Growing in Hydroponic and Soil-less Culture

Cary Rivard, KSU

Content provided by Chieri Kubota (UA-CEAC), Mark Kroggel (UA-CEAC), and Kimberly Williams (KSU)

Total Area in Major Greenhouse Production Countries in the World

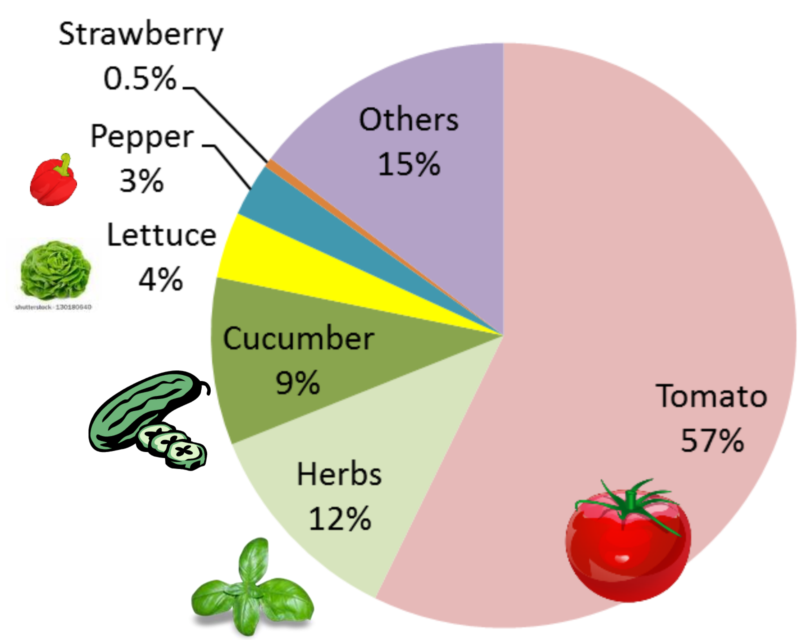
	Country	Greenhouse area (ha)	Reference
1	China	2,760,000 (2010)	Yang, 2011
2	Korea	57,444 (2009)	Lee, 2011
3	Spain	52,170	EuroStat, 2005
4	Japan	49,049	MAFF, 2011
5	Turkey	33,515	TurkStat, 2007
6	Italy	26,500	EuroStat, 2007
7	Mexico	11,759	SAGARPA, 2010
8	Morocco	11,161	Choukr-Allah, 2004
9	Netherlands	10,370	EuroStat, 2007
10	France	9,620	EuroStat, 2005
11	United States	8,425	US Census of Hort. Spec., 2010

(Kacira 2010)

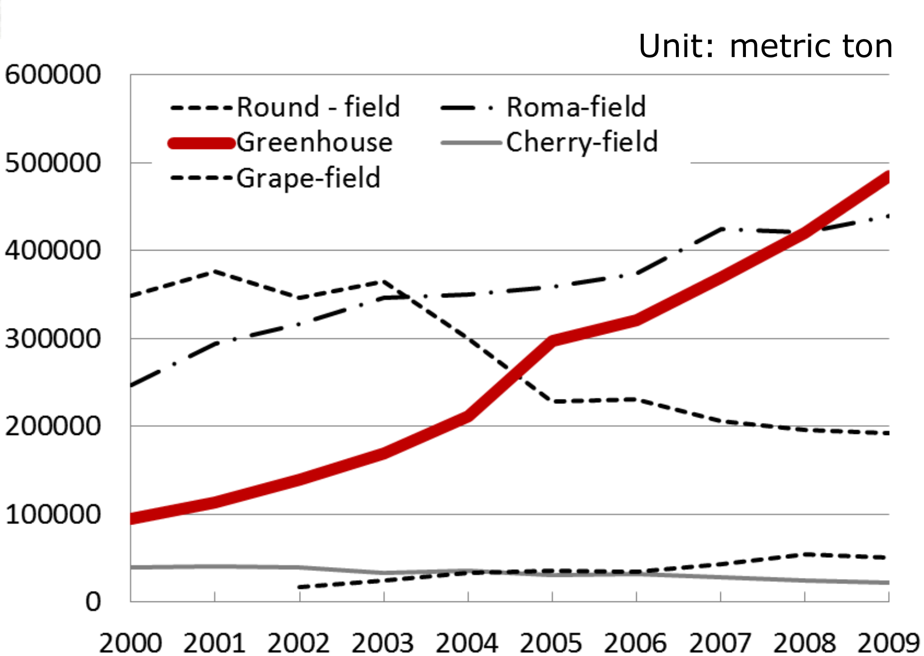
(The data presented excludes low tunnel and shade structures covered areas)

Fresh tomato production in CEA

- Tomato dominates CEA in US (~60% of total production area under controlled environment)
- Increasing competition in North American tomato market



CA production area % in the US (USDA, 2015)



Fresh tomato importation in the US (USDA, 2009)

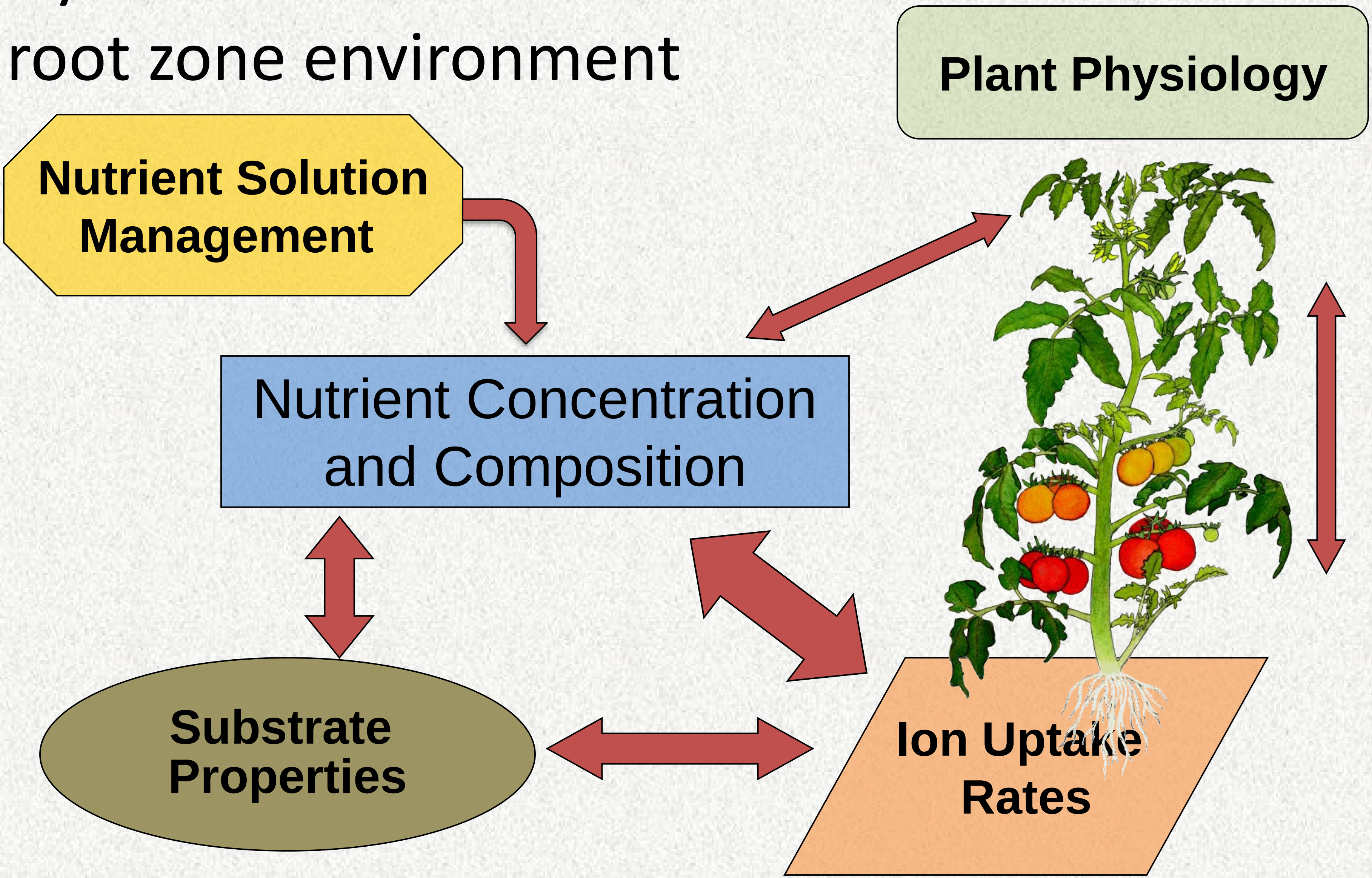
Most common high-production system: High-wire system with drip irrigation

Ballpark yield (mid to large fruit type): 60 kg/m^2 per year (132 lb/ft^2)

