from ants.

1) Apply glue or grease to the legs of the hive support.
2) Remove routes such as overhanging leaves.
3) Place the hive supports in containers of water to create a barrier.

*__Once the hive is placed__ in a secure location:

*Open the flight door (a plastic plate on the side of the box). Push/pull the plate upwards until the lower two flight holes are open.

NOTE: Because this bumble bee is not native to the southwest the holes are slits, big enough for the workers to get out but too small for the queen. These are called "queen excluder doors".

NOTE: Hives come with a plastic mesh over the exit door. It will take the workers 30 – 60 minutes to chew through this. This will give the bees time to acclimate to their new surroundings and will give the grower time to vacate the area before the bees begin to emerge.

*If the flight door is pushed down part way, one hole will be open. This is called the "bee home" position. Due to the engineering of the holes, once a bee enters this single hole it can not get back out. Within 1 – 2 hours after setting the flight door in the "bee home" position all bees should be back in the hive. (This is important if the hive must be moved.)

*Pushing the flight door all the way down closes the hive completely.

NOTE: Remember to re-open the flight door so the bees can forage. Forgetting this can kill the colony!

*__The bees find "receptive" flowers__ (the pollen is mature and ready to shed) by smell. The bees will only visit receptive flowers.

*__The bumble bee pollinates a flower__ by clamping onto the anther cone with its jaws and then rapidly shaking the flower – called "buzz pollination". Within a few hours a pair of dark spots will appear on either side of the anther cone where the bee clamped on.

*__Pollination and subsequent fertilization__ of flowers happens "by accident" as the bees collect pollen to feed themselves, the queen and the developing brood.

*__Tomato and pepper flowers__ are "self pollinating". Pollen from the anthers can be transferred to a stigma on the same flower and pollination/fertilization will take place. (As opposed to "obligate outcrossers" that require the pollen from flowers on one plant to be transferred to stigmas on flowers of another, separate, plant.)

*__Check the "pollination percentage"__ (a count of how many flowers are being visited) as often as twice a week.

1) Either remove 30 – 50 flowers that have closed within the last day OR observe 30 – 50 flowers while still on the plants.
2) Check for the dark spots on the anther cones that indicate bee visitation.
3) Pollination percentage = # of marked flowers/total # of flowers counted x 100.
4) Pollination percentage should be 80 – 100%.

***Low pollination percentage** may be due to:

*Toxic chemicals that kill the bees.

*High temperatures (above 85F). Bees will stay in the hive to fan the brood and keep them cool.

*Low temperatures (below 60F). Bees will stay in the hive to keep the brood warm.

*Too many flowers for the size of hive (purchase the proper number of hives) or too many flowers due to a bright period following a cloudy period which causes a flush of flowers (the bees will catch up within a couple of days).

*An expired hive (see above under “Sizes of hives”).

*NOTE: If a hive is placed into a small greenhouse (less than 5,000 sq.ft.) or a hive is obtained before enough flowers are open there may be more bees that can be accommodated by the number of flowers present. The anther cones will appear brownish black and withered. In this case, food grade bee pollen from a health food store can be introduced onto the center of the plastic top cover (1 teaspoon to 1 tablespoon every few days). Store extra pollen in a freezer.

***When using bees** chemical pesticides should not be used in the greenhouse. Bees are very sensitive to pesticides. However, if surfactants, neem extract or other organic compounds need to be applied, set the flight door in the “bee home” position at least 2 hours before closing the door. Then remove the hive to a safe, stable location between 65 – 70F but not for more than 3 days. Make sure the hive is returned to the same location and orientation in the greenhouse and the flight door is opened.

***Bee stings:**

To avoid stings:

DO NOT use strong smelling compounds including alcohol, perfume, scented soaps or deodorants or other chemicals. Bees are sensitive to smells.

DO NOT move quickly near the hive. Bees are agitated by rapid movements.

DO NOT stand in from of the hive or in their flight path. The bees may run into you, become confused and sting you.

If someone is stung:

Make sure the person is not allergic to bee stings (if so call for medical help).

Applying a cold pack tends to reduce swelling and pain.

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3. **Hydroponic Food Production.** 2001. H.M. Resh. Woodbridge Press Publishing, P.O. Box 209, Santa Barbara, CA, 93160. ISBN 0-88007-222-9
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CHAPTER 7

PLANT NUTRITION AND NUTRITIONAL DISORDERS

INTRODUCTION

***Fresh plant material is usually made up of between 80 and 95% water** (depending on plant species and turgidity of the plant – and that depends on time of day the sample was taken, the amount of water available to the roots, temperature, wind velocity, etc.).

***Plants require certain elements** (referred to as mineral nutrients) for growth.

***These elements are usually taken up by the roots in their ionic form** (an element or compound that has an electrical charge).

***So far, there are 16 elements that have been found to be essential for plant growth.** Early researchers in plant nutrition established 3 criteria for an "essential element":

1. The plant can not complete its life cycle without the element.
2. Action of the element must be specific – no other element can substitute for it.
3. The element must be directly involved in the nutrition of the plant.
    a) As a structural component or constituent of an essential metabolite.
    b) Required for the action of an essential enzyme.

***The plant uses these 16 elements along with light in the process of "photosynthesis" to create all of the other compounds it needs** including carbohydrates (sugars), proteins (structural, enzymes, etc.), vitamins, fats, etc. NOTE: Animals do not perform photosynthesis and therefore have to ingest all of these, including mineral nutrients.

PLANT MINERAL NUTRIENTS AND THEIR FUNCTIONS

Nutrients absorbed in large amounts from the air, water and soil.

1. **Carbon:** All life on Earth is considered to be "carbon based" – all carbohydrates, proteins and fats are composed of a backbone of carbon atoms. The carbon atoms in all living things initially come from the air in the form of carbon dioxide and are "fixed" into plant carbohydrates through the process of photosynthesis (photo = light, synthesis = to make; or to make compounds using the energy from light).
    Deficiency Symptoms: Not usually a problem with abundant carbon dioxide (CO_2) in the atmosphere. HOWEVER, in a closed greenhouse during winter, or early in the morning before the vents open, plants can use up enough CO_2 such that the reduced level reduces growth. Carbon dioxide enrichment is advised using a CO_2 generator (burns natural gas).

2. **Oxygen:** This element is also a part of all carbohydrates, proteins and fats and is therefore critical. It is also required for the metabolic process of respiration. Both plants and animals take in oxygen from the air, use it to "burn" or metabolize molecules in order to form energy, and then give off carbon dioxide. Plants also take in oxygen as part of water molecules (H_2O) and as part of the ionic forms of the mineral nutrients (e.g., $MgSO_4$). In a hydroponic system, where the roots can be submerged in nutrient solution, this is most important. If the roots are completely submerged, oxygen must be supplied by aeration of the solution.
   Deficiency Symptoms: Respiration will be curtailed and the tissue will die. In roots this appears as browning followed by rotting of the roots.

3. **Hydrogen:** This element is also a part of all carbohydrates, proteins and fats and is therefore critical. It is derived from water molecules (H_2O) and is part of the ionic forms of the mineral nutrients (e.g., KH_2PO_4). This element, in and of itself, should never be limiting.
   Deficiency Symptoms: Usually, not a problem.

MACROELEMENTS: Nutrients required in large amounts and absorbed from the soil or a complete hydroponic nutrient solution.

4. **Nitrogen:** Elemental nitrogen (N_2) in the air can not be utilized by plants. In nature N_2 must first be "fixed" into the nitrate or ammonium forms by certain bacteria that live in association with "legume" plants (the pea and bean family which includes clover, alfalfa, mesquites, etc.). These "fixed" forms of nitrogen can then be absorbed through the roots as part of such molecules as ammonium nitrate (NH_4NO_3), potassium nitrate (KNO_3) and calcium nitrate ($Ca(NO_3)_2$). What we use in hydroponics are chemical fertilizers where the nitrogen is already fixed. Nitrogen is also available to the plant roots over a wide range of pH's.
   Overall function: This element is a part of every "amino" acid and therefore every protein. It is also a part of nucleic acids (RNA and DNA) and the chlorophyll molecule (necessary for photosynthesis). Nitrogen stimulates above-ground growth (stems and leaves) and helps the plant produce the "healthy green" color. It also stimulates the increase of proteins in fruits and grains and helps in the utilization of other nutrients including phosphorus and potassium.
   Deficiency Symptoms: Nitrogen is highly translocatable, therefore, deficiency symptoms will appear first on the older growth. Growth is restricted. Leaves become light green, then yellow (chlorotic), then die. Stems, petioles and lower leaf surfaces of corn and tomato can turn purple.
   Toxicity Symptoms: Too much nitrogen in the soil or nutrient solution will cause the plant to be dark green with abundant foliage but a restricted root system, few blossoms and a restricted fruit set. There can also be a build up of nitrites in the plant tissue that can cause the plant to be more susceptible to disease BUT can also be harmful to the animals, including humans, who eat the plants.

5. **Phosphorus:** This element, like nitrogen, can not be absorbed by the plant in its elemental form, but first must be combined to form the orthophosphate ion ($H_2PO_4^-$). A typical compound used in hydroponic solutions that contains phosphorus is monopotassium phosphate (KH_2PO_4). In soilless mixes, increasing pH may limit the availability of phosphorus to the plant

   Overall function: Phosphorus is part of the "energy currency" of the cells of all living things (ATP, etc.). It encourages root development, encourages rapid strong growth, hastens the maturity of plants and stimulates blooming. By promoting early cell development it helps the plant build resistance to disease.

   Deficiency Symptoms: Phosphorus is highly translocatable so deficiency symptoms will appear first on older growth. Leaves, and later stems and petioles, turn dark bluish-green changing to purplish in color on the lower surfaces. There may also be a "silvery tinge" on the underside of the leaves and the leaves may curl downward. Plants are slow to develop, flowering may be delayed, the root systems may be poorly developed and plants may be more susceptible to infection.

   Toxicity Symptoms: No direct effects are known. However, excess phosphorus in a hydroponic nutrient solution, if the solution has a pH below 5.5, may be converted into a precipitate that could effect the uptake and translocation of iron, zinc or copper (which could cause deficiencies of these "micro" elements – see below).

6. **Potassium:** This element is found in its ionic form (K^+) in the soil solution or in a hydroponic nutrient solution. This is also the form that the plant can absorb. Changes of pH do not effect the availability of potassium to the plant.

   Overall function: Potassium acts as a catalyst or activator of certain enzymes. It helps encourage healthy root development and has a lot to do with the vigor and health of the overall plant. It may participate in organic salt transport and storage and is critical in controlling the turgor of the guard cells of the stomates (pores through which water leaves the plant (transpiration) and though which gases (oxygen and carbon dioxide) pass (i.e., gas exchange). It also enhances the translocation of magnesium and photosynthates through the phloem.

   Deficiency Symptoms: Potassium is highly translocatable, therefore deficiency symptoms will appear first on older growth. Enzyme reactions are inhibited which leads to poor growth, weak root systems, weak stems and may contribute to a reduced tolerance to drought, frost, fungal attack and/or salinity. In dicot plants chlorotic (yellow) then necrotic (dead) areas appear on the leaves. In monocots the tips and edges of the leaves die first. The stomates do not function properly and may not open in the light resulting in reduced transpiration and gas exchange. In tomatoes low potassium in relation to nitrogen may cause blotchy fruit ripening and/or fruit cracking.

Toxicity Symptoms: Potassium is not usually absorbed in excessive amounts. However, high potassium may cause calcium, magnesium and perhaps manganese, zinc and/or iron deficiencies.

7. **Calcium:** This element is found in its ionic form (Ca^{++}) in the soil solution and in a hydroponic nutrient solution. This is also the form that the plant can absorb. Acidification of the nutrient solution when using soilless mixes can cause a slight reduction in the availability of calcium to the plant.

    Overall function: In the cell, calcium can combine with bicarbonate to form the base, calcium bicarbonate, that is an effective neutralizing agent for acids formed during cellular metabolism. Calcium is also an activator of the enzymes amylase and ATPase. A primary role for calcium is as a cementing or cross-linking agent within the plant cell walls that adds to the general vigor and strength of the plant.

    Deficiency Symptoms: In its role as a cell wall cross-linking agent, calcium is not translocatable. Therefore, deficiency symptoms tend to appear first in the new growth. Apical meristems (shoots and roots) show misshapen, poor or no growth. The "terminal bud" may be "hooked", the stems weakened and flowers/buds may drop off. Older leaves may be downturned with marginal chlorosis. In tomato fruit calcium deficiency is expressed as "blossom end rot", a leathery brown patch on the blossom end of the fruit. In lettuce, an increase in tip burn may result. Since calcium is moved up the plant via the water stream in the xylem (a result of "root pressure" and "transpiration"), conditions that slow that water movement (i.e., problems with absorption at the root or low transpiration and/or humid condition surrounding the leaf surfaces) will slow the movement of calcium and cause calcium deficiencies.

    Toxicity Symptoms: None consistent. However, any symptoms are usually associated with high carbonate levels ($CaCO_3$ formation).

8. **Magnesium:** This element is found in its ionic form (Mg^{++}) in the soil solution and in a hydroponic nutrient solution. This is also the form that the plant can use.

    Overall function: Magnesium is the heart of the complex ring molecule called "chlorophyll", the green pigment used in plants to absorb radiant energy (from a natural (e.g., the sun) or artificial light source) that drives the process of photosynthesis. Magnesium also combines with ATP and ADP and acts as a "metal activator" for enzymes that use these two substrates. Magnesium also activates enzymes needed in photosynthesis, respiration and the formation of DNA and RNA.

    Deficiency Symptoms: This element is easily translocatable and therefore deficiency symptoms appear first in the lower parts of the plant. With less chlorophyll formed the lower leaves show interveinal chlorosis (yellow to white color between the veins) and finally necrosis (death). Leaves are often brittle and tend to curl upward. A reduction in enzyme activity causes reduced growth.

    Toxicity Symptoms: Very little information is available.

9. **Sulfur:** Sulfur must be oxidized (i.e., in the sulfate form – $SO4^{=}$) in order to be absorbed by plants. Absorption does not appear to be effected by solution pH.

   Overall function: Sulfur is an integral part of two amino acids, cysteine and methionine. Amino acids are the building blocks of proteins and the sulfur atom serves in the formation of "disulfide bonds" or "sulfur bridges" which aid in the conformation or structure of proteins. These proteins are critical to all metabolic processes of the plant cell.

   Deficiency Symptoms: This element is only moderately translocatable and therefore deficiency symptoms occur in younger parts of the plant. Since sulfur is critical to protein synthesis, a deficiency of sulfur will cause a reduction of protein synthesis and all molecules dependent upon them, including chlorophyll. Therefore, middle or younger leaves will show chlorosis. Stems and roots will have smaller diameters but will increase in length and the root system will be more massive and invasive than normal. Stems may also be rigid and brittle.

   Toxicity Symptoms: Excesses of sulfur may cause a reduction in growth and leaf size as well as interveinal chlorosis or burning of the leaves.

MICRONUTRIENTS: Elements required in small amounts and absorbed from the soil or a complete hydroponic nutrient solution.

10. **Iron:** This element can be added in several forms: ferrous sulfate, ferric chloride or iron chelate (a "metal" atom bound to an organic compound by two or more bonds forming a ring structure, e.g., Sequestrene). The latter is expensive but the best source of iron. pH is critical for iron availability. A solution that is especially too basic (above about 8) can cause problems in uptake. Also, a solution too acidic or basic (or even neutral - pH 7) can cause the iron and phosphate to combine forming an insoluble iron phosphate precipitate (Fe_2PO_4 – a whitish compound that will settle to the bottom of the tank and no amount of mixing or heating will dissolve it). Best pH: 5.6 - 6.6. Note that iron can also be applied as a foliar spray.

    Overall function: Iron is involved in enzyme activation as a catalyst, in redox reactions and electron transfer, and it acts as an oxygen carrier. It is involved as an enzyme activator or cofactor in the synthesis of chlorophyll, and in the functioning of several other enzymes including catalase, peroxidase, ferredoxin and the cytochromes. It is therefore crucial for chlorophyll production, protein synthesis and respiration. In legume plants, iron is important in nitrogen fixation.

    Deficiency Symptoms: Since iron is usually bound (chelated) to various compounds in the plant it is fairly immobile. Therefore, symptoms appear first on the young growth in the form of interveinal chlorosis.

    Toxicity Symptoms: Not usually seen. However, if foliar applications of iron are used in excess, necrotic (dead spots) on the leaves may appear.

11. **Manganese:** This element is actively absorbed by plant roots as the manganous ion (Mn^{++}). It can also be applied in a foliar spray as an inorganic ion or in the chelated form. Manganese is best absorbed by plant roots at lower pH's (less than 6.5).

Overall function: Manganese is involved in enzyme activation as a catalyst in carbohydrate reduction, chlorophyll formation, and RNA and DNA synthesis. It is important in energy storage metabolism and directly involved in the production of oxygen during photosynthesis. It also oxidizes excess iron in the plant.

Deficiency Symptoms: Interveinal chlorosis is evident and similar to that for magnesium, except that manganese is relatively immobile, therefore symptoms appear in the younger growth first. Symptoms may also be confused with those for zinc or iron. In advanced cases necrotic spots and leaf shedding may occur, however the veins always remain green. Flower formation is reduced or halted and growth is erratic.

Toxicity Symptoms: Brown spots in the older foliage, sometimes chlorosis and uneven chlorophyll distribution may be evident. High manganese levels may cause iron deficiency. There is usually an overall reduction of growth.

12. **Boron:** This element is probably taken up in the undissociated boric acid form. It is best taken up from a solution that is below about pH 6.5.

Overall function: Boron seems to be related to the metabolism of calcium and potassium. It is used to regulate carbohydrate metabolism and is involved in RNA synthesis.

Deficiency Symptoms: Boron seems to be very mobile within the leaf but is not translocated back down the phloem to the stem. Therefore, it is not translocatable within the plant and younger growth shows symptoms first. Shoots show abnormal or retarded growth, then blackening, and both shoots and roots tend to die back. Stems and petioles may be brittle and develop cracks. Young leaves may appear thick and curled. Flowering and fruiting are restricted or inhibited. Typical rots of fruits and vegetables may be attributable to boron deficiency.

