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.

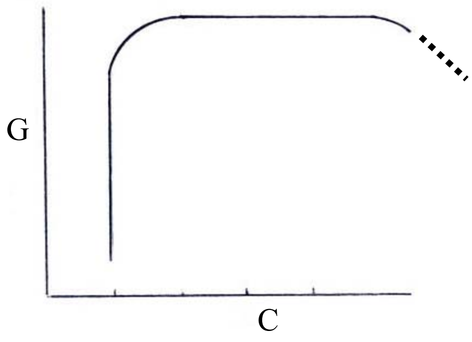
***Recommended nutrient levels (ppm) according to plant species (Agrodynamics):**

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 **Calcium** (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 **$Ca(NO_3)_2$**:

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 nitrogen 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 Nitrogen** will come from potassium nitrate – **KNO_3**

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:

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THE UNIVERSITY OF ARIZONA
CONTROLLED ENVIRONMENT AGRICULTURE CENTER

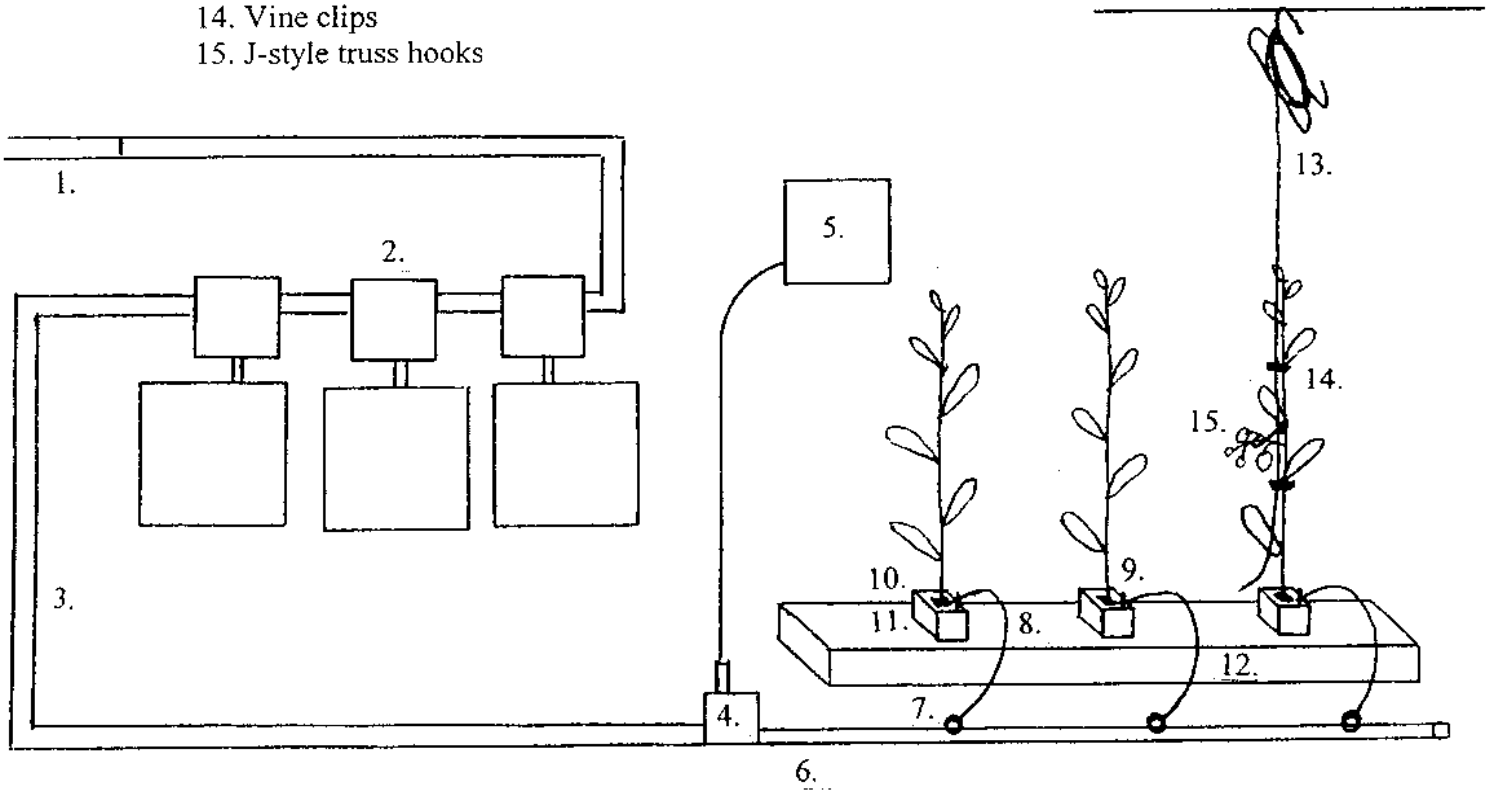
SYSTEM DESIGN: INJECTOR SYSTEM/BAG CULTURE

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.