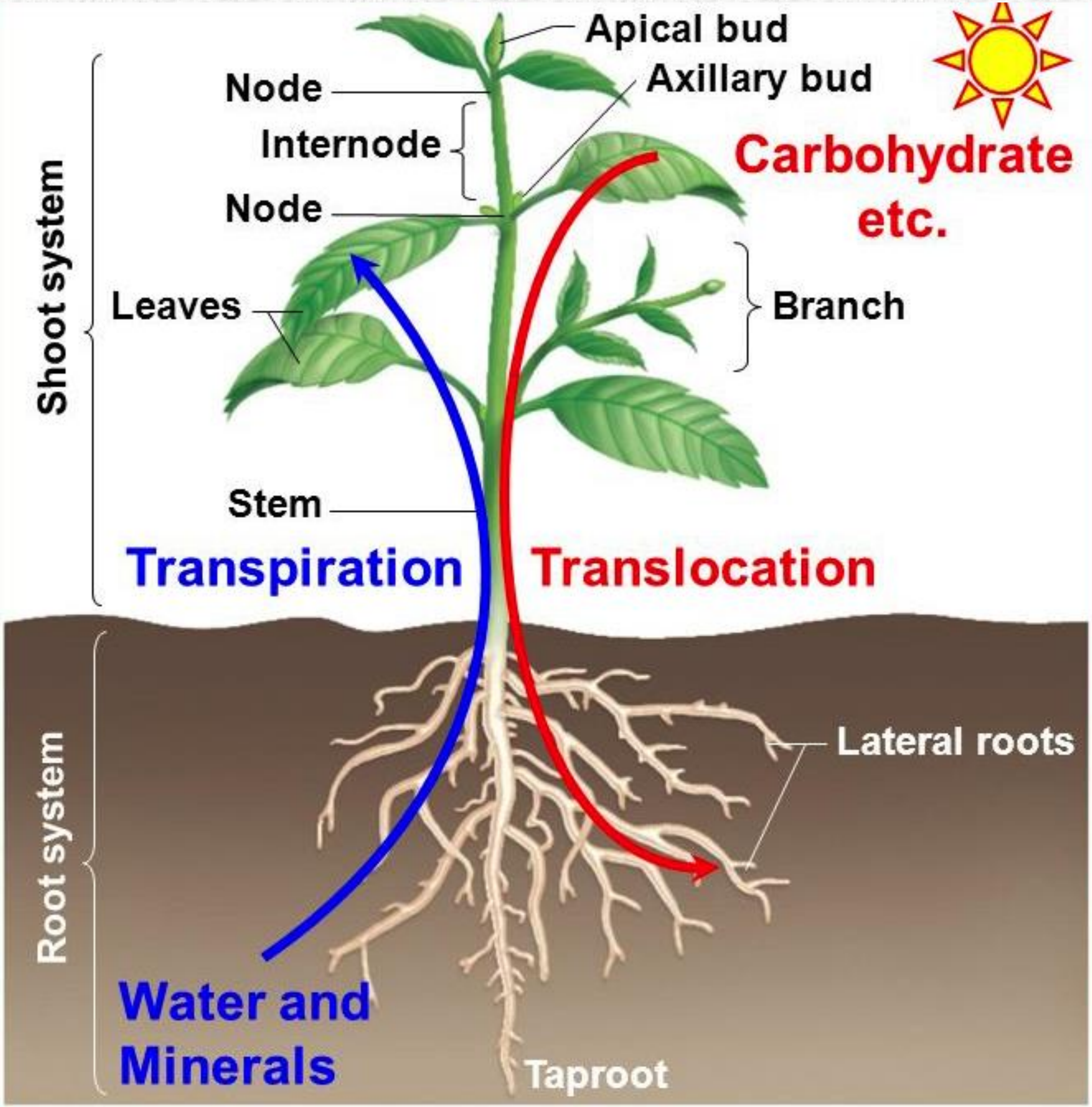
Growing Without Soil

Hydroponics

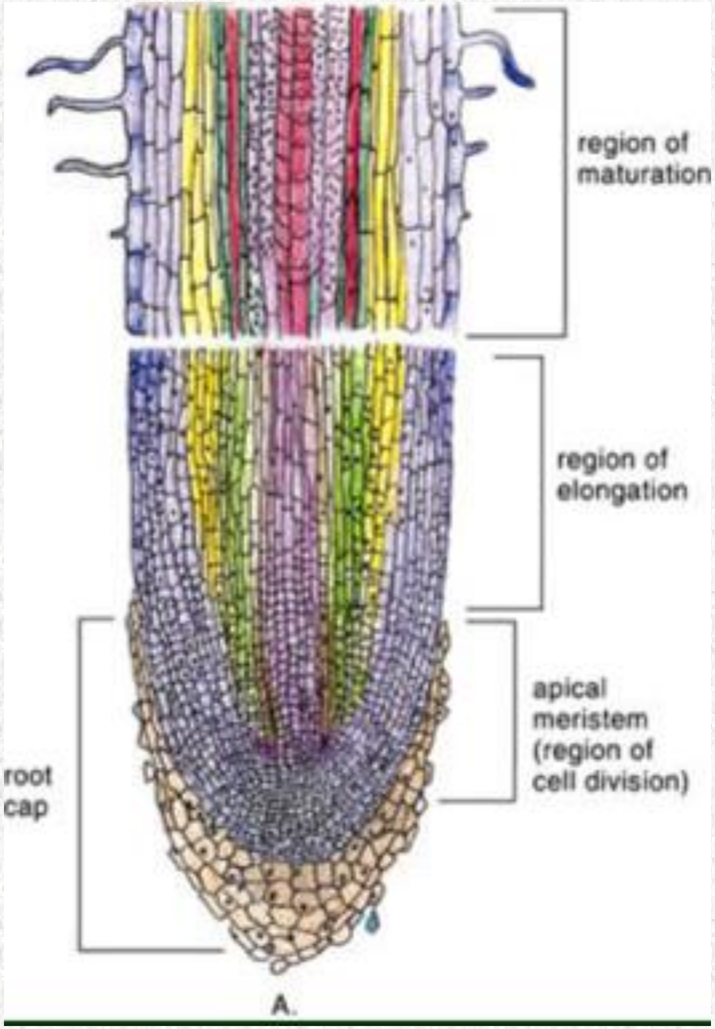
Dynamic features of the root zone environment



Hydroponics


Apical bud
Axillary bud
Node
Internode
Node
Shoot system
Leaves
Carbohydrate
etc.
Branch
Stem
Transpiration
Translocation
Lateral roots
Root system
Water and
Minerals
Taproot

Functions of Plant Roots



- Living plant cells
  - Respiration (need O_2)
  - Affected by temperature
- Ion exchange
  - Passive and active
- Root growth
  - Need carbohydrates
  - Root cap
- Interact with microbes
  - Root exudation

Essential Elements for Plant Growth

- Macronutrients

  Primary: N, P, K,

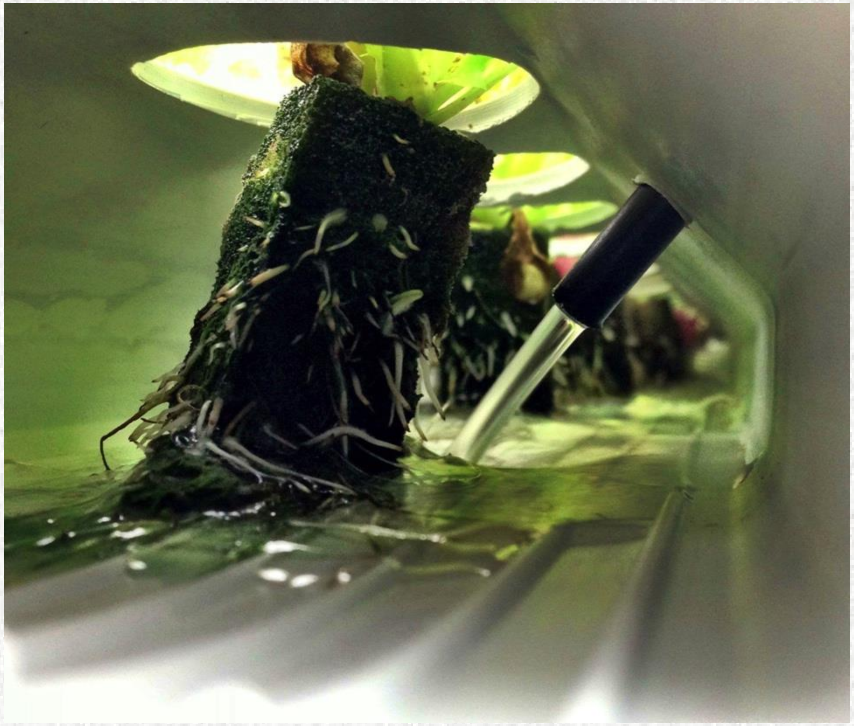
  Secondary: Ca, Mg, S

- Micronutrients

  Fe, Mn, Zn, Cu, B, Mo, Cl

- Essential but not applied as fertilizers

  C, H, O



Chemical forms in solution when absorbed by plants

- **Cations** (positively charged ions)

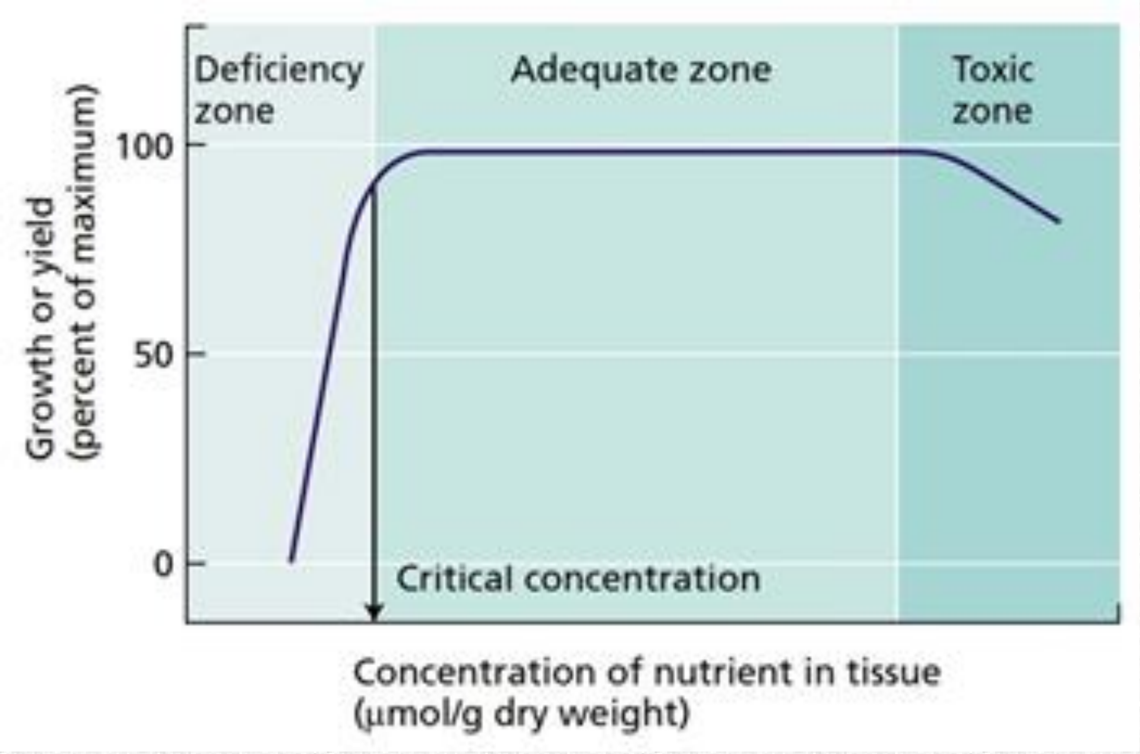
  Ammonium (NH_4^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Iron (Fe^{2+}, Fe^{3+}), Manganese (Mn^{2+}), Zinc (Zn^{2+}), Copper (Cu^{2+})

- **Anions** (negatively charged ions)

  Phosphorus (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$), Nitrate (NO_3^-), Sulfur (SO_4^{2-}), Boron (BO_3^{2-}), Molybdenum (MoO_4^{2-}), Chloride (Cl^-)

Nutritional Disorders

- Deficiency – less nutrient is available than required in tissue
- Toxicity – Excessive amount of nutrient in tissue



(Taiz and Zeiger, 2006)

Element Mobility in Plants

Mobile	Immobile
Nitrogen	Calcium
Potassium	Sulfur
Magnesium	Iron
Phosphorus	Boron
Chlorine	Copper
Sodium	
Zinc	
Molybdenum	

Do not translocate to part of the plant with highest need (i.e. growing point)

Nutrient Deficiencies in Tomatoes

Cu
Young leaf wilting

Fe
Interveinal chlorosis in young leaves

Mg
Interveinal chlorosis in older leaves.