Toxicity Symptoms: This can be a problem in arid and semi-arid regions where the ground water can have high boron levels (as much as 0.8 ppm). Levels in the final nutrient solution should be around 0.44 ppm. Toxicity symptoms may appear as deficiencies. Also, leaf tip chlorosis may be followed by necrosis starting at the tip or margins and progressing inwards.

13. **Zinc:** Uptake of zinc into the plant appears to be an active process and it may compete with copper, manganese and iron for the same carrier. Zinc uptake is not as pH sensitive as that of manganese or boron. However, it does appear to be related to light availability, more light resulting in more zinc uptake.

Overall function: Zinc is an enzyme activator and involved in protein, hormone (i.e., IAA) and RNA/DNA synthesis and metabolism and in ribosome complex stability.

Deficiency Symptoms: Zinc deficiencies can be induced by high levels of phosphorus, nitrogen, copper or iron. Symptoms can include abnormalities in the roots and shoots with a general stunted appearance. Internode length and leaf size may be reduced. Leaf edges can be puckered or distorted. Since this element is not easily translocatable, apical or younger growth is inhibited. However, both young and older leaves can show interveinal chlorosis (pale green, yellow or even white).

Toxicity Symptoms: There may be a reduction in leaf expansion and root growth with high levels of zinc resulting in iron deficiency symptoms (i.e., interveinal chlorosis).

14. **Copper:** Uptake into the plant in the ionic form (Cu^{++}) appears to be an active process and can be inhibited by zinc. Copper uptake does not appear to be as sensitive to pH changes as does manganese or boron.

Overall function: Copper is involved in chlorophyll synthesis with nearly 70% of all copper in the leaves found in the chloroplasts. It is also a constituent of plastocyanin, a chloroplast protein that is part of the photosynthetic electron transport system. Copper is also a constituent of several oxidases (enzymes that catalyze oxidation-reduction reactions). It may play a role in elemental nitrogen fixation in legumes and in the production of vitamin A. It may also be involved in RNA and DNA synthesis.

Deficiency Symptoms: Since this element is not easily translocatable symptoms appear first in the younger tissue. These can include short stem internodes with resulting death of the tip, stunting and/or twisting of new leaf growth with dark green to bluish-green coloration and necrotic spots, a loss of turgor (firmness) in the leaves and stems, stunted root development and a reduction of flowering and fruiting. Severe copper deficiency may be similar to potassium deficiency. Copper deficiency may also be caused by excesses in phosphorus.

Toxicity Symptoms: High levels of copper can displace iron causing the iron deficiency symptom interveinal chlorosis. Other symptoms include overall reduced growth and stunting as well as thickening and darkening of the roots. Copper tubing and fixtures should be avoided in irrigation systems to reduce the input of unwanted copper.

15. Molybdenum: This element is needed in the smallest amounts of all the mineral elements and is absorbed into the plant in the molybdate form ($MoO_4^{=}$). Uptake can be inhibited by sulfate ions and low pH, but enhanced by phosphate ions. Foliar sprays of 0.5% ammonium molybdate can be used on vegetables.

Overall function: Molybdenum is involved in nitrogen metabolism as a part of the nitrogenase enzyme (nitrogen fixation in legumes) and as an electron carrier for nitrogen reductase (the enzyme responsible for nitrate reduction). It is also involved in carbohydrate metabolism.

Deficiency Symptoms: Since this element is somewhat translocatable within the plant, symptoms usually start with the older growth and progress to younger growth. This includes interveinal chlorosis, similar to nitrogen deficiency, mottling and sometimes marginal scorching or inward cupping of the leaves. Chlorotic areas may turn puffy and severe stunting may occur in advanced stages.

Toxicity Symptoms: This is rarely seen but tomato leaves can turn yellow while cauliflower seedlings will turn bright purple.

16. Chlorine: This element is actively taken up by plant roots in the chloride (Cl^-) form.

Overall function: Though required by plants in small amounts, chloride is now known to have many roles in plant growth. It is an activator for the enzyme that releases oxygen from water during photosynthesis. It also appears to be involved in respiration. Recent preliminary studies indicate that "adequate" levels of chloride in the nutrient solution may reduce the amount of nitrogen required without effecting plant growth or yield. The negatively charged chloride "anion" also acts as a counter ion to the positively charged "cations" in the cell. Chloride is involved in regulating turgor pressure and growth of cells and is important in drought resistance. Chloride may also be beneficial in disease prevention, especially of the roots, by promoting healthy growth of the plant while creating a root zone environment (pH and osmotic properties) detrimental to pathogens (disease causing organisms).

Deficiency Symptoms: Since chloride is mobile within the plant, symptoms appear first on the older growth. Leaves will become chlorotic and finally necrotic with leaf area being reduced. Wilting is common and transpiration can be reduced. There is an overall stunting of the plant and subsequent die back.

Toxicity Symptoms: High amounts of chloride produce typical "salt stress" or salinity effects including leaf tip or edge burning, chlorosis, "bronzing" and premature leaf drop.

NOTE: Tomatoes are highly tolerant of high levels of chloride ion and recent use at almost "macronutrient" concentrations in the nutrient solution are proving beneficial.

OTHER NUTRIENTS: Elements that have been found in plant tissue and are most likely required by some plants in some amounts for growth.

1. **Sodium:** Essential for some C4 plants – may increase PEP carboxylase activity.
2. **Silicon:** May be involved in cellulose formation and carbohydrate metabolism. Seems to protect against insects, diseases and many environmental stresses. Beneficial for C4 and CAM plants.
3. **Cobalt:** Required by nitrogen fixing bacteria in legume plants.
4. **Vanadium:** Essential for a green alga. Toxic in high amounts in water culture.
5. **Iodine:** Stimulates growth at low concentrations, but toxic at high levels.
6. **Bromine:** Can substitute in part for chloride. Toxic to some plants producing salt stress symptoms. Tomato and some others are insensitive to high levels.
7. **Fluorine:** Toxic to most plants. However, some plants accumulate it and the resulting “fixed” form is toxic to animals. Commercial teas have high levels.
8. **Aluminum:** Required for normal growth of the tea bush. There are tolerant species but, in most plants, aluminum is toxic.
9. **Nickel:** May be required by nitrogen fixing plants and others that use urea as a nitrogen source. Toxic to other plants.
10. **Selinium:** Has been seen at high levels in certain milk vetches (*Astragalus*). Resembles sulfur in its chemical properties, but is toxic to most plants.

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CHAPTER 8

FERTIGATION SYSTEMS AND NUTRIENT SOLUTIONS

INTRODUCTION

*Plants can tolerate a wide range of watering and nutritional conditions…
However…for a commercial operation,
the bottom line is profit which means optimizing plant growth and yield.

*Optimum watering and mineral nutrition are critical for optimum plant growth.

*Optimum watering and nutritional conditions can vary
For different plant species
For the same plant species at different times of its life cycle
For the same plant species at different times of the year
For the same plant species under different environmental conditions

*This chapter describes
Properties of the nutrient solution
The physical systems required to deliver the nutrient solution to the plants
How to calculate how much of each compound to use

DEFINITIONS

***Irrigation =** The supplying of water to dry land using ditches, pipes, streams, etc.

***Fertilizer =** Inorganic "salts" containing the essential macro and micro elements necessary for plant growth (see Chapter 7). Also organic compounds that contain such elements (i.e., manure, fish emulsion, bat guano, etc.) that, when added to the soil or water, increase it's "fertility".

***Fertigation =** The use of fertilizers (usually inorganic for commercial greenhouse hydroponics and smaller systems, though some hobbyists use organic mixtures), in the appropriate combination, concentration and pH, for every irrigation cycle.

***Nutrient solution recipe =** A list of inorganic compounds, and their final concentrations in **ppm** ("parts per million" or "milligram per liter") or mMol (millimole), etc. This can also include actual amounts of the compounds needed to achieve the prescribed concentrations, given specific tank volumes, dilution factors, etc.

NUTRIENT DELIVERY SYSTEMS

***Simple systems:**

Non-recirculating/air gap system or the raft system (see Chapter 5) where the roots hang down directly into the nutrient solution.

Basic wick system (see Chapter 5) in which the nutrient solution is drawn up by an absorbent wick into an aggregate where the roots grow.

***Complex systems:**

The flood and drain, top feeder, NFT or Aeroponic systems (see Chapter 5) all of which require pumps to move the nutrient solution from a reservoir or series of tanks to the plants via PVC, poly and drip tubing, emitters, etc.

See attached: SYSTEM DESIGN: INJECTOR SYSTEM/BAG CULTURE

NUTRIENT SOLUTIONS

***The importance of good quantity/quality water for hydroponic plant production:**

Any hydroponic nutrient solution begins with the "source water".

A grower can obtain **source water** from

- City water supply
- Private wells
- Water harvesting (channeling rain water into catchments)

The source water must have the appropriate **quantity and quality.**

Quantity: There must be sufficient water available for plants and for cooling.

Ex: For tomatoes in greenhouse hydroponics:

~4 liters/plant/day

or if 2.5 plants/m^2, then 10 liters/m^2/day.

If evaporative cooling is used, especially in desert areas, water needs may be doubled!

Quality: Factors to consider include pH, EC (salt levels) and contaminants:

pH: The p(otential of) H(ydrogen): Acid or base character of the water.

$pH = -\log [H^+]$ (neg. log of the H^+ conc.) Scale = 0-14

Ex:
- If $[H] = 10^{-7}$, then pH = 7 (Neutral)
- If $[H] = 10^{-4}$, then pH = 4 (Acidic)
- If $[H] = 10^{-9}$, then pH = 9 (Basic)

Ways to test the pH: Litmus paper (color change)
pH meter (analog or digital)- meas. $[H^{+}]$

For most plants: pH 5 – 7. **For tomatoes: 5.8 – 6.3**

Above pH 7 may cause problems with nutrient uptake.

Below pH 5 may cause abnormal absorption of certain ions resulting in deficiencies or toxicities.

EC (Electrical conductivity): a measure of the total salts in water.
Pure water (no salts) does not conduct electricity: EC = 0.
The higher the salt levels, the higher the EC.
Measured in: mS/cm (milli-Siemens per centimeter)
TDS (total dissolved solids)
For tomatoes: EC = 2.5 – 3.5 mS/cm
(depends on light, plant architecture desired, etc.)

Elevated salt levels:
Certain geographic areas have high salt levels in the water.
High boron, fluoride, chloride, sulfates and sodium:
-Can cause poor plant growth.
-May influence soluble salt levels in the water.
High iron, especially in "hard water" (having high Ca and Mg):
-Can cause rusty spots on leaves with overhead irrigation.
High salt levels can also cause rapid salt buildup on cooling pads.
-May need to bleed off and replace pad water regularly.

Heavy metal contaminants:
Certain geographic areas have high levels in the soil and/or water.
High lead, cadmium, aluminum, silver, etc.:
-May be excluded or absorbed on a limited basis by plants.
-May be absorbed and stored (but not toxic to the plants).
Ex: Vegetables grown in Colorado mining areas
contain excess lead and cadmium!
-May be toxic to the plants.

The QUALITY of the water MUST BE ASSESSED by an ANALYSIS
Several labs across the country analyze source water. Ex: CropKing (5050 Greenwich Rd. Seville, OH 44273, 800-321-5211, www.cropking.com) has a service: You send a sample of your source water to a specific lab. CropKing gets the results and sends you specific instructions on how to make up your nutrient solution including any adjustments for pH, etc.

***Mineral elements or nutrients:** 16 elements required for plant growth (see Chapter 7)
Elements from air and/or water: C, O, H
Elements from the soil/nutrient solution:
Macros: N, P, K, Ca, Mg, S Micros: Fe, Mn, B, Zn, Cu, Mo, Cl

The 13 essential mineral elements can be obtained in the following compounds:

$MgSO_4$*7 H_2O (Magnesium Sulfate)	H_3BO_3 (Boric Acid)
KH_2PO_4 (Monopotassium Phosphate)	$MnCl_2$*4H_2O (Manganous Chloride)
KNO_3 (Potassium Nitrate)	$CuCl_2$*2H_2O) (Cupric Chloride)
K_2SO_4 (Potassium Sulfate)	MoO_3 (Molybdenum trioxide)
$Ca(NO_3)_2$ (Calcium Nitrate)	$ZnSO_4$*7H_2O (Zinc Sulfate)
	Fe 330 – Sequestrene (chelated iron)

In solution these compounds dissociate into ionic forms (see Resh or a chem. book):

Ex: $MgSO_4$ dissociates into the **cation** Mg^{++} and the **anion** $SO_4^{=}$

Ex: KNO_3 dissociates into the **cation** K^+ and the **anion** $NO3^-$

Ex: $CuCl_2$*$2H_2O$ dissociates into the **cation** Cu^{++}, the **anions** $2Cl^-$ plus 2 H_2O

***Nutrient interactions:**

Plants maintain a balance between the **cations** (positively charged ions) and **anions** (negatively charged ions) in their cells and tissues.

NOTE: In a chemical equation the cations are listed first, then the anions.

Plants also maintain a constant sum of **cations** in their cells and tissues.

Therefore, if one cation is increased, it may decrease the uptake of others.

Ex: Increasing Mg^{++} can cause decreases in Ca^{++} and calcium deficiencies.

Ex: Increasing $NH4^+$ (to increase acidity) can cause decreases in Ca^{++} uptake.

Interactions between **anions** are not as common.

Ex: Increasing Cl^- can decrease $NO3^-$ uptake and visa versa.

***Nutrient uptake rates and mobilities:**

Plant roots take up mineral nutrients at different rates.

Ex: NO_3^-, K^+ and Cl- are taken up quickly; Ca^{+2} and SO_4^{-2} are taken up slowly.

This results in unequal removal of nutrients from the solution.

Once in the plant different ions have different mobilities within the plant.

Ex: Mobile ions include N, K, P (PO_4^{-2}), Mg and Cl.

Deficiency symptoms for these ions usually appear in the old growth.

Slightly mobile ions include S (SO_4^{-2}), Mn and Mo.

Deficiency symptoms usually appear in the middle and old growth.

Immobile ions include Ca, B, Zn, Fe and Cu.

Deficiency symptoms for these ions usually appear in the new growth.

***Recommended nutrient levels (ppm) according to plant species (Agrodynamics):**

CROP	**N**	**P**	**K**	**Mg**	**Ca**
Tomatoes	200	50	360	45	185
Cucumbers	230	40	315	42	175
Peppers	175	39	235	28	150

However, several crops can grow perfectly fine on the same nutrient solution.

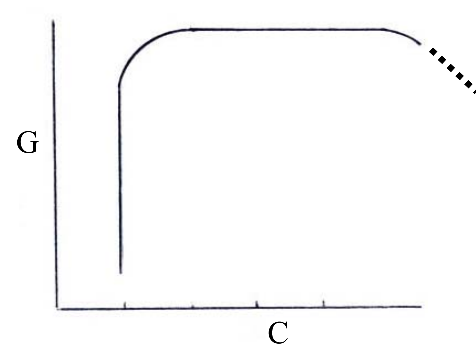
Recipe with three crops (UA CEAC GH): N=189, P=39, K=341, Mg=48, Ca=170

***Plant growth as a function of nutrient concentration in plant tissue:**

Plant nutritionists, in the mid-1900's, discovered that there is a **critical nutrient concentration (C),** below which plant growth **(G)** is reduced or terminated.

Above the critical nutrient concentration is the **adequate zone** where growth is 100% of maximum.

At high nutrient concentrations, plant growth is again reduced. This is the **toxic zone.**



***Open (drain to waste) verses Closed (recirculating) systems:**

In an open system the nutrient solution is only used once on the crop plants.

In a closed system the nutrient solution is used then recycled.

- The solution is analyzed for pH and individual nutrient concentrations.
- The solution is then adjusted using acid/base, water and/or nutrients to the appropriate pH and nutrient concentration levels.
- The solution is also sterilized to control the spread of water-borne pathogens.
  - This can include UV, ozone or other treatments.
- The solution is then returned to the plants.

NUTRIENT SOLUTION CALCULATIONS

*Mineral nutrients are available in several forms:

- Pre-mixed liquid concentrates that are then diluted with water.
  - "A" and "B" formulas that when mixed have all essential elements.
- Pre-mixed powder concentrates that are then diluted with water.
  - Many are a teaspoon per gallon mixes – fairly simple.
  - NOTE: DO NOT USE Miracle Gro – This is meant for soil culture and does not have all the essential elements for hydroponic use.
- Many commercial growers buy the individual compounds and mix the nutrient solution themselves.
  - See above under **Mineral elements or nutrients** for a list of the compounds required (other compounds can be substituted).
  - **Macroelements (or macronutrients)** are usually purchased in 50 lb bags.
    - These are called **horticulture grade.**
    - These need to be in a **soluble form.**
  - **Microelements** (needed in much smaller amounts) can be purchased as
    - Pre-mixed powders: specific for hydroponics.
    - Individual compounds: at least **horticultural grade**, but can be **technical or reagent grade** and need to be **soluble.**

PRECAUTIONS:

- Note above the "A" and "B" formulas…
- There is a reason…
- Usually, the **calcium containing compounds** are kept separate from the **phosphate and sulfate compounds.**
- **Why?** In high concentration the calcium will combine with the phosphates and sulfates to form **insoluble precipitates.**

THEREFORE:

- A typical nutrient solution will be divided into **3 tanks:**
  - **Calcium/iron tank** (iron gives it a reddish color)
  - **Macro/Micro tank** (all other macro and micro elements)
  - **Acid tank** (kept separate so pH can be adjusted individually)

*A grower will start with a nutrient solution **recipe**:
The choice of recipes is up to the grower (many variations exist).
Choose a recipe that has been successful:
For the plant you want to grow.
For the regional location and environmental conditions.
For the time of year you wish to grow.
IF a grower notices deficiency/toxicity symptoms,
THEN adjustments to the recipe can be made to compensate.

