# Precision growing:
# Faster, Bigger, Better!

*Bringing new concepts to plant growing*

SUNSHINE BOOSTERS

TopTropicals.com
We Grow Happiness

clarify.one
hi tech :) job done right

# Bios

SUNSHINE BOOSTERS

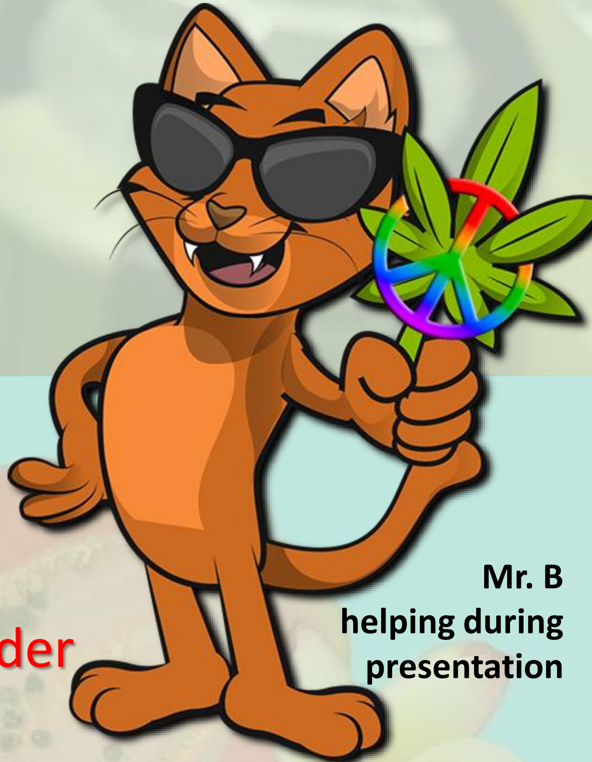
TopTropicals.com We Grow Happiness

clarify.one hi tech :) job done right

**Jack Waterman – jackw@clarify.one – Electronics Expert**

- Clarify LLC (AZ) — Founder and Director of Electrical Engineering
    - Instrumentation systems and biological sensing
    - Created cloud based smart plant irrigation system
- Compound Photonics
    - Electronics for augmented and virtual reality applications
- OIS Optical Imaging Systems
    - Display systems in Apache helicopter and F18E/F fighter
- Raytheon
    - Air and space systems for DOD/NASA including F18E/F and Patriot missile
- Stanford University graduated

*Fun fact… Jack used to design electronics for American spy satellites*



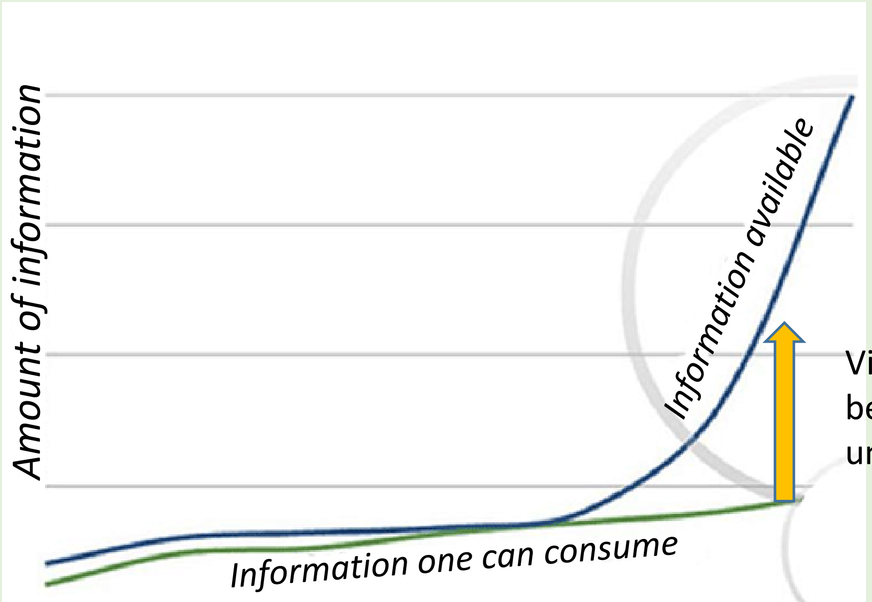
**Mr. B helping during presentation**

**Michael Dubinovsky – michael@toptropicals.com – Lighting and Plant Growing Expert**

- Clarify LLC (AZ) — Founder and CTO
    - Optical / Lighting design and Computer-Generated Holography (hardware and software)
- Top Tropicals (FL) — World's leading tropical plant grower and store — Founder
    - Founded in 2003. Growing and shipping yearly over 30,000 plants worldwide, including exotic and rare flowering and fruiting tropical plants
- Compound Photonics
    - Optical design and research for augmented and virtual reality applications
- High End Systems / Fusion Lighting / Hubbell Entertainment Lighting / BK Lighting
    - Lighting engineering design

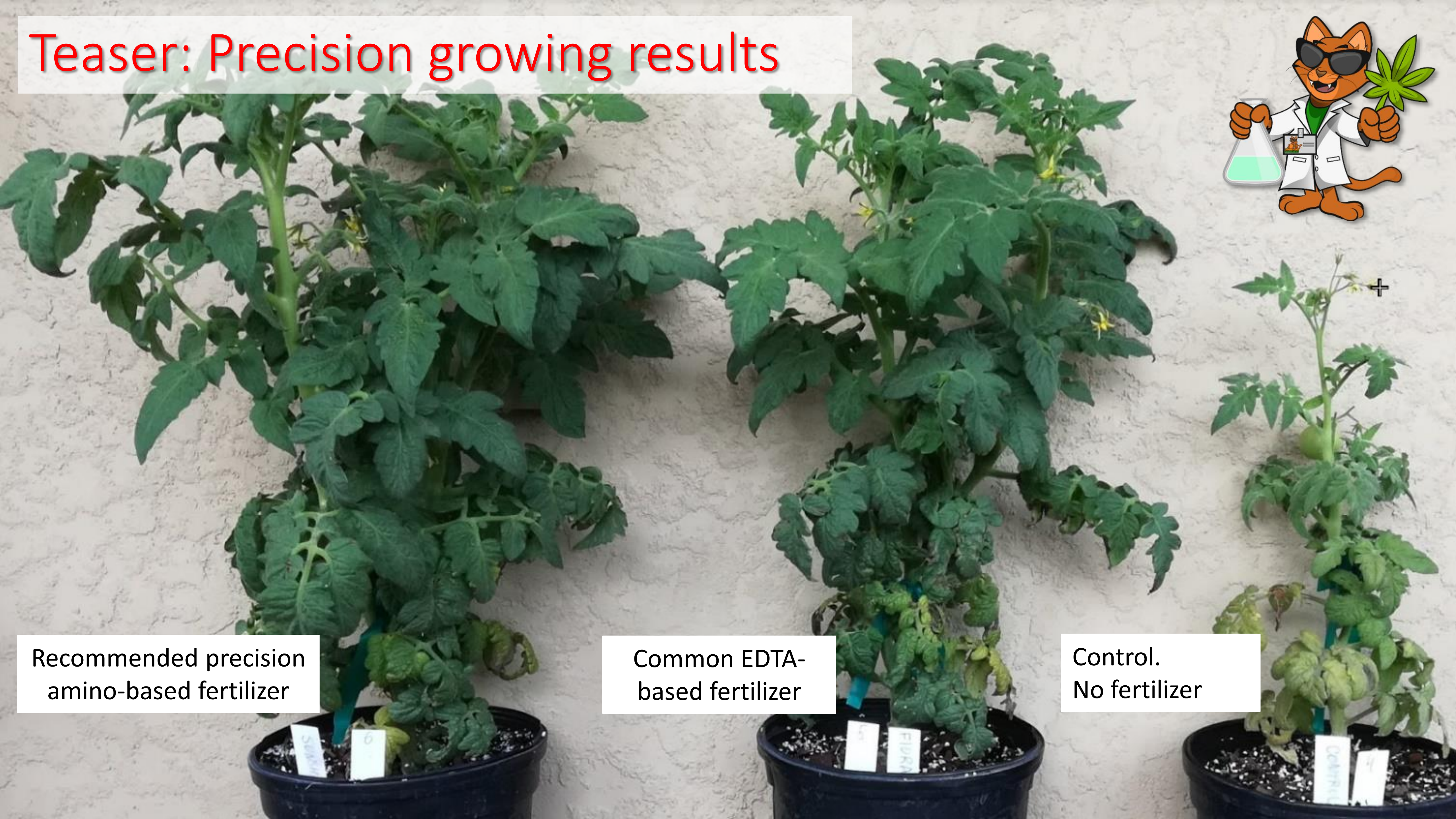
*Fun fact… Michael used to design optics for Soviet spy satellites*

- What is this presentation about?
  - It explains some **important** details of plant growing from **scientific** point of view
  - It explains some critical moments
  - **Understanding** and following those rules helps you to grow plants **faster, bigger, and with higher yield**
- What is this presentation NOT about?
  - It does not discuss various cannabis strains and plant biology. We assume you know cannabis cultivation basics
  - This is not a silver bullet, however, if you follow methods you greatly improve your chances to get a great reward
- We are engineers. Is this presentation overloaded with scientific mumbo jumbo?
  - While some slides can be overwhelming they are not really difficult
  - Some deep insights are very critical for your success
  - This presentation will be available on our website SunshineBoosters.com. You can always check it again
  - We'd be glad to answer your questions.
- Who is this cat?
  - This is Mr B. He is going to help us

