



# Hydroponic Tomato Production in Soilless Culture

## Outline

- **Cropping Schedule**
- **Plant Spacing and Extra Stems**
- **Crop Management**
  - ... Training
  - ... Side-shooting and Trimming
  - ... Leaf Pruning
  - ... Pollination
  - ... Truss Pruning and Development
  - ... Topping plants at the end of the crop
- **Substrates and Substrate Systems**
- **Nutrition**
  - ... pH, Salinity, Alkalinity
  - ... Imbalances
  - ... N:K Ratio, N-form
  - ... Recipes
- **Irrigation**
- **Controlling Growth**
- **Environmental Control**
- **Harvest**
- **Potential Production**

## Cropping Schedule

- **Two cropping options:** two crops per year (set plants in spring and fall) and one crop per year (set plants in fall)
- Large commercial greenhouse operations **produce** almost **year-round** in order to lower costs per pound of produce and to avoid the problem of buyers switching to alternative sources
- **Typically** grown for 11 months, 1 month for cleaning and pest and disease control
- A second crop might even be **intercropped** within the existing crop
- **Spring and Fall cropping**, to avoid hottest and coldest periods of the year.

## Plant Spacing and Extra Stems

- **Rows** are **1.2 to 1.5 m (4 to 5 ft.)** apart (5 ft. from center-to-center of 2 sets of twin-rows)
- **Plant populations** can be altered at **planting** (in-row spacing) and later in the season by allowing **extra stems** (side shoots) to develop
- **2.5 plants per m<sup>2</sup> or 4.3 sq. ft. per plant** give best results
- In **December** optimal **in-row plant spacing** is 50 to 56 cm (20 to 22 inches)
- In the **spring spacing** is set at **46 cm (18 inches)** in the row

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Training Systems



Source: <https://www.dutchplantin.com/>



Source: Petrus Langenhoven

PURDUE  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

5

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Training Systems

- **High-wire system**, can be as high as 3.5 meters (12 ft.) above the floor
- Maximum **canopy height** in **summer** of about 2.5 meters (8 ft.)
- Depending on **variety, growing height, and cropping system**; plan on the **wire** bearing a **load** of 7 kg per linear 30 cm (15 pounds per linear foot), or 3 tons for 600 plants
- Growing tip remains at the top of the canopy, but the stem is lowered and trails along the base of the plants (**leaning and lowering**)
  - ... **Advantages**: maximum **light interception** by young leaves with **increased labor efficiency** resulting from easier removal of leaves and fruit at the lower part of the plant
- Plants are **trained up a string** attached to the cable above the plant and extending to the base of the plant
- Plant **stems** are secured to plastic twine with **clips** every 18 cm (7 inches), allow for 10-15 meters (400-600 ft.) unwind on hook

PURDUE  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

6

## Crop Management, Training Systems

- **Twinning** (second stem) should take place approximately 9 or 10 weeks after seeding (week 5 in higher radiation conditions)
- **Flowering** of the 4<sup>th</sup> cluster is a good developmental stage to **start leaning and lowering**, as the stem is relatively vigorous and should resist breakage
- **Every 7-10 days** the vines are '**leaned and lowered**', head of the plant remain upright
- When using **upright bags**, the vines rest on special holders designed to give support
- At the **end of row, vines are wound around the corner** and back down the next row. Upright rods or wire supports are placed at the corners to turn the vines

## Crop Management, Side-shooting (laterals) and Trimming

- **Indeterminate** growth habit
- **Prune side shoots** weekly, when a few inches long
- Be careful not to prune the main stem out
- **Fruit size** can be **manipulated** with crop density and leaving extra stems (side shoots)



Side shoot

Source: Petrus Langenhoven



Source: [www.theplantguide.net](http://www.theplantguide.net)

Main Stem

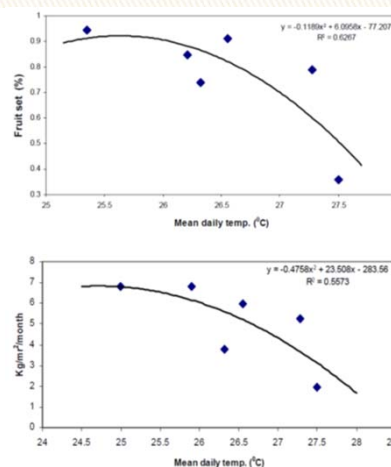
## Crop Management, Leaf Pruning

- When vines are lowered, leaves are removed to prevent disease development
- To avoid introducing Botrytis, **leaves should be cut** with a knife or pruned flush to the stem
- Typically between **14-18 leaves are left**
- Tomato **plant canopy** is usually maintained at 2 to 2.5 meters (7 or 8 feet) in height
- A **vigorously growing plant** will produce **0.8–1 truss** and **three leaves per week**
- **When total leaf numbers reach the maximum desired**, from that point on the bottom two to three leaves are removed each week
- Typically, all leaves are removed below the bottom fruit cluster
- Pruning may be less severe during the final months of a crop, leaving 18–21 leaves

## Crop Management, Pollination

### Problems?

- **Poor pollination:** flower abortion and/or small, puffy or misshapen fruit
- **Flower abortion** can be affected by **temperature**
  - high daytime temperatures - above 85°F
  - high nighttime temperatures - above 70°F
  - or low nighttime temperatures - below 55°F
  - Pollen becomes tacky and nonviable, preventing pollination from occurring
- **High temperatures** or **low light** conditions can promote the **exsertion of the style from the anther cone**
- Ideal **relative humidity** is between 50% and 70%
- High and low rates of **nitrogen** can cause **flower abortion**
- Particularly important to get **good fruit set** on the **first three clusters** to establish an early pattern of **generative growth**



Source: Harel, D. et al., 2014. The Effect of Mean Daily Temperature and Relative Humidity on Pollen, Fruit Set and Yield of Tomato Grown in Commercial Protected Cultivation. *Agronomy* 4, 167-177.