***An example:** Recipe used by **Sunco, Ltd.**, **Las Vegas NV,** for **tomatoes** during **Winter** in the mid to late 1990's (See table below).
Most recipes will vary according to stage of plant growth.
Ex: 0 – 6 Week recipe: Higher nitrogen, calcium and magnesium for good structure/vegetative growth.
6 – 12 Week recipe: Lower nitrogen and higher potassium to enhance flower (reproductive) production
12 + Week recipe: To maintain balance – vegetative/reproductive

WEEK 0-6		**WEEK 6-12**		**WEEK 12 +**	
PPM		**PPM**		**PPM**	
N	**224**	**N**	**189**	**N**	**189**
P	**47**	**P**	**47**	**P**	**39**
K	**281**	**K**	**351**	**K**	**341**
Ca	**212**	**Ca**	**190**	**Ca**	**170**
Mg	**65**	**Mg**	**60**	**Mg**	**48**
Fe	**2.00**	**Fe**	**2.00**	**Fe**	**2.00**
Mn	**0.55**	**Mn**	**0.55**	**Mn**	**0.55**
Zn	**0.33**	**Zn**	**0.33**	**Zn**	**0.33**
Cu	**0.05**	**Cu**	**0.05**	**Cu**	**0.05**
B	**0.28**	**B**	**0.28**	**B**	**0.28**
Mo	**0.05**	**Mo**	**0.05**	**Mo**	**0.05**

NOTE: Sulfur (a macronutrient) and chloride (a micronutrient) concentrations are not given in this recipe. That does not mean that sulfur and chloride are not present. Usually sulfur is added with magnesium and chloride is added with the manganese and copper. Enough will be added with these other elements to be sufficient (see calculations below).

NOTE: Two significant changes to this type of standard recipe have recently been tried in hot, high light areas to improve growth of the plants and quality of the fruit.

To avoid over-vegetative growth during hot fall weather, begin with low nitrogen (~95ppm) during the first 6 weeks. This will keep the plants "lean" and encourage reproductive growth. Increase to 145ppm N at 6 weeks and then 189ppm by 12 weeks.

Chlorides can be added during fruiting in macronutrient levels (150-200 ppm) to improve fruit quality and taste. Note, significant adjustments must be made to the recipe.
** These changes should only be attempted by experienced growers.

***CALCULATING NUTRIENT SOLUTIONS** (how much to add of what…):

In this example use the **"injector system with bag culture"** design pictured at the end of this chapter.

Important factors:

1 ppm = 1 mg/l
1 gallon = 3.785 liters
2.2 pounds = 1 kg

The nutrient calculations depend on several things:

What is the final concentration desired, in ppm, of a particular element?
Does the source water already contain any essential elements (from water analysis)? If so, less of that nutrient will be needed ($$ savings!).
You know the final concentration in ppm desired for a particular element, BUT that element is part of a compound.
SO, what is the percentage of the element in the compound?
If you use concentrated nutrient solution stock tanks and injectors:
What is the size of the tanks?
What dilution factors are the injectors set for?

NOTE: Do not round off until the end of your calculation!

In this example we use the Sunco Recipe, 12+ weeks (see above):

Always start with **<u>Calcium</u>** (it starts a "cascade" of calculations)

Final concentration of calcium desired = 170 ppm
In this example: the source water contains = 29 ppm

Therefore, amount of calcium needed = **141 ppm Ca**

BUT, we don't add the element Ca, we add the compound **<u>$Ca(NO_3)_2$</u>**:

The % of calcium in **$Ca(NO_3)_2$** (from bag) = 19 %

Therefore, to find the ppm required for the compound calcium nitrate:

141 ppm Ca / 0.19 = 742.105 ppm
or 742.105 mg/l

In this example the nutrient tank is = 50 gallons

BUT ppm is mg/LITER not gallons, so
50 gallons x 3.785 liters/gal = 189.25 liters

Therefore, the amount of calcium nitrate required is

742.105 mg/l x 189.25 liters = 140,443.37 mg

HOWEVER, **in this example** the solution will also go through an injector system with the dilution rate set at 1:200.

Therefore, the FINAL amount of calcium nitrate required to obtain a final calcium concentration of 141 ppm is

140,443.37 mg x 200 = 28,088,674 mg

IF your scale is in kilograms (kg=10^6 mg)
Then 28,088,674 mg / 1,000,000 mg/kg = **28.088674 kg calcium nitrate for 141 ppm Ca**

IF your scale is in pounds (lb)
Then 28.088674 kg x 2.2 lb/kg = 61.795 lb calcium nitrate

OKAY… So you've added the appropriate amount of calcium nitrate to get 141 ppm of Ca…

BUT**, how much <u>nitrogen</u> did you add?** NEED TO WORK BACKWARDS!

The final amount of calcium nitrate = 28,088,674 mg

Divide by the dilution factor (200) = 140,443.37 mg

Divide by 189.25 L in a 50 gal tank = 742.105 mg/L

The amount of nitrogen in calcium nitrate = 15.5%

Therefore, 742.105 mg/L x 0.155 = 115 mg/l or **115 ppm N from calcium nitrate**

HOWEVER, the total N that is needed from the recipe (week 12+) = 189 ppm

The difference is 189ppm – 115ppm = 74 ppm

This **74 ppm of <u>Nitrogen</u>** will come from potassium nitrate – **<u>KNO_3</u>**

Instead of getting the % of nitrogen from the bag…
Calculate the % of nitrogen in potassium nitrate using molecular weights:

MWt KNO_3 = K(39.1) + N(14) + 3O(3X16=48) = 101.1

AWt N (14) / MWt KNO_3 (101.1) = 0.1385 or 13.85% N

To find the ppm required for the compound potassium nitrate

74 ppm / 0.1385 = 534.3 ppm or 534.3 mg/l

Take into account the tank size (50 gallons or 189.25 liters)

534.3 mg/l x 189.25 l = 101,116.275 mg

Take into account the dilution factor (1:200)

101,116.275 x 200 = 20,223,255 mg

OR 20,223,255 mg / 10^6 mg/kg = **20.223255 kg of KNO_3 for 74 ppm N**

BUT, **how much <u>potassium</u> did you add when you added 20.2 kg of <u>KNO_3</u>**?
YOU HAVE TO WORK BACKWARDS, AGAIN!

Convert back to mg:

20.223255 kg x 10^6 mg/kg = 20,223,255 mg

Dilution factor: 20,223,255 / 200 = 101,116.275 mg

Tank size: 101,116.275 mg / 189.25 l = 534.3g/l

% K in KNO3: AWt K (39.1) / MWt KNO_3 (101.1)
= 0.3867 or 38.67% K

0.3867 x 534.3 mg/l = 206.6 mg/l or **206.6 ppm K added with 20.2 Kg KNO_3**

HOWEVER, the total **K** needed from the recipe is **341 ppm**.

The difference is 341 – 206.6 = **134.4 ppm K** still needed

To get the needed **K use <u>KH_2PO_4</u>**.
HOWEVER, this is the **only source for <u>Potassium</u>**.
THEREFORE, figure the P first. Need **39 ppm P**

Figure the % P in KH_2PO_4 using molecular weights:
MWt KH_2PO_4 = K (39.1) + 2H (2x1+2) + P (31) + 4O (4x16+64) = 136.1
AWt P (31) / MWt KH_2PO_4 (136.1) = 0.2278 or 22.78% P

ppm KH_2PO_4 needed = 39 ppm P / 0.2278 = 171.2 ppm or mg/l KH_2PO_4

Tank size: 171.2 mg/l x 189.25 l = 32,399.6 mg KH_2PO_4

Dilution factor: 32,399.6 x 200 = 6,479,920 mg KH_2PO_4

Conversion: 6,479,920 mg / 10^6 mg/Kg = **6.47992 Kg KH_2PO_4**

To figure the amount of <u>K</u> added from 6.47992 Kg <u>KH_2PO_4</u>,
WORK BACKWARDS

Dilution factor: 6,479,920 mg KH_2PO_4 / 200 = 32,399.6 mg KH_2PO_4

Tank size: 32,399.6 mg KH_2PO_4 / 189.25 l = 171.2 mg/l KH_2PO_4

%K in KH_2PO_4 = AWt K (39.1) / MWt KH_2PO_4 (136) = 0.2875
or 28.75 % K

171.2 mg/l KH_2PO_4 x 0.2875 = **49.2 mg/l or ppm of K from KH_2PO_4**

Total K so far = K from KNO_3 (206.6ppm) + K from KH_2PO_4 (49.2ppm)
= **255.8 ppm K**

HOWEVER, total K needed from recipe = 341 ppm
341 ppm K – 255.8 ppm K = **85.2 ppm <u>K</u> still needed. Use <u>K_2SO_4</u>**.

Figure % K in K_2SO_4 by using molecular weights.
MWt K_2SO_4 = 2K (2x39.1=78.2) + S (32.1) + 4O (4x16=64) = 174.3
AWt K (78.2) / MWt K_2SO_4 (174.3) = 0.4487 or 44.87% K

ppm needed of K_2SO_4 = 85.2 ppm K / 0.4487 = 189.9 ppm or mg/l K_2SO_4

Tank size:189.9 mg/l K_2SO_4 x 189.25 l = 35,938.575 mg K_2SO_4

Dilution factor: 35,938.575 mg x 200 = 7,187,715 mg K_2SO_4
= **7.187715 Kg K_2SO_4 to get 85.2 ppm K**

Final total of K = K from KNO_3 (206.6 ppm) + K from KH_2PO_4 (49.2 ppm)
+ K from K_2SO_4 (85.2 ppm)
= 341 ppm K

NOTE: **<u>S</u> is also added in <u>K_2SO_4</u>**. How much? WORK BACKWARDS
Dilution factor: 7,187,715 mg K_2SO_4 / 200 = 35,938.575 mg K_2SO_4

Tank size: 35,938.575 mg K_2SO_4 / 189.25 l = 189.9 mg/l or ppm K_2SO_4

% S in K_2SO_4 = AWt S (32.1) / MWt K_2SO_4 (174.3) = 0.184 or 18.4%
189.9 ppm K_2SO_4 x 0.184 = **34.9 ppm of S from K_2SO_4**

Finally, calculate the **amount of <u>$MgSO_4$ * $7H_2O$</u> needed to give <u>Mg</u> = 48 ppm.**
From the bag, the % Mg in $MgSO_4$ * $7H_2O$ = 9.8%
ppm needed of $MgSO_4$ * $7H_2O$ = 48 ppm Mg / 0.098
= 489.8 ppm or mg/l $MgSO_4$ * $7H_2O$

Tank size: 489.8 mg/l $MgSO_4$ * $7H_2O$ x 189.25 l
= 92,694.65 mg $MgSO_4$ * $7H_2O$
Dilution factor: 92,694.65 mg $MgSO_4$ * $7H_2O$ x 200
= 18,538,930 mg $MgSO_4$ * $7H_2O$

Conversion: 18,538,930 mg $MgSO_4$ * $7H_2O$ / 10^6
= 18.538930 Kg $MgSO_4$ * $7H_2O$
needed to supply 48 ppm Mg

But, **how much <u>S</u> is added?** WORK BACKWARDS (ppm of S not specified)
Added 18,538,930 mg $MgSO_4$ * $7H_2O$

Dilution factor: 18,538,930 mg $MgSO_4$ * $7H_2O$ / 200
= 92,694.65 mg $MgSO_4$ * $7H_2O$

Tank size: 92,694.65 mg $MgSO_4$ * $7H_2O$ / 189.25 l
= 489.8 mg/l or ppm $MgSO_4$ * $7H_2O$

From the bag the % S in $MgSO_4$ * $7H_2O$ = 12.9%
489.8 ppm $MgSO_4$ * $7H_2O$ x 0.129
= **63.2 ppm S from 18.538930 Kg $MgSO_4$ * $7H_2O$**

The final amount of S added
= 63.2 ppm from $MgSO_4$ * $7H_2O$ + 34.9 ppm of S from K_2SO_4
= **98.1 ppm S**

Calculations for the microelements are done the same. Always take into account the desired concentration (ppm), the percentage of the element in the compound, the tank size and the dilution factor from the injectors.

REFERENCE MATERIAL:

1. **Hydroponic Food Production.** 2001. H.M. Resh. Woodbridge Press Publishing, P.O. Box 209, Santa Barbara, CA, 93160. ISBN 0-88007-222-9
2. **Hydroponic Nutrients.** 1993. M.E. Muckle. Growers Press Inc., P.O. Box 189, Princeton, B.C., Canada, V0X 1W0. ISBN 0-921981-33-3
3. **Hydroponic Vegetable Production.** 1985. M.H. Jensen and W.L. Collins. Horticultural Reviews, Vol 7: 483-558. ISBN 0-87055-492-1
4. **Protected Agriculture. A Global Review.** 1995. M.H. Jensen and A.J. Malter. The International Bank for Reconstruction and Development/The World Bank. 1818 H St., NW, Washington, DC 20433. ISBN 0-8213-2930-8
5. **Tailoring Nutrient Solutions to Meet the Demands of Your Plants.** 1992. M. Schon. In: Proceedings of the 13th Annual Hydroponic Society of America Conference on Hydroponics. pp 1-7.

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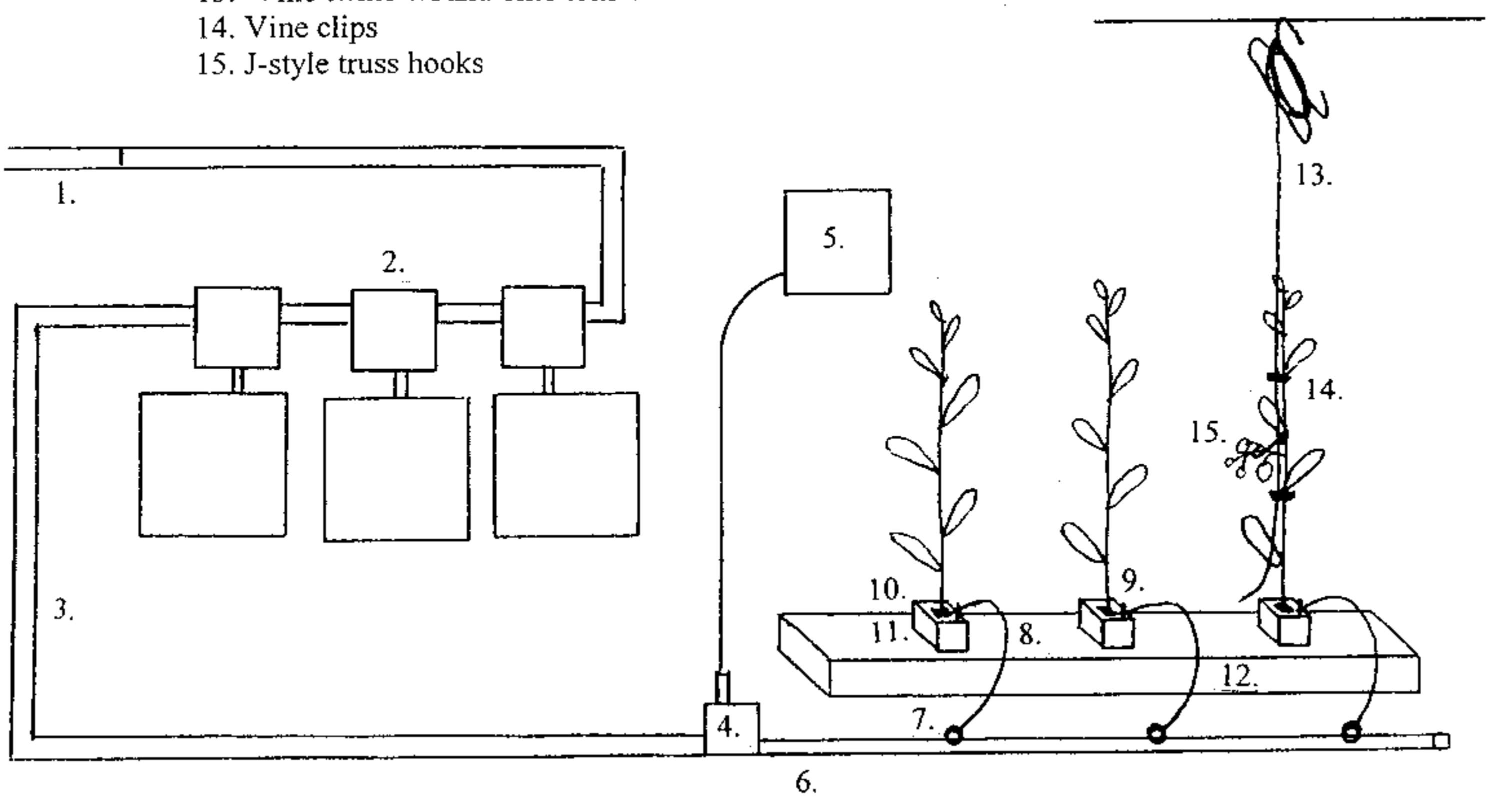
SYSTEM DESIGN: INJECTOR SYSTEM/BAG CULTURE

Introduction: This system is

*Active (requires electricity and pumps and/or injectors to operate)
*Open (the nutrient is "drained to waste") OR
closed (the nutrient can be recycled)
*An aggregate system (roots grow through an aggregate medium)
*Best for larger plants (indeterminant tomatoes, peppers, cucumbers, etc.).