N
Light green overall starting from older leaves

Zn
Light green overall, higher anthocyanin (purple pigmentation) in abaxial leaf surface

B
Abnormal (stunted) growth in growing points

Ca
Tipburn, blossom-end rot

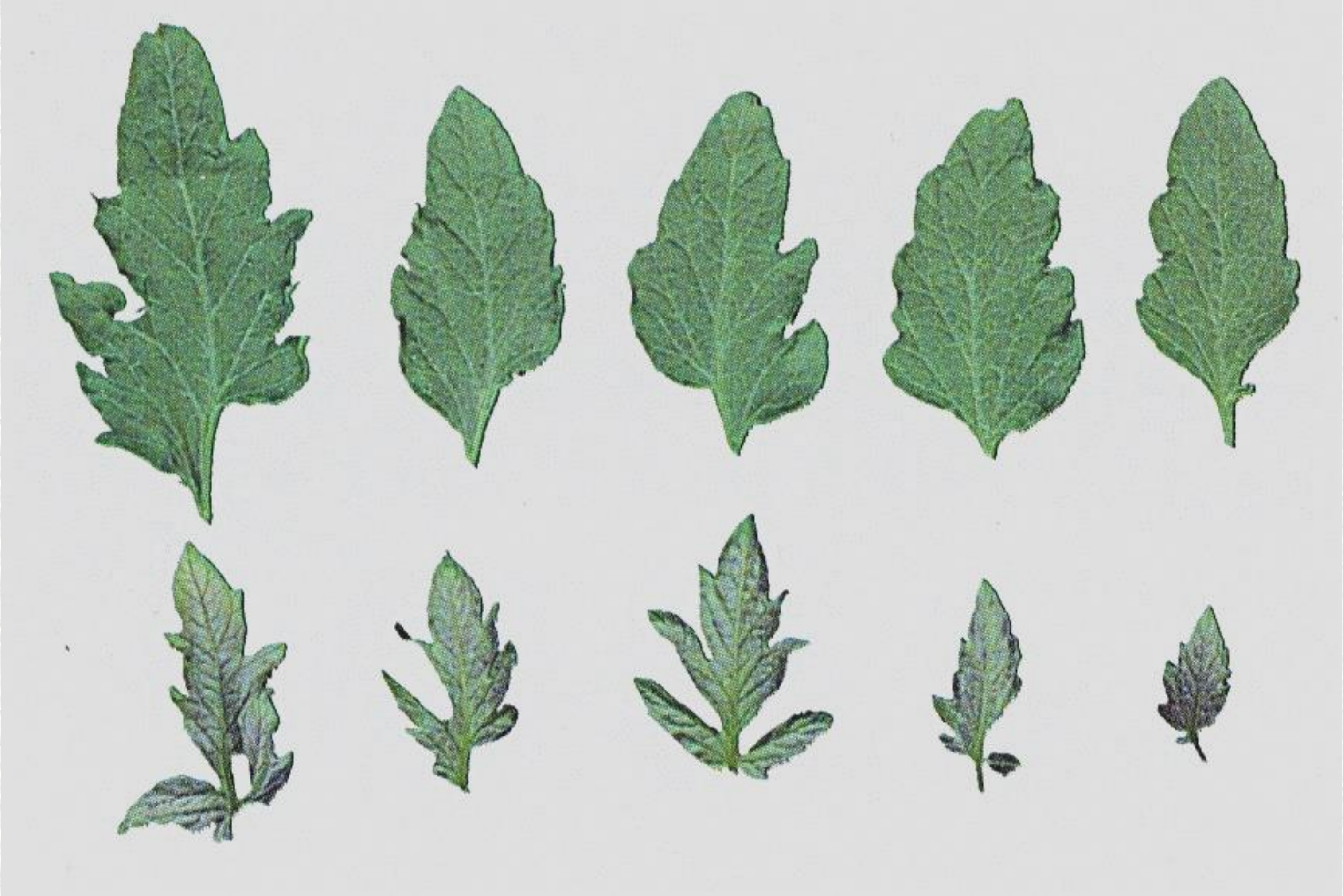
Mn
Interveinal chlorosis in younger leaves

K
Interveinal chlorosis in older leaves, scorch

P
Anthocyanin (purple pigmentation) in older abaxial leaves

Tomato plants with low N (left) and high (standard) N (right) application

Tomato leaves with standard P application (above) and low P application (bottom)

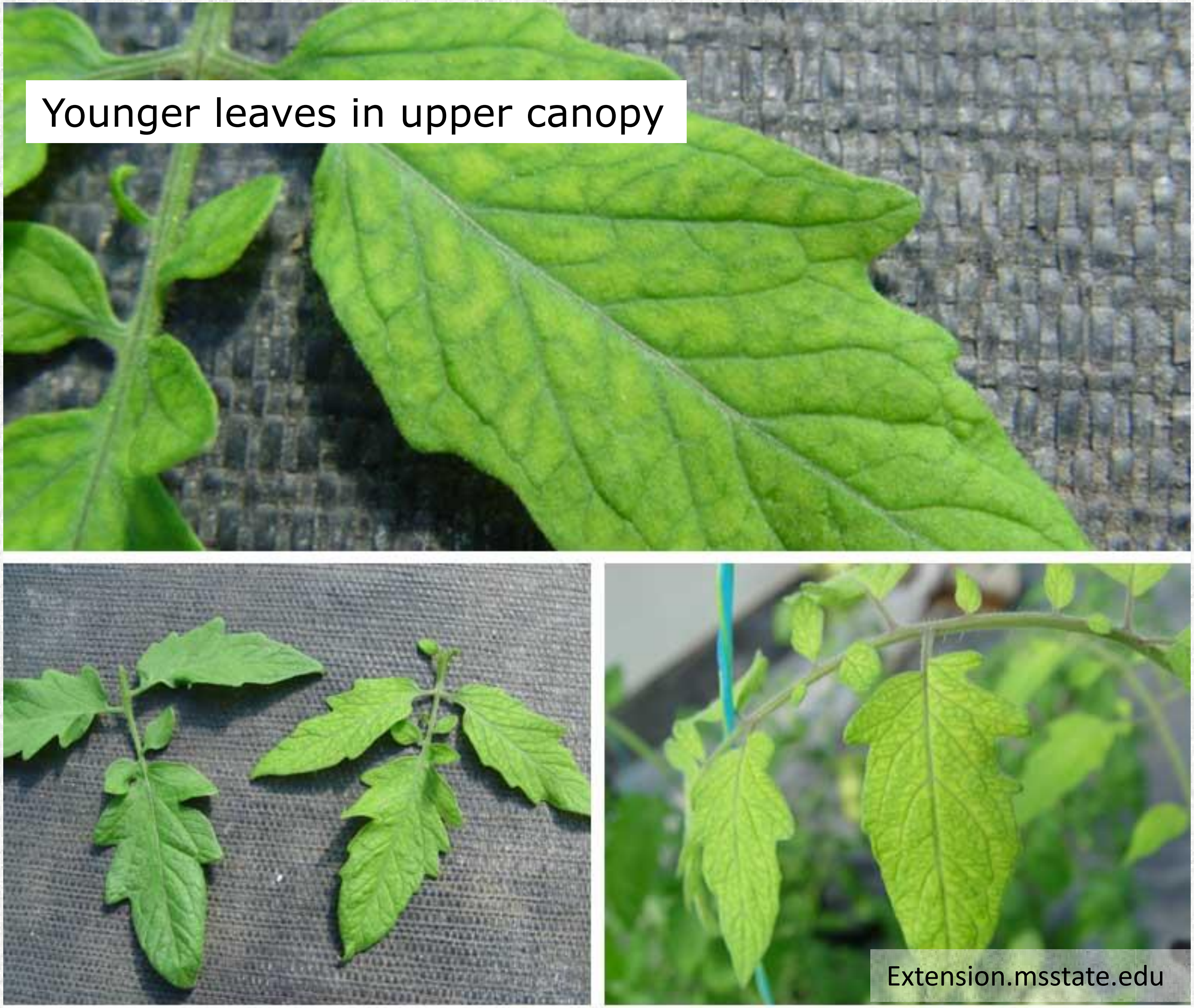


K deficiency in tomato leaves

Tomato leaves with standard K application (above) and low K application (bottom)

Tomato leaves showing magnesium deficiency – interveinal chlorosis

Tomato leaves showing iron deficiency – interveinal chlorosis



Sampling – Monitoring the Crop

Foliar

First fully expanded mature leaf
Multiple plants from across greenhouse
Oven dry to completely dry and grind (costs less)
Regular schedule best – not waiting for symptoms

Nutrient solution

Collect drip
Make a dilution
500 ml
Ship no later than next day after sampling
Ship overnight

Tissue Analysis

TEST	RESULTS	NORMAL RANGE
Nitrogen % N	2.65*	3.50 - 4.60
Phosphorus % P	0.51	0.20 - 0.60
Potassium % K	2.69	2.00 - 8.80
Calcium % Ca	1.08	1.00 - 2.60
Magnesium % Mg	0.31*	0.40 - 1.90
Boron ppm B	48.16*	50.00 - 175.00
Iron ppm Fe	47.29*	90.00 - 250.00
Manganese ppm Mn	73.9*	75.00 - 300.00
Copper ppm Cu	8.04	5.00 - 28.00
Zinc ppm Zn	21.51*	25.00 - 100.00
Molybdenum ppm Mo	1.53	0.20 - 5.00
Aluminum ppm Al	5.84	0.00 - 0.00
Sodium ppm Na	80.69	0.00 - 0.00
Sulfur ppm S	675.78	0.00 - 0.00

Hydroponic Solution Analysis

FERTILIZER ANALYSIS

University of Arizona
303 Forbes Building
PO Box 210036
Tucson, AZ 85721

Lab ID: 051573-1
Received: 08/25/05
Completed: 08/26/05
Phone: 520-626-3928
Fax:

Sample Description: Hydroponic F2 Low EC

MAJOR NUTRIENTS: *	**--ppm-**
Nitrate (NO3-N)	181.00
Ammonium (NH4-N)	21.60
Phosphorus (P)	43.63
Potassium (K)	233.02
Calcium (Ca)	198.23
Magnesium (Mg)	22.49

MINOR NUTRIENTS	**--ppm-**
Iron (Fe)	1.99
Manganese (Mn)	0.40
Boron (B)	0.32
Copper (Cu)	0.97
Zinc (Zn)	0.30
Molybdenum (Mo)	0.00
Sodium (Na)	49.65
Aluminum (Al)	4.45

	--ppm-
pH	5.60
Conductivity (mmho/cm)	2.00

* Urea not determined

Conversions: To convert P to P205 multiply by 2.29
To convert K to K20 multiply by 1.20

Lysimeter: A device or system to measure drip (input) and drain (output)

What we want to know:

Is drip in expected range of volume, EC and pH?

If not, what is wrong?

Controller failure, injector failure, stock made incorrectly.

Is drain in expected range of volume, EC and pH?

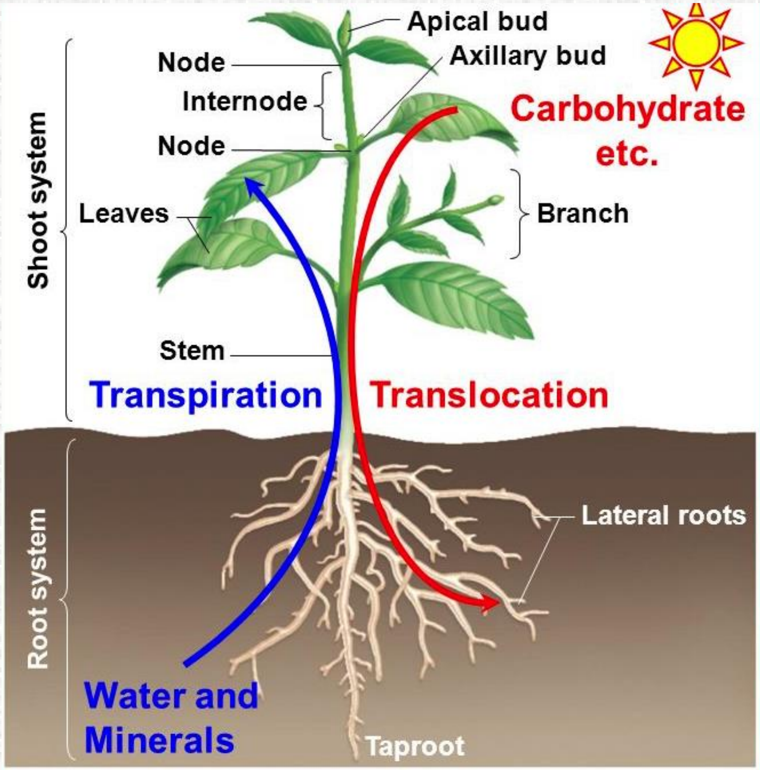
If not, what is wrong?

Same as drip plus transpiration, root zone issues.