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Pollination

#### How?

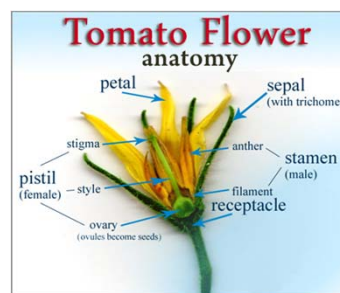
- **Tomato flowers** have both male and female parts within every flower
- Each flower **cluster to be vibrated** with an **electric pollinator** at least three times weekly to release pollen
- Commercially, **bumble bees** (*Bombus impatiens*) are used for pollination
- Generally, **one hive can service**: 2,000-2,500 m<sup>2</sup> (22,000-27,000 ft<sup>2</sup>)
- **Cherry tomatoes require 2-3 times more hives** than beefsteak and round tomatoes
- **Advantages**: saving labor, increases yield and quality compared to manual vibration



<https://www.biobestgroup.com/>



<https://www.koppert.com/>



Source: [www.geochembio.com](http://www.geochembio.com)

11

Purdue University is an equal access/equal opportunity institution.

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Pollination

#### How?

- **Do not use broad spectrum insecticides** or those with residual action once hive is in place
- All pesticides should be checked for effects on bees. **Close hive during application** (bee-home position will allow all bees to return to the hive within 1-2 hours). Hives can remain closed for a number of days (max. 3 days) after treatment
- Efficiency: **look for brown or dark bruise marks on the anther cone** as evidence of flower visitation. At least 80% of withered flowers should have evidence of bee visits
- Shelf life: will **remain active for 6-8 weeks** after placement



Source: <http://www.bushelboy.com/>



Source: <http://pollinator.com/tomato.htm>

12

Purdue University is an equal access/equal opportunity institution.

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Pollination

#### When?

- **Around midday**, when humidity conditions are most favorable (50-70%; 25-28°C, 77-82°F)
- **If humidity is too high in winter**, temperatures can be raised by 2°C at midday to reduce humidity
- Bumblebees **need UV light for their orientation**
- Bumblebees **only fly in natural daylight**. Therefore switch on the artificial light not before 2.00 a.m., to create enough hours where flowers can be pollinated and bumblebees are able to fly
- Use the BEEHOME system to let the bumblebees fly only during the lightest part of the day
- Aim for **4 hours of effective pollination per day**



PURDUE  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

13

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Truss Pruning and Development

- Truss pruning works to **balance a weak plant**, to allow it to strengthen vegetatively, which in turn allows for the **fruit size to begin to increase**
- The **greater the number of tomato fruit** that are allowed to set on any given truss, the **smaller the fruit size**
- **Removal of young fruit** from the truss to maintain optimum plant balance
- Good **balance** for tomato plants would be approximately **20 - 25 fruit to 20 leaves**, however this balance can vary with cultivar
- Truss pruning can be based on the individual plant
- Prune the **first truss** to allow **3 fruit** to set and **4 fruit per truss** on the following trusses



Source: Petrus Langenhoven



Source: <http://www.bushelboy.com/>

PURDUE  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

14

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Truss Pruning and Development

- **Cluster tomatoes of 4 to 6 tomatoes** with all tomatoes showing a touch of mature color
- The weight of the clusters should be between 454 to 680 grams (16 to 24 oz.)
- It takes **about 6-9 weeks from flowering to fruit pick** under optimum light conditions
- **Kinking (snapping)** –
  - Grown under relatively **low light conditions**, the **peduncles** of the inflorescences (trusses) are too **weak** to support the weight of fruit they bear and are likely to bend
  - **High temperature** during the **vegetative phase**, which causes the **truss** to become almost **vertical** can also cause kinking
  - Use **truss hooks** or apply a **truss support** or truss brace to the cluster before fruit development



PURDUE  
UNIVERSITY



Source: <http://www.paskal-tech.com/>



Source: <http://www.bato.nl/en/home>



Purdue University is an equal access/equal opportunity institution.

15

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Crop Management, Topping Plants at the End of the Crop

- **Growing point is removed** 5–8 weeks before the anticipated crop termination date
- A **week later**, all remaining **flowers** are removed
- In **summer**, **leave** some **shoots or leaves** at the **top of the plant** to shade the fruit and prevent sunscald
- High-wire system, plant stems continue to grow from December of one year until November of the following year

PURDUE  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

16

## Substrates and Substrate Systems

- **Rockwool, Coconut Coir, Perlite and Peat popular.** Also substrate mixes
- In **slabs, buckets, and lay-flat or upright bags**
- Greenhouse **floor** should be covered with **white polythene** to suppress **weeds** and **increase light** to the crop
- If the **greenhouse floor is not heated**, rockwool or coconut coir **slabs** may be **placed on polystyrene for insulation**. In closed systems, return **gutters** are placed under the slabs to recapture excess water
- 2% slope to **drainage ditch**
- **Control of the slope** is more accurate when using a hanging gutter system
- **Hanging gutters** place the plants at a **convenient working height** and allows for the installation of **cooling or CO<sub>2</sub> systems**