Materials:

1. Water source (make sure water is of good quality (low EC) and quantity
2. Injectors with nutrient reservoirs
3. PVC pipe, connectors, elbows, etc.
4. Solenoid valves with appropriate plumbing and electrical connections
5. Irrigation controller/timer (wired to solenoid valves)
6. Poly tubing (for drip irrigation)
7. Emitters (drippers) – typical is 0.5 GPH CNL pressure compensating
8. Drip (spaghetti) tubing (for drip irrigation)
9. Stabilizer pegs
10. 1" Rockwool propagation cubes (transplant into 3" or directly into bags)
11. 3" Rockwool cubes (optional if planting 1" cubes directly into bags)
12. Rockwool slabs, or grow bags filled with perlite, coconut coir, etc.
13. Vine twine wound onto tomahooks
14. Vine clips
15. J-style truss hooks



ATOMIC WEIGHTS

(Order of Atomic Number)

Atomic number	Element	Symbol	Atomic weight	Atomic number	Element	Symbol	Atomic weight
1	Hydrogen	H	1.00794	55	Cesium	Cs	132.90543
2	Helium	He	4.002602	56	Barium	Ba	137.327
3	Lithium	Li	6.941	57	Lanthanum	La	138.9055
4	Beryllium	Be	9.012182	58	Cerium	Ce	140.115
5	Boron	B	10.811	59	Praseodymium	Pr	140.90765
6	Carbon	C	12.011	60	Neodymium	Nd	144.24
7	Nitrogen	N	14.00674	61	Promethium	Pm	144.9127*
8	Oxygen	O	15.9994	62	Samarium	Sm	150.36
9	Fluorine	F	18.9984032	63	Europium	Eu	151.965
10	Neon	Ne	20.1797	64	Gadolinium	Gd	157.25
11	Sodium	Na	22.989768	65	Terbium	Tb	158.92534
12	Magnesium	Mg	24.3050	66	Dysprosium	Dy	162.50
13	Aluminum	Al	26.981539	67	Holmium	Ho	164.93032
14	Silicon	Si	28.0855	68	Erbium	Er	167.26
15	Phosphorus	P	30.973762	69	Thulium	Tm	168.93421
16	Sulfur	S	32.066	70	Ytterbium	Yb	173.04
17	Chlorine	Cl	35.4527	71	Lutetium	Lu	174.967
18	Argon	Ar	39.948	72	Hafnium	Hf	178.49
19	Potassium	K	39.0983	73	Tantalum	Ta	180.9479
20	Calcium	Ca	40.078	74	Tungsten	W	183.85
21	Scandium	Sc	44.955910	75	Rhenium	Re	186.207
22	Titanium	Ti	47.88	76	Osmium	Os	190.2
23	Vanadium	V	50.9415	77	Iridium	Ir	192.22
24	Chromium	Cr	51.9961	78	Platinum	Pt	195.08
25	Manganese	Mn	54.93805	79	Gold	Au	196.96654
26	Iron	Fe	55.847	80	Mercury	Hg	200.59
27	Cobalt	Co	58.93320	81	Thallium	Tl	204.3833
28	Nickel	Ni	58.69	82	Lead	Pb	207.2
29	Copper	Cu	63.546	83	Bismuth	Bi	208.98037
30	Zinc	Zn	65.39	84	Polonium	Po	208.9824*
31	Gallium	Ga	69.723	85	Astatine	At	209.9871*
32	Germanium	Ge	72.61	86	Radon	Rn	222.0176*
33	Arsenic	As	74.92159	87	Francium	Fr	223.0197*
34	Selenium	Se	78.96	88	Radium	Ra	226.0254*
35	Bromine	Br	79.904	89	Actinium	Ac	227.0278*
36	Krypton	Kr	83.80	90	Thorium	Th	232.0381
37	Rubidium	Rb	85.4678	91	Protactinium	Pa	231.0359*
38	Strontium	Sr	87.62	92	Uranium	U	238.0289
39	Yttrium	Y	88.90585	93	Neptunium	Np	237.0482*
40	Zirconium	Zr	91.224	94	Plutonium	Pu	244.0642*
41	Niobium	Nb	92.90638	95	Americium	Am	243.0614*
42	Molybdenum	Mo	95.94	96	Curium	Cm	247.0703*
43	Technetium	Tc	97.9072*	97	Berkelium	Bk	247.0703*
44	Ruthenium	Ru	101.07	98	Californium	Cf	251.0796*
45	Rhodium	Rh	102.90550	99	Einsteinium	Es	252.083*
46	Palladium	Pd	106.42	100	Fermium	Fm	257.0951*
47	Silver	Ag	107.8682	101	Mendelevium	Md	258.10*
48	Cadmium	Cd	112.411	102	Nobelium	No	259.1009*
49	Indium	In	114.82	103	Lawrencium	Lr	262.11*
50	Tin	Sn	118.710	104	Unnilquadium	Unq	261.11*
51	Antimony	Sb	121.75	105	Unnilpentium	Unp	262.114*
52	Tellurium	Te	127.60	106	Unnilhexium	Unh	263.118*
53	Iodine	I	126.90447	107	Unnilseptium	Uns	262.12*
54	Xenon	Xe	131.29				

Based on 1987 IUPAC Table of Standard Atomic Weights of the Elements.
* Relative atomic mass of the isotope of that element of longest known half-life.

CHAPTER 9

TRANSPLANT PRODUCTION

INTRODUCTION

***Transplants**: Young plants produced specifically for transplant into pots (houseplants), the ground (field production), hydroponic systems (greenhouse hydroponics), etc.

*The production of transplants has become an industry in and of itself.

*In the case of greenhouse hydroponic tomatoes, the separation of transplant production and the growing of the mature plants for tomato harvest means that each grower can tailor the growing conditions for their plant's life stage needs.

*Separate production of transplants is also advantageous for the tomato producer. Precious greenhouse space does not have to be used for seeding and grow out.

*In deciding whether or not to go into transplant production, a grower should consider:
- *The overall operation. Would transplant production fit the business scheme?
- *Can the required number of transplants be grown successfully?
- *Resident management skills and knowledge of transplant production for the specific crop desired. Remember, the transplant grower may be held responsible for weak or failed crops! So the best possible transplants are desired.
- *Availability of the money needed to establish such an operation.
- *Is there a market for the transplants and will the operation be profitable?
- *The time and resources need for such an operation.

*Greenhouse transplant growers are usually growing transplants
- *For commercial sale only
- *For personal use only
- *For both commercial sale and personal use

*Transplants can be started from seeds, or vegetatively using cuttings, grafting, or micro-propagation (tissue culture) methods. However, even with cuttings or grafting the original material will still come from seed.

TRANSPLANTS FROM SEEDS

*Most vegetable transplants are produced from seed.

*The choice of seed is one of the most important initial decisions a grower can make.

*As mentioned previously, most varieties used in commercial greenhouse hydroponic production are F1 hybrids (see Chapter 2).
The pollen from one parent plant is transferred to a second parent plant.
The resulting fruits contain the F1 (first filial) seeds that are then sold.
F1 hybrid seed is preferred because most of the plants will have the same characteristics and produce the same quality and quantity of fruit.
Also note that the seeds in fruit from plants grown from the F1 hybrid seed will NOT produce the same type of plant/fruit as the F1 seed.

*Make sure the seed comes from a reputable company. A less well known company may have a "bargain" product… full of problems (diseases, weed seeds, etc.)!
Companies with good reputations include (but are not limited to):
Burpee Seeds, 300 Park Ave. Warminster, PA 18974
1-800-888-1447
Carolina Seeds, PO Box 2658, HWY 105 Bypass, Boone, NC 28607, www.carolinaseeds.com
DeRuiter Seeds, Inc. PO Box 20228 Columbus OH 43220
www.deruiterusa.com
Johnny's Selected Seeds, 1 Foss Hill Rd. RR1 Box 2580, Albion, ME, 04910-9731, www.johnnyseeds.com
Novartis Seeds, Inc., PO Box 4188 Boise ID 83711-4188
208-322-7272
Rijk Zwaan, PO Box 40, 2678 ZG DE LIER, The Netherlands
Email: export@rijkzwaan.nl

*Make sure the seed is disease-free. Reputable companies should guarantee this.

***Seeds** can be sown in a variety of ways depending upon the ultimate use:
Into individual plant containers or plastic flats filled with various types of sterile growing media (soil, sand, peat moss, vermiculite, perlite, rock wool, rice hulls, coconut coir, compost, etc.). Sterilization excludes insects, disease, nematodes and weed seeds…. OR
Typically for tomatoes in greenhouse hydroponics, into "grow cubes" such as rock wool, Oasis cubes, foam cubes, peat pellets, etc….. OR
For research or classroom purposes, in moist paper towels or filter paper in petri dishes or other containers with loose-fitting lids. Make sure the paper toweling or filter paper is not too wet or too dry.
NOTE: Mechanical seeders are available for commercial operations.

***Containers** include a variety of forms.
Individual containers may be more appropriate for foliage plants and come in paper, plastic, clay, peat moss, Styrofoam, etc.
Individual plastic containers called net pots or web pots, filled with perlite, clay pellets, rock wool, etc. are routinely used in air gap, floating or NFT hydroponic systems (see Chapter 5).

Molded plastic or Styrofoam "plug" or cavity trays, in various sizes and containing tens to hundreds of cavities, can be filled with growing medium or cubes for production of multiple seedlings per tray.

Plastic flats can be filled with growing medium or, typically for greenhouse hydroponic tomatoes, pads of rock wool or foam are used that are sized to fit these trays and divided into small cubes (1"x 1" or even smaller plugs called "sugar cubes") which are connected at the top but partially separated at the bottom to keep roots from mingling and reduce root breakage at transplant.

Plastic and Styrofoam containers can be sterilized using 10% bleach. Rinse containers thoroughly to avoid chlorine toxicity.

***Sowing of seeds**

In growing media (like perlite): follow package instructions for depth.

In rock wool or foam cubes, Oasis cubes or other preformed material:

- these usually have a small hole in the top of each cube into which the seed is placed. Vermiculite can then be sprinkled over the top to maintain moist conditions around the seed.

Time the sowing of seeds so that the resulting transplants are beyond the first true leaf stage but have not yet reached much flowering or any fruiting.

Ex: Most beef type tomato varieties and colored peppers take 4 weeks from seed to final transplant, whereas long cucumbers only take 2 weeks from seed to final transplant!

***Watering and fertilization:**

After sowing, seeds should receive water only, no fertilizer.

- Apply by hand. Use a watering can or hose. Round sprinkler heads (give more water with less plant damage) are preferred to fan types.
- Apply by overhead misters, sprinklers or programmable traveling irrigation booms (if for foliage plants, or in areas with cool, humid conditions make sure last watering is early enough so that the leaves dry before dark to avoid foliar disease).
- Apply by flooding the plant trays or water-tight floor (concrete, plastic, etc.) then draining the excess "to waste" or to a tank for recycling. (Caution: recycling can cause spread of disease – See Chapter 4.)

After the cotyledons have opened and the first true leaf is expanded:

- Apply liquid fertilizer in dilute form with every watering:
  - Ex: 110-175 g of a 20-20-20 fertilizer per 200 liters over a 20 square meter area.
  - Ex: ¼-½ strength hydroponic nutrient solution…. OR
- Apply liquid fertilizer at a stronger rate every 2 weeks:
  - Ex: 500-700 g of a 20-20-20 fertilizer per 200 liters over a 20 square meter area.
  - Ex: 3-4 times full strength hydroponic nutrient solution.
  - NOTE: To avoid leaf burn, rinse leaves with pure water after each concentrated feeding.

***Boosting seedlings to larger containers/cubes/etc.:**

For tomato seedling production:

If seeds are planted in small plugs or 1-1 ½ rockwool cubes, the seedlings will need to be transplanted into larger blocks (3” with one hole or larger blocks with 2 holes) at least 2 weeks after seeding (sooner, if roots begin emerging from cube to prevent root damage). Plants will be ready for planting onto rock wool slabs or perlite bags, etc. in another 2 weeks. Plants may have a couple of flowers open on the first truss but should not have any set fruit at transplant.

If seeds are planted as above, but the grower (or this is especially good for schools on a limited budget) does not want the expense of larger blocks, the smaller seedlings in their cubes can be placed directly onto rock wool slabs or into perlite bags.

For other types of crops – general criteria:

Seedlings should be boosted to larger containers/cubes/etc. when leaves from neighboring plants overlap and shade each other or when roots begin to protrude from the current container/cube/etc.

***Structures for seed-generated transplant production:**

Most vegetable transplant production occurs in some type of controlled environment structure so that the environment can be tailored for the crop being grown.

Cold frames: low plastic covered structures without heat

Hot beds: similar to cold frames but with heat

Greenhouses: transparent enclosed structures with environmental control utilizing light directly from the sun (can be supplemented with artificial lights)

Growth chambers or rooms: opaque enclosed structures with environmental control using artificial light (can use solar light via fiber optic light pipes).

TRANSPLANTS FROM CUTTINGS:

***Cuttings** are portions of the stem, root, leaf or leaf bud removed from a “parent plant”.

These portions are then induced to form roots and shoots by chemical, mechanical and/or environmental means.

The resulting plants will be “clones” of the parent plant with exactly the same genetic makeup.

Ex: Tomato plant suckers can be removed, the severed ends placed in water (no nutrients until roots form) and within a few days to a week roots will form.

Parent plant stock material must be free of disease and insect pests.

Material selected for cuttings needs to be in the proper physiological state so that roots and shoots develop readily.

This method is used mainly to propagate ornamental shrubs, evergreens, floral and foliage crops, as well as various fruit species.

***Typical uses for cuttings:**

Commercial: transplants from cuttings can be grown either in the ground or by using an aggregate medium or soil mix for rooting in plug trays, flats, etc.

When vegetable crops (including tomatoes, pepper and cucumbers) are grown from cuttings they are usually produced by small-scale farmers for retail/wholesale or by individuals for home use.

NOTE: Cutting production of vegetable crops is very labor intensive, which is why seeds are usually used.

Educational/school: cuttings can be used in the classroom and easily rooted using

*Aeroponic type hydroponic systems in which the severed ends of, for example, tomato suckers can be bathed in water until they root.

*Floater or air-gap systems where the cutting ends are kept moist by water wicked up into perlite, etc. from the reservoir below.

When roots form, nutrient solution can be added to the reservoir.

NOTE: See Chapter 5 for system descriptions.

***Facilities and special considerations:**

Most cuttings are produced in some type of protected structure (cold frames, hot beds, greenhouses or growth rooms), though some hardwood cuttings (willow, poplar, rose, etc.) are planted directed into the soil outside.

Because cutting material initially has no roots, misting is typically used in greenhouses to maintain a humid environment around the cutting and reduce water loss while roots are forming.

NOTE: For a small number of cuttings (home or school use) even a simple plastic dome over the cuttings will help maintain a moist environment.

Also, to reduce water loss, all but the uppermost 4-5 leaves should be removed.

Research in the physiology of plant growth has shown that auxin-type plant hormones, including the naturally occurring IAA (indoleacetic acid) and the synthetic chemicals, IBA (indolebutyric acid) and NAA (naphthaleneacetic acid) promote root growth. Therefore, treating the cut ends increases the number and hastens the development of roots.

The use of "bottom heat" will also help to induce faster root growth. This is achieved by electric cables, electric mats or hot water tubes running beneath the beds or trays containing the cuttings.

TRANSPLANTS FROM GRAFTING

***Grafting**

A technique for connecting two previously separate plant parts such that the resulting plant will live and grow as one.

Stock = the lower part of the graft including the roots.

Scion = the upper part of the graft including the shoot and dormant buds from which new stems, leaves, etc., will grow.

Although this technique is very labor intensive it has become widely used over the last year or so in vegetable production.

***Why use grafting?**

There are several reasons to use grafting including to maintain clones that can not be easily maintained by other asexual methods, to repair damaged parts of trees, or to create specialized growth forms.

Vegetable growers, in Europe, have been using root stocks with resistance to such root pathogens as *Fusarium* and *Verticillium* wilt with soil agriculture.

Hydroponic vegetable growers are also now using grafted plants, not necessarily for pathogen protection (plants are grown in sterile media) but to increase yields of many greenhouse vegetable crops, including tomatoes.

***Special considerations:**

The root stock and scion must be compatible.

The cambium (new cell generating tissue) of the root stock and scion must be in direct contact with each other.

Both the root stock and scion must be in the proper physiological stage to promote the fusion of the two parts into one.

Cut surfaces must be wrapped after joining to prevent water loss.

As the new plant heals, care must be taken to promote the desired growth habit.

Once the graft has healed the plant can be treated as any other plant.

TRANSPLANTS USING MICRO-PROPAGATION (TISSUE CULTURE)

***Micro-propagation:** The use of sterile tissue culture methods to propagate important crops including woody plants, orchids, palms, ferns, bulbs and ornamentals.

***This technique is used:**

For mass propagation of important clones.

To produce pathogen-free plants.

Potentially, to provide plants year-around for nursery sale.

Specifically for tomatoes and other vegetable crops, micro-propagation has the potential to produce mass numbers of clones for hybrid seed production. NOTE: This is already being done for some hybrid seed.

***Special considerations:**

Micro-propagation requires a large monetary input for facilities and labor.

Specialized laboratories, growth chambers, high-tech equipment as well as trained personnel are required.

A large storage facility will also be required for the transplants produced.

Precautions must be taken to prevent contamination and the occurrence of "off-type" plants.

Since plants are started from various tissue masses in agar, special methods are required to acclimate the new plant to the greenhouse or the out-of-doors.

Agar (callus formation)	→	Growing medium (root development)	→	Growing conditions (GH or outside)

REFERENCE MATERIAL:

1. **Commercial Production of Vegetable Transplants.** 1997. D.M. Granberry. Published by The Cooperative Extension, The University of Georgia, Athens, GA. Bulletin #1144.
2. **Hydroponic Food Production.** 2001. H.M. Resh. Woodbridge Press Publishing Company, P.O. Box 209, Santa Barbara, CA, 93160. ISBN 0-88007-222-9
3. **Plant Propagation: Principles and Practices.** 1990. H.T. Hartmann, D. E. Kester and F.T. Davies. Fifth Edition. Prentice Hall, Englewood Cliffs, NJ, 07632. ISBN 0-13-681016-0
4. **Protected Agriculture: A Global Review. Part 3: Production Aspects.** 1995. M.H. Jensen and A.J. Malter. The International Bank for Reconstruction and Development/The World Bank. 1818 H Street, N.W., Washington, D.C. 20433. World Bank Technical Paper. ISBN 0-8213-2930-8

CHAPTER 10

SITE SELECTION

INTRODUCTION

*Selecting a "good" site for the location of a greenhouse is crucial.

*But what constitutes a "good" site?

*There are several things that should and must be considered in order to increase the chances of a successful operation and business.