Tomato - Optimal Fertility Management

Nutrient	Stage 1 (ppm)	Stage 2 (ppm)	Stage 3 (ppm)	Micro (ppm)	
	Up to 2nd truss	2nd to 5th	After 5th truss	All stages	
N	90	120	190	B	0.34
P	47	47	47	Mn	0.55
K	144	350	350	Cu	0.05
Ca	144	160	200	Mo	0.05
Mg	60	60	60	Zn	0.33
S	116	116	116	Fe	2.00
Cl	89	89	89		

Don't Forget About CO_2



- CO_2 is an essential part of photosynthesis.
- Closed systems and winter-time growing
- CO_2 enrichment

Fertilizing with CO_2

- Combustion base system (natural gas)
- Liquid CO_2

Tips for CO_2 Enrichment

- CO_2 conc. inside a closed greenhouse with soilless system can be as low as ~200 ppm (half of atmosphere) during the day.
- Set point for CO_2 enrichment needs to be at an ambient or lower level when vents are open.

CO_2 generator based on combustion of natural gas

Hydroponic and Soil-less Systems

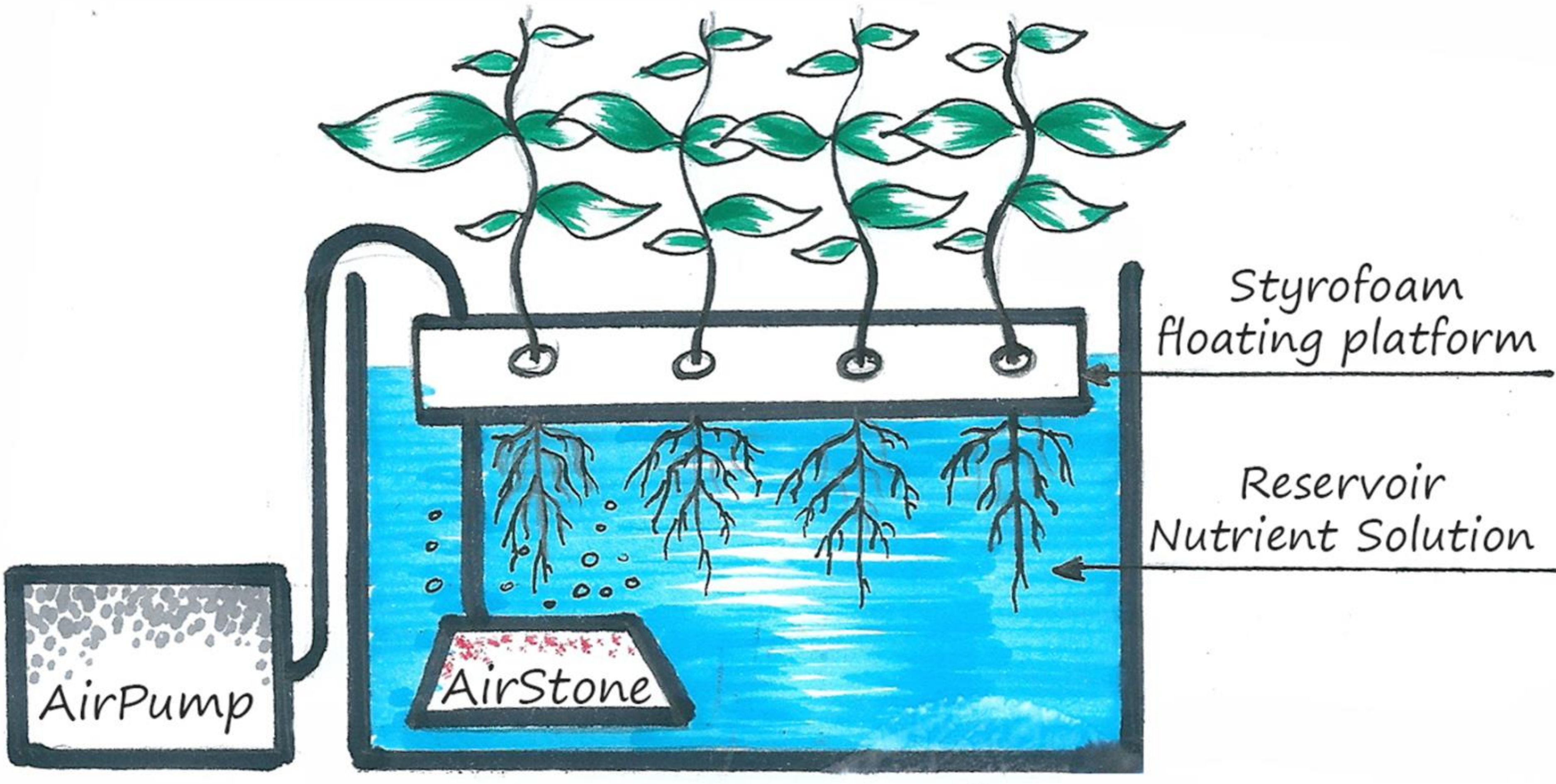
- DFT (Deep Flow Technique)
- NFT (Nutrient Film Technique or Nutrient Flow Technique)
- Soil-less culture systems
  - Rockwool
  - Other aggregates
- Aeroponics
- Others

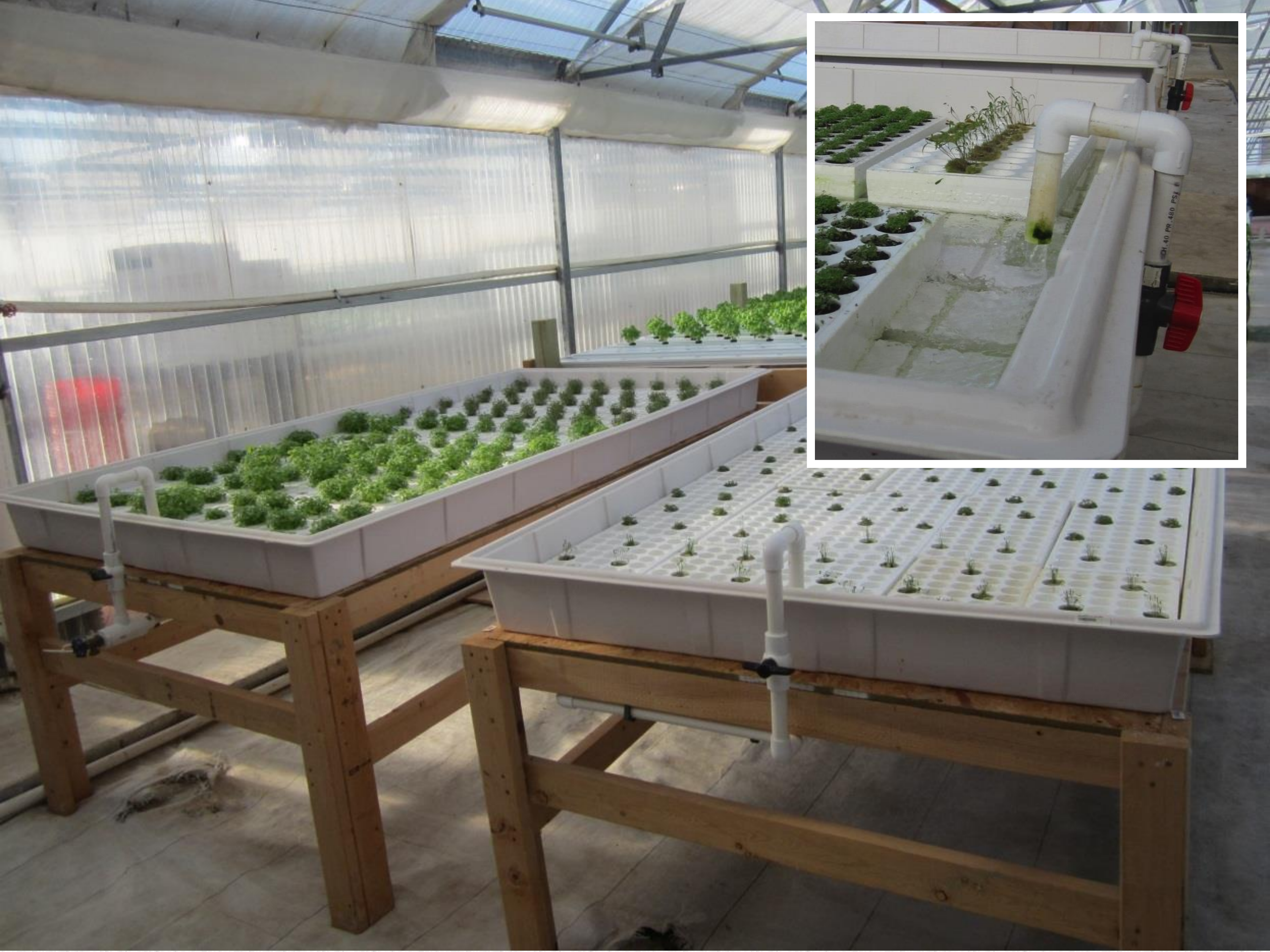
DFT (deep flow technique)

Plants are suspended through styrofoam boards which float on the surface of the nutrient solution. Since roots are entirely in the liquid, oxygen must be constantly supplied to the roots by aerating nutrient solution.

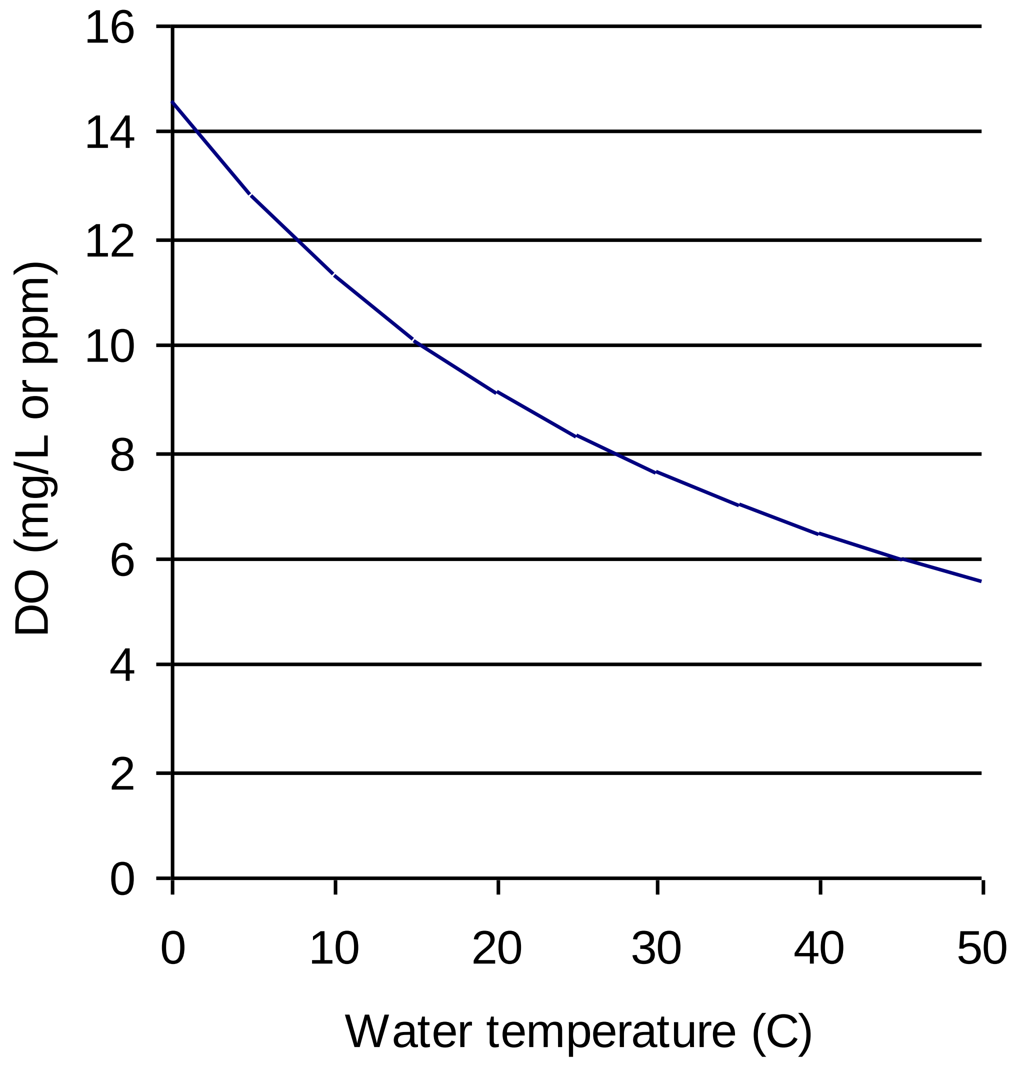
DFT based commercial-scale lettuce production unit at Cornell Univ.