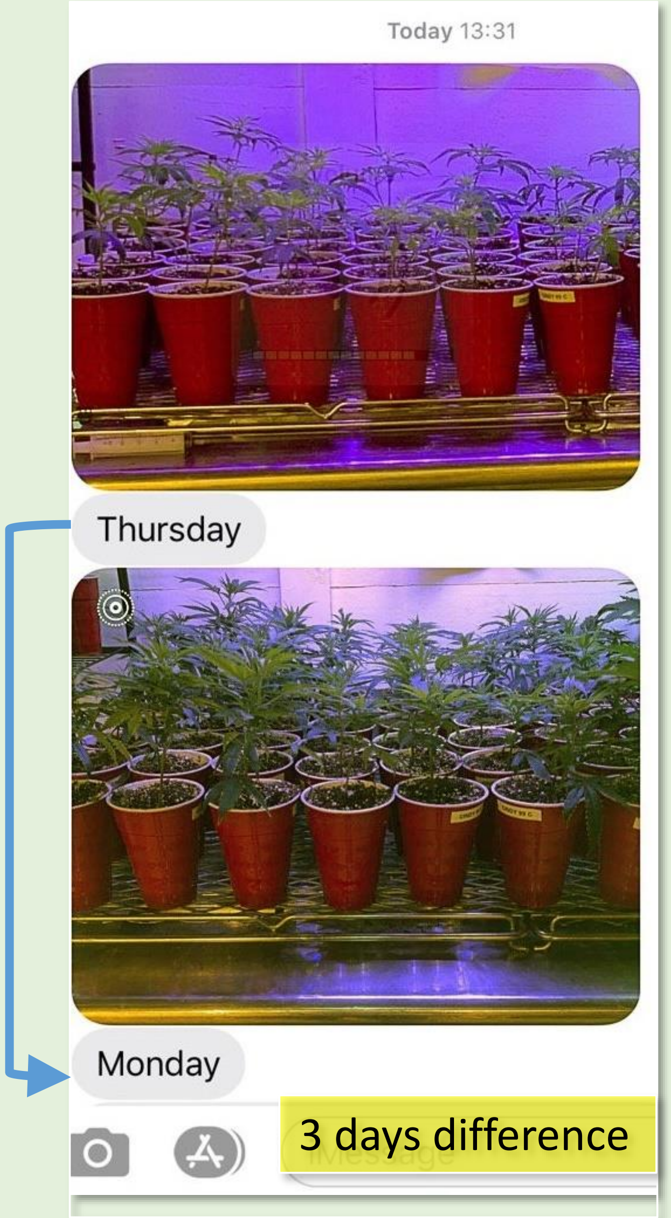



Visit us again for better understanding

# Teaser: Precision growing results



# Precision growing results


Cannabis farm in OK

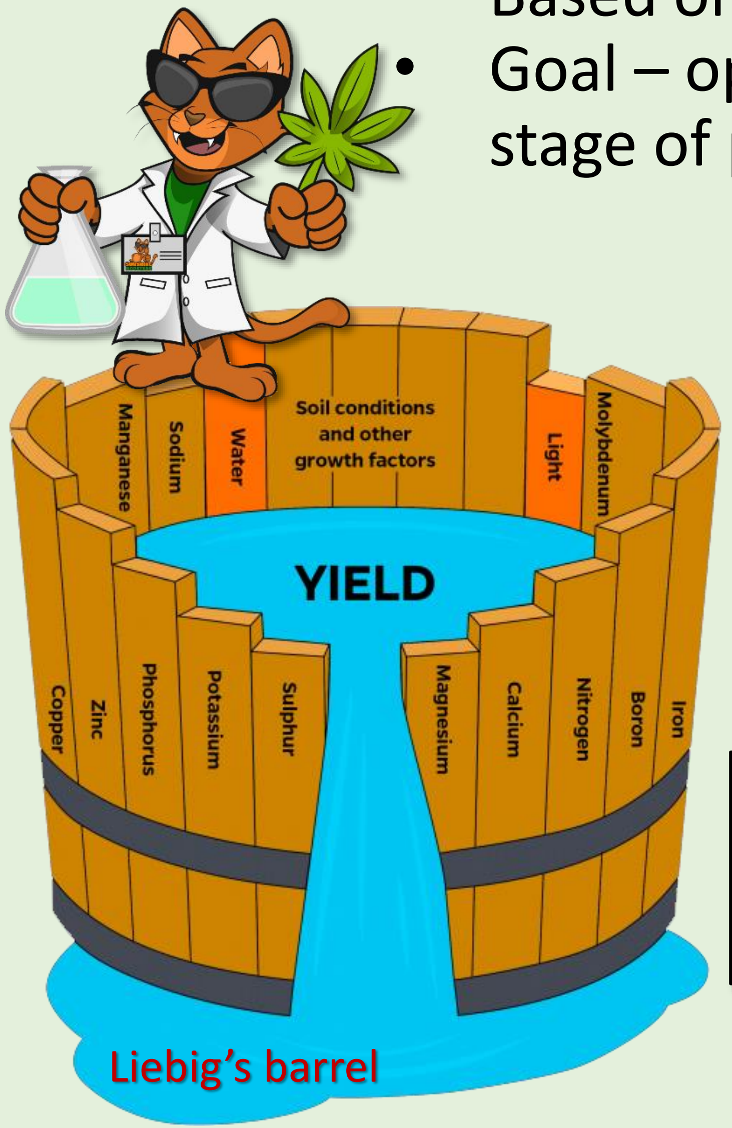
# Why a precision approach?

- Controlled environment
- Growing consistency and predictability
- Eliminating "green thumb" human factor
- Faster growing and development
- Maximizing plant potential

Higher yield, better quality crop

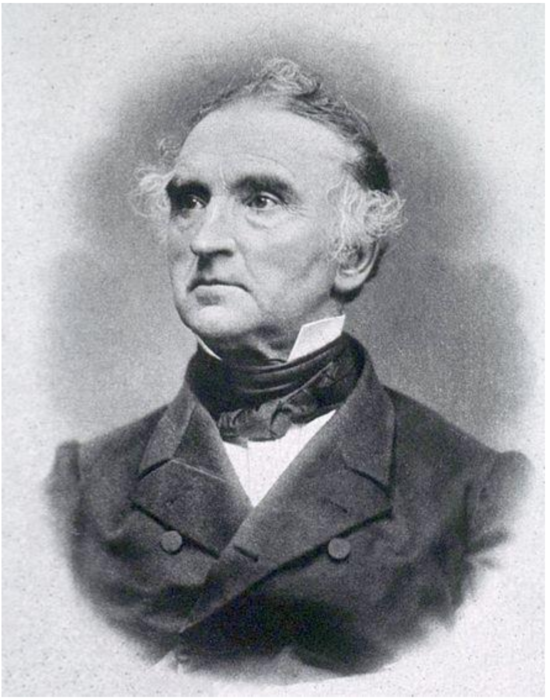
MORE PROFIT

# Precision approach to plant growing




Liebig's barrel

- Based on the "Law of the Minimum"
- Goal – optimize all essential components for each stage of plant growth:
  - Six essential elements: light, nutrients, temperature, humidity, air, water
  - Scientifically designed substrate and nutrients
  - Hi-tech engineering controls:
    - Light, $CO_2$, temp, pH, humidity, water and nutrient levels
    - Sensing, sequencing, charting, logging, and alarms



Justus Freiherr von Liebig (1803-1873). German scientist who made major contributions to agricultural and biological chemistry, and was considered the founder of modern organic chemistry.

"Liebig Law of the Minimum" states that if one of the essential plant elements is deficient, plant growth will be poor even when all other essential elements are abundant.

# Covered in this presentation

- Optimal substrate
- Precision nutrients
- Precision $CO_2$ supplementation
- VPD / Temperature / Humidity
- Environmental control

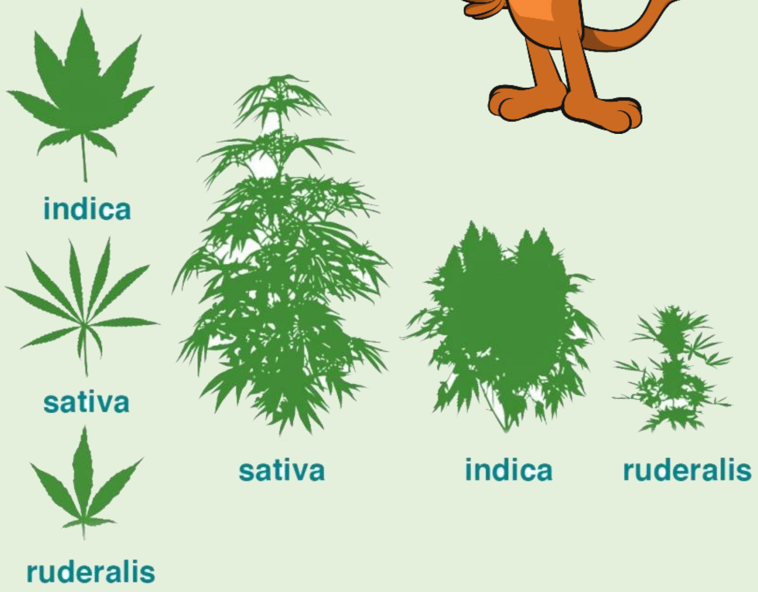
## Not covered:

- Lighting – this is very important topic. It requires separate, in-depth presentation. Will do it next time

Local growing facility. Long and leggy plants. Can use extra light.
Using proper combination of light / $CO_2$ can **double growth rate**

# Cannabis strains

- There are thousands upon thousands of different cannabis strains and hybrids, all with varying growing traits, tastes, aromas, yields and effects
- They belong to one of three groups of cannabis – sativa, indica or ruderalis




- *C. sativa* – taller and slimmer. Longer and thinner leaves. High THC content
- *C. indica* – shorter and bushier. Shorter and wider leaves. Grown mostly for CBD
- *C. ruderalis* – very low THC. Mostly used for hybridization
- Hemp – low THC content.

# Cannabis growing

- Cannabis is an annual, dioecious (male and female plants), flowering herb
  - Male — very low THC
  - Unpollinated female plant — high THC (*Sin-sinella* in Spanish)
  - Preferred method of propagation — vegetative (cuttings or tissue culture)
- The trichomes are tiny glandular outgrowths of resin, covering all or part of the plant, having the appearance of sugar-frosting
- The trichomes are the only part of the plant that contain significant levels of THC, along with other cannabinoids, terpenes, and flavonoids
- Buds and small leaves produce the most trichomes
- The quantity of THC/CBD can be increased significantly (15-20%) with science-based growing techniques

# Growing requirements for highest yields

| | |
|---|---|
| Lighting | Bright lighting is required during growth stage. Plant begins to flower when day length reaches a ratio of 12 hours light to 12 hours dark, as in the autumn. Controlling the light cycle, duration, and spectrum is a **tremendous advantage** of indoor / greenhouse growing. |
| $CO_2$ | Increasing $CO_2$ from 400 ppm (ambient level) to 1200 ppm can **double the growth rate**. Higher levels of lighting and nutrients are then required to support these higher growth rates. |
| Temperature | 75 to 86°F (24 to 30°C) |
| pH | 5.4 – 6.0<br>Typical substrate are soil (6.0 – 7.0), hydroponics (5.5 – 6.5), coconut coir (5.5 – 6.5). |
| Water | RO water preferred. Tap water: should be dechlorinated (by aerating) and may require pH adjustment. |
| Nutrients | Cannabis grows extremely fast and has higher water and nutritive needs than most plants grown indoors. **Providing optimal nutrients is essential** |
| Substrate | Good drainage required. Poor drainage leads to anaerobic conditions, low pH, and nutrients become unavailable. Coconut coir is best. Mycorrhizae inoculation is highly beneficial. Container growth: 2 – 5 gallon of growing substrate. Better to start from small container. |

# Cannabis life cycle

The life cycle of cannabis is usually complete in four to nine months. Actual time depends on plant variety, and is regulated by local growing conditions, specifically the photoperiod (length of day vs night).