12 THINGS TO CONSIDER WHEN SELECTING A GREENHOUSE SITE:

1. Solar Radiation – Plants require sunlight in order to perform photosynthesis. When plants experience cloudy days their photosynthetic rates, and therefore their ability to grow and yield a product, such as tomatoes, cucumbers, peppers, etc., will be reduced.

*Therefore, a region and location with high light intensity year-round is desired.

*See "Solar radiation data for selected cities" at the end of this chapter.
Note that the southwestern United States has some of the highest light levels in the world. This is, therefore, an optimal region for crop production.

*See "Microclimate" below for natural/manmade structures that reduce light.

2. Water – Water quantity and quality is crucial.

*Water will be needed for irrigation (maximum of 1 gal/plant/day for tomatoes).

*Water will be needed for the evaporative cooling system and can equal or exceed the irrigation water amounts (10,000 – 15,000 gal/acre/day).

*In the past, excess irrigation and bleed-off water from the evaporative cooling system was allowed to "run off" onto the ground adjacent to the greenhouse (with a rec. minimum percolation rate into the soil of 1"/hr.)

*HOWEVER, due to more strict regulations and a desire to avoid ground water contamination with high concentrations of salts, large greenhouses are now recirculating the nutrient solution.

*THEREFORE, excess nutrient solution should be recycled and/or mixed with the cooler bleed-off water and redirected onto designated areas, such as grass, shrubs, trees/windbreaks, etc.

*No matter what the source of the water, a water analysis should be done.

*Note: Sea water = 32,000 ppm (mg/l) VS Tucson water = 200-400 ppm.

Note: 640 ppm TDS (total dissolved solids) = 1 mmhos/cm or 1 mS/cm.
See Chapter 8 for a discussion of EC or electrical conductivity.

*Desired salt levels in the source water:

SO4	< 240 ppm	Cl	< 140 ppm	Non-Fertilizer Salts	
Ca	< 120 ppm	Fe	< 5 ppm	Na	<50 ppm
Mg	< 24 ppm	Zn	< 5 ppm	Al	< 5 ppm
K	< 10 ppm	Mn	< 2 ppm	F	< 1 ppm
P	< 5 ppm	B	< 0.8 ppm		
NO3	< 5 ppm	Cu	< 0.2 ppm		
		Mo	< 0.02 ppm		

3. Elevation – will effect the summer maximum and the winter minimum temperatures.

*Choosing an appropriate elevation will minimize heating costs in the winter and cooling costs in the summer.

*Example: In Arizona tomato production is most economical between 4000 and 5000 feet (1220m-1520m). Below 4000 feet cooling costs in summer will be more whereas above 5000 feet heating costs in the winter will be more. Lower elevations might be suitable for peppers or cucumbers.

4. Microclimate –

*Latitude – Unless the global climate changes drastically, sea level at the poles will be colder than sea level in the tropics… latitude makes a difference!

*Large bodies of water – will tend to moderate the temperature (e.g., coastal areas tend to have smaller day/night temperature differences than inland areas).

*Trees, mountains or other obstructions – may cast shadows on the greenhouse, especially in the morning or afternoon hours. Mountains can also effect wind and/or storm patterns.

*Clouds and fog – Note that certain areas (e.g., on the lee side of certain mountain ranges, or near coastal regions) may develop clouds or fog during certain times of the day or year that will reduce potential sunlight.

*High Wind Areas – High winds can "suck" heat away from the greenhouse structure and therefore increase the heating energy demands.

*Blowing dust/sand – High winds can "kick up dust or sand", especially in desert regions, which can damage some greenhouse glazings.

*Snow – The weight of heavy, wet snow on a greenhouse could crush it. However, high winds in snow areas can also blow snow up against the greenhouse structure (snow drifts) and cause damage to it. This danger can be reduced by using windbreaks (trees, snow fences, etc.).

5. Pest Pressure – Choose a site away from existing agriculture production areas which could harbor insect pests in the fields. Insect pests of concern include white flies, aphids, spider mites and thrips (see Chapter 4 for pests and control methods).

6. Level and Stable Ground – The ground upon which the greenhouse will sit must be

*Graded for routing surface water to a drainage system or a holding pond. (Typical grade = ½ % or a 6 inch drop over a distance of 100 feet.)

*Compacted such that there will be no settling of the site after the greenhouse has been constructed.

7. Utilities – Availability of utilities should include telephone service, three-phase electricity and fuel for heating and carbon dioxide generation.

*Note that, when compared to propane, electricity or fuel oil, **natural gas** is the most economical heating energy source.

8. Roads – Need access to good roads to transport the "product". Good roads close to a large population center, or to a brokerage center aids wholesale and retail marketing.

9. North-South Orientation – The greenhouse should be oriented north-south, AND the plant rows within the greenhouse should be oriented north-south.

*If oriented north-south, the greenhouse structure itself will not cast consistent shadows on any one area of the plants throughout the day.

*If oriented north-south, the plant rows will receive equal light throughout the day. If oriented east-west the south most rows (in the northern hemisphere) will shade the rows to the north.

10. Capability of Expansion – Purchase more land than you anticipate using in the beginning so that you have the ability to expand your operation. Locate the initial greenhouses such that future expansion will utilize the land area most efficiently.

11. Availability of Labor – The grower needs people who will want to work as laborers and who are "trainable" to become a retainable workforce.

*Such skills included pruning/training the plants and harvesting/packing the fruit.

*SPECIALTY LABOR will include people with additional training in such fields as plant production, plant nutrition, plant protection (insects and diseases) computers, labor management, marketing, etc. These may or may not be part of the regular workers, but could be call on as consultants as needed.

12. Management residence – The grower/manager residences should be close to the greenhouse so that they can get to the greenhouse quickly in case of emergencies.

COMMUNITY PROFILE:

*Prior to selecting a site for greenhouse construction the grower should obtain a "Community Profile" for potential locations (see example of a community profile from Willcox, AZ at the end of this chapter).

*These are available at the city or area Chamber of Commerce and contain information concerning weather, economics, labor, etc.

REFERENCE MATERIAL:

1. **Energy Conservation for Commercial Greenhouses.** W.J. Roberts, J.W. Bartok Jr., E.E. Fabian, J. Simpkins. Northeast Regional Agricultural Engineering Service, Cornell University 152 Riley-Robb Hall, Ithaca, NY, 14853, Cooperative Extension, Greenhouse Series - NRAES-3.
2. **Hydroponic Food Production.** 2001. H.M. Resh. Woodbridge Press Publishing Company, P.O. Box 209, Santa Barbara, CA 93160. ISBN 0-88007-222-9
3. **Protected Agriculture: A Global Review. Part 7: Water supply, water quality and mineral nutrition**. 1995. M.H. Jensen and A.J. Malter. The World Bank (Techincal Paper #253), 1818 H. Street, N.W., Washington D.C., 20433. ISBN 0-8213-2930-8
4. **Web Pages**:
   http://ag.arizona.edu/ceac/

Solar radiation data for selected cities MJ/m2/day

Data ordered according to total light October - March

	oct-mar	total	jul	aug	sep	oct	nov	dec	jan	feb	mar	apr	may	jun
El Paso Tx.	96	259	28	26	23	19	14	12	13	17	22	27	30	30
Tucson Az.	93	255	27	25	23	18	14	11	13	16	21	27	30	31
Miami Fl.	89	213	21	20	18	15	14	12	13	16	19	22	22	21
Albuquerque NM	88	249	28	26	22	18	13	11	12	15	20	25	29	30
Prescott Az.	88	247	26	24	22	18	13	11	12	15	20	26	30	31
Las Vegas Nv.	87	254	29	27	23	18	12	10	11	15	21	26	30	32
Farmington NM	83	241	28	26	22	17	12	10	11	15	19	24	28	30
San Diego Ca.	82	218	25	23	20	16	12	10	11	14	19	22	23	23
Riverside Ca.	80	218	25	23	20	15	12	10	10	14	18	20	23	26
Santa Maria Ca.	78	217	26	23	20	16	12	9	10	13	18	21	24	26
Los Angeles WBAS	73	202	24	22	19	14	11	9	9	12	18	19	22	22
Grand Junction Co.	73	219	27	23	21	15	10	9	9	13	18	22	25	28
Denver Co.	73	214	26	23	20	15	10	8	10	13	17	21	24	27
Los Angeles WBO	71	197	25	22	19	14	11	9	9	12	16	18	21	22
La Jolla Ca.	66	172	19	17	15	12	10	8	9	11	15	17	19	18
Fresno Ca.	63	203	26	23	19	14	9	6	7	11	16	21	24	26
Davis Ca.	58	195	26	23	19	13	8	6	7	10	15	20	24	26
Madison (Wi.)	48	162	22	19	15	10	6	4	6	9	13	16	20	22
Pennsylvania	48	158	22	18	14	11	7	5	5	8	12	15	19	22
Columbus Oh.	44	152	21	16	13	10	5	4	5	8	12	16	20	23
Buffalo NY	37	141	20	17	13	9	5	3	4	6	10	15	18	21
Seattle Wa.	32	144	26	18	13	8	4	2	3	6	10	15	20	21
S. England	31	131	19	17	12	7	4	2	3	5	9	14	19	20
N. England	24	108	16	13	9	5	3	2	2	4	8	12	16	17

*****shaded data adapted from other sources reported in Langleys*****

conversion factor applied 1MJ/m2=0.03784 Langley

Includes data for northern and southern England.
Data for Holland would be very similar to southern England

Arizona

Willcox
Community Profile

INTRODUCTION

Willcox, at an elevation of 4,167 feet, was established in 1880 and is located in the northern part of the Sulphur Springs Valley in Cochise County. The Sulphur Springs Valley cuts through Cochise County for nearly 100 miles, and averages over 15 miles in width. Willcox, located on I-10 halfway between Phoenix and El Paso, Texas, serves as the major trade and service center for agriculture and tourism within the County. The City of Willcox was incorporated in 1915.

WEATHER

Month	Average Temperature (°F) Daily Max	Daily Min.	Average Total Precipitation (Inches)
January	58.3	24.8	0.78
February	63.1	26.5	0.57
March	68.2	30.7	0.59
April	77.6	36.5	0.27
May	86.4	43.1	0.13
June	95.0	52.3	0.43
July	95.4	62.7	2.60
August	92.2	60.4	2.66
September	89.5	53.3	1.18
October	80.1	40.9	0.59
November	67.8	29.7	0.39
December	59.3	24.8	1.00
Year	77.7	40.5	11.19

Average Total Snow, Sleet and Hail Annually: 4.0 inches
(Based on a thirty year average)
Willcox Weather Station

COCHISE COUNTY EMPLOYMENT STRUCTURE

	Percent of Total
Agriculture & Mining	3.5%
Construction	3.4
Manufacturing	6.4
Transportation, Communication & Public Utilities	6.4
Wholesale & Retail Trade	22.1
Finance, Insurance & Real Estate	2.6
Services	19.7
Public Administration	35.9

Source: Arizona Department of Economic Security

LABOR FORCE DATA

	1980	1989	1990
Civilian Labor Force	1,206	1,545	1,560
Employed	1,128	1,477	1,487
Unemployed	78	68	73
Unemployment Rate	6.5%	4.4%	4.7%

Source: Arizona Department of Economic Security

GROWTH INDICATORS

	1988	1989	1990
Taxable Sales ($)	28,941,900	30,375,400	33,025,650
Postal Receipts ($)	430,993	454,533	469,617
New Building Permits Issued*	57	80	84
Public School Enrollment	1,381	1,300	1,385
Net Assessed Valuation ($)	9,622,826	9,535,495	10,983,052

*Arizona Business, Arizona State University

PROPERTY TAX RATE PER $100 ASSESSED VALUE

	1988	1989	1990
Arizona State Tax	$0.47	$0.47	$0.47
Community College	1.52	1.52	1.62
Flood Control (Cnty)	0.18	0.33	0.26
Library	0.15	0.16	0.14
County Fire District	0.10	0.10	0.10
County	3.65	3.68	3.67
County Total	6.07	6.26	6.26
School District #13	5.17	5.25	5.07
City of Willcox	1.33	1.32	2.16
Total	$12.57	$12.83	$13.49

Source: Arizona Tax Research Foundation

POPULATION

	1980	1990	1980-1990 Percentage Change
Willcox*	3,243	3,122	—3.7%
Cochise County	85,686	97,624	+13.9
Arizona	2,716,546	3,665,228	+34.9

Local sources estimate the trade area population at 20,000.

Sources: Arizona Department of Economic Security
U.S. Census Bureau

PRINCIPAL WILLCOX ECONOMIC ACTIVITIES

Willcox was known as the Cattle Capitol of the nation due to the use of the railroad as a shipping point. Cattle are still an important aspect of the economy, and the largest livestock auction in the state is held in Willcox. Row crops such as cotton and small grains are an important part of the economy.

With diversification of agriculture in the last few years, nearly 4,500 acres of apple orchards, peaches, cherries and grapes are grown in Sulphur Springs Valley. Spin-offs of this diversification have resulted in two apple packing companies. Vegetables, pistachios and pecans are also important activities in the area.

Tourists , as well as traveling business people have an important impact on the City's economy. Development on the Interstate has resulted in increased traffic. With a mild year-round climate, relatively low cost land and housing, and a pleasant rural lifestyle, Willcox is also a desirable retirement community. The City, with its historical downtown, is part of the Arizona Main Street Program. Willcox has also developed a diversity of support industries such as finance, utilities, schools, government, communications and a full-scale health center. It serves as the corporate headquarters for several large corporations.

Arizona
Department of Commerce
3800 N. CENTRAL AVE • PHOENIX ARIZONA 85012 • (602) 280 1321

FINANCE

Inter West Bank:	1 office
Desert Finance Co.:	1 office
Valley National Bank:	1 office
Farmers Home Administration:	1 office

Willcox businesses are eligible for assistance in financing fixed assets through the Development Finance Division, Arizona Department of Commerce. Information on availability of industrial development bonds within the City may be obtained from the same source or from the Industrial Development Authority of Willcox; 151 W. Maley; Willcox, Arizona 85643.

TRANSPORTATION

Highways:	I-10, U.S. 666, AZ 86 and 186
Railroads:	Southern Pacific (freight only)
Bus:	Continental Trailways, Greyhound
Truck:	Pacific Motor Transport, Bestway, Antelope, United Parcel Service (interstate); Whitefield (intrastate), Jenney Freight Lines, Consolidated Freight Way (Intra & Interstate)
Airport:	Cochise County Airport; one lighted, paved 6,100-ft runway; UNICOM radio, fuel and maintenance

COMMUNICATIONS

Newspapers:	Daily:	Arizona Republic (Phoenix); Arizona Daily Star, Tucson Citizen (Tucson)
	Weekly:	Arizona Range News
Radio:	KHIL (5,000 watts), KWCX-FM	
Television:	4 Tucson channels via antenna, 24 stations available via cable	

UTILITIES

Electricity:	Sulphur Springs Valley Electric Cooperative
Natural Gas:	Municipal, South West Gas
Butane:	Cal-Gas
Telephone:	Valley Telephone Coop., Inc., U.S. West
Water & Sewer:	Municipal

MEDICAL FACILITIES

Hospital:	1 [24 beds		
Nursing Homes:	2 [1, 24 bed extended care 1 private home with 23 beds]		
Physicians:	6	Dentists:	3
Chiropractors:	1	Optometrist:	1
Veterinarians:	2		

GOVERNMENT SERVICES

Local Government:	Mayor, 6 Council Members, City Manager
Police Department:	1 Director, 10 officers, 5 dispatchers, 3 civilians
Sheriff's Department:	12 deputies, 1 civilian
Dept. of Public Safety:	4 officers
I.N.S.:	7 patrolmen
Fire Department:	20 volunteers, 6 EMT
Underwriters Rating:	Grade 6

EDUCATIONAL FACILITIES

	No.	Faculty	Enrollment
Public Elementary [K-4]	1	31	549
Middle School [5-8]	1	29	412
Public High School [9-12]	1	28	424
Private School [1-12]	2	10	56

Cochise College, Willcox campus serves as an extension campus (350 students), where an Associate Arts degree can be earned.

CHURCHES

1	Catholic	15	Protestant
1	Church of Jesus Christ LDS		

COMMUNITY FACILITIES

Bowling Alley:	1	Library:	1
Art Center:	1	Pool:	1 [olympic size]
Golf Courses:	1 [9-hole]	Tennis Courts:	8 [3 lighted]
Parks:	5 [ramada, playground equipment]		
Athletic Facilities:	6 [lighted baseball/softball fields, 1 soccer field]		

Historic Railroad Avenue
Community Center with meeting facilities

Museum of the Southwest (adjacent to I-10): Wilcox Cowboy Hall of Fame and a Heritage Park. Rex Allen memorabilia is located in the Rex Allen Arizona Cowboy Museum, located in downtown Willcox.

ANNUAL EVENTS

Willcox, home of the famous TV, movie and radio personality Rex Allen, annually celebrates "Rex Allen Days." The event, held the first weekend of October, includes a parade, country fair, air show, PRCA rodeo, a Rex Allen concert, golf tournament and cowboy dances.

The Willcox History Fest, held in May during National Historic Preservation Week, celebrates more than 100 years of Cowboys, Indians and Railroads. Willcox also hosts the Magic Circle Bike Challenge (Labor Day weekend), the Christmas Apple Festival (first weekend in December), the Cowboy Hall of Fame Induction and Dinner; and AG Day (including demonstrations, seminars, etc. for farmers and ranchers).

SCENIC ATTRACTIONS

Cochise County, located in the southeastern corner of Arizona, is unparalleled in its historical, cultural, scenic and recreational features. From the rugged Dos Cabezas Peaks and the Chiricahua Mountains to Cochise Stronghold in Dragoon Mountains, part of the Coronado National Forest, the dramatic changes in scenery and wildlife will both delight and amaze visitors. These awe-inspiring mountains and mystifying deserts were once the homeland of the Chiricahua Apache Indians, and it is from the great Apache Indian Chief, Cochise, that the County gets its name.