Aeration is Critical in DFT Systems

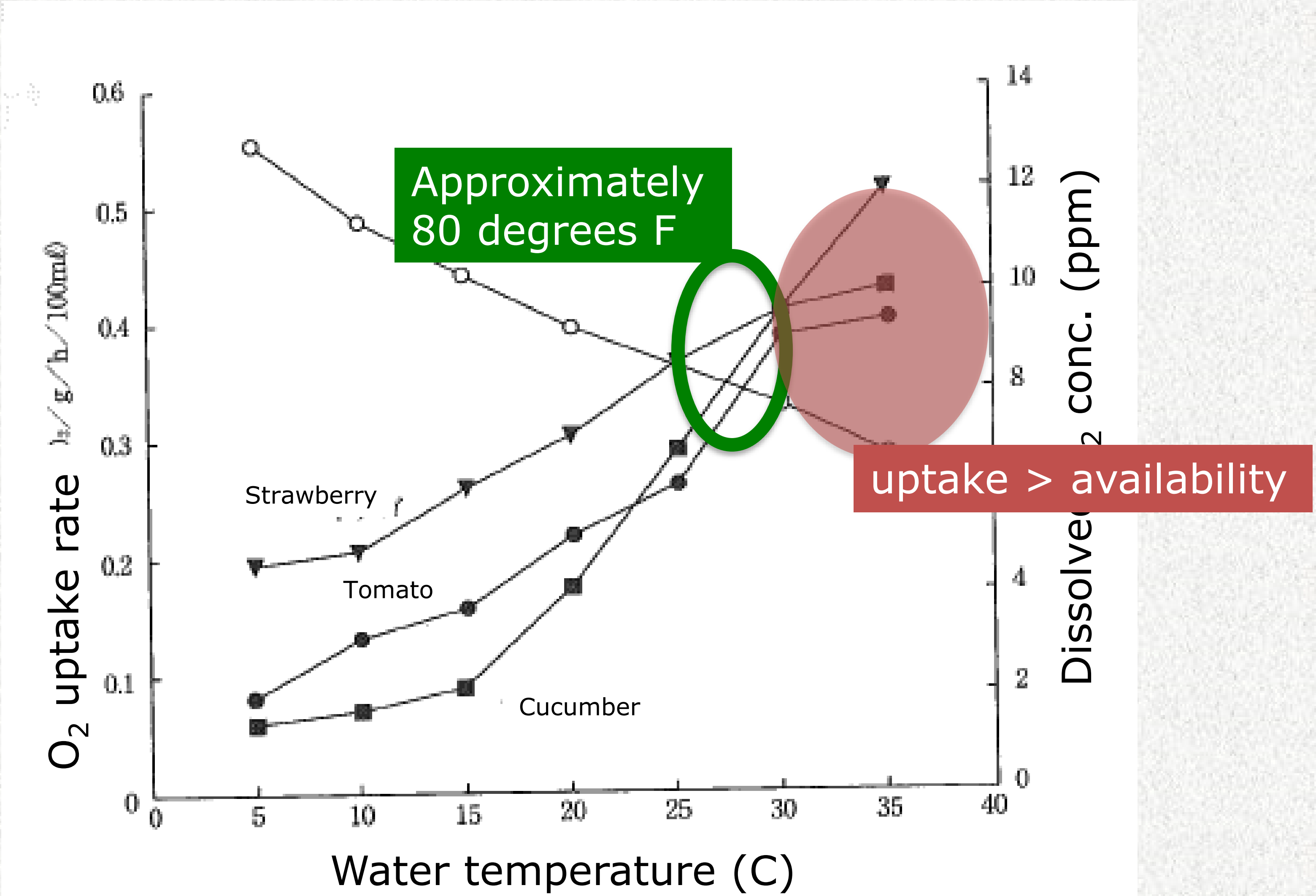




Dissolved Oxygen and Temperature

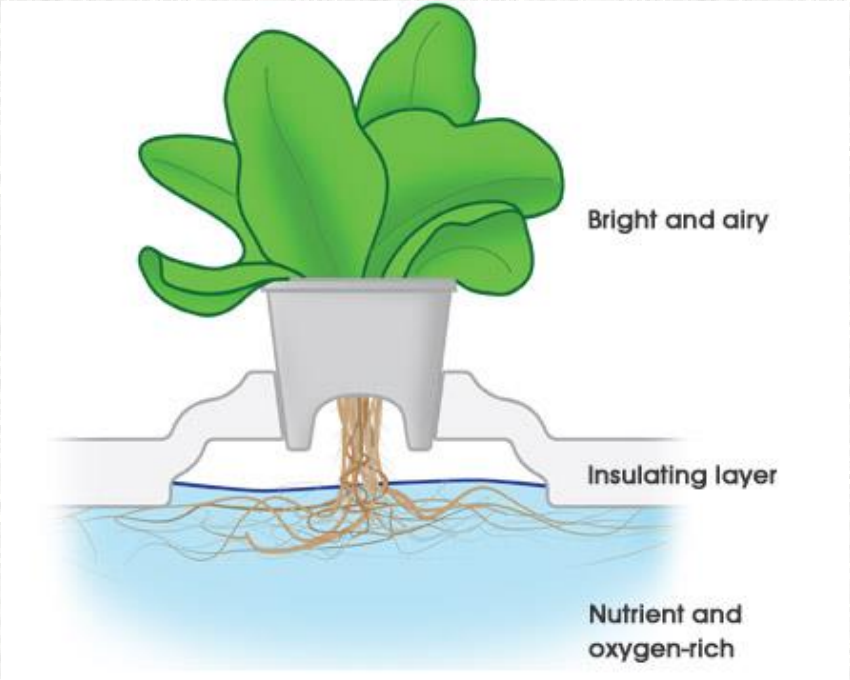


Root oxygen absorption rates measured for three greenhouse crop species

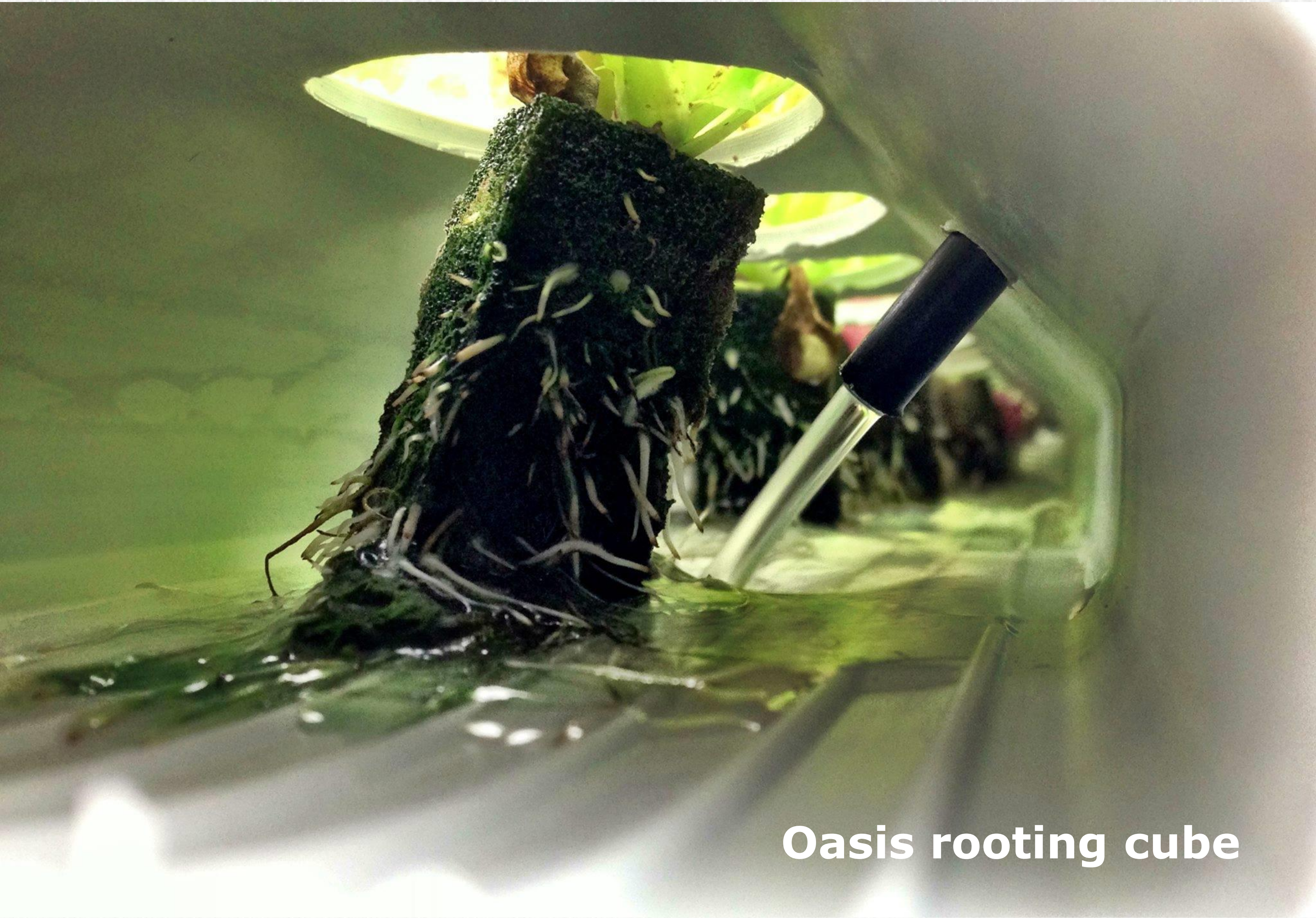


"Dry" DFT Systems

- Packaged growing system(s)
- Cultivation Systems, Viscon B.V.
- Special plastic cups and foam floats
- Efficient use of space, automation