## Substrates, pH and Cation Exchange Capacity

| Materials              | Average | Range   |
|------------------------|---------|---------|
| Wood fibre             | 4.8     | 3.8–5.4 |
| Expanded clay granules | 8.1     | 7.7–8.6 |
| Coir chips             | 5.7     | 5.4–6.1 |
| Coir dust              | 6.2     | 6.0–6.7 |
| Perlite                | 6.3     | 5.2–7.7 |
| PU-foam                | 6.6     | 4.7–8.9 |
| Pumice                 | 6.3     | 4.7–7.6 |
| Rock wool              | 6.2     | 5.2–7.8 |
| Peat                   | 3.9     | 3.4–4.4 |

**Table 11.9** The pH of different substrates and substrate constituents as given by Kipp et al. (2000)

CEC - Capacity to hold and exchange mineral nutrients

**Table 11.10** Cation exchange capacities (CEC) of some substrates and substrate constituents expressed as C<sup>+</sup> mmol kg<sup>-1</sup> dry matter

| Material                     | CEC      | References                                             |
|------------------------------|----------|--------------------------------------------------------|
| Humus                        | 2000     | Bunt, 1988                                             |
| Peat                         | 560–1580 | Lamaire, 1995; Lamaire 1998; Puustjärvi, 1977          |
| Coir dust                    | 350–600  | Evans et al., 1996; Verhagen, 1999                     |
| Sawdust (fresh) <sup>1</sup> | 100      | Jokova et al., 1997                                    |
| Compost (fresh)              | 270–1080 | Jokova et al., 1997; Lamaire, 1998                     |
| Compost (stable)             | 640–1810 | Chen et al., 1989; Jokova, et al., 1997; Lamaire, 1998 |
| Clay <sup>1</sup>            | 100–300  | RHP, 2007                                              |
| Vermiculite <sup>1</sup>     | 390–530  | Van der Mark, 2008                                     |
| Perlite                      | 10–70    | Bunt, 1988; Gizas et al., 2001; Lamaire, 1995          |
| Zeolite                      | 400–1200 | Stamatakis, 2001; Maloupa, 2002                        |
| Tuff <sup>2</sup>            | 70–600   | Silber et al., 1994                                    |
| Pumice                       | 60–80    | Gizas et al., 2001                                     |
| Rockwool                     | 0        | Lamaire, 1995                                          |

<sup>1</sup> See text; <sup>2</sup> Within pH 4.0–7.0.

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Substrate Characteristics

#### • Rockwool

- ... Low bulk density and high porosity
- ... **High water-holding capacity (80%)** and good aeration
- ... **Chemically inert with pH 7.0 to 8**
- ... **No CEC or buffering capacity**
- ... Dissolve at low pH, below 5.0

#### • Perlite

- ... Lightweight, sterile, white, porous aggregate
- ... Finished product is a "closed cell" that does not absorb water. **Water will adhere to surface**
- ... Usually included in mixture to **improve drainage** or increase aeration
- ... **Neutral pH** of between 6.5 and 7.5
- ... **Low CEC**
- ... **Chemically inert**

#### • Coconut Coir

- ... **Good aeration and water-holding**
- ... Water and air content varies according to texture components (**fiber vs. dust/peat**)
- ... Coir is **hydrophilic**, moisture disburse evenly over surface of fibers
- ... Higher pH than peat moss, **pH is 5.6 to 6.6**
- ... **Not inert** and can store lots of nutrients, high CEC
- ... Require more Ca, S, Cu and Fe than peat moss. Greater N-immobilization than peat moss
- ... **May contain excessive levels of K, Na and Cl.** Soak and rinse well before use
- ... More lignin and less cellulose than peat, **more resistant to microbial breakdown**
- ... Easier to re-wet than peat

PURDUE  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

19

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Substrates and Substrate Systems

Source: <http://www.farmhydroponics.com/hydroponic-systems/dutch-bucket-system>



Source: [www.hortidaily.com](http://www.hortidaily.com)

Source: <http://www.bomgroup.nl/welcome/>

Source: Petrus Langenhoven

20

Purdue University is an equal access/equal opportunity institution.

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Nutrition, pH and Salinity

- **Root-zone pH affects nutrient availability.** In acid substrates, Ca, P, Mg and Mo are the nutrients most likely to be deficient
- **Optimum pH** value for tomatoes is about **5.5 to 6.0**
- **Water quality: High salinity** reduces plant uptake of both water and nutrients
- In rockwool systems, **salinity** may be increased above recommended levels to **improve fruit quality**. Use NaCl instead of raising concentrations for all nutrients
- Tomatoes can be grown in a solution containing 100 ppm Cl without too much difficulty
- **Salinity rises rapidly as water is depleted. High temperatures** couple with **high salinity** can cause **severe wilting** and permanent damage

| Water class | EC <sup>a</sup> (dS/m) | Sodium (ppm) | Chloride (ppm) | Sulphate (ppm) |
|-------------|------------------------|--------------|----------------|----------------|
| 1           | < 0.5                  | < 30         | < 50           | < 100          |
| 2           | 0.5–1.0                | 30–60        | 50–100         | 100–200        |
| 3           | 1.0–1.5                | 60–90        | 100–150        | 200–300        |

Not for NFT  
avoid

PURDUE  
UNIVERSITY

<sup>a</sup> Electrical conductivity or soluble salts level.