- Indica grows faster, usually blooming in 8-9 weeks
- Sativa blooms in 12-16 weeks

| Life cycle stage | Days |
|---|---|
| Germination | 3 to 10 |
| Seedling | 30 to 45 |
| Vegetative growth | 90 to 150 |
| Pre-flowering (Transition) | 7 to 14 |
| Flowering | 30 to 60 |
| Seeding | 10 to 30 |

# Photoperiod manipulation

- Photoperiod is used to manipulate the plants in two basic ways:
  1. Long dark periods force plants to flower.
  2. Preventing long nights (by using artificial light to interrupt the dark period) forces plants to continue vegetative growth.
- Potency by plant age
  - In general, the longer the life cycle of the plant, the higher the concentration of cannabinoids.
  - Plant development, rather than age, determines this difference in potency. A plant that is more developed or more mature is generally more potent. **<u>Using scientific approach you can greatly increase yield</u>**
  - If you control the photoperiod, you also control when plants bloom

Goal: Grow largest, most developed plant by blooming time → higher yield

# Agriculture 101: Compare growing methods

| | Soil  | Classical hydroponics  | Substrate controlled method  |
|---|---|---|---|
| Substrate | Rich organic soil (outdoors) | Inert: rockwool, pebbles, suspended in water | Soil-less mix. Coconut coir-based or similar |
| Root microbiome (rhizosphere) | Very diverse. Both beneficial and pathogenic | Usually harmful to plants. Mold needs to be controlled by regular biocide additions | Diverse. Beneficial microorganisms (Mycorrhizae) added to sterile substrate. |
| Nutrient addition | Poorly controlled. Soil analysis required | Controlled. Constant correction required | Very tightly controlled |
| Method of nutrient addition | Dry fertilizers, irrigation, foliar spray | Recirculating, wick, drip, drain-to-waste | Drip, Drain-to-waste |
| Environment (temperature, humidity) | Uncontrolled or difficult to control | Controlled | |
| Productivity | Low to moderate | High | |
| Problems and diseases | Difficult to control – pests, theft, etc. | Controlled by enclosed environment | |
| Lighting and photoperiod | Uncontrolled, natural sunlight | Controlled. Artificial light or natural sunlight (“light deprivation greenhouse”, “sunroom”) | |
| Maintenance cost | Low | Moderate to high | |
| Difficulty | May be difficult. Green thumb is required | Easy in precise controlled environment. Maybe difficult with manual control | |

# Agrochemistry 101: Micronutrient Chelating

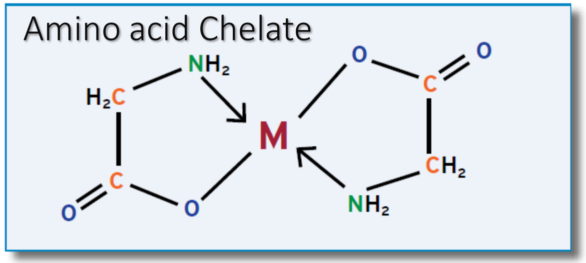
**Chelating:** bonding micronutrients (Fe, Mn, Zn, etc.) to an organic molecule (chelator) to keep them in a soluble form. Without chelator, micronutrients quickly precipitate from solution, becoming unavailable for plants

**Commonly used chelator:** EDTA, Fe-DTPA (Fe-EDTA is unstable)

Iron (Fe) is very abundant element in the Earth crust (5.6%). However, it's oxidized and not available for plants. Leaf chlorosis (above) is caused by iron deficit.

**Alternative chelator:**

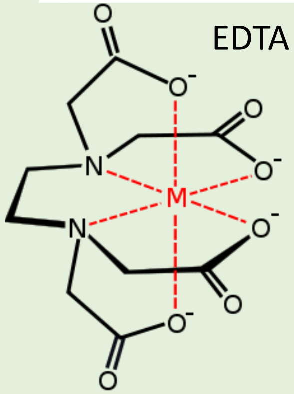
- Various organic and amino acids
- Humic acids (not practical) – chelates are not soluble in water
- Citric acid (not practical) – not stable, Fe(II) oxides quickly into Fe(III)



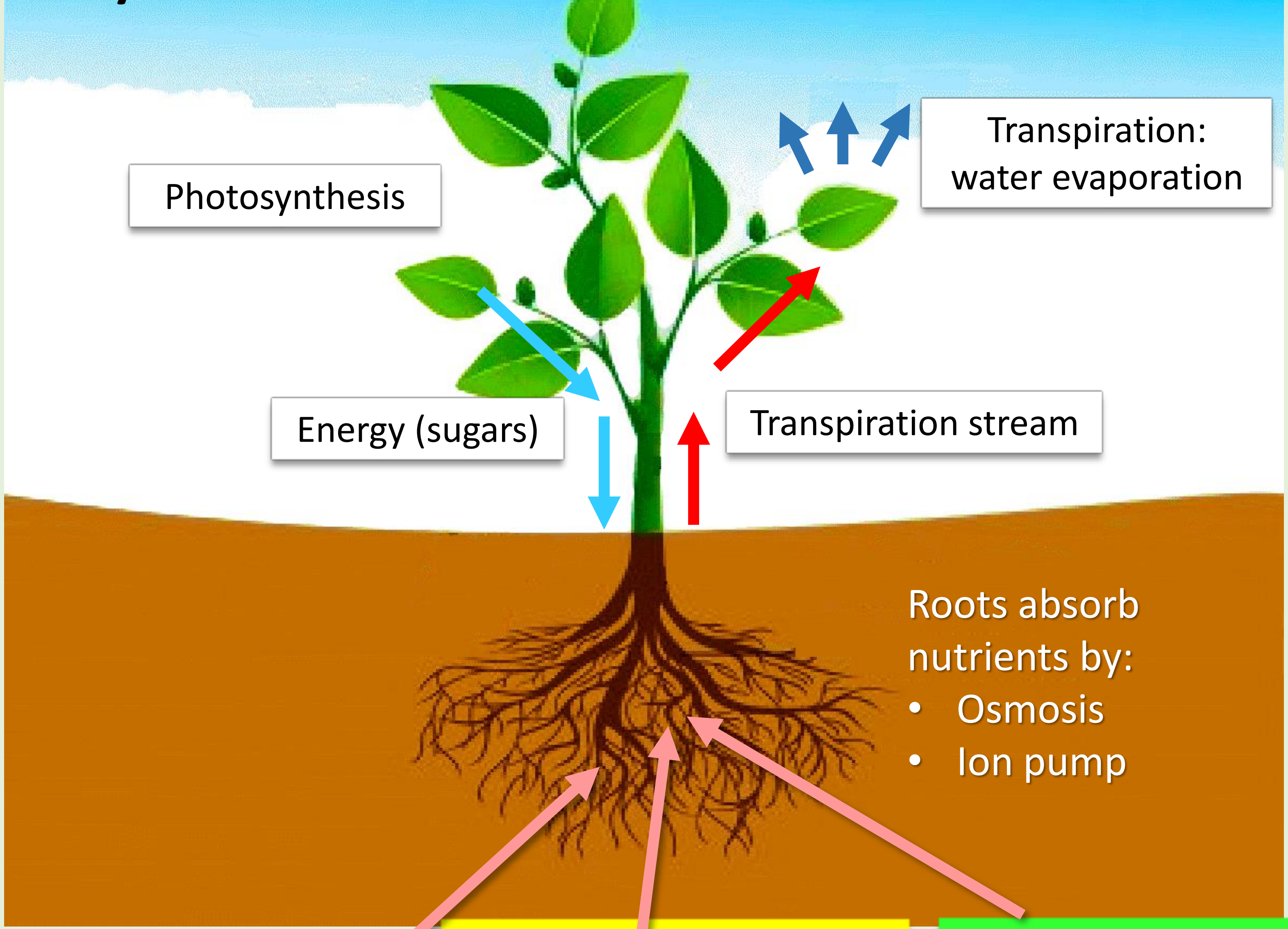

## <u>EDTA vs Amino acids</u>

- EDTA is not a naturally occurring compound. Plants do not have "mechanism" to process it
- EDTA accumulates inside plant tissue and soil, while continuing to lock-up important nutrients
- Environmental concerns: EDTA becomes persistent organic pollutant that is resistant to environmental degradation
- Amino acids are very efficient chelating compounds, which allows micronutrients to stabilize in solution
- <u>**Amino acids are used by plant for faster growth and development**</u>