Visitors to the area are encouraged to "Travel the Magic Circle of Cochise", a journey through the area that will bring its rich history and unique and dramatic geology to life. The Magic Circle tour begins at the Museum of the Southwest and Tourist Information Center which is operated by the Willcox Chamber of Commerce and Agriculture. From there, visitors travel down modern highways through this high desert region, exploring the vast beauty of the land where the Apache Indians rode, where settlers scratched a living from the soil, where prospectors searched for mineral wealth and where wildlife roams freely. The sights and stories of Cochise, the great Apache Chief, Dos Cabezas, the Town of Pearce, the Cochise Stronghold, the Chiricahua National Monument, the Amerind Foundation and Fort Bowie, as well as the exciting history of the City of Willcox itself make for a delightful and memorable experience.

INDUSTRIAL PROPERTIES AVAILABLE

Industrial Park: 1, with utilities, served by rail and truck routes is available. Contact the City Manager's Office, City of Willcox.

LODGING AND MEETING FACILITIES

Motels:	15 with 523 rooms
Meeting Facilities:	Numerous facilities with the largest seating 300 persons
Mobile Home & Trailer Park:	10 with 250 spaces
R.V. Parks:	3 with 170 spaces

This profile was prepared in cooperation with the Willcox Chamber of Commerce.

For further information, contact:

Willcox Chamber of Commerce and Economic Development Group	City of Willcox
1500 N. Circle 1 Road	151 West Maley
Willcox, AZ 85643	Willcox, AZ 85643
(602) 384-2272	(602) 384-4271

 6/91

CHAPTER 11

GREENHOUSE STRUCTURES

INTRODUCTION

***Protected agriculture:** the modification of the natural environment to achieve controlled or improved plant growth.

***Protected agriculture** can include

*Mulches of organic or synthetic materials placed on the soil around the plants to make conditions more favorable for plant growth.
*Shade cloth to protect plants against high light intensity.
*Plastic row covers to protect young plants against the cold early in the season
*Open-sided, plastic roofed structures to protect against rain
*Totally enclosed structures, or "greenhouses"

***Controlled environment agriculture (CEA)**: The "ultimate" in protected agriculture. The growing of plants, usually in a greenhouse or totally enclosed structure (e.g., growth chamber), with control at the aerial and root levels of temperature, humidity, gas composition, light, water, growing medium and plant nutrition.

GREENHOUSES

***Greenhouse:**

*A framed or inflated structure used for cultivating plants.
*It is covered with a transparent material that allows for optimum light transmission of the appropriate wavelengths (i.e., photosynthetically active radiation or PAR).
*It protects against adverse climatic conditions.
*Control of the environment to achieve goals (e.g., opt. yield, etc.)

***One of the first recorded greenhouses** was built during the first century A.D. It was covered with "transparent stone", probably sheets of mica, to grow cucumbers out of season for the Roman Emperor, Tiberius.

***A greenhouse must provide protection** from adverse "abiotic" conditions such as

heat	cold	rain	wind	sleet
hail	snow	salt	blowing sand	

NOTE: Structures can also be built to protect plants against "biotic" factors, for example, cages covered with insect or bird netting to protect against insect and bird predation, respectively. However, these structures will not be considered here.

***Structural members** must be strong enough to prevent structural failure during adverse weather conditions but be kept to a minimum size and number to reduce the amount of shading and to provide for maximum light transmission.

***Greenhouse structures are rated for certain "design loads"** (the load or weight supported by the structure).

Dead Load = the greenhouse framing and everything hanging from it including the glazing (covering), pipes, heaters, fans, pads, shade cloth, motors, support cables AND any hanging crops or baskets in place more than one month.

Live Load = transient greenhouse assembly or repair equipment, people (not swinging from the rafters!) who must climb onto the structure to perform various repairs, cleaning, servicing, etc. AND any hanging crops (e.g., tomatoes, peppers, cucumbers) or baskets in place less that one month.

Wind Load = the load, in pounds per square foot, placed on the exterior of the greenhouse by wind. This will depend on

*The angle at which the wind strikes the greenhouse.
*The shape of the greenhouse (height, width, number of bays, etc.).
*Whether or not vents, doors, etc. are open or closed.
*NOTE: If a sufficient wind strikes the side of a greenhouse it could rip the roof off! (Local windbreaks – trees – can help.)

Depending on the location, a typical "wind load" is 80 mph or 16 lb/ft2.
The greenhouse frame needs to be secured to the ground against wind.

With permanent structures, anchor the supports in concrete.
With temporary structures a cork screw device is used to anchor the greenhouse to the ground.

Snow Load = the load, in pounds per square foot, placed on the exterior of the greenhouse by snow accumulation. The type of snow makes a difference:

*12 inches of dry snow equals 5 pounds per square foot of load.
*3 inches of wet snow also equals 5 pounds per square foot of load.
*and 9 inches of wet snow can collapse a greenhouse

When it starts to snow hard – increase the heat in the greenhouse to melt it.

Early snow will melt easily. Succeeding snows will slide off.

Building Codes:

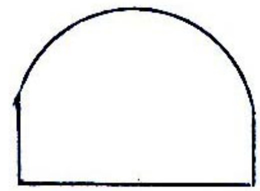
*Each state/country will have its own codes.
*Sometimes agricultural buildings will be exempt from the codes or be treated as "special structures".
*Example: Greenhouses can be built very cheaply in Mexico because Mexico has no building codes. However, these greenhouses may also not be as safe as if they were built to USA code.
*Always make sure the builder/contractor is insured.

TYPES OF GREENHOUSE STRUCTURES

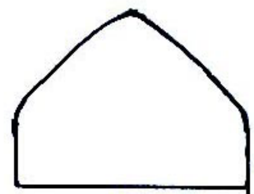
Typical structures include:

***Hoop House or Quonset:** A semi-circle design usually covered with a single layer of polyethylene film or with a double layer of film separated by an air layer maintained by a small fan for insulation. Used for low crops: potted plants, lettuce, etc.

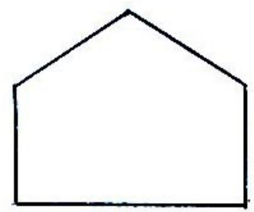
*__The Arch:__ A semi-circle design elevated by side walls. Can grow higher crops: taller potted plants, vining tomatoes, cucumbers, peppers, etc.



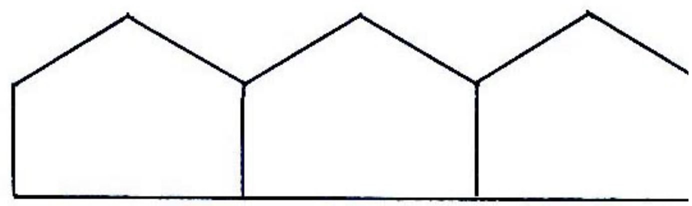
***Gothic Arch:** A variation on the Arch with more rounded side walls.



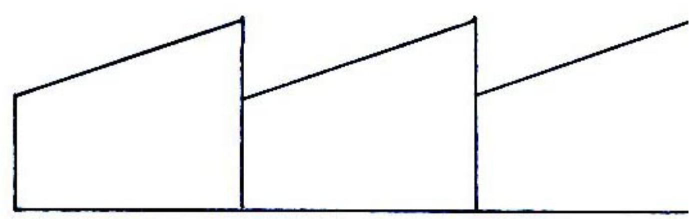
***The Gable:** A structure with side walls and a peaked roof. Optimum for high crops including vining tomatoes, cucumbers, peppers, etc.



***Ridge and Furrow or Gutter-Connected:** Several gable (or arch style) greenhouses connected together usually with no internal separations between the bays. Used for high crops such as vining tomatoes, peppers and cucumbers.



***Sawtooth Design:** A variation of the gutter-connected style with tall vents on the vertical sections of the roof to allow for natural ventilation. Used for high crops such as vining tomatoes, peppers and cucumbers.



GREENHOUSE FRAMING MATERIALS

***Wood:** Due to increasing cost and availability of more suitable materials, wood is no longer generally used in large commercial greenhouse construction. If used for smaller greenhouses or in areas where other types of framing materials are not available, wood must be treated for protection against decay, especially the sections that come in contact with the soil. Treatments must be non-toxic to plants and animals (Ex: do not use creosote or pentachlorophenol). Chromated copper arsenate (CCA), ammonical copper arsenate (ACA) or other preservatives containing combinations of copper, chromium and/or arsenic are safe to use around plants. Also treat woods with "natural decay properties" such as redwood or cypress, especially in desert or tropical regions.

***Reinforced concrete:** Usually used for the greenhouse foundation and low walls.

***Reinforced concrete and bamboo:** In the People's Republic of China, the concrete has been used as support posts for a frame of bamboo.

***PVC (polyvinyl chloride):** Hollow tubes of this plastic material (typical inside diameter of ½ inch) can be used for small scale hoop or arch style greenhouses. These are not necessarily considered "permanent" structures.

Electrical conduit: This can also be used, like PVC pipe, for small scale hoop or arch style greenhouses. These are not necessarily considered "permanent" structures.

***Air or air tubes:** The structures of some greenhouses of the hoop or arch style (covered with flexible polyethylene film) can be maintained solely by air pressure either by inflating the entire greenhouse or by inflating air tubes that act as structural members. This requires air handling equipment, and if the power fails the greenhouse will collapse.

***Steel (galvanized):** Almost all steel used in greenhouses today is single or double dip galvanized to protect against corrosion. It may be used in conjunction with aluminum. It is usually protected from direct contact with the ground (and subsequent corrosion) by being encased in concrete.

***Aluminum:** It may be used alone or in conjunction with galvanized steel. It is much lighter than steel but is only about one half the strength of an equally sized steel member. It is usually protected from direct contact with the ground (and subsequent corrosion) by being encased in concrete.

GREENHOUSE GLAZING (OR COVERING) MATERIALS

Introduction: The materials used to cover greenhouse structures can be rigid or flexible, double-walled or single-walled, smooth or corrugated. Most "glazing" materials made today incorporate compounds that inhibit rapid degradation by ultraviolet (UV) radiation.

However, all glazing material will age and they are therefore rated by the number of years they will maintain a certain level of light transmission capability.

As mentioned earlier, mica sheets were used in the 1st century A.D. as a glazing on Roman greenhouses. However, this material is no longer used, except perhaps as a demonstration of “ancient technology”.

***Glass:** This has been in use for at least a century in Northern Europe (Holland, England, etc.). Early glasshouses required significant wood and later metal structures to hold small but relatively heavy panes of glass. This reduced incoming light. Modern glasshouses have large panes of glass with reduced framing of stronger materials to increase light levels. Light transmission (PAR) is between 71 and 92 % depending on the type of glass and the estimated lifetime is 25 years or more. However, glass is inflexible, heavy, easily broken (unless tempered) and expensive and many growers are now opting for plastic materials.

***Polyethylene:** First developed in England in 1938, this flexible, lightweight material is used extensively on hoop or arch style greenhouses because it is easy to work with and inexpensive. A single layer can be used or two layers can be applied with an air layer (maintained by a small fan) in between. This air layer adds insulation from heat and cold and adds structural strength with the double layer polyethylene houses being more stable in areas of high winds or typhoons. Light transmission (PAR) is around 85-87 %. Unfortunately, the estimated lifetime is only 2-4 years, depending on location and quality of the polyethylene.

***Polyvinyl chloride (PVC):** Another flexible film that has light transmission qualities similar to glass. This material has been used extensively in Japan. While polyethylene sheets can be wide, PVC is narrow which is a disadvantage in covering greenhouses.

***Corrugated Fiberglass (also known as fiber reinforced polyester):** This is a common greenhouse glazing. It is inexpensive, strong and easy to work with. Light transmission (PAR) is between 60 (double walled) and 88 %. However, it is susceptible to UV light, dust and pollution (hose down or wash periodically), yellows with age and is extremely flammable. The estimated lifetime is 7-15 years, depending on type of fiberglass.

***Acrylic:** This glazing material is lightweight, easy to work with and resistant to UV radiation and weather. Light transmission (PAR) is 83 % for double wall and 93 % for single wall. The estimated lifetime is 20 years or more. However, it is easily scratched, has a high expansion and contraction rate, becomes brittle with age, is expensive, and is flammable.

***Polycarbonate:** This glazing material is lightweight, easy to work with and is resistant to high impacts. Typical light transmission (PAR) is 79 % for double wall and 87 % for single wall. However, recent advances have produced polycarbonates (e.g., “Dynaglas”, a single walled, corrugated material) with light transmission properties equal to or even exceeding glass. The estimated lifetime is 5-10 years, or more, depending on type.

Previously, polycarbonate was known to scratch easily and have poor weatherability and UV resistance. However, recent advances in material properties have alleviated some of these earlier problems by coating the outer layer with acrylic.

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1. **Protected Agriculture: A Global Review. Part 2: Protecting materials and structures.** 1995. M.H. Jensen and A.J. Malter. The World Bank (Technical Paper #253), 1818 H. Street, N.W., Washington, D.C., 20433. ISBN 0-8213-2930-8
2. **Energy Conservation For Commercial Greenhouses.** W.J. Roberts, J.W. Bartok, Jr., E.E. Fabian and J. Simpkins. Northeast Regional Agricultural Engineering Service/Cooperative Extension, Cornell University, 152 Riley-Robb Hall, Ithaca, NY 14853.
3. **Stuppy Greenhouse Solutions.** 2000. A commercial catalogue distributed by Stuppy Greenhouse Manufacturing, Inc., 1212 Clay Street, P.O. Box 12456, North Kansas City, MO 64116.
4. **Web Pages:**
   http://ag.arizona.edu/ceac/

CHAPTER 12

GREENHOUSE CONTROL SYSTEMS

INTRODUCTION:

*Once a greenhouse structure is built various techniques, devices, etc. must be added in order to control the environment.

*Control systems include those for lighting, heating, cooling, relative humidity and carbon dioxide enrichment.

LIGHT:

***Importance:** Maximum light transmission, of the appropriate quantity and quality (photosynthetically active radiation, 400-700 nm), through the greenhouse structure to the plants is crucial for optimum photosynthesis, growth and yield.

***Structural considerations:**

Large sections of glazing material (glass, polyethylene, polycarbonate, etc.), held in place by few supports, results in higher light levels and less shading.

Minimize other opaque structures above the crop that would cause shading such as heaters, carbon dioxide generators, opaque vents, etc.

***Too much light:** Occurs in high light regions such as the desert southwest USA (including Arizona), Mexico, Spain, Israel, etc. during the summer months.

Shade paint/white wash: A mixture sprayed on the outside of the greenhouse. This will either wear off by the end of the summer or it can be washed off.

External shade cloth: Fabric cloth, placed on the outside of the greenhouse, made of varying degrees of mesh size to exclude specific amounts of light (ex.: 30%, 40%, 50% shade).

Internal shade cloth: Fabric cloth, as above, hung inside the greenhouse.

***Too little light:** Occurs above/below 30^0 north/south latitudes during the “winter”.

White reflective ground covers: These are now in common use in commercial greenhouses in all locations and can significantly increase light levels to the plant canopy.

Artificial lights:

Used above 30^0 north/south latitudes to extend the winter growing season.

Provide day length control (photoperiod) that can initiate plant processes.

Provide proper timing of light to control growth (photomorphogenesis).

Typical lamp types include incandescent, fluorescent, mercury vapor, high pressure sodium and low pressure sodium.

Artificial lighting COSTS MONEY! Therefore, choosing a location that minimizes the use of lights increases profits. Artificial lighting is most cost effective for “transplants” since they require less space.

HEATING:

***Importance:** Each plant species has an optimum temperature range. Heating devices will maintain the temperature within that range during periods of cold weather.

***Types of heat loss from a greenhouse**

Conduction = Heat transfer either through an object or between objects in contact. Conduction depends on area, path length, temperature differential and physical properties of the object(s).
Example: Heat loss through the glazing material on the greenhouse.

Convection = Heat transfer by the movement of warm gas or liquid to a colder location. Convection depends on temperature differential.
Example: Movement of warm air near the plants upward toward the roof.

Radiation = Heat transfer between separated objects. Radiation occurs from all objects and depends on the areas, temperatures and surface characteristics of the objects involved.
Example: Heat transfer from all objects in the greenhouse.

***Heat loss calculations**

It is important to be able to estimate the heat loss from the greenhouse in order to choose the correct size of heater to replace that heat.

Although radiation and convection transfer heat around the greenhouse, the main type of heat loss from a greenhouse is through conduction, i.e., the heat loss through the glazing material.

Conduction heat loss can be estimated:

Q = U A (Ti – To)

Where:
Q = conduction heat loss in Btu's (British thermal units) (also, the size of the heating unit needed)
U = heat transfer coefficient: Btu/hr*sq.ft.*deg F temp diff
A = surface area (sq. ft.) of greenhouse glazing not ground
Ti-To = temp req'd inside–lowest temp expected outside

Typical U coefficients for glazing materials:

1.14	Btu/hr*sq.ft.*deg F	Glass, single layer
0.65	"	Glass, double layer, ¼" space
1.15	"	Polyethylene or other film, single layer
0.7	"	Polyethylene or other film, double layer
1.0	"	Fiberglass reinforced panel
0.6	"	Acrylic or polycarbonate, double layer

Ex:

A gable greenhouse	2 Sq ends = 2x8x24 =	384
Double layer acrylic	2 Triangle ends = 24x6 =	144
15 F – lowest outside temp	2 Sides = 2x8x48 =	768
65 F – required inside temp	2 Sq roofs = 2x48x13.42=	1288.32
	Total square feet =	2584.32

Q = (0.6) (A) (65-15)
= (0.6) (2584.32) (50)
= 77,529.6 Btu's/hr

***The basic system:**

Consists of a **fuel burner**, **heat exchanger**, **distribution system** and **controls**.
Heat delivery to the crop is by **convection** and **radiation**.
The fuel = usually burn **natural gas**, but can also use oil, coal, wood, etc.

***Heating by hot water or steam:**

Hot water or steam can be produced using boilers fired by natural gas, etc.
The hot water or steam is then transported throughout the greenhouse in pipes.
The pipes can end in a heat exchanger where a fan distributes heated air.
The pipes can run along the floor and also be used as cart rails between aisles.
 Heat will then rise upward through the crop by convection.
Heat pipes can also be positioned within the crop to steer plant growth (Ch. 3).
Heated tubes can create "bottom heat" for propagation or growing.