Source: CAB International 2005. Tomatoes (ed. E. Heuvelink)

Purdue University is an equal access/equal opportunity institution.

21

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Nutrition, Alkalinity

- **Ability of water to neutralize acids;** it buffers water against changes in pH
- Reported in terms of parts per million (ppm) CaCO<sub>3</sub> or milli-equivalent (meq·L<sup>-1</sup>)
- Water alkalinity can **vary between 50-500 ppm** (1-10 meq·L<sup>-1</sup>)
- Alkalinity affects **how much acid is required to change the pH**

**ALKCALC**  
[https://extension.unh.edu/Agric/AGGHFL/alk\\_calc.cfm](https://extension.unh.edu/Agric/AGGHFL/alk_calc.cfm)

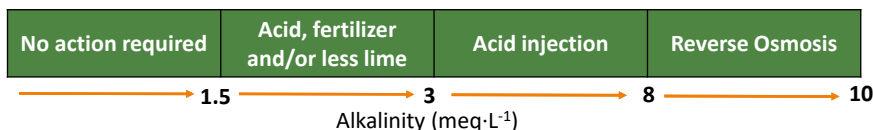
| Range meq·L <sup>-1</sup> | Classification |
|---------------------------|----------------|
| 0 to 1.5                  | Low            |
| 1.5 to 4                  | Marginal       |
| > 4                       | High           |

| meq·L <sup>-1</sup> | ppm CaCO <sub>3</sub> | ppm HCO <sub>3</sub> <sup>-</sup> | ppm CO <sub>3</sub> <sup>2-</sup> | ppm Ca <sup>2+</sup> |
|---------------------|-----------------------|-----------------------------------|-----------------------------------|----------------------|
| 1                   | 50                    | 61                                | 30                                | 20                   |
| 2                   | 100                   | 122                               | 60                                | 40                   |
| 3                   | 150                   | 183                               | 90                                | 60                   |
| 4                   | 200                   | 244                               | 120                               | 80                   |
| 6                   | 300                   | 366                               | 150                               | 120                  |

| Element | Molecular Weight |
|---------|------------------|
| Ca      | 40               |
| C       | 12               |
| O       | 16               |
| H       | 1                |

Source: Nelson, P.V. Greenhouse Operation and Management

PURDUE  
UNIVERSITY



Purdue University is an equal access/equal opportunity institution.

22

## Nutrition, Imbalances

- **Excessive fertilization** can create an **imbalance**
- **High N** levels encourage **vegetative** growth, which can be **detrimental to reproductive growth** under low light
- **Plant growth** can also be **slowed** by increasing the K:N ratio
- As the **fruit load increases**, so does the **K uptake**
- **High K** levels will **reduce Ca and Mg uptake**
- In general, **N and P** have **antagonistic effects** and **induce or accentuate K deficiency**
- Other **conditions** that **reduce calcium uptake** include the presence of **high concentrations of Na and Mg**.
- **Ca** (and to a **smaller extent Mg**) **antagonize K uptake**.  $\text{NH}_4$  greatly decreases the rate of **K uptake**
- **K deficiency** tends to **induce or accentuate Fe deficiency**

## Nutrition, N:K ratio and N-forms

- **Optimal ratio of K to N varies with growth stage**
  - ... When the **first truss is in flower**, the K:N ratio should be **1.2:1**, which is the same K:N requirement as in most plants during the vegetative stage
  - ... This ratio increases to **2:1** as the **fruit load** on the plant **increases**, since about 70% of the potassium absorbed moves into the fruit
  - ... By the time the **ninth cluster flowers open**, the ratio should be **2.5:1**
- **Low K** during times of high fruit load **reduces tomato quality**, especially **flavor**
- **Too much  $\text{NH}_4\text{-N}$**  will **reduce Ca content** of the crop, may reduce growth - **BER**
- **$\text{NH}_4\text{-N}$**  is particularly likely to **harm the plant early in the season** when **conversion** of  $\text{NH}_4\text{-N}$  to  $\text{NO}_3\text{-N}$  is slow
- Up to **10% of N** requirement can be supplied in **ammonium form**, but a level of more than 20% will result in BER

# PURDUE EXTENSION

# HORTICULTURE & LANDSCAPE ARCHITECTURE

**Table 9.4.** Final delivered nutrient solution concentration (ppm) and EC recommendations for tomatoes grown in Florida in rockwool, perlite or nutrient film technique (Hochmuth and Hochmuth, 1995). Numbers in bold denote changes from previous stage.

| Nutrient        | Stage of growth             |                                 |                                 |                                |                              |
|-----------------|-----------------------------|---------------------------------|---------------------------------|--------------------------------|------------------------------|
|                 | Transplant to first cluster | First cluster to second cluster | Second cluster to third cluster | Third cluster to fifth cluster | Fifth cluster to termination |
| N               | 70                          | <b>80</b>                       | <b>100</b>                      | <b>120</b>                     | <b>150</b>                   |
| P               | 50                          | 50                              | 50                              | 50                             | 50                           |
| K               | 120                         | 120                             | <b>150</b>                      | 150                            | <b>200</b>                   |
| Ca <sup>a</sup> | 150                         | 150                             | 150                             | 150                            | 150                          |
| Mg              | 40                          | 40                              | 40                              | <b>50</b>                      | 50                           |
| S <sup>a</sup>  | 50                          | 50                              | 50                              | <b>60</b>                      | 60                           |
| Fe              | 2.8                         | 2.8                             | 2.8                             | 2.8                            | 2.8                          |
| Cu              | 0.2                         | 0.2                             | 0.2                             | 0.2                            | 0.2                          |
| Mn              | 0.8                         | 0.8                             | 0.8                             | 0.8                            | 0.8                          |
| Zn              | 0.3                         | 0.3                             | 0.3                             | 0.3                            | 0.3                          |
| B               | 0.7                         | 0.7                             | 0.7                             | 0.7                            | 0.7                          |
| Mo              | 0.05                        | 0.05                            | 0.05                            | 0.05                           | 0.05                         |
| EC (dS/m)       | 0.7                         | <b>0.9</b>                      | <b>1.3</b>                      | <b>1.5</b>                     | <b>1.8</b>                   |