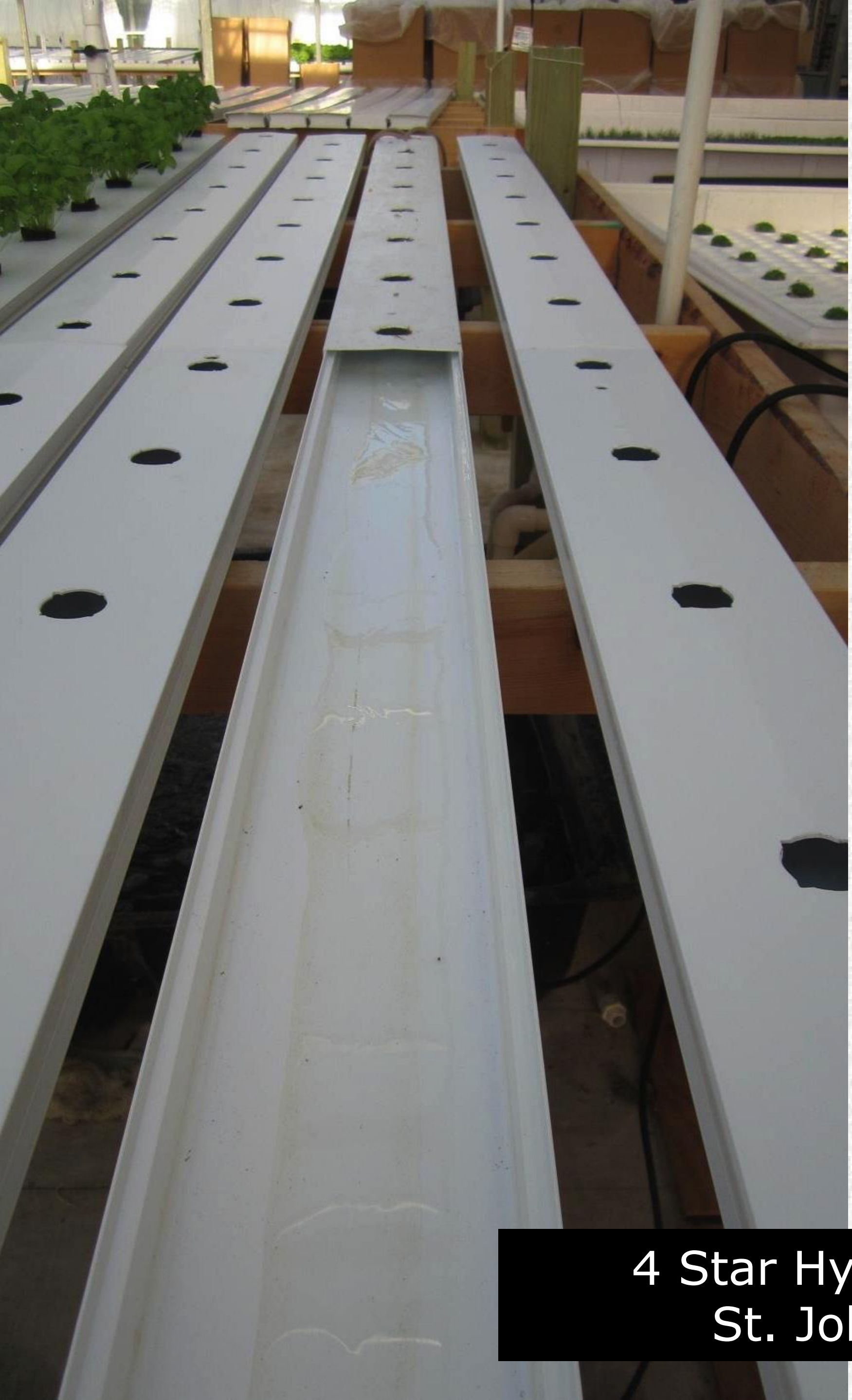


NFT (nutrient film technique)
The roots are hang into a slightly slanted tube or trough. The nutrient solution is pumped to the higher end, flows past the hanging roots and then back to the reservoir.


Oasis rooting cube

Shelton Farms
Whittier, NC

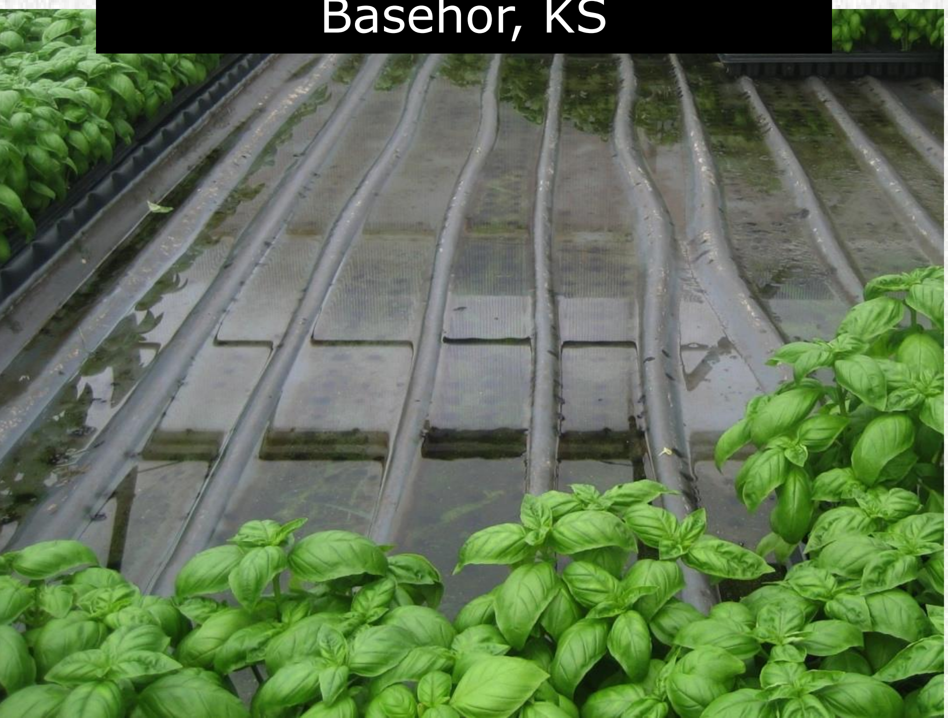
Linda Gray



4 Star Hydroponics
St. John, KS

Ebb-and-Flow (subirrigation)
Plants are grown in trays or pots filled with substrates such as perlite, vermiculite, peat moss, foam, coconut coir, granulated rockwool, etc. in benches or in the greenhouse floor, which is flooded periodically to subirrigate.

Cal’ann Farms
Basehor, KS



Pocket Farms
Middle Pocket, NSW

Aeroponics
The roots are suspended in an enclosed space and, at regular intervals, sprayed with the complete nutrient solution.

Commercial lettuce production by aeroponics

Aeroponically cultivated medicinal burdock roots

Soilless culture with rockwool or other aggregates with drip irrigation

The roots grow into aggregate medium (substrate) such as sand, gravel, Rockwool, perlite, vermiculite, peat moss, foam, coconut coir, etc. and are then irrigated with a complete nutrient solution using drip irrigation.

Rockwool
Great air : water
Rapid response
Industry standard

Low H_2O capacity
Disposal

Both require pre-use saturation

Coco coir
High H_2O capacity
Custom blends
Widely used

Slow response
Source issues

Coir-based Systems

Harbour Head Growers,
Wikuku, NZ

Mixed Media Systems

Nick's Greenleaf Gardens, Kansas City, MO

Nick's Greenleaf Gardens,
Kansas City, MO

Grow Bag Systems

Ring's Grow and Sell,
Wichita, KS

Grow Bags may contain various types of substrate/media

Grow Bag Systems

Spencer Ring

Factors for Consideration

- Plant Species
  - Oxygen requirement
  - Response to EC and porosity
  - Response to root zone restriction
  - Transpiration demand
- Growing stage
- Irrigation and nutrient delivery methods
  - Nutrient compositions and concentrations
  - Frequency
  - Container (or root-zone) size
- Substrates (if used)
  - Kind (chemical and physical characteristics)
  - Source (particularly for organic substrates)
  - Mixing ratio (if more than one kind is used)

Tomato growth/yield in different media

Media in bags	Water holding capacity (%)	Air porosity (%)	Yield (kg/plant)	Fruit size (g)
Coconut coir	88.4	23.5	10.6	196
Perlite	19.6	41.1	10.3	195
Peat-lite	84.8	20.0	9.9	193
Coir/Perlite	57.4	35.0	9.7	192
Rockwool	86.9	10.3	9.6	185

Data by M. Jensen

Substrates affect plant growth

(strawberry example under ebb-and-flow irrigation)

Cultivar ‘Camino Real’

50%Coco/50%Perlite

70%Coco/30%Perlite

100%Coco

Loose rockwool

Granulated rockwool

50%Vermiculite/
50%Perlite

Cultivar ‘Albion’

50%Coco/50%Perlite

70%Coco/30%Perlite

100%Coco

Loose rockwool

Granulated rockwool

50%Vermiculite/
50%Perlite

Discussion

Example 1: Tomato

- **Impact of substrate is relatively small**
  - Greater LAI (4-6)
  - Leaf transpiration rate: ~8 mmol m^{-2} s^{-1}
  - Root respiration rate: moderate
  - Typical root-zone volume in soilless culture: 2 L per plant
  - Irrigation: up to 2-4 L per plant per day per plant (20-40 times a day)
  - Drainage rate: 30-40%

Example 2: strawberry

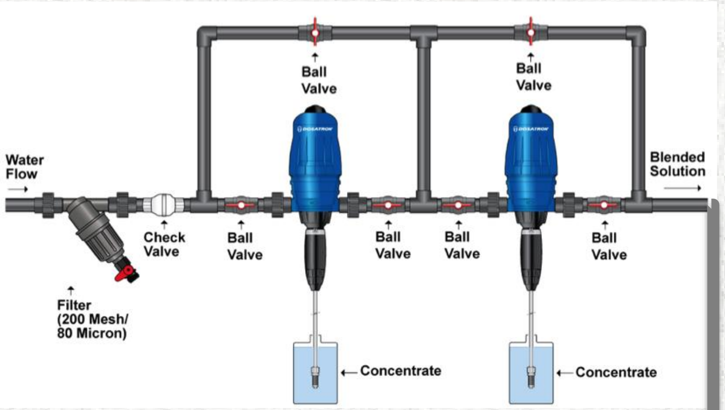
- **Impact of substrate is relatively large**
  - Smaller LAI (1-2)
  - Leaf transpiration rate: ~7 mmol m^{-2} s^{-1}
  - Root respiration rate: relatively high
  - Typical root-zone volume in soilless culture: 2-3 L per plant
  - Irrigation: up to 300 mL per day per plant (3-10 times a day)
  - Drainage rate: 10-20%

Drip Irrigation With Substrate

- Designed to provide small amount of nutrient solution at a time with frequent cycle.
- This way, the root zone environment (ions, O_2) can be maintained relatively constant.
- Some discharge (>30% for high-wire crops) is needed to avoid ion accumulation.

- Less water-use efficient system than other soilless culture systems when no nutrient recycling is introduced.

Irrigation Lines and Emitters



Solenoid valve connected to timer/controller

PVC main line

Pressure-compensating in-line emitters along the drip tube going into each row. Could be drip tape or similar.