***Heating by hot air:**

Fuel is burned to heat air that is then distributed by fans around the greenhouse.
 Horizontal air flow (HAF) fans circulate warm air above the crop.
 Fan jet systems, with unit heaters or heat exchangers and perforated polyethylene tubes, distribute warm air and improve air movement and ventilation throughout the greenhouse.

***Moveable nighttime insulation:** Insulating material (cloth or film curtains) can be positioned above the crop or near the roof to retain heat near the crop. The insulating material used during the night can be the same material used for shading during the day.

COOLING:

***Importance:**

High temperatures can be detrimental to plant growth.
High temperatures can cause such problems as
 Thin, weak stems or, as in tomatoes, stick trusses (thin, weak truss stems)
 Reduced flower size or, as in tomatoes, flower fusion and boat formation
 Delayed flowering and/or poor pollination/fertilization and fruit set
 Flower and bud/fruit abortion

***Cooling requirements and calculations:**

The National Greenhouse Manufacturer's Association 1993 standards =
 8 cubic feet per minute/square feet of greenhouse floor area OR…
 1 full greenhouse volume exchanged per minute in warm climates.
 CFM = height x width x length (i.e., volume)

Example: Using the greenhouse dimensions in the heat calculation example:

CFM = volume lower section + volume triangular top
 = (8 x 24 x 48) + (6/2 x 24 x 48)
 = 9216 + 3456
 = 12,672 cubic feet per minute => size fans/pads accordingly

***Passive ventilation systems:**

Shading: Shade cloth or shade paint/white wash, besides regulating the light intensity, can also help cool the greenhouse.

Ridge Vents: Vents in the roof of a greenhouse that allow hot, interior air to escape. The area of the vents should be 25% of the floor area.

Roll-up Side Walls: Can be used in flexible glazing (polyethelene film) single bay greenhouses where the side walls can be rolled up several feet allowing a natural horizontal flow of air over the plants. As with ridge vents, the area of the side wall vents should be 25% of the floor area.

Cooling Towers: Water cooled pads at the top part of tall towers cool the surrounding air which then drops displacing warmer air below.

Removable Roof: Recent greenhouse designs can include a roof that retracts completely for natural ventilation. This would allow for adaptation of greenhouse grown plants to outside conditions prior to movement outside.

***Active cooling systems:**

Fan and Pad: "Evaporative cooling" where air from the outside is pulled through porous, wet pads (usually cellulose paper). Heat from the incoming air evaporates water from the pads, thereby cooling the air. Evaporative cooling will also help to increase the relative humidity in the greenhouse.

Fogging Systems: Uses evaporative cooling like the fan and pad but incorporates a dispersion of water droplets that evaporate and extract heat from the air. This system gives better uniformity since the fogging is distributed throughout the greenhouse and not just near one a pad end as with the fan and pad system. The smaller the droplet size, the faster each droplet evaporates and therefore the faster the cooling.

Mist droplets = 1000 microns in diameter.

Air Conditioning: Too expensive for most greenhouses.

RELATIVE HUMIDITY: $\dfrac{\text{Amount of water in the air}}{\text{Amt. of water poss. at a given temp.}} \times 100$

***Importance:**

High or low relative humidity can be detrimental to plant growth.

Effects on transpiration – When RH is too high, transpiration (the movement of water from inside the leaf to the outside) is reduced along with movement of mineral nutrients. When RH is too low, transpiration may be increased significantly resulting in plant wilt.

Effects on pollination – When RH is too high, the pollen can clump on the stigma causing cat facing or the pollen may not be released from the anthers at all. When RH is too low, the normally sticky stigma can dry out and the pollen may not stick to it's surface, decreasing pollination.

Note that many greenhouse crops are bred for higher humidity conditions.

If those same crops are grown outside, in lower humidity environments, they usually perform poorly.

***Ways of controlling RH in the greenhouse:**

Relative humidity can be increased by running the cooling pads or by fogging.

Relative humidity can be decreased by running the heaters or simply venting.

CARBON DIOXIDE ENRICHMENT:

***Importance:**

The rate of photosynthesis is dependent upon the availability of carbon dioxide.

Carbon dioxide enrichment is most important during the winter months in the morning. The sun has risen and photosynthesis has begun. The plants can reduce the levels of carbon dioxide from the ambient level of about 330 ppm (higher in cities due to industry and vehicles) to around 220 ppm.

Lowered carbon dioxide levels will reduce growth and can cause flower and fruit drop reducing overall yields.

***Ways of controlling carbon dioxide levels in the greenhouse:**

Ventilating (bringing air in from the outside) may provide sufficient carbon dioxide during the Spring, Summer and Fall months.

Ventilating during the Winter months, or anytime in cold climates, will, however, result in cold outside air being brought into the greenhouse. Heating will then be needed to maintain the proper temperature which may become uneconomical.

Therefore, carbon dioxide generation is a typical and effective way to increase levels in the greenhouse during the Winter or in cold climates. Carbon dioxide generators can burn various types of fuel including natural gas (most economical)or propane. Carbon dioxide levels above 800 ppm, even as high as 1200 ppm, have been shown to be beneficial to plant growth.

AIR CIRCULATION:

***Importance:**

One reason for having a greenhouse is to create a "controlled environment" for all of the plants. And each plant within the greenhouse should receive the same conditions. However, especially during times when the heating and cooling systems are not in operation, pockets of high or low temperature, relative humidity or carbon dioxide may develop which can be less than optimal for plant growth or flower/fruit development.

***Ways of improving air circulation:**

Horizontal air flow (HAF) fans can be placed in the rafters of the greenhouse to circulate air above the crop. This helps to minimize pockets of warm or cold air and high or low humidity or carbon dioxide within the greenhouse.

HAF fans can be used in conjunction with hot air heating systems (see above) to circulate warm air throughout the greenhouse.

HAF fans can also be used at anytime to enhance air mixing in the greenhouse.

ENVIRONMENTAL CONTROL SYSTEMS:

***Control systems can be very simple or very complex. Examples include:**

The "original" environmental control systems were manual:
- Manually rolling up a side vent.
- Manually opening a roof vent or door.
- Manually turning on a heater or cooler.

Simple controllers operate from a thermostat in the greenhouse and:
- Automatically set day and night temperature ranges.
- Automatically open and close vents (side, roof, etc.).
- Automatically turn on or off heaters and coolers.

Step controllers operate from a thermostat in the greenhouse and:
- Automatically set day and night temperature ranges.
- Automatically control 1 or 2 heating stages (depends on # of heaters).
- Automatically control several cooling stages using cooling fans and pump(s) to wet the pads.

Sophisticated computers operate from a temperature sensor in the greenhouse and:
- Automatically set day and night temperature ranges.
- Automatically control heating equipment including boilers, root zone heating, heat retention curtains, etc.
- Automatically control other equipment including HAF fans, exhaust fans, vents, pad pumps, fogger systems, etc.
- Automatically control relative humidity.
- Automatically control shade curtains and artificial lighting depending on light requirements.

Sophisticated computers can also monitor an external weather station and use data from that station to control internal conditions in the greenhouse.
- Data monitored includes: outside light, temperature, RH, rain and wind.

Sophisticated computers can also operate the fertigator system (see Chapter 8)
- Automatically using light quantity (e.g., X ml of solution/Y amt. of light)
- Automatically controlling timing of watering, duration of watering, nutrient solution pH and EC, misting, watering booms, etc.

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CHAPTER 13

GREENHOUSE ENERGY CONSERVATION AND ALTERNATIVES

INTRODUCTION:

*In northern latitudes (Canada, England, Holland, etc.) the cost for heating, especially, and cooling a greenhouse can amount to 70 – 85% of the total operating costs. In warmer areas (the Southwest United States, Mexico, Spain, Israel, etc.) the costs can still be around 50% of the total operating costs.

*Therefore, heating and cooling are obviously a significant part of the operating budget.

*Any measures that reduce the need for heating and cooling will reduce the costs for these as well, and will therefore increase profit (the bottom line for a commercial grower, schools and even home gardeners!).

*This chapter presents methods to conserve energy in a greenhouse as well as alternatives to "traditional" methods of heating and cooling.

GREENHOUSE ENERGY CONSERVATION MEASURES FOR HEATING

*__Greenhouse orientation:__

In northern latitudes single bay greenhouses can be oriented east-west to allow maximum light reception in the late fall, winter and early spring.

For multiple bay, gutter-connected greenhouses the orientation is usually north-south so that the shadows from the gutters track from west to east across the crop rather than shading the same areas all day.

In either case, the rows of plants within the greenhouse should run north-south to optimize equal light to all plants throughout the day.

***Windbreaks to save on heating:**

A wind of only 15 mph can double the heat loss from a greenhouse.

A wind reduces the thickness and therefore the insulating effectiveness of the thin air layer (boundary layer) along the greenhouse glazing. A wind will essentially "suck" heat away from a greenhouse faster than if the air was still.

Windbreaks, in the form of fences, trees, buildings, etc. can slow the wind and therefore cut heat losses from the greenhouse.

Windbreaks are most effective with older, leaky greenhouses or in high wind areas. However, older greenhouses should be upgraded since this will save far more money in heating costs than any windbreak.

***Use of double verses single layer glazings:**

Double layer glazings, with at least a ¼" insulating layer of air in between, can reduce the conductive heat loss by up to 40% over single layer glazings.

Using triple layered glazing or, for example, a double layer of polyethylene over glass, can further cut heat loss, but it will also reduce solar radiation, so this is very rarely done.

***Structural insulation:**

Insulating materials can be applied to the foundation of the greenhouse, to the north wall (in the northern hemisphere) and to the walls up to the height of the plants to reduce conductive heat loss.

Weather stripping and other insulating materials should be added where ever there are gaps in the structure. This includes around doors and vents and where glazing panels meet the structural supports.

If the glazing material is cracked (ripped polyethylene, broken glass panes or cracked poly acrylic or carbonate) replace immediately to reduce heat loss.

***Inflatable tube insulation:**

Polyethylene tubes (6-18" in diameter) can be hung from the greenhouse ceiling.

When inflated they create an effective insulating barrier to heat loss through the ceiling (up to 40%). Make sure the tubes fit snuggly along the walls.

Since polyethylene above the crop will reduce light transmission, tube systems have been designed to be retractable or removable during the day.

Though effective, these systems are rarely used in commercial operations.

***Retractable heat or insulating blanket or curtain:**

Porous, non-porous and aluminized materials are all used as insulation blankets.

The material can be single or multiple layers: more layers giving more insulation.

The material, placed between the ceiling and the crop, must be secured along the walls to minimize cold air above falling through onto the crop.

These curtains can be used during the day in the summer for shading as well.

These retractable curtains are perhaps the most cost effective.

***IR coatings on polyethylene films:**

These infrared barrier films allow heat into the greenhouse during the day (requiring a bit more venting or cooling) but significantly reduce heat loss at night by as much as 30%.

***Other insulating methods – experimental:**

Polystyrene beads have been used by blowing them into the air space between two glazing layers. Energy savings may amount to 60-90% annually.

Liquid foam (or soaps) can be blown into the air space between two glazing layers for an energy savings of perhaps as much as 50%.

A disadvantage of this is that most foams break down in cold.

Unfortunately, neither of these experimental methods are currently practical.

***Equipment operation and maintenance:**

Maintain the heating equipment (check for leaks, valve operation, thermostats, etc.) so that it operates at peak efficiency.

Insulate supply and return hot water/steam pipes. Inspect regularly.

Choose the most efficient and cost effective fuel: In most places, natural gas.

GREENHOUSE ENERGY CONSERVATION METHODS FOR COOLING

***Structural considerations:**

As with heating conservation, insulation and weather stripping can reduce infiltration of hot outside air into the greenhouse which will reduce cooling needs.

Damaged glazing materials should also be replaced.

Taller greenhouses (16-22 feet, about 5 to nearly 7 meters) are better since hot air will rise away from the crop.

***Equipment operation and maintenance:**

Maintain the cooling equipment so that it operates at peak efficiency.

***Passive measures:**

Energy savings can be realized by using shade cloth or paint as mentioned in Chapter 12.

ENERGY ALTERNATIVES FOR GREENHOUSE HEATING

***Compost energy**

The breakdown of plant material in a compost pile generates heat.

Example: Although the outside temperature can be 55^{o}F (~13^{0}C) or colder, the temperature within a compost pile can be as much as 120^{o}F (49^{0}C) or more.

PVC pipe, with an opening to the outside air, can be installed within the compost pile. The heat from the pile will be transferred to the air in the pipe which can then be drawn into the greenhouse with a small fan. Unfortunately, this technique also tends to add moisture and odors to the air.

Pipes filled with water can also be placed inside the pile and the heated water can be used to heat the greenhouse. This is much better and odor free.

***Solar energy**

During the day the sun can be used to heat either water or air.

This heated air or water can then be used during the night to heat the greenhouse.

However, at present it would take a solar collector at least 500 m^2 to heat a greenhouse 1000 m^2.

Also, solar collectors do not work effectively on hazy or cloudy days. Other types of heat generation would be needed.

***Geothermal energy**

Water heated by energy from the Earth's interior is being used extensively in Iceland to heat all structures including homes, businesses and greenhouses.

There are also several installations in the western United States that use geothermal energy.

Problems of using geothermal energy include corrosion and sealing of the pipes, toxic gases such as hydrogen sulfide, mercury, radon, ammonia and boric acid, silica deposition in the equipment, heavy metal contamination and complications with disposal of the waste thermal fluids.

***Waste heat utilization from power plants**

Large industrial units, electrical generating stations and nuclear power plants all produce waste heat mainly in the form of hot water.

During the 1970's and 1980's research was conducted to determine the feasibility of using this waste energy to heat greenhouses.

Facilities were tested in France, England, the United States and other countries.

Most tests showed that the cost of connecting the greenhouse and power plant could be too high and that the resulting heat source might be unreliable during repair and maintenance of the power plant.

***Co-generation**

These are total energy systems which produce both heat and electricity from the same unit.

It consists of an engine which turns a generator to produce electricity onsite. Small units can produce 20-100 kilo watts.

Reject heat from the operation of the engine can be used to heat the greenhouse.

One might also be able to obtain an extra added benefit by tapping the engine exhaust for carbon dioxide for use by the plants in the greenhouse.

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CHAPTER 14

FRUIT HARVESTING, GRADING AND STORAGE

INTRODUCTION

*Although a grower may produce healthy plants with a significant fruit load, improper handling and/or storage of the fruit can result in significant losses of fruit and therefore money.

*This chapter presents techniques for tomatoes, but also discusses cucumbers and peppers for comparison.

FRUIT MAINTENANCE FOR OPTIMUM HARVEST

Tomato

*The initial selection of a tomato (or other crop) variety can be significant as some varieties are predisposed to produce less than optimum fruit under certain conditions. Consult with the seed company for specific details.
Ex.: Some tomato varieties are more likely to produce boat shaped fruit.
Ex.: Some tomato varieties are sensitive to heat, producing weak stick trusses.
Ex.: Some tomato varieties perform better with higher or lower EC.

*Remove damaged or imperfect tomato fruit including scarred, boats, blossom end rot, cat faced, etc., so the plant will not waste nutrients on unmarketable fruit. HOWEVER, excessive fruit pruning may require leaf pruning.

*Depending on season, light levels, etc., maintain 3-5 tomato fruit per cluster.
If too many fruit are left on one cluster, the average size of those fruit may be reduced and nutrients can be diverted from the upper portion of the plant reducing growth and the number and size of the fruit on the trusses above.
If only 1 or 2 flowers/fruits appear on upper clusters, as many as 6 fruit may be left on a lower cluster.
Rule of thumb: 9-15 fruit per every 3 clusters (depending on season, light levels, health of plant, variety, etc.).

*To prevent rotting, fruit should not rest on the floor.
The overhead support cables should be high enough for the variety.
Horizontal stem supports on the ground can also be used.

*If flowers close but do not develop into fruit, or if the fruit remains small and/or dull in appearance remove from the truss. These will not develop properly and will only drain nutrients from the plant.

Pepper

*Remove the crown fruit flower (develops at the first branch point – see Chapter 2). The plant is usually not large enough to support a fruit at this level as well as set good fruit higher up.

*At each branch point 1-2 flowers may develop. Leave only 1 flower. However, during winter or times of lowered light, the plant may only be able to maintain 1 flower/fruit every 2 branch points.

*Remove damaged fruit including blossom end rot, oddly shaped fruit, sunscald, etc.

Cucumber

*In lower light areas the standard practice has been to remove all flowers/fruit up to 80-100 cm above the base of the plant to allow the stem and root systems to develop sufficiently to support subsequent fruit development. (May modify in high light.)

*Depending on the season, light levels, etc., leave 1 or 2 flowers/fruit per node. In low light the plant may only be able to support a fruit every other node.

*Remove damaged or crooked (bent) fruit that will not be "marketable" but will drain nutrients away from other fruit and the plant.

HARVESTING

Tomato

*Tomato fruit should be harvested every 3-4 days or 2-3 times per week.

*For beef type tomatoes, each fruit should be removed at the abscission zone so that the green stem and green sepals are left on the fruit. This gives the fruit a "home grown" appearance which commands a higher price at the market. It has also become a "trademark" of greenhouse, hydroponic, vine-ripened fruit.

*For TOV's (tomato on the vine or cluster tomatoes) the entire cluster, containing 4-5 fruit, is removed as a unit when most of the fruit are showing color.

*Fruit should be harvested when there is color showing.
Some growers harvest when only a little pinkish color is apparent.
Other growers wait until the pinkish color is even all the way around the fruit.
If the fruit will be sold locally and soon after harvest, it can be picked red.
Some varieties ripen with an orange tinge. Check with the seed supplier.
REN Gene: Some varieties contain the REN gene (incorporated through traditional breeding techniques, NOT genetic engineering). This gene imparts long shelf life (LSL) and is common now for field and some greenhouse varieties. The fruit from these varieties will begin ripening orange and will remain that way for up to 2 weeks before fully ripening.