<sup>a</sup>Ca and S concentrations may vary depending on Ca and Mg concentrations in well water and amount of sulphuric acid used for acidification.

**PURDUE**  
UNIVERSITY

**Table 9.5.** Final delivered nutrient solution concentrations (ppm) recommended for greenhouse tomato production in rockwool in Ontario, Canada (OMFRA, 2001).

| Nutrient         | Stage of growth     |                              |             |                  |
|------------------|---------------------|------------------------------|-------------|------------------|
|                  | Saturation of slabs | For 4–6 weeks after planting | Normal feed | Heavy fruit load |
| N                | 200                 | 180                          | 190         | 210              |
| NH <sub>4</sub>  | 10                  | 10                           | 22          | 22               |
| P                | 50                  | 50                           | 50          | 50               |
| K                | 353                 | 400                          | 400         | 420              |
| Ca <sup>a</sup>  | 247                 | 190                          | 190         | 190              |
| Mg               | 75                  | 75                           | 65          | 75               |
| S <sup>a</sup>   | 120                 | 120                          | 120         | 120              |
| Fe               | 0.8                 | 0.8                          | 0.8         | 0.8              |
| Cu               | 0.05                | 0.05                         | 0.05        | 0.05             |
| Mn               | 0.55                | 0.55                         | 0.55        | 0.55             |
| Zn               | 0.33                | 0.33                         | 0.33        | 0.33             |
| B                | 0.5                 | 0.5                          | 0.5         | 0.5              |
| Mo               | 0.05                | 0.05                         | 0.05        | 0.05             |
| Cl               | 18                  | 18                           | 18          | 18               |
| HCO <sub>3</sub> | 25                  | 25                           | 25          | 25               |

<sup>a</sup> Ca and S concentrations may vary depending on Ca and Mg concentrations in well water and amount of sulphuric acid used for acidification.

Source: CAB International 2005. Tomatoes (ed. E. Heuvelink)

Purdue University is an equal access/equal opportunity institution.

25

# PURDUE EXTENSION

# HORTICULTURE & LANDSCAPE ARCHITECTURE

**Table 4.** Two hydroponic nutrient solution recipes to prepare 100 gal. of fertilizer suitable for hydroponic production of tomatoes, cucumbers and peppers.

| Jack's Hydroponic (5-12-26) + Calcium nitrate               |                                                             |
|-------------------------------------------------------------|-------------------------------------------------------------|
| Tank A                                                      | Tank B                                                      |
| 360 g Calcium nitrate (15-0-0)                              | 360 g 5-12-26                                               |
| UA CEAC Recipe*                                             |                                                             |
| Tank A                                                      | Tank B                                                      |
| 3478 g Ca(NO <sub>3</sub> ) <sub>2</sub> ·3H <sub>2</sub> O | 64.9 g KH <sub>2</sub> PO <sub>4</sub>                      |
| 152.5 g KNO <sub>3</sub>                                    | 184.3 g MgSO <sub>4</sub> ·7H <sub>2</sub> O                |
| *76 g 10% Iron-DTPA                                         | 114.7 g K <sub>2</sub> SO <sub>4</sub>                      |
| Sprint 330 or                                               | *0.641g MnSO <sub>4</sub> ·H <sub>2</sub> O                 |
| Sequestrene 330                                             | *0.606g H <sub>3</sub> BO <sub>3</sub>                      |
|                                                             | *0.048g Na <sub>2</sub> MoO <sub>4</sub> ·2H <sub>2</sub> O |
|                                                             | *0.549g ZnSO <sub>4</sub> ·7H <sub>2</sub> O                |
|                                                             | *0.074g CuSO <sub>4</sub> ·5H <sub>2</sub> O                |

\*A precise scale is needed to weigh the micronutrients  
Adapted from University of Arizona, Controlled Environment Agriculture Center,  
<http://tinyurl.com/yj785/>

|                 | Jack's Hydroponic (5-12-26) + Calcium nitrate | UA CEAC Recipe |
|-----------------|-----------------------------------------------|----------------|
| Nitrogen (N)    | 190                                           | 189            |
| Phosphorus (P)  | 50                                            | 39             |
| Potassium (K)   | 205                                           | 341            |
| Calcium (Ca)    | 176                                           | 170            |
| Magnesium (Mg)  | 60                                            | 48             |
| Iron (Fe)       | 2.85                                          | 2.00           |
| Manganese (Mn)  | 0.48                                          | 0.55           |
| Zinc (Zn)       | 0.14                                          | 0.33           |
| Boron (B)       | 0.48                                          | 0.28           |
| Copper (Cu)     | 0.14                                          | 0.05           |
| Molybdenum (Mo) | 0.10                                          | 0.05           |

Source: Neil Mattson and Carl Peters. A recipe for hydroponic success. InsideGrower.