EDTA Chelate



# Agrochemistry 101: EDTA vs Amino-acid




Osmosis : water

Ion pump mechanism: Ca, Mg, and trace elements

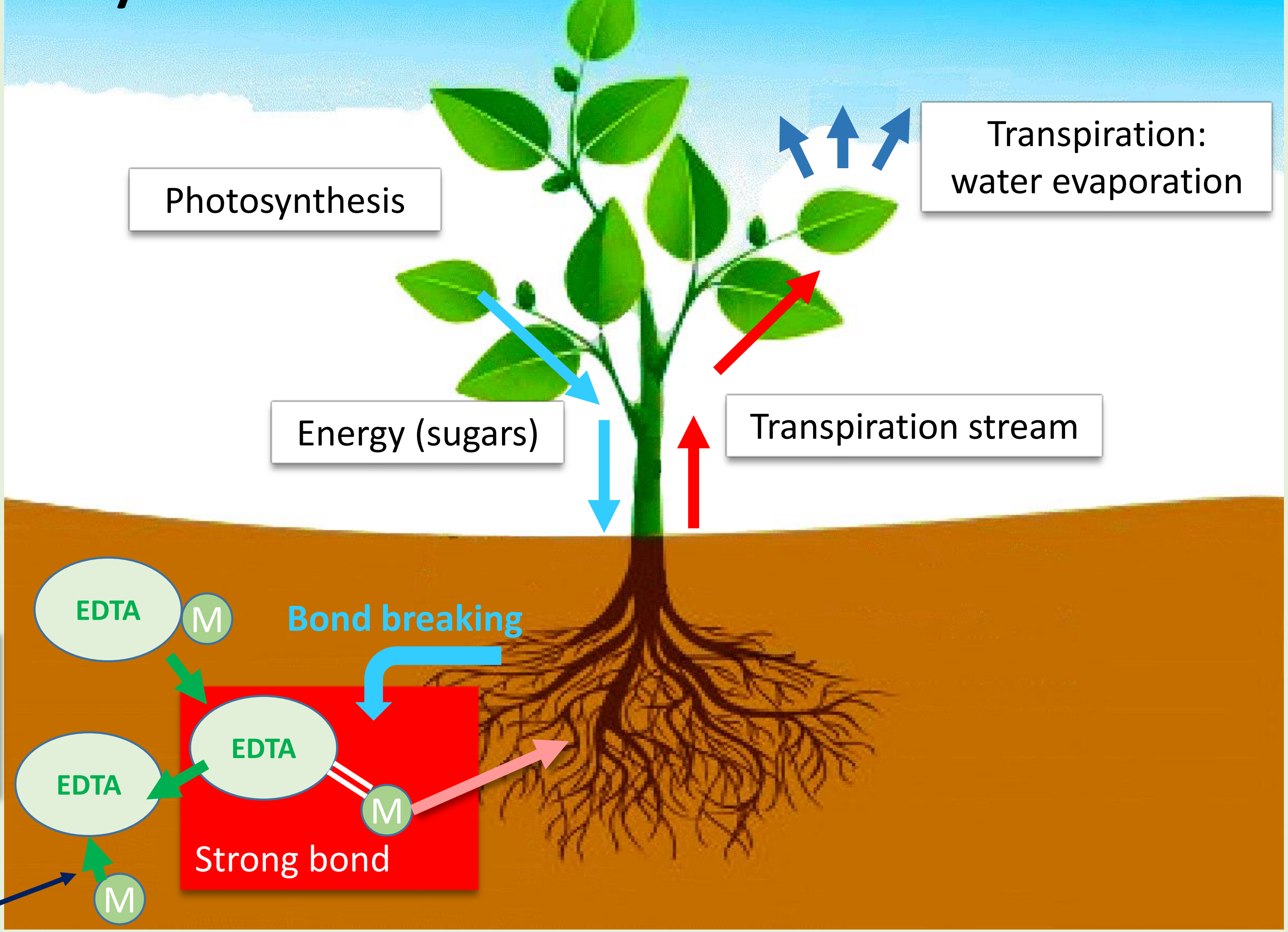
Osmosis: Low molecular weight ions - Na, K.

High energy required

Moderate energy required

Low energy required

# Agrochemistry 101: EDTA vs Amino-acid




Molecular weight:
- EDTA: 292 – really large

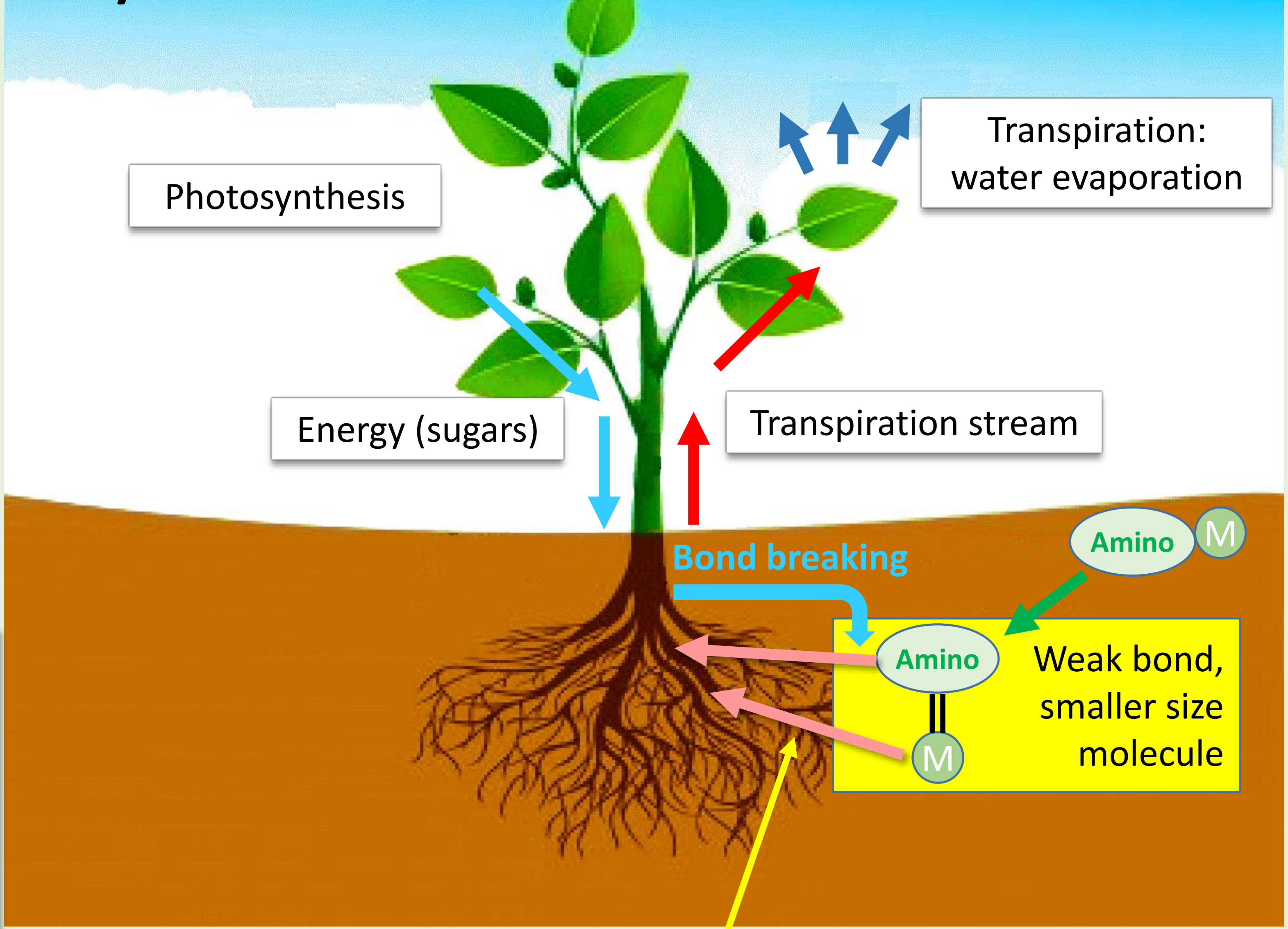
High energy required

Moderate energy required

Low energy required

EDTA "grabs" another ion

# Agrochemistry 101: EDTA vs Amino-acid




Roots absorb both amino-acid and trace element

High energy required

Moderate energy required

Low energy required

Molecular weight:

- EDTA: 292 – really large
- Glycine: 75. 4 times smaller

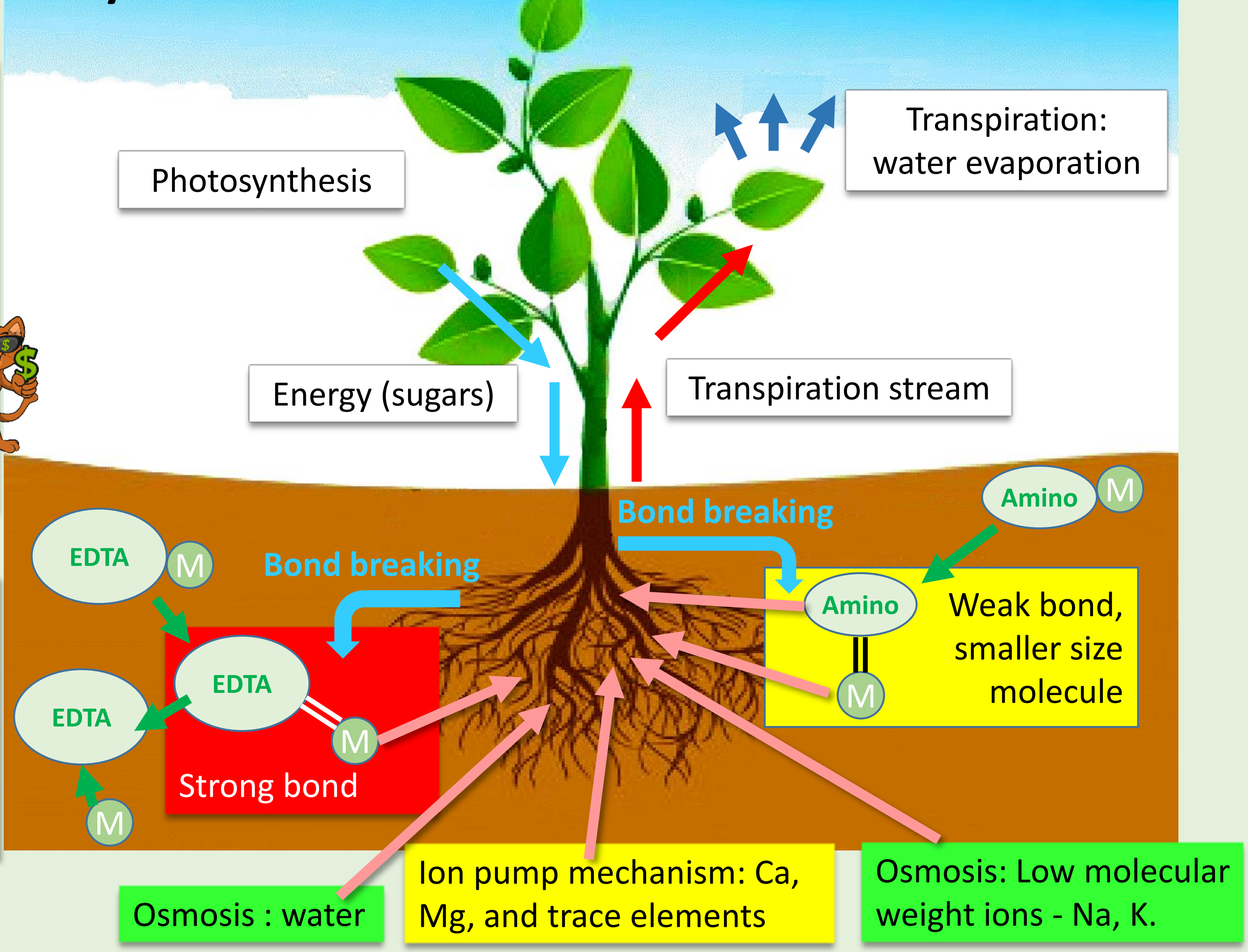
# Agrochemistry 101: EDTA vs Amino-acid

Amino-acids: Lower energy required for nutrient uptake.