Pepper

*Greenhouse hydroponic growers usually grow the colored bell pepper varieties. These peppers will “size” (grow to final size) while they are still green then turn color (yellow, orange or red depending on the variety).

*Colored peppers, in a commercial setting, are harvested either as mature green or fully turned but can also be removed when the fruit is about half way turned in color.

*As with beef type tomatoes, pepper fruit should be removed at the abscission point.
CAUTION: The pepper fruit is attached directly to the main stem which is brittle. Hold the main stem firmly while removing the pepper fruit to minimize stem cracking.

*The standard for pepper fruit is to harvest once a week but twice a week is common.

Cucumber

*Long cucumber fruit can also be harvested 2-3 times per week.

*The young fruit will have small, prickly hairs, ridges along it’s length and a pointed flower end (furthest from the stem). Wait until the fruit fills out and the flower end is somewhat rounded before harvesting.

*Cut the cucumber fruit off at the stem.
CAUTION: Once removed from the plant, the cucumber fruit will begin to loose moisture. Wrap the fruit in plastic for storage or transport.

FRUIT GRADING

Tomato (We use the 1’s/2’s/culls system.)

*Beef type tomatoes can be categorized as #1’s, #2’s or culls.
#1’s = good shape; no or only minor blemishes; equal to or greater than 150 g.
#2’s = boat shaped; larger blemishes (scars, minor cracking, etc.); any size.
Culls = large boats, cat face, blossom end rot, cracking, extra smalls, etc.

*Beef type tomatoes are also categorized by size:

CLASSIFICATION	AVERAGE FRUIT WEIGHT (g)	NUMBER OF FRUIT PER 15 POUND BOX
Jumbo	290 - 320	18 - 22
XL (Extra Large)	219 - 289	25 - 32
L (Large)	180 - 218	35 - 39
M (Medium)	156 - 179	45
S (Small)	135 - 155	52

*Beef type tomatoes are placed in single layer boxes containing thin plastic inserts with molded cups to accommodate each fruit.

*Sorting and grading of commercial beef type tomatoes is usually done by machine.
The tomatoes are brought in from the greenhouse and placed on a conveyor belt.
The tomatoes pass under a camera and any defective fruit is 'tagged' electronically by workers with special wands.
These tagged fruit (sever boats, cat face, scarred, sunscald, etc.) are directed to the cull bins.
The other fruit is carried along the conveyor in cups that drop the fruit gently into the appropriate lane according to size and color.

*Since TOV types tomatoes are picked as a unit on the cluster stem, all of the tomatoes must be #1's. If a cluster has 5-6 tomatoes and 1 or 2 are not #1's, they must be removed before packaging.
NOTE: Preliminary sorting, grading and boxing of TOV's is done in the greenhouse by the pickers.
NOTE: Boxes for TOV's are smaller than those for beef type tomatoes, have a thin, flat, cushion layer to protect the fruit and accommodate 7-10 clusters.
NOTE: TOV's may also be packaged in net bags depending on the buyer's specifications. Many supermarkets prefer cluster packaging to distinguish individual TOV tomatoes that could easily be removed from the cluster from the less expensive field grown tomatoes also available in the store.

Pepper
*As with beef type tomatoes, colored peppers can be categorized as #1's, #2's and culls.
#1's = good shape and color; no or only minor blemishes
#2's = somewhat oddly shaped; larger blemishes
Culls = very oddly shaped; sunscald, withered, blossom end rot, etc.

*Since peppers are hollow inside, they are usually graded by diameter size rather than by weight: 50-60 mm, 60-70 mm and 70-90 mm.

Cucumber
*Cucumber fruit should be sorted by length and should be uniform in each box.

*Severely crooked (bent) fruit or scarred fruit should be separated out and marketed as #2's or culls.

FRUIT STORAGE

Tomato
*Tomato fruit should be stored in a cold room at between 50^{o} and 65^{o} F.

*For home use, put not-quite-ripe tomato fruit on the counter, NOT in the refrigerator.
Refrigeration will stop the ripening process.
When the fruit is sufficiently ripe, it can then be placed in the refrigerator.
Also, DO NOT place ripening fruit in direct sunlight.

Pepper
*Pepper fruit should also be stored in a cold room.
However, even if picked half way turned in color, the color change will continue even in the refrigerator.

*Do not leave pepper fruit on the counter for long as it will begin to loose water and the skin will wrinkle.

*Wrap pepper fruit in plastic and store in the refrigerator.

Cucumber
*Cucumber fruit should be stored in a cold room at 50-55^{0}F or can be stored in the refrigerator for up to 2 weeks.

*Fruit MUST be wrapped in plastic to retain water in the fruit. The long cucumber fruit has a thin skin that looses water very quickly after picking if not wrapped.

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CHAPTER 15

MARKETING – LARGE VERSUS SMALL SCALE OPERATIONS

INTRODUCTION

*Once the grower has a prime product, that product needs to be marketed.
How the grower goes about marketing their product will determine the success or failure of their operation.

*Marketing is a specialty in itself and should not be attempted by the novice.

*This chapter covers a few of the basics that must be kept in mind when marketing your greenhouse hydroponic tomatoes, peppers, cucumbers, lettuce, etc.

ABOUT THE PRODUCT

*Most crops grown using controlled environment agriculture and hydroponics are high cash value and perishable.
An exception: China grows both horticultural and agronomic crops (cotton, peanuts, etc.) using CEA in the form of plastic mulches.

*They are also usually regarded as luxury crops (as opposed to staple crops such as wheat, corn, rice, etc., which usually can not be grown economically using CEA/hydroponics).
"Luxury foods", such as tomatoes, peppers, cucumbers, lettuce, specialty greens, etc., add color and variety to a meal as well as vitamins and minerals.
Herbs add flavors to our meals and medicinals provide high quality alternative medicines.
Floriculture crops (much of which is grown using CEA) add beauty to our environment.

*Definition: **Greenhouse, hydroponic vegetable product** =
(From the proposed Federal Marketing Order On Greenhouse Tomatoes)

"A greenhouse hydroponic product is from a permanent structure (glass or plastic) using a hydroponic (artificial) growing system, integrated pest management practices and a controlled environment, computerized/automated system, controlling temperature and other parameters utilizing a permanent heating and ventilation system."

NOTE: This proposed definition has only recently been needed to differentiate product grown in this manner from product not grown in this manner but advertised as if it had been!

*For tomatoes (beefsteak and TOV), the proposed Federal Marketing Order On Greenhouse Tomatoes also defines the tolerances on different types of defects allowed:

DEFECT	TOLERANCE
Wet, open damage	0%
Severe shoulder cracks	0%
Blossom end rot	0%
Splits (shoulder, side, etc.)	0%
Over ripe, soft fruit	0%
Soft, watery spots	5%
Severe misshape	5%
Dry, small stem holes	5%
Scarring	5%
Blotchy, uneven color	5%
Light cracks	5%

METHODS OF MARKETING AND SALES

NOTE: Only the basics are discussed here. Marketing can be very complex!

***Direct Farm Market**

An example of this would be where the grower sells the product at a roadside stand or takes the product to a farmer's market . This is typical of a small family business.

When selling at a stand, etc., the idea is to make the product look "natural". Use wooden crates or baskets and hand written signs.

Mirrors in back make it appear as though there is more product than there actually is.

Lights brighten the area and can be used to highlight certain items.

***Grower/Packer/Shipper**

Similar to the above but on a much larger scale where the grower packs and ships their product to a place of sale. Ex.: Bonita Nurseries, Willcox AZ.

***Sales Agent/Distributor**

Usually this person receives a commission of 10% or more.

*They can sell direct to supermarket chains.

*They can sell to a wholesale or terminal market (under the jurisdiction of the USDA).

*They can sell through a broker. (Note: The more people involved in the transaction, the higher the final price of the product to the consumer.)

***Wholesaler/Handler**

This person operates within a terminal market.

They sell produce at a price and "mark-up" agreed upon with the buyer.

METHODS OF PAYMENT

*Sale based on **cash to the seller**.

The buyer pays the seller outright for the product and takes all responsibility for it after the purchase.

***Sale on consignment.**

The seller delivers the product to the buyer/distributor.

The seller is paid for all sold product, BUT…

Whatever product is not sold the seller must take back and will not be paid for!

This is common when the product is not in good condition or can not be guaranteed.

Therefore, the value of the product rests with the grower/shipper with no risk to the buyer.

The person buying on consignment often receives a 15% commission but may also pay for the handling and freight.

*Note that, depending upon the terms of the agreement, the price of produce can shift with the market or be fixed (contract pricing).

With variable pricing a greenhouse hydroponic tomato grower would make far more money per unit in the Winter when competition (see below) is low and demand is high, but not fair so well, or even have to cease production, during the Summer.

With contract pricing the grower would receive a fixed price year around. This might be lower in the Winter than what could be obtained with variable pricing, but the grower would make up the difference in the Summer when prices would otherwise be much lower.

COMPETITION CONCERNS FOR GREENHOUSE HYDROPONIC TOMATOES

***Open field, fresh market tomatoes**

Open field tomatoes are sold in direct competition with greenhouse hydroponic tomatoes and will always be sold for a lower price.

These tomatoes are primarily from:

30%	California
10%	Virginia, Georgia and South Carolina
25%	Florida
5%	other states
30%	other countries

One disadvantage for open field tomatoes is the climate.

Therefore, most states in the United States (except perhaps Florida) will only produce field tomatoes in the late Spring, Summer and early Fall.

During the late Fall, Winter and early Spring greenhouse hydroponic tomatoes can command a larger part of the market, and the entire market in some areas, with the main competition coming from foreign growers in southern latitudes.

***Fresh market imports (other countries) of tomatoes.**

These countries produce significant quantities of open field and greenhouse hydroponic tomatoes for domestic use and for export. Shown are the percentages of the import market for each country into the United States.

86%	Mexico	1%	Israel
7%	Canada	1/3%	Belgium
4%	Holland	1/3%	France
1%	Spain	1/3%	Chile

***Greenhouse tomato demand and consumption in the United States:**

Although open field, fresh market tomatoes are cheaper than greenhouse hydroponic tomatoes, 61% of consumers purchased greenhouse product during the Winter of 1999-2000.

Greenhouse tomatoes are purchased by all consumer groups.

Although more open field, fresh market tomatoes are produced, greenhouse tomatoes make up 5-10% of the total tomato consumption in the United States.

CONSUMER CONCERNS ABOUT PRODUCE IN TODAY'S MARKET

*Today's consumer is aware of many factors that impact the produce they buy.

*These factors have been categorized as to the level of concern by consumers:

42%	Use of chemicals and pesticides
31%	General freshness of the product
12%	Cleanliness of the product
11%	How the product was handled
10%	Disease/sickness
9%	Bacteria/"germs"
8%	Spoilage
8%	Wash product properly
6%	Condition/appearance
6%	Where product was grown
5%	Contamination
5%	Insect free
3%	Packaging issues

ADVERTISING AND "SALES BULLETS"

*Unless the public knows about the grower's product they won't buy it!

*Also, the grower's product must be better than other's for the consumer to want it!

*Remember, in the case of tomatoes, open field tomatoes are cheaper than greenhouse hydroponic tomatoes. So the grower must convince the consumer that it is worth the added price to buy their greenhouse hydroponic product!

*One advertising technique is to use what are called “sales bullets”.

Sales bullets = short phrases that emphasis a particular positive factor or attract a particular audience.

- Pesticide free
- High in cancer-fighting lycopene
- Sunshine sweet
- Nature sweet
- Nature’s finest
- Vine ripened
- Vitamin rich
- Hand picked with care
- Arizona grown
- Arizona sunshine
- Hydroponically grown
- You’ll love every healthy bite
- Tomato eaters make better lovers
- Grown in Wildcat country

These “sales bullets” can be added to advertising or packaging to promote the product.

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2. **Proposed Federal Marketing Order On Greenhouse Tomatoes:** 2000. As proposed by the Arizona Department of Agriculture in conjunction with the United States Department of Agriculture (USDA).
3. **Protected Agriculture: A Global Review. Part 4. Economic Factors.** 1995. M.H. Jensen and A.J. Malter. The International Bank For Reconstruction and Development/The World Bank. 1818 H Street, N.W., Washington, D.C. 20433. World Bank Technical Paper ISBN 0-8213-2930-8.

CHAPTER 16

ECONOMICS OF CEA/HYDROPONICS AND BUSINESS PLANS

INTRODUCTION

*Controlled environment agriculture and hydroponics is often labeled as "intensive".
To an economist, intensity is related to the labor and capital inputs per unit of land involved.
Compared to open field agriculture, the labor and capital inputs per unit of land for CEA/hydroponics are much greater.

*However, because of the potential for multiple cropping and higher yields, as well as the high cash value of crops chosen for CEA/hydroponics, the high returns can more than make up for the costs.

POTENTIAL ECONOMIC ADVANTAGES OF CEA/HYDROPONICS

*__Multiple cropping__
With almost all forms of CEA and hydroponics growers can produce multiple crops in a single year. Open field agriculture is usually limited to one.
Greenhouse hydroponic tomatoes are now grown year around with 2 overlapping crops, one that produces from October to March and the second that produces from March until either July or the next October (see Chapter 3).
Greenhouse hydroponic cucumbers mature faster than tomatoes and can produce 3 crops: July to October, November to March and April to June.
Greenhouse hydroponic lettuce, with as little as 40-45 days to maturity, can yield up to 10 crops per year.

***Higher yields**
Several factors contribute to higher yields with CEA and hydroponics:
Control of the aerial environment – temperature, relative humidity, carbon dioxide levels, light, etc. – to maximize plant growth and productivity.
Control of the root environment – temperature, moisture levels, nutrient composition, oxygen levels, etc. – also to maximize plant growth and productivity.
Higher planting densities that result in higher productivity per unit area.
Even mulches and row covers can double, even quadruple early yields (before open field products are ready for market and the prices are therefore higher).

*However, these increased returns, in the form of multiple crops and higher yields, are realized only by an increase in costs.

THE COSTS OF CEA/HYDROPONICS

***The land:**

The initial cost of the land, roads and utility installation (water, sewer, natural gas, electricity, phone, etc.) will usually need to be paid up front via a loan and will then be paid off over the first several years of operation.

The land may also need to be modified to accommodate greenhouse and support buildings including grading, fencing, wind breaks, etc.

***Structures:** These can be amortized over several years.

The greenhouse itself (frame, glazing, construction labor, environmental control system, white reflective ground cloth for the greenhouse floor and the nutrient delivery system – injectors, mixing tanks, PVC delivery tubing).

Support buildings
- Office space with restrooms
- Packing area
- Storage area for produce which might include a cold room
- Storage areas for supplies including seeds, growing media, fertilizers, boxes, irrigation equipment, support devices (clips, tomahooks, etc.), tools, ladders, gloves, smocks, etc.
- Workshop with equipment for fabrication and repairs

***Annual expenses:**

Seeds or transplants
Growing media (rockwool, perlite, etc.) – cubes, blocks, slabs, bags, etc.
Irrigation equipment (poly and drip tubing with stakes, emitters, misc. plastic)
String for plant support
Tomahooks, vine clips and cluster clips (if these are not recycled)
Fertilizers
Labor: May divide duties (plant care, harvest, packing, office, etc.)
 Should also include training costs
Management costs
 May include training costs, travel, etc.
Misc. tools, ladders, gloves, etc.
Repairs and replacement parts on the structure, environmental control system, nutrient delivery system, tools, etc.
Marketing expenses
Utility costs (water, electric, natural gas, phone, sewer, etc.)
Bee hives (tomatoes and peppers) and beneficial insects
Limited pesticide equipment
Insurance, taxes and interest payments
Carts, bicycles and other vehicles

***Other expenses** may be incurred depending upon the type of structure, crop, location, and other considerations.

PREPARING A BUSINESS PLAN

*A business plan is a formal document that will help you
- Define the purpose of your business including personal and business goals
- Discover problems before you begin the business
- Take advantage of new opportunities as they occur
- Estimate the cash needs for your business
- Explain your business goal to others including loan agents, investors, etc.
- List your skills and abilities as well as what is needed
- Outline marketing prospects

***Elements of a business plan** (As described in the booklet "Preparing a Business Plan")

- **Title page**
  - Make this look as professional as possible.
  - Include the company name, the date, contact person, contact information
- **Table of Contents**
  - Gives an outline of your plan
- **Business Profile and Summary**
  - Purpose and concept of your business
  - Financing and financial resources required
  - Business activities and targets – marketing, production, labor, financial and projected income/net worth
- **Business Organization**
  - How the business is organized
  - Any required registrations and/or licenses
  - Business managers and advisors and their roles
- **The Marketing Plan**
  - About the industry including market trends and competition
  - Political and legal constraints
  - Consumer responses
  - Pricing
  - Advertising/promotion
  - Targets and future sales
- **The Human Resources Plan**
  - Employee plan – how many employees, job titles, functions
  - Organizational chart – How the employees are organized
  - Compensation and benefits
  - Labor relations: training, motivation, discipline procedures, etc.
- **The Production Plan**
  - Description of the land, buildings and facilities
  - A list of all the equipment needed (environmental control, auxiliary power units, spray equipment, scales, meters, tools, heavy lift equipment, electric or other carts, vehicles, etc.)
  - A list of all the materials and supplies needed
  - The production strategy (specifics about the crop and system to be used)
  - Construction/production schedule (week by week plan)

The Financial Plan

Income statement (income from sales, operation expenses, net income)
Projected cash flow summary
Projected statement of assets, liabilities and equity for the next 3 years
Capital sales and purchases (land, buildings, equipment
Loan summary (type of loan, security given, interest rate, etc.)
Financial performance indicators (profit, growth and risk ratios for the first 3 years)

The Long-Range Plan

Should cover the next 5-10 years
Include business goals and objectives, additional production, financial and management or marketing skills required

*Final note: Any person considering starting a CEA/hydroponic business should as much as they can about plant science, nutrition, diseases and IPM techniques, greenhouse structures and control systems, marketing and business management practices. More information about business planning can be obtained from local financial institutions, state departments of agriculture, or other appropriate agencies.

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