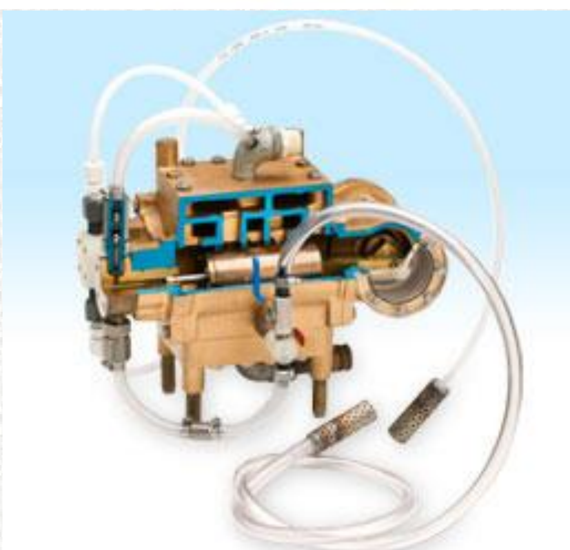
Polyethylene tubing
“1/2 inch” (0.71 OD)

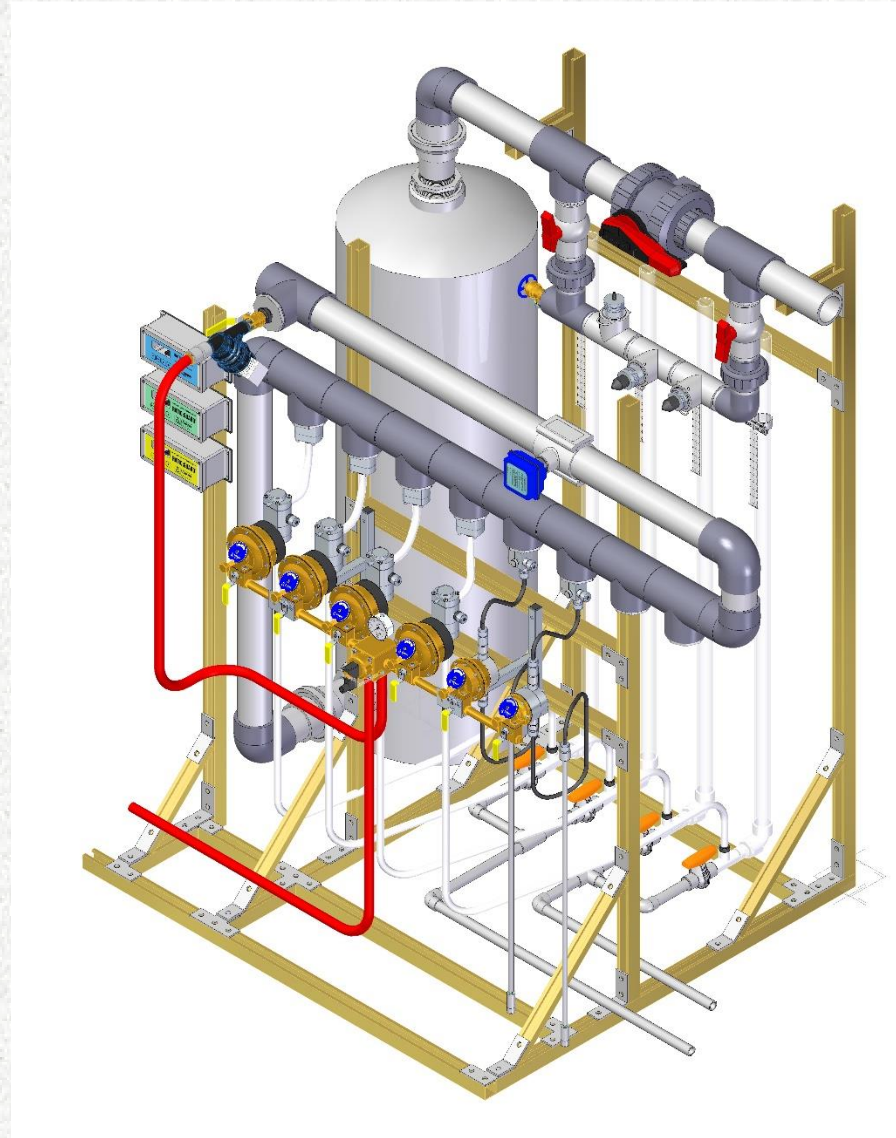
Pressure compensated
emitters (2 L/hr)

Drip tubing

Drip stakes

Nutrient Delivery Systems



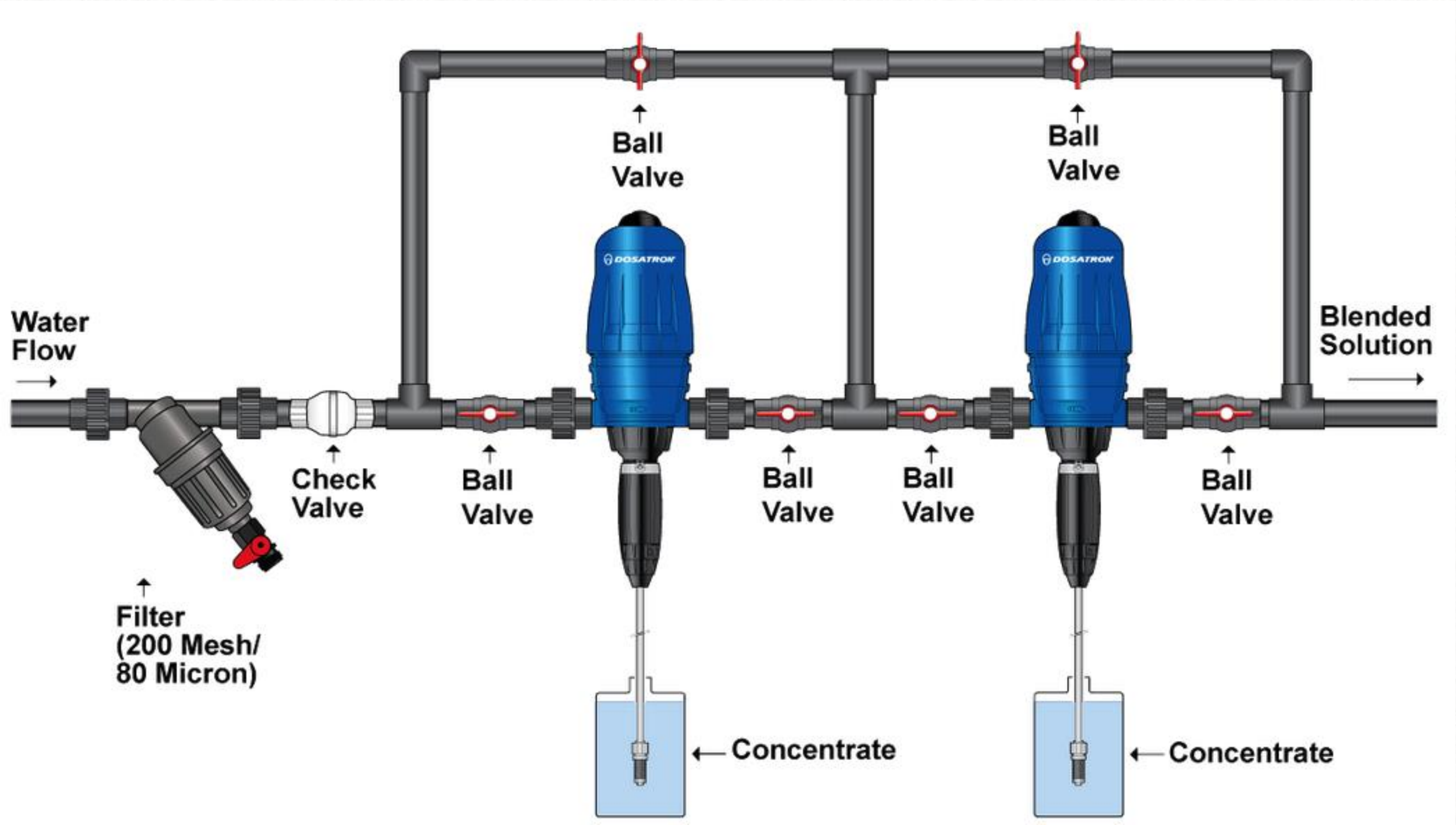


Managing Nutrient Solutions

Challenges when recycling nutrient solution

- Spread of disease
- Biofilm development
- Nutrient imbalance
  - Depletion/accumulation of specific elements
- Accumulation of toxic compounds
- Costs
- Precipitate formation

Injectors



http://www.dosatronusa.com/markets-served/livestock/installation-tips.aspx

Why Two Injectors??

Nutrient Stock Preparation

Need to separate Ca^{++} and SO_4^- and PO_4^-
At 100X these react to form gypsum and calcium phosphate

Tank A

KNO_3	Potassium nitrate
$MgSO_4$-$7H_2O$	Magnesium sulfate (Epsom salt)
KH_2PO_4	Mono-potassium phosphate (MKP)
K_2SO_4	Potassium sulfate (Sulfate of potash)
$(NH_4)_2SO_4$	Ammonium sulfate
Micronutrients	
Phosphoric acid	

Tank B

$Ca(NO_3)_2$	Calcium nitrate
$CaCl_2$	Calcium chloride
Fe chelate	Iron chelate (EDTA, DTPA, and EDDHA)

Tank C

Nutrient Solution Disinfestation

1) **Heat** to 200° F+ for about 30 sec, then cool as quickly as possible
2) **Ionization** device uses Copper & Silver to kill microorganisms
3) **Chlorine / Bromine injected** as microbiocide
4) **Ultra-violet light** zaps recirculating solution
5) **Ozone** injection, free radicals
6) **Filtration** with membrane filters or sand

In-line UV Irradiation System

pH and EC Monitoring

- Daily
- Lysimeter
- Input and output
- pH = -log[H^+]
  - Increases with NO_3-N fertilizer
  - Must add dilute acid to maintain optimal range
- EC = electrical conductivity; total salt
  - Decreases with plant use, water additions
  - Must add fertilizer salts to avoid deficiencies

Irrigation management (EC, pH, and %discharge)

- Target EC (3.5-4.5) and Target pH (6.0-7.0) of the root zone
- For aggregate hydroponics, % discharge is maintained at ~30%
- Solar radiation (Σ, J m^{-2}) based irrigation control
- 100 ml per irrigation

Monitoring nutrient status

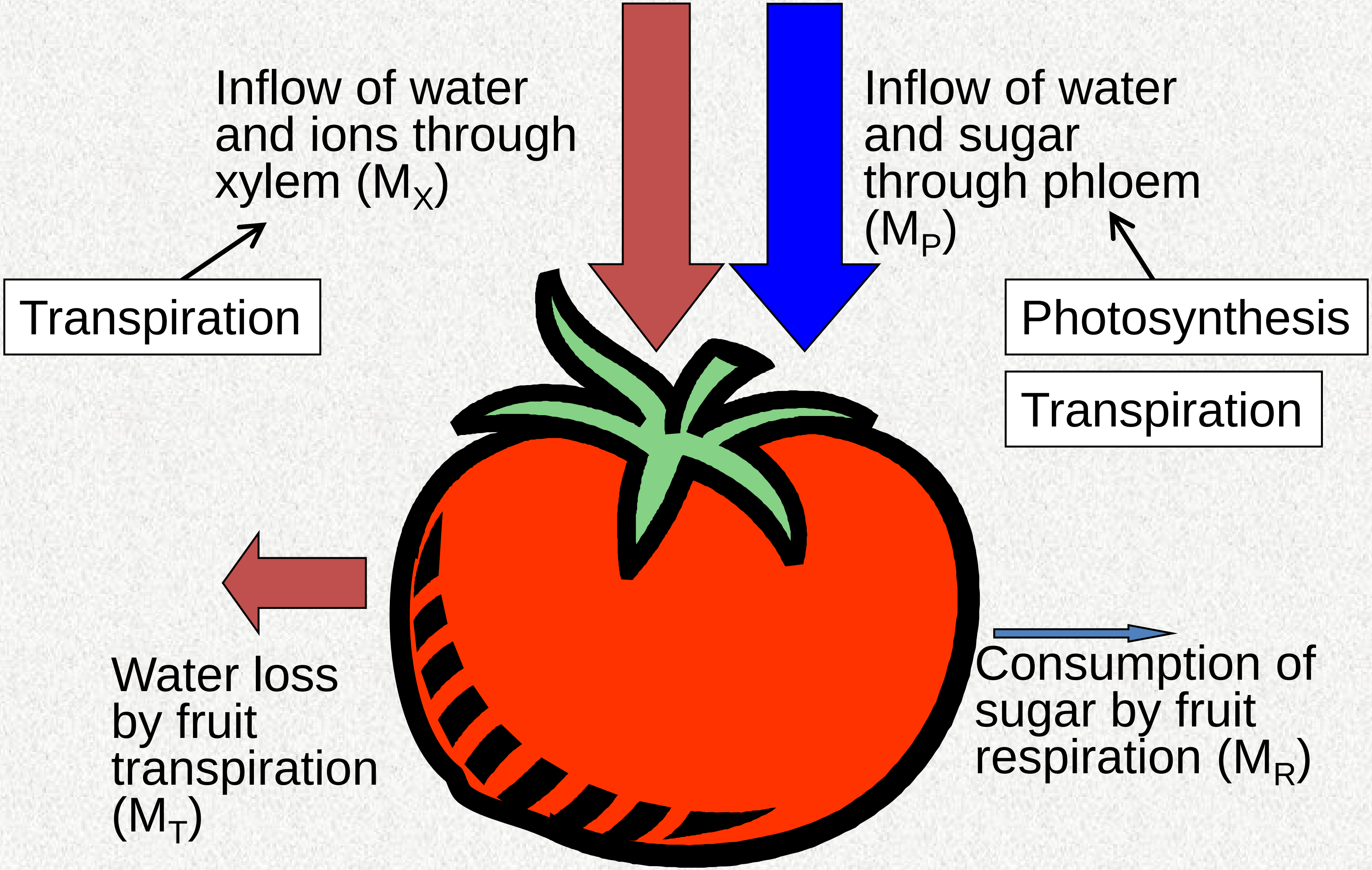
- Visual evaluation
- Solution analysis (monitoring)
- Tissue analysis