**More energy left for plant development. FASTER GROWTH.**

Molecular weight:

- EDTA: 292 – really large
- Glycine: 75. 4 times smaller

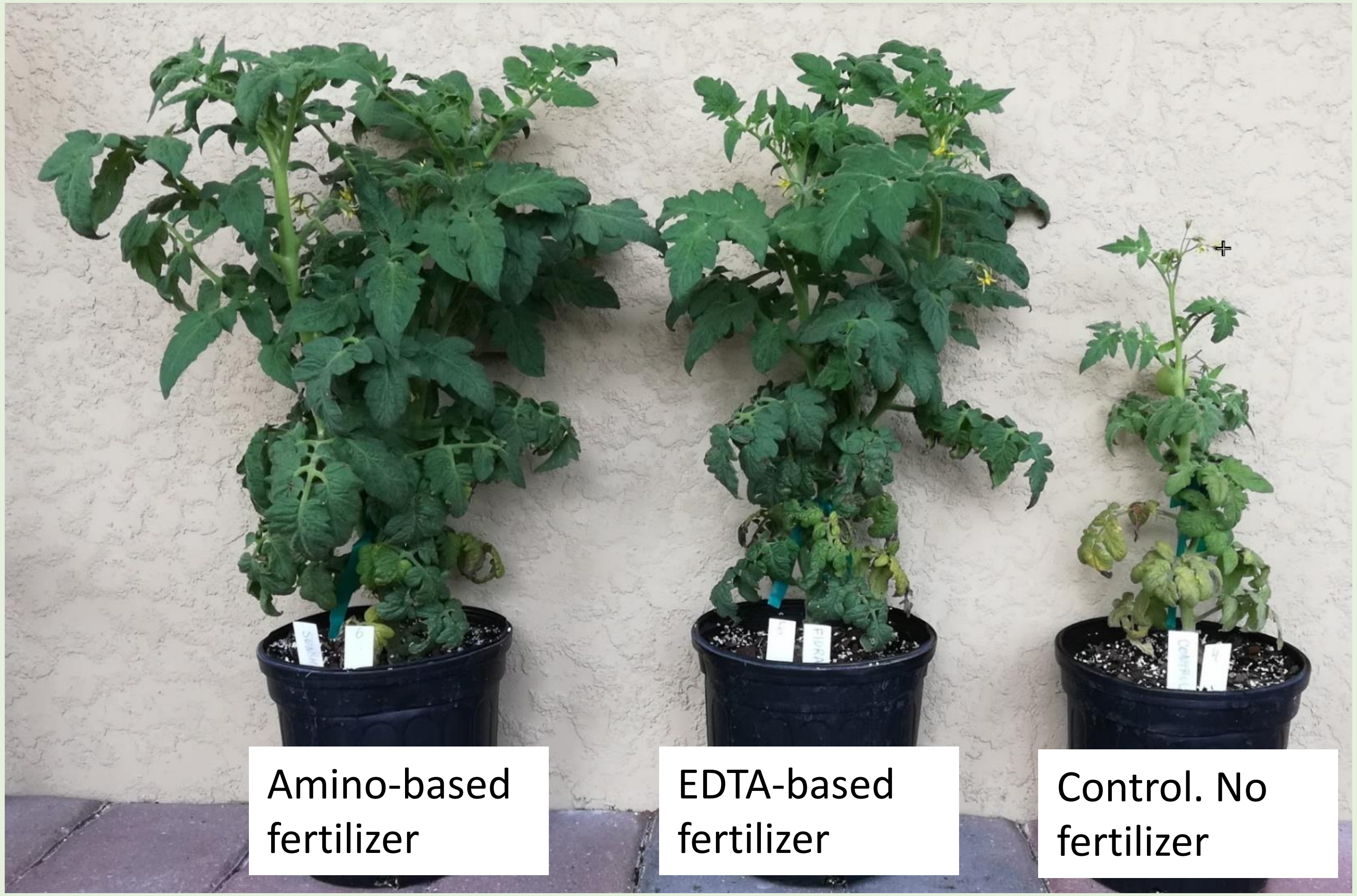



High energy required

Moderate energy required

Low energy required

# Agrochemistry 101: EDTA vs Amino-acid




- 2 month old tomato seedling. Grown outside in Florida. Full sun. Temperature 85F (daytime), 75F (night)
- Soil-less mix, 1 gal pot size
- Water: 1 qt daily per plant
- Fertilizing by corresponding feeding chart

# Agriculture 101: Growing substrate

Growing substrate often called "soil". However, this is not common outdoor soil. This is specially prepared soil-less mix.

Coconut coir, perlite, and pine bark

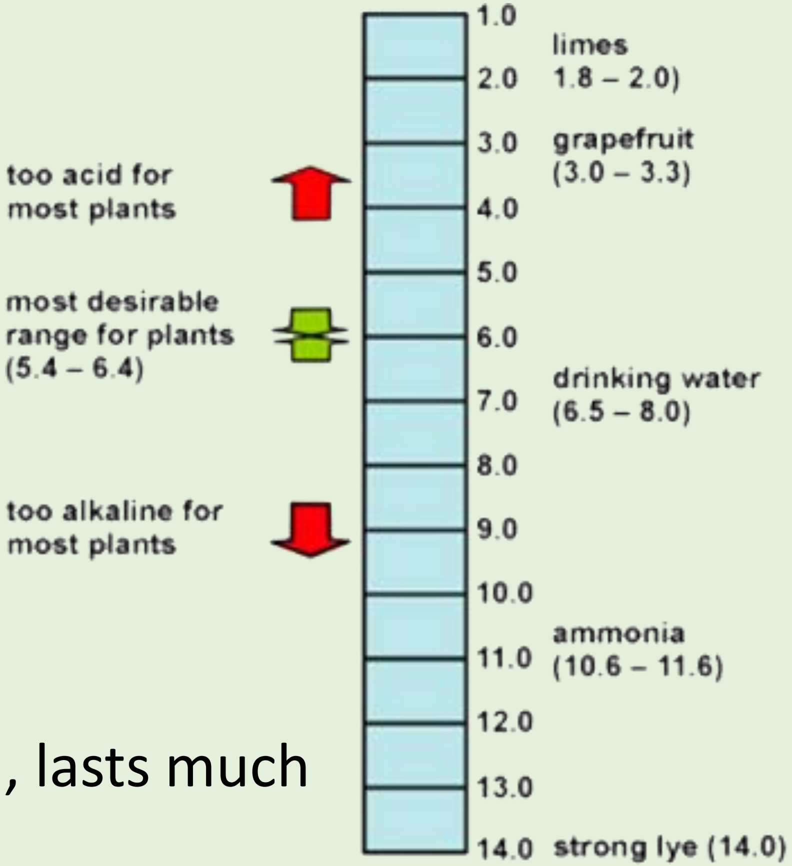
**None** of these should ever be used in controlled environment!

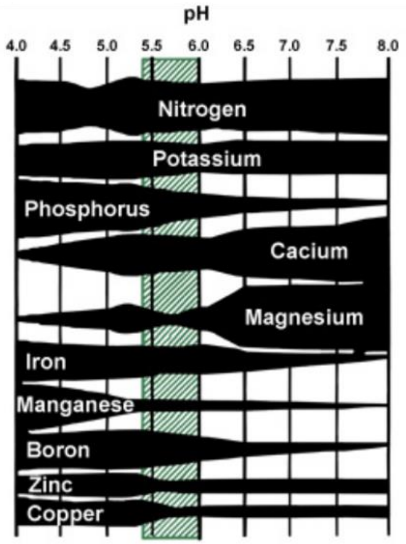
- Sphagnum peat moss - makes substrate too acidic. Dolomite is added with peat-moss
- Ground-up leftovers of plant or animal origin *(Soybean meal, Fish meal, Oyster shell flour, Worm castings, Bat guano, Fish meal, Crab meal, Bone meal, Blood meal, Yucca extract, Crustacean meal, Kelp meal, Feather meal).* They creates more problem in controlled environment:
  - Changes pH
  - Anaerobic decomposing
- Compost, slow release pre-mixed fertilizers - no control over nutrient release
- Leonardite / humic acids
  - Slows plant development
  - Humic acids already present in soli-less mix organic content

# Agriculture 101: Optimal Growing substrate

## Optimal substrate

- Coconut-coir based
  - High CEC (Cation Exchange Capacity)
    - 40 to 60 meq/100g
    - Ability to store nutrients and release as needed
  - Optimal pH
    - Between 5.4 and 6.0
  - Holds water exceptionally well
  - Good drainage, good aeration
  - Resists compacting and breaking down, lasts much longer
  - Contains lignin to maintain thriving beneficial bacteria



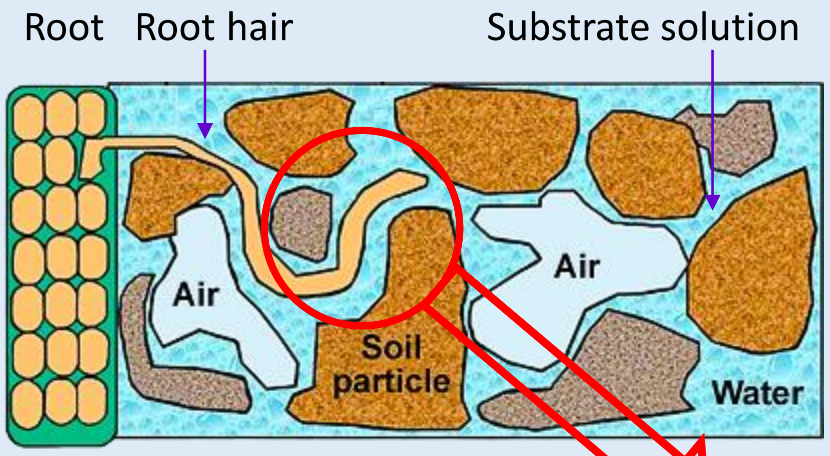




Nutrient availability affected by substrate pH. Black areas indicate relative availability. A pH range of 5.4 to 6.0 suits all nutrients