**PURDUE**  
UNIVERSITY

Purdue University is an equal access/equal opportunity institution.

26

## UA CEAC Nutrient Solution Recipe

**Table 6.** Recipe for tomatoes in winter according to crop growth stage (units are ppm).

|                 | Weeks 0-6<br>Higher N, Ca and Mg for<br>vegetative growth | Weeks 6-12<br>Lower N, higher K for<br>reproductive growth | Week 12+<br>Maintain balance of vegetative /<br>reproductive growth |
|-----------------|-----------------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------|
| Nitrogen (N)    | 224                                                       | 189                                                        | 189                                                                 |
| Phosphorus (P)  | 47                                                        | 47                                                         | 39                                                                  |
| Potassium (K)   | 281                                                       | 351                                                        | 341                                                                 |
| Calcium (Ca)    | 212                                                       | 190                                                        | 170                                                                 |
| Magnesium (Mg)  | 65                                                        | 60                                                         | 48                                                                  |
| Iron (Fe)       | 2.00                                                      | 2.00                                                       | 2.00                                                                |
| Manganese (Mn)  | 0.55                                                      | 0.55                                                       | 0.55                                                                |
| Zinc (Zn)       | 0.33                                                      | 0.33                                                       | 0.33                                                                |
| Boron (B)       | 0.28                                                      | 0.28                                                       | 0.28                                                                |
| Copper (Cu)     | 0.05                                                      | 0.05                                                       | 0.05                                                                |
| Molybdenum (Mo) | 0.05                                                      | 0.05                                                       | 0.05                                                                |

Source: Sunco, Ltd., and University of Arizona, Controlled Environment Agriculture Center, <http://tinyurl.com/jj785/>

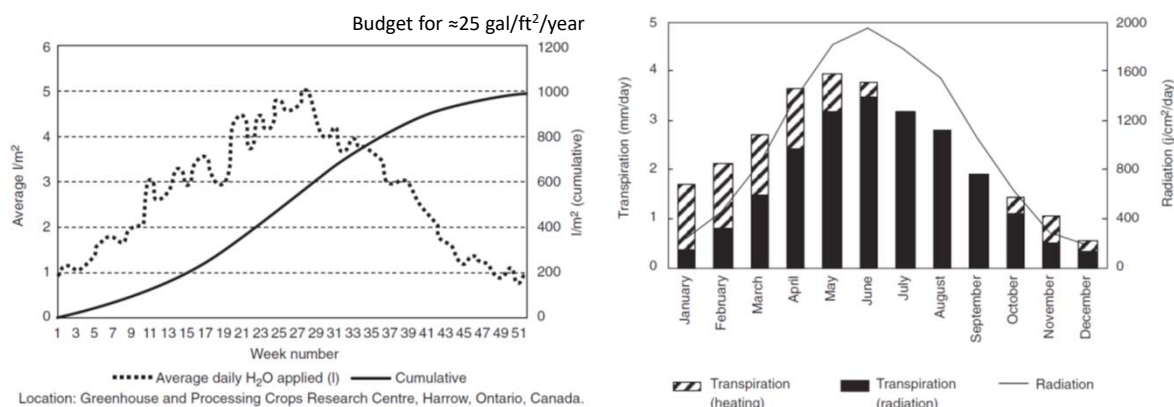
## Irrigation

- **Large amounts of high quality water** needed for plant transpiration, which serves both to **cool the leaves** and to **trigger transport of nutrients** from roots to leaves and fruits
- Irrigation system **capacity** – up to 8 L/m<sup>2</sup>/day (0.2 gal/ft<sup>2</sup>/day)
- Mature **tomato crop uses** 2 to 3 L (0.5 to 0.8 gal.) water per plant per day when light levels are high
- **Plant density:** 2.5 plants per m<sup>2</sup> or 4.3 sq. ft. per plant
- **Budget** for ≈ 800 to 1000 L/m<sup>2</sup>/year (25 gal/ft<sup>2</sup>/year), this includes leaching factor
- **Plant uses** most of this water (90%) in **transpiration** and only uses 10% for **growth**
- **Holland**, climate-controlled glass, CO<sub>2</sub> enriched, 22 L/kg (2.6 gal/lb) tomato (2008)

## Irrigation, When and How Much?

- **Frequency of irrigation** varies with **substrate**, **substrate rooting volume** and **water-holding capacity**
- **Amount needed** depends on **stage of growth and season**, and **leaching fraction**
- **Daily timing** of irrigation cycles varies with **water demand**
- **Fertigation** should **start** 1-2 hours after sunrise and **end** 1-2 hours before sunset; depending on substrate
- **Night watering** may be needed in **winter**, humidity low due to night-time heating (or **in summer** when hot and dry)
- **Irrigation based on drainage** – rockwool, 30–50% **overwatering daily** in sunny weather and 10–20% in cloudy weather
- **Irrigation based on solar radiation** - amount of **transpiration** depends on radiation, **vapor pressure deficit (VPD)** and other conditions in the greenhouse, such as **air movement** and the location of the **heating pipes**
- **Irrigation models** developed – plant and environmental conditions, with moisture sensors and weighing of slabs