EC – Grower's Tool to Improve flavor

TOV type tomato
under high EC
(4.8 mS/cm)
Brix = 4.8-6.1
Higher lycopene

TOV type tomato
under standard low EC
(2.4 mS/cm)
Brix = 3.5-4.8

EC was increased by adding NaCl

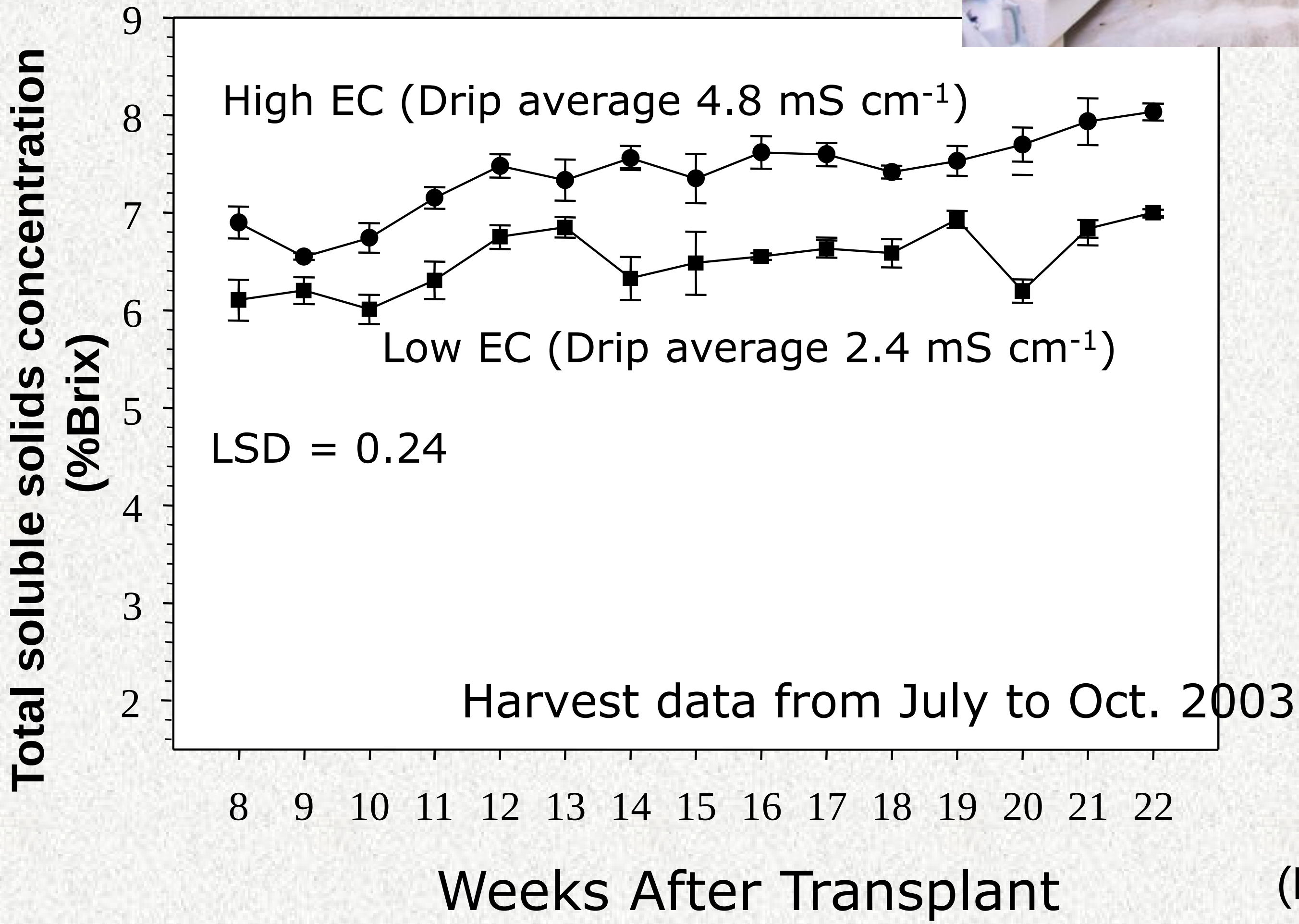


EC in nutrient solution reduces the water fluxes to fruit, condensing sugars and acids.

How High Should the EC Be?

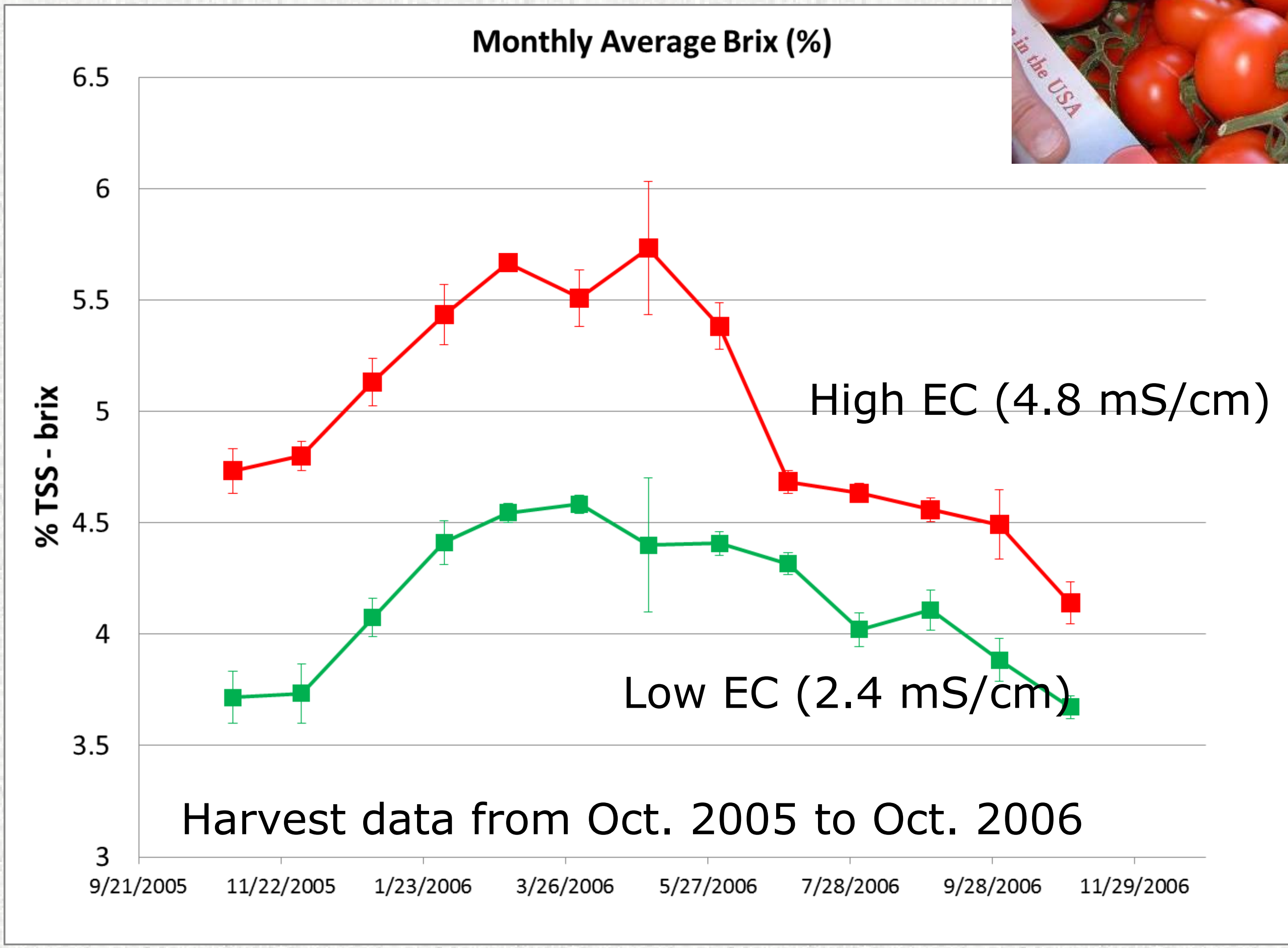
- EC levels need to be determined based on the climate (high light vs. low light; dry vs. wet)
- Start with a small increase (0.5 – 1.0 mS/cm at a time)
- Too high EC can cause BER (blossom end rot) – Ca deficiency in fruit due to limited transpiration
- Control **drainage EC** in a target range (at UA, 6-8 mS/cm when applying ~4.8 mS/cm drip solution)
- Keep good (30%) drainage rate

Demonstration of high EC cherry tomato production in Arizona



(Buck, 2005)

Demonstration of high EC TOV tomato production in Arizona



Your Choice

- 60 kg/m^2
- Ordinary flavor

- 50-55 kg/m^2
- High flavor

Further Resources

- "Greenhouse Hydroponics – From Seed to Harvest"
  - http://youtu.be/KaRIdEBegFo
- "Tomatoes" – A textbook edited by Dr. E. Heuvelink
  - http://www.cabi.org/bookshop/book/1863
- University of Arizona PLS 217 course open-access materials online (Dr. Patricia Rorabaugh)
  - http://ceac.arizona.edu/pls-217-introduction-hydroponics-and-cea

Hydroponic Tomato Training and Education

- University of Arizona CEAC Short Course Series
  - Annual Greenhouse Crop Production and Engineering Design Short Course – **April 2-7, 2017. Tucson, AZ**
  - Tomato Intensive Short Course and Hands-on
- Crop King Grower Workshop
- Mississippi State University Greenhouse Tomato Short Course
- Online courses (for further study on greenhouses)
  - Univ. of Arkansas ‘Greenhouse Management’
  - Univ. of Arizona ‘Greenhouse plant physiology and technology’

Acknowledgements

ARIZONA

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CEAC

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- Mark Kroggel
- Kimberly Williams

KANSAS STATE UNIVERSITY

Horticulture and Natural Resources