Stable pH is very important. Changing pH by 1 means changing concentration of hydrogen ions ($H^+$) 10 times. How does it taste: 1 spoon of sugar per cup or 10 spoons?
**Stable pH is more important even if slightly wrong. Never allow large pH swings**

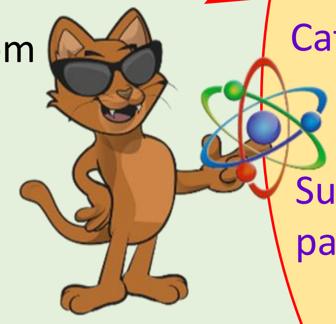
# Agriculture 101: Substrate, CEC, pH

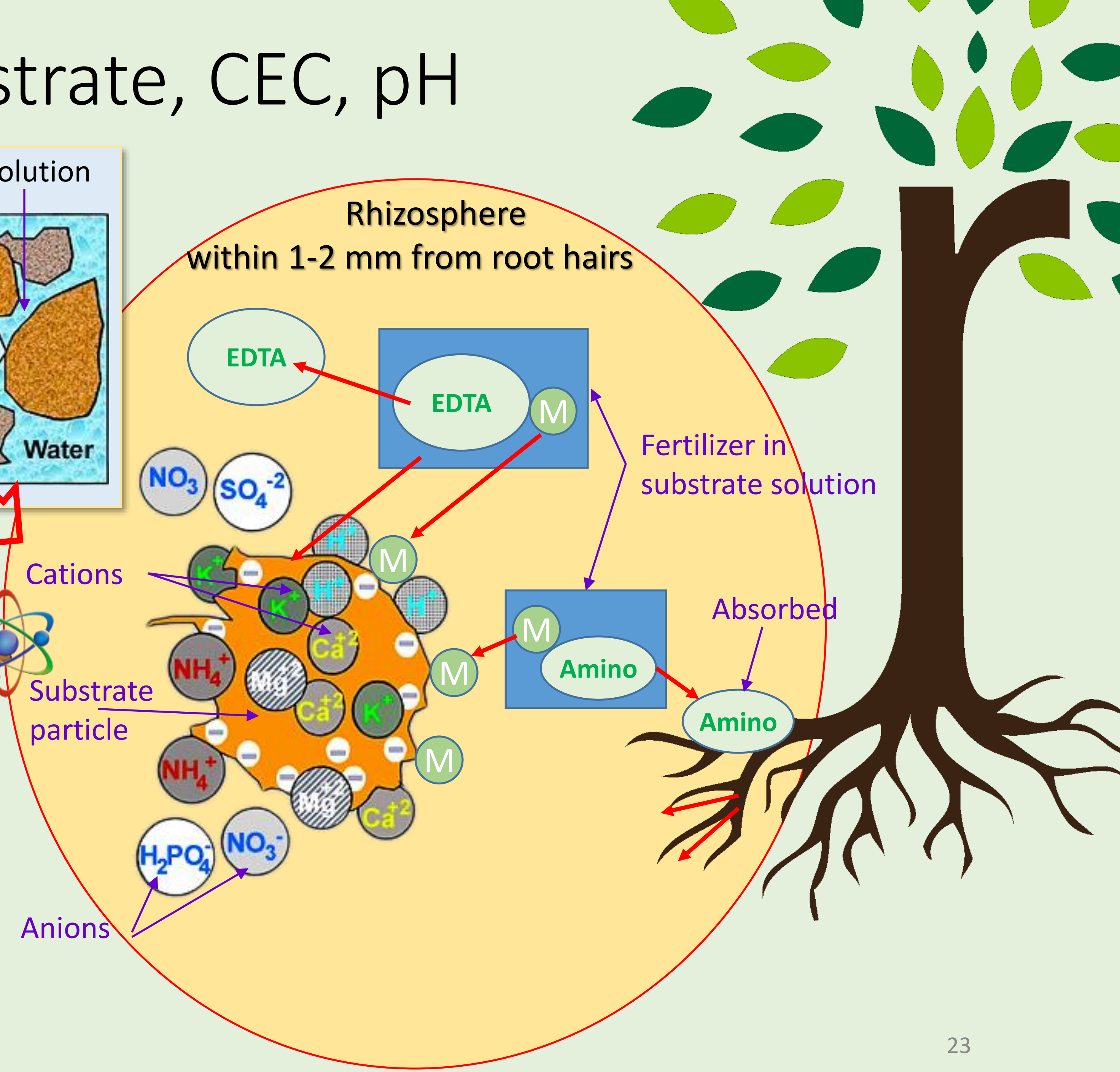
Plant roots are exposed to the substrate solution. The root hairs are the interface between the plant and the substrate solution. The acidity or basicity of the substrate solution (pH) determines how well the roots can take up nutrients.




The substrate should:

- absorb / hold excess of trace elements from solution






**Step 1: Substrate absorbs excess of trace elements**

# Agriculture 101: Substrate, CEC, pH

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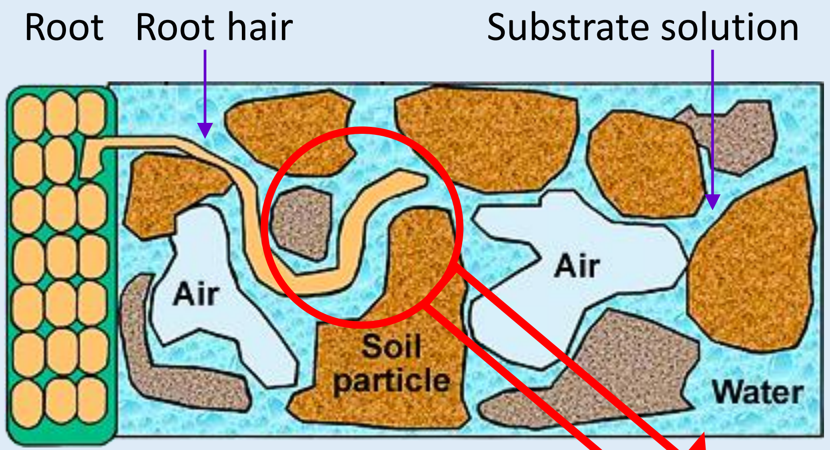
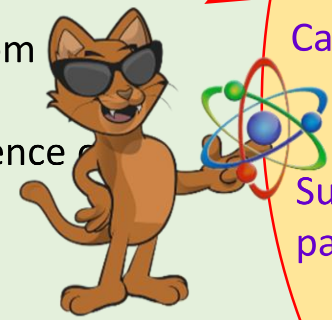
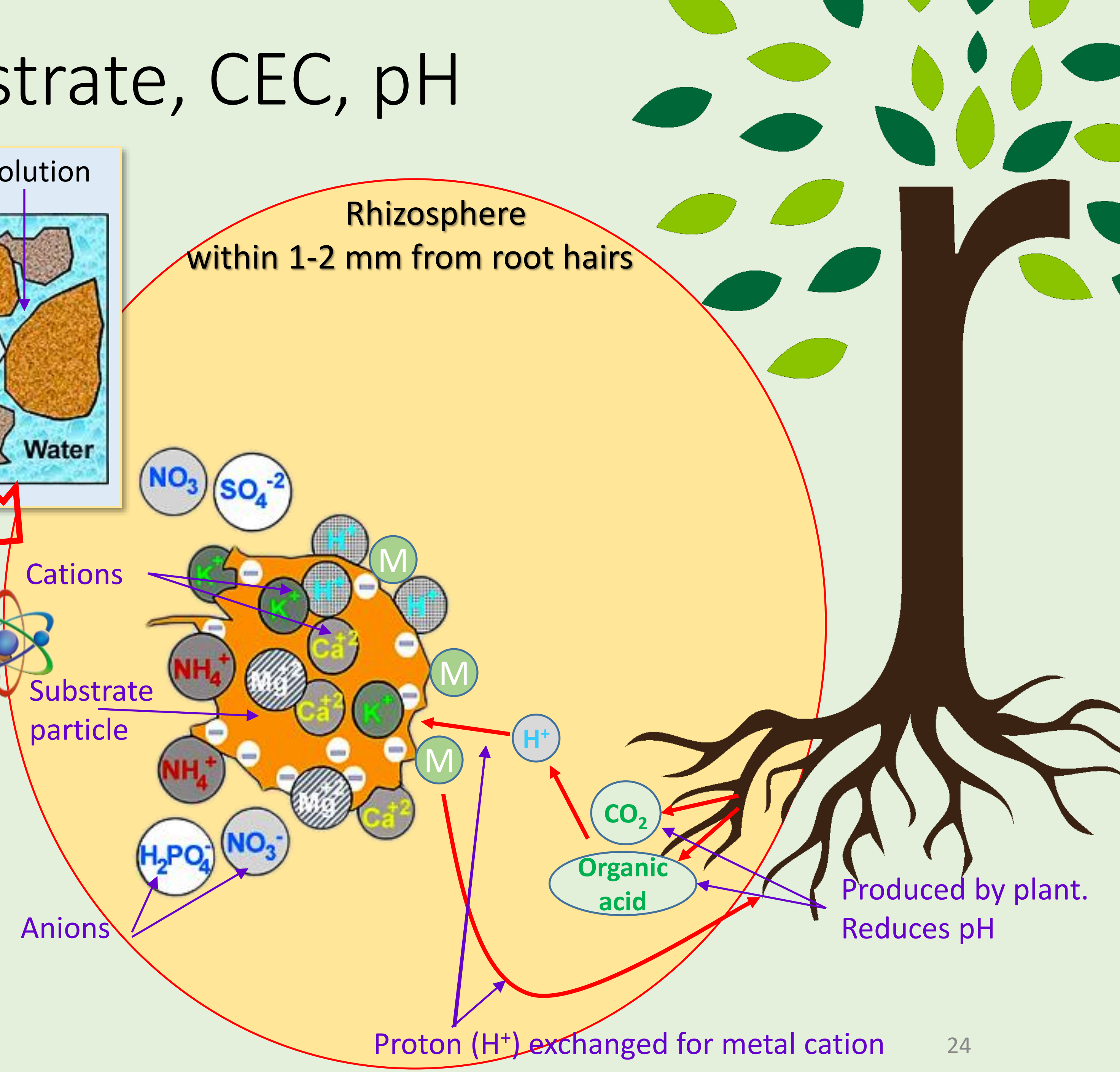