## Irrigation: Transpiration, Radiation, and Water Use



## Controlling Growth, Balance Between Vegetative and Generative Growth

- **Well-balanced plant** has a **thick stem, dark green leaves and large, closely spaced flower clusters** that set well  
... Specifically, the **stem** should be **1 cm (0.4 inches) thick 15 cm (6 inches) below the growing tip**
- **Thicker stems** indicate **excessive vegetative growth** and are usually associated with **poor fruit set and low productivity**
- **Thinner stems** usually indicate **carbohydrate starvation, slow growth** and, ultimately, **low overall productivity**
- Number of ways to **control plant balance**  
... Environmental controls, EC, Water supply, K:N ratio in the feed

## Controlling Growth, Irrigation and Fertilization Practices

**Table 6.10.** Summary of irrigation and fertilization practices that can be used to steer plants between vegetative and generative growth.

| Practice/environmental condition           | Effect on plant growth                       |                                     |
|--------------------------------------------|----------------------------------------------|-------------------------------------|
|                                            | Vegetative                                   | Generative                          |
| Humidity level                             | High (low VPD)                               | Low (high VPD)                      |
| Solution and slab EC                       | Lower                                        | Higher                              |
| Length of each irrigation event            | Shorter                                      | Longer                              |
| Frequency of irrigation events             | More frequent                                | Less frequent                       |
| Timing of irrigation start in the morning  | Early                                        | Later                               |
| Timing of last irrigation in the afternoon | Continue until later in afternoon or evening | Stop sooner in afternoon or evening |

Source: CAB International 2005. Tomatoes (ed. E. Heuvelink)

## Environmental Control

**Table 6.2.** Vapour pressure deficit in millibars (mbar) in relation to temperature and humidity (adapted from OMAFRA, 2001).

| Temperature<br>(°C) <sup>a</sup> | Relative humidity |      |      |      |      |      |     |     |     |     |
|----------------------------------|-------------------|------|------|------|------|------|-----|-----|-----|-----|
|                                  | 50%               | 55%  | 60%  | 65%  | 70%  | 75%  | 80% | 85% | 90% | 95% |
| 15                               | 8.5               | 7.7  | 6.8  | 6.0  | 5.1  | 4.3  | 3.4 | 2.6 | 1.7 | 0.8 |
| 16                               | 9.1               | 8.2  | 7.3  | 6.4  | 5.5  | 4.6  | 3.6 | 2.7 | 1.8 | 0.9 |
| 17                               | 9.7               | 8.7  | 7.8  | 6.8  | 5.8  | 4.9  | 3.9 | 2.9 | 1.9 | 1.0 |
| 18                               | 10.3              | 9.3  | 8.3  | 7.2  | 6.2  | 5.2  | 4.1 | 3.1 | 2.1 | 1.0 |
| 19                               | 11.0              | 9.9  | 8.8  | 7.7  | 6.6  | 5.5  | 4.4 | 3.3 | 2.2 | 1.1 |
| 20                               | 11.7              | 10.5 | 9.4  | 8.2  | 7.0  | 5.9  | 4.7 | 3.5 | 2.3 | 1.2 |
| 21                               | 12.4              | 11.1 | 9.9  | 8.7  | 7.5  | 6.2  | 5.0 | 3.7 | 2.5 | 1.2 |
| 22                               | 13.2              | 11.9 | 10.6 | 9.3  | 7.9  | 6.6  | 5.3 | 4.0 | 2.6 | 1.3 |
| 23                               | 14.1              | 12.6 | 11.2 | 9.8  | 8.4  | 7.0  | 5.6 | 4.2 | 2.8 | 1.4 |
| 24                               | 14.9              | 13.4 | 11.9 | 10.4 | 9.0  | 7.5  | 6.0 | 4.5 | 3.0 | 1.5 |
| 25                               | 15.8              | 14.3 | 12.7 | 11.1 | 9.5  | 7.9  | 6.3 | 4.8 | 3.2 | 1.6 |
| 26                               | 16.8              | 15.1 | 13.4 | 11.8 | 10.1 | 8.4  | 6.7 | 5.0 | 3.4 | 1.7 |
| 27                               | 17.8              | 16.0 | 14.2 | 12.5 | 10.7 | 8.9  | 7.1 | 5.4 | 3.6 | 1.8 |
| 28                               | 18.9              | 17.0 | 15.1 | 13.2 | 11.3 | 9.5  | 7.6 | 5.7 | 3.8 | 1.9 |
| 29                               | 20.0              | 18.0 | 16.0 | 14.0 | 12.0 | 10.0 | 8.0 | 6.0 | 4.0 | 2.0 |
| 30                               | 21.2              | 19.1 | 17.0 | 14.8 | 12.7 | 10.6 | 8.5 | 6.4 | 4.2 | 2.1 |

<sup>a</sup> Refers to plant tissue temperatures, not air temperatures.

Note: **Bold area** indicates optimal range for most greenhouse crops of 4–7 mbar.

1 mbar = 0.1 kPa

0.1 kPa = 0.7 g/m<sup>3</sup> = 3% RH

- Transpiration rate increases as the difference between fully saturated atmosphere inside leaf (100% RH) and water vapor content outside leaf increases
- Difference is Vapor Pressure Deficit (VPD)
- **Nutrient uptake and photosynthesis are optimal at 4–8 mbar**
- Transpiration is reduced when VPD is too low
- High VPD, transpiration may be excessive, stressing the plant

**Table 9.3.** Growing recommendations for tomato cropping (adapted from OMAFRA, 2001).

|                        | Germination | Plant raising | Transplanting | Harvesting | Full harvest |
|------------------------|-------------|---------------|---------------|------------|--------------|
| Temperature (°C)       |             |               |               |            |              |
| Day                    | 25          | 19–21         | 24            | 19         | 20–22        |
| Night                  | 25          | 19–21         | 24            | 19         | 17–19        |
| EC (dS/m)              | 0.0–0.1     | 2.5–3.0       | 2.5–3.0       | 2.7–3.5    | 2.7–4.0      |
| pH                     | 5.8         | 5.8           | 5.8           | 5.8        | 5.8          |
| Volume of feed (l/day) | –           | 0.2–0.3       | 0.2–0.3       | 0.5–1.5    | 0.5–2.5      |

Source: CAB International 2005. Tomatoes (ed. E. Heuvelink)

Purdue University is an equal access/equal opportunity institution.