The substrate should:

- absorb / hold excess of trace elements from solution
- easily give out the trace elements in presence of organic acids produced by roots

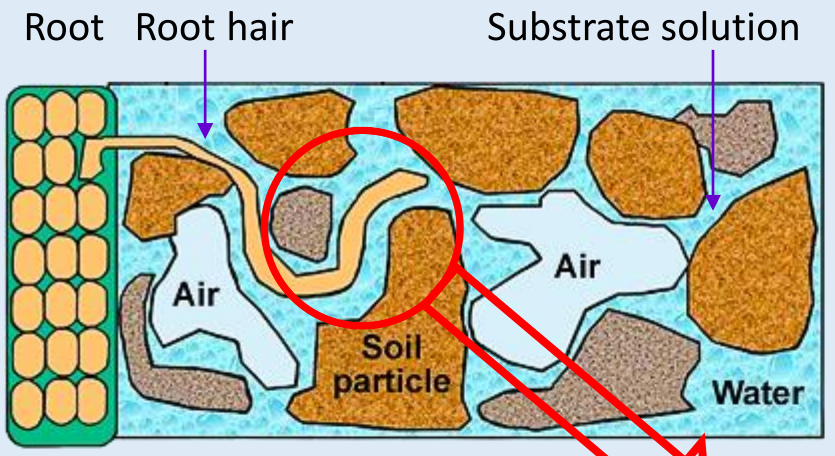





**Step 2: Substrate gives out trace elements**

# Agriculture 101: Substrate, CEC, pH

Plant roots are exposed to the substrate solution. The root hairs are the interface between the plant and the substrate solution. The acidity or basicity of the substrate solution (pH) determines how well the roots can take up nutrients.

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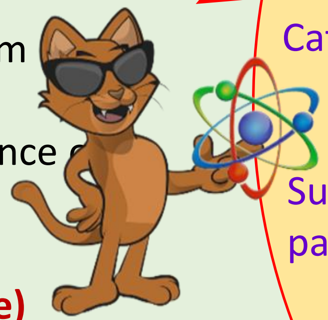
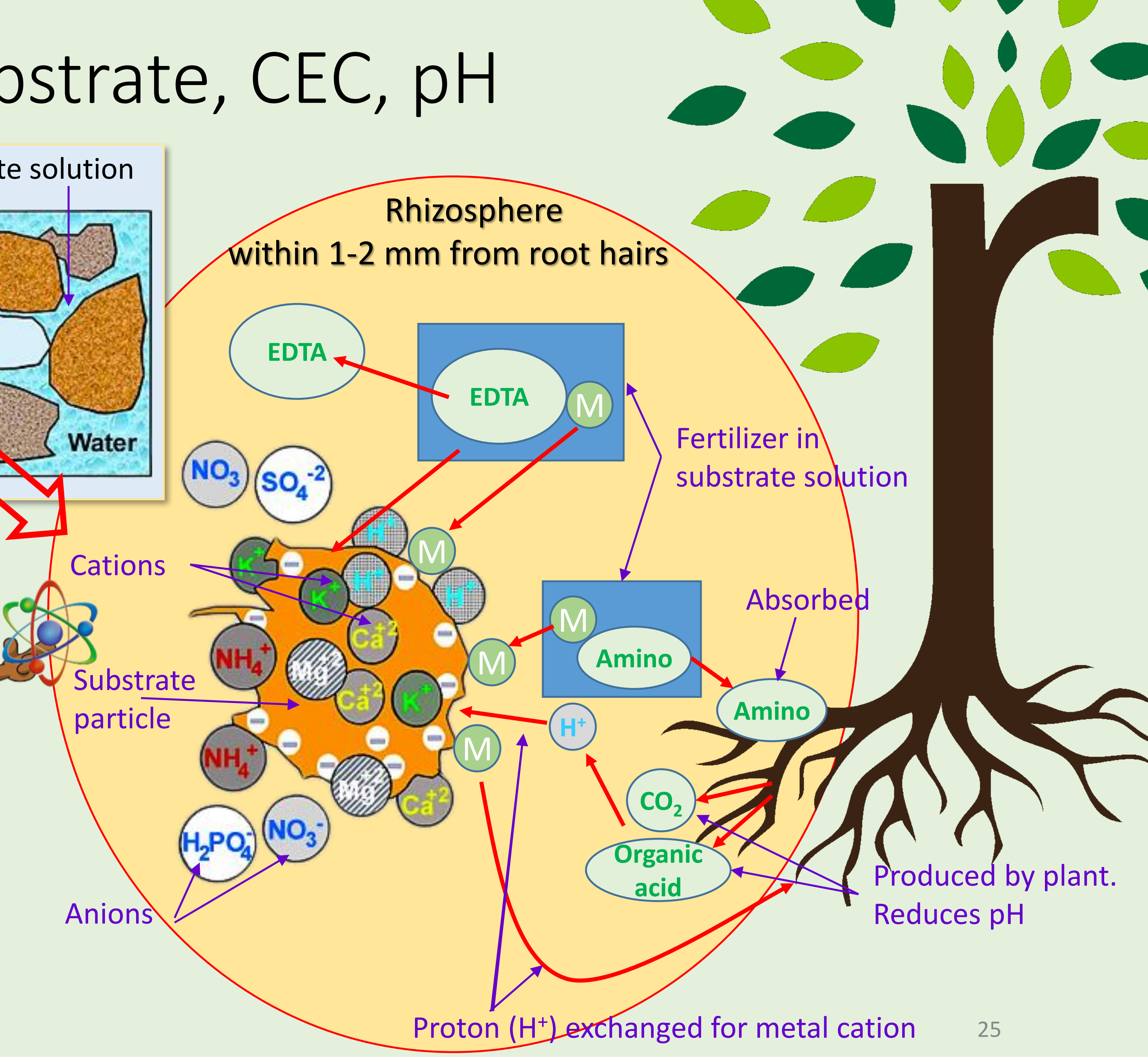


Substrate with:

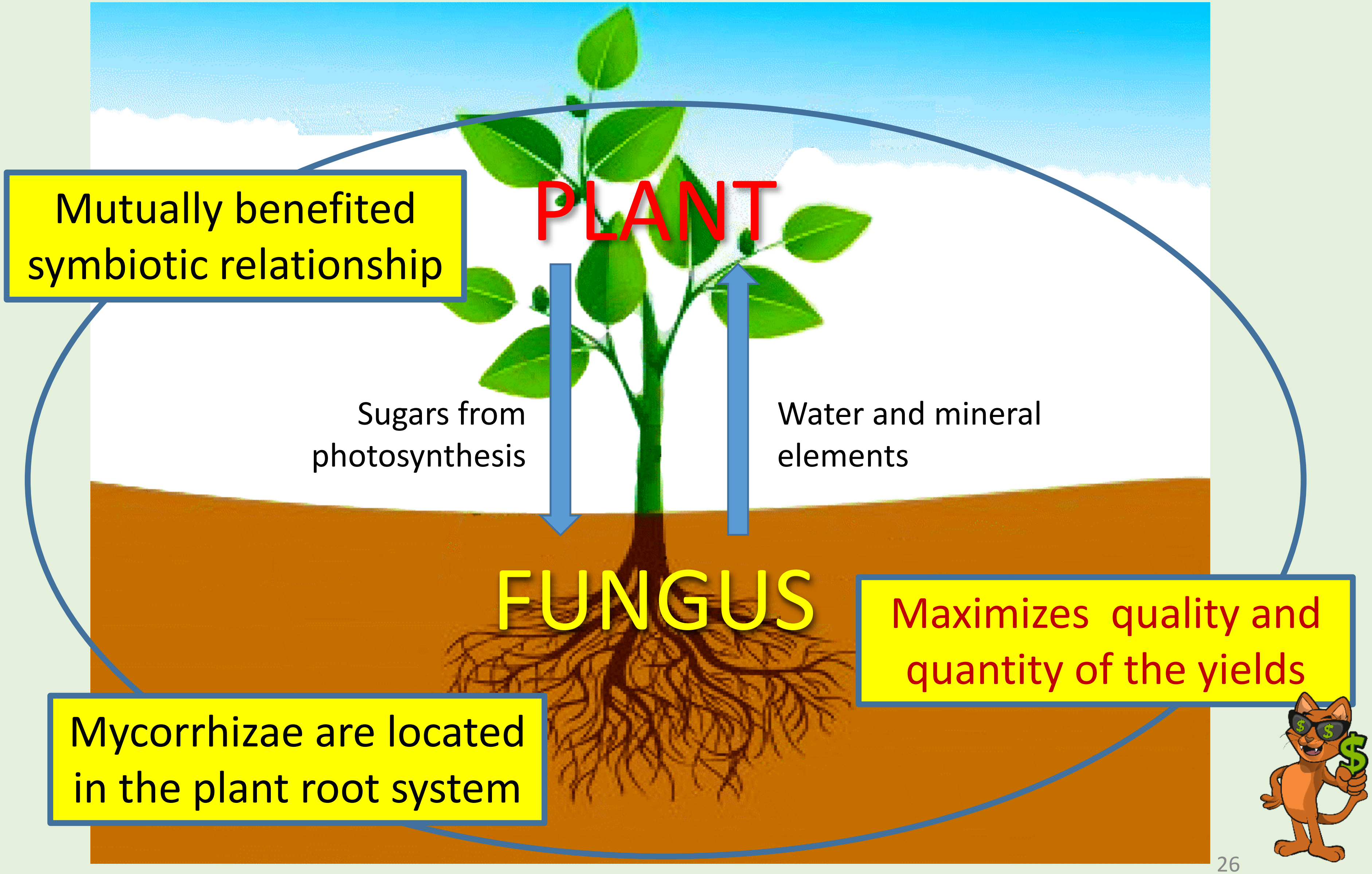
- **Low cation exchange capacity, CEC (perlite)**
  no capability to hold trace elements
- **Optimal CEC (Coconut coir)**
  trace elements held for plant to absorb.
- **Too high CEC (Peat moss)** – plant can't absorb trace elements or needs to spend extra energy.