33

## Harvest, Ripening Stages

-  **GREEN** The tomato surface is completely green. The shade of green may vary from light to dark.
-  **BREAKERS** There is a definite break of color from green to tannish-yellow, pink or red of 10% or less of the tomato surface.
-  **TURNING** Tannish-yellow, pink or red color shows on over 10% but not more than 30% of the tomato surface.
-  **PINK** Pink or red color shows on over 30% but not more than 90% of the tomato surface.
-  **LIGHT RED** Pinkish-red or red color shows on over 60% but red color covers not more than 90% of the tomato surface.
-  **RED** Red means that more than 90% of the tomato surface, in aggregate, is red.

Cantwell, M. 2010. Optimum Procedures for Ripening Tomatoes. In: Fruit Ripening and Ethylene Management, J.T. Thompson and C. Crisosto (eds.), UC Postharvest Horticulture Series 9:106-116. <http://postharvest.ucdavis.edu/files/93536.pdf>

## Potential Production

- **7-8 month cropping period**

- 8 to 18 kg per plant
  - or 18 to 40 lb per plant

- Translates to:

- 20 to 45 kg/m<sup>2</sup>
- or 4 to 9 lb/ft<sup>2</sup>

- **11 month cropping period**

- 28 to 36 kg per plant
  - or 62 to 79 lb per plant

- Translates to:

- 70 to 90 kg/m<sup>2</sup>
- or 14 to 18 lb/ft<sup>2</sup>

## The Netherlands: Record Tomato Yield

Headline: Dutch start third trial on tomatoes with 100% LED-lighting: **100,6 Kg/m<sup>2</sup> at the Improvement Center in Bleiswijk (2014-15 season). What's next?**



Lighting strategy was made up of 105 µmol GreenPower LED top lighting and 2 x 53 µmol GreenPower LED inter-lighting

| Yield 2014/15 Season |       |                        |         |                            |       |
|----------------------|-------|------------------------|---------|----------------------------|-------|
| kg·m <sup>-2</sup>   | 100.6 | ton·ha <sup>-1</sup>   | 1,006   | ton·ha <sup>-1</sup>       | 1,006 |
| lb·ft <sup>-2</sup>  | 20.6  | lbs·acre <sup>-1</sup> | 897,352 | US tons·acre <sup>-1</sup> | 448.8 |



## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

### Information Resources

#### University resources – Extension publications

##### Professional magazines

Greenhouse Management, [www.greenhousemag.com](http://www.greenhousemag.com)

Greenhouse Grower, [www.greenhousegrower.com](http://www.greenhousegrower.com)

Practical Hydroponics and Greenhouses,  
[www.hydroponics.com.au](http://www.hydroponics.com.au)

Greenhouse Canada, [www.greenhousecanada.com](http://www.greenhousecanada.com)

##### Books

Greenhouse Technology and Management, Nicolas Castilla

Greenhouse Operation and Management, Paul V. Nelson

Soilless Culture, Michael Raviv & J. Heinrich Leith

Growing Media for Ornamental Plants and Turf, Kevin Handreck & Niel Black

Plant Nutrition of Greenhouse Crops, Cees Sonneveld & Wim Voogt

Hydroponic Food Production, Howard M. Resh

Tomatoes, Eb Heuvelink

#### Trade shows and conferences

- Indiana Small Farm Conference, March 1-3, 2018 – Danville IN
- Indoor Ag Con, May 2-3, 2018 – Las Vegas NV
- Cultivate'18, July 14-17, 2018 – Columbus OH
- Great Lakes Fruit, Vegetable and Farm Market Expo & Michigan Greenhouse Growers Expo – Dec 4-6, 2018

#### Manufacturers and distributors (list is not complete but it's a good start):

- <http://www.tunnelberries.org/single-bay-high-tunnel-manufacturers.html>
- <http://www.tunnelberries.org/multi-bay-high-tunnel-manufacturers.html>

#### USDA NRCS Indiana EQIP Grant

- <https://www.nrcs.usda.gov/wps/portal/nrcs/main/in/programs/financial/eqip/>
- [https://www.nrcs.usda.gov/wps/portal/nrcs/detail/in/technical/ecoscience/bio/?cid=nrcs144p2\\_068639](https://www.nrcs.usda.gov/wps/portal/nrcs/detail/in/technical/ecoscience/bio/?cid=nrcs144p2_068639)



Purdue University is an equal access/equal opportunity institution.

37

## PURDUE EXTENSION | HORTICULTURE & LANDSCAPE ARCHITECTURE

# THANK YOU

# Questions?

Contact details:

Dr. Petrus Langenhoven

Horticulture and Hydroponics Crop Specialist

Department of Horticulture and Landscape Architecture

Purdue University

Tel. no. 765-496-7955

Email: [plangenh@purdue.edu](mailto:plangenh@purdue.edu)



Purdue University is an equal access/equal opportunity institution.

38