Optimal substrate pH is 5.4 to 6.0

Optimal CEC is around 50 meq/100g

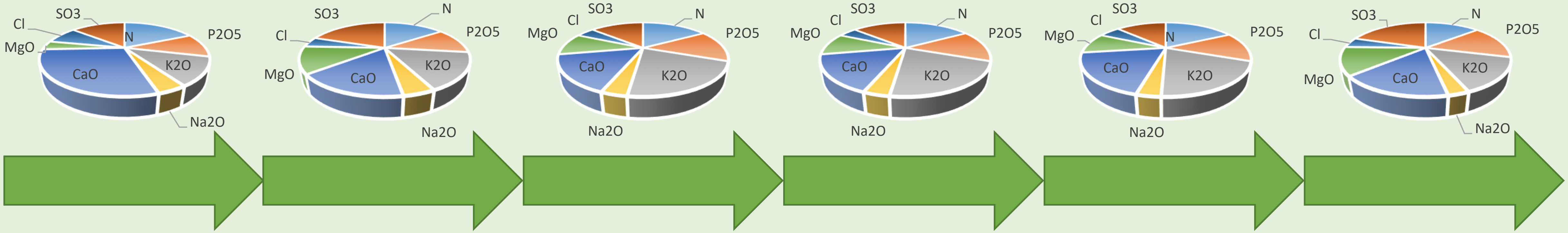


# Agriculture 101: Mycorrhiza

# Plant nutritional system

- Cannabis growth stages: seedling, vegetative growth, pre-flowering transition stage, flowering, and ripening
- For optimal yield, plant needs a controlled level of macro and micronutrients at each stage
- Nutrient solutions provide optimal combination of everything necessary for growth and development at each stage: N, P2O5, K2O, CaO, SO3, Cl, Na2O, MgO, Fe, Mn, B, Zn, Cu, Mo, Co.
- **<u>Optimal amounts help avoid overfertilization / excess salts</u>**
- **<u>More attention to plant nutrients results more developed plants.</u>**




Seedling
30 – 45 days

Vegetative growth
90 – 150 days

Transition
7 – 14 days

Early bloom
15 – 30 days

Mid bloom
15 – 30 days

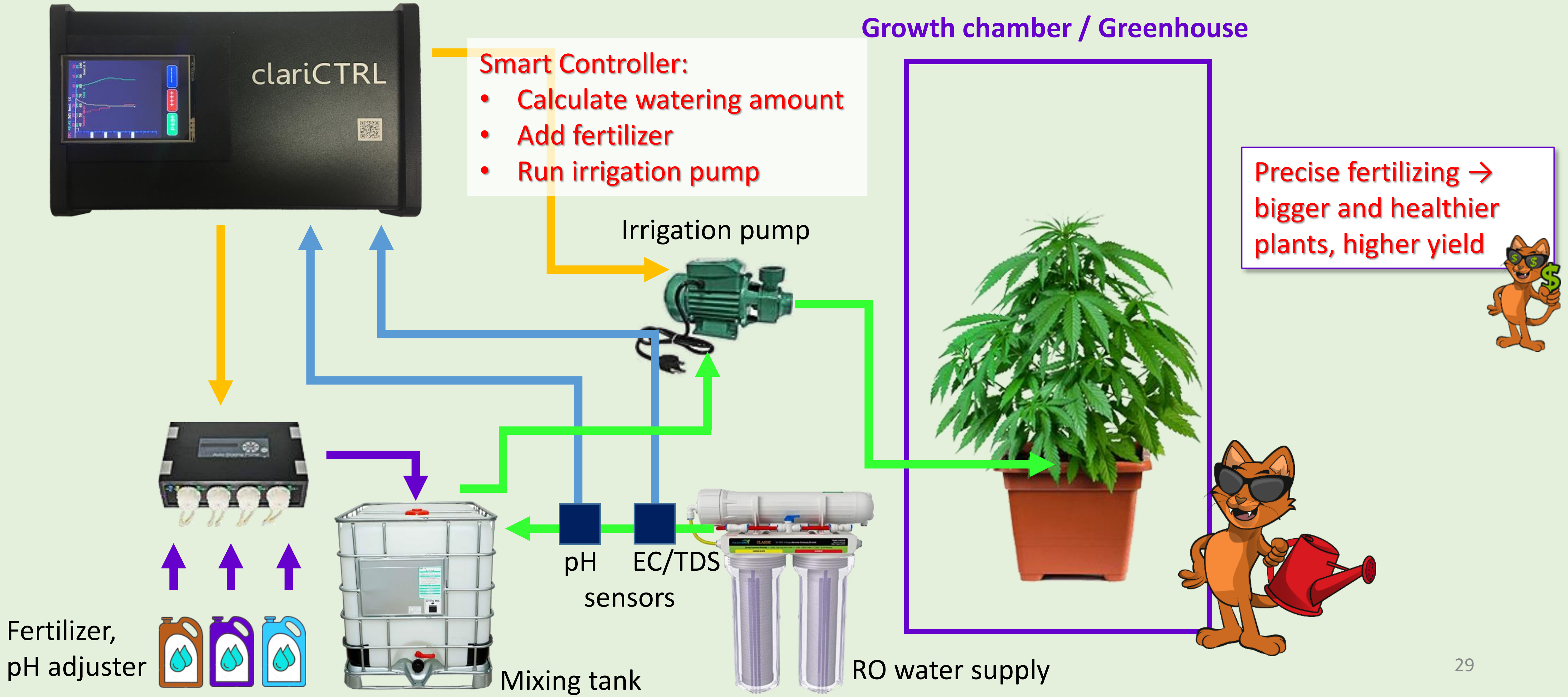
Ripening
10 – 30 days

# What is optimal cannabis fertilizer?

- Provides complete set of macro and micronutrients
- Minimal number of containers to create optimal combination for every growing stage
- Water soluble to use with irrigation systems with streaming dispensers
- Designed  to use with every watering eliminating dosing errors
- Amino acid based stable solutions having no EDTA chelators to eliminate nutrients lockup in substrate
- Contain no excess salts and do not require additional soil flushing.
- Does not affect crop taste
- Minimized fertilizer cost by optimizing fertilizer application
- Provides best ROI: maximize plant development and crop yield and quality

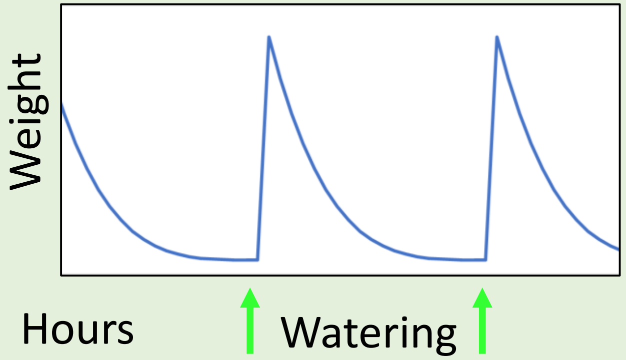
Let’s talk about fertilizer delivery….

# Precision Irrigation and fertilization control / delivery

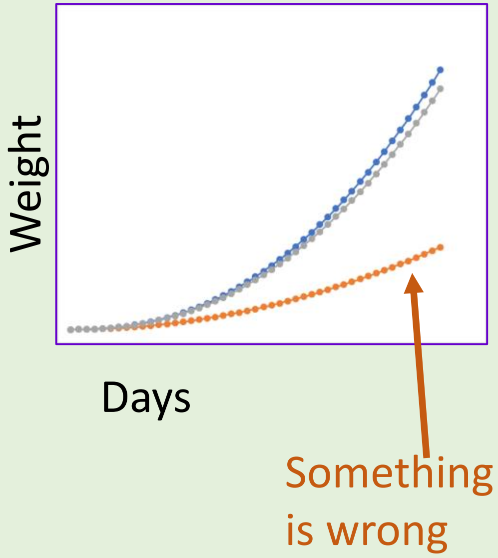


# Real time precision weight monitoring


Smart Controller:
- Calculate precise watering amount
- Measure transpiration rate




Irrigation pump / valve

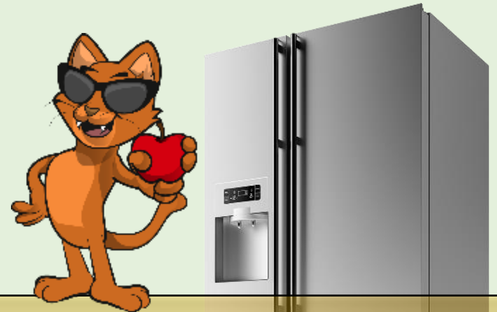




Constant monitoring → bigger and healthier plants, higher yield

# Environmental science 101: **Vapor Pressure Deficit (VPD)**

Why VPD is important? Combining optimal VPD with elevated $CO_2$ level increases photosynthesis rate → bigger and healthier plants, higher yield

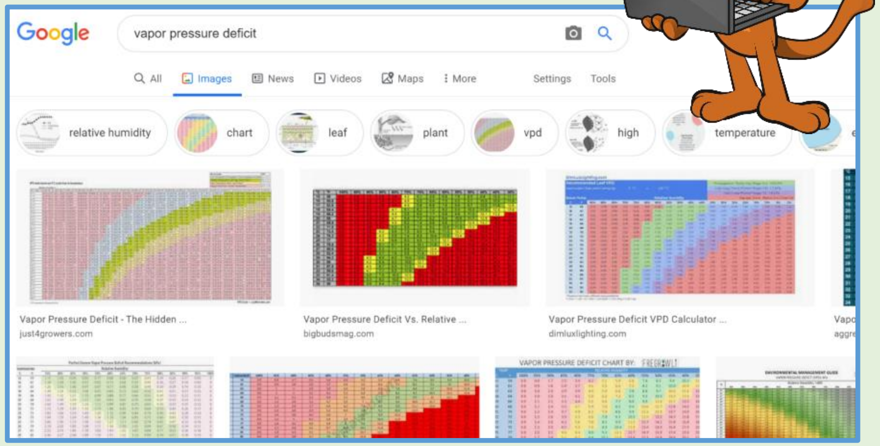
- Air can only hold a certain amount water vapor at a given temperature before it starts condensing. It's called **saturated vapor pressure (SVP)**.
- SVP goes up as air gets hotter. SVP goes down as air cools down.
- The current amount of water vapor in the air called **actual vapor pressure (AVP)**.
- **Relative humidity:** RH=AVP / SVP × 100%. RH is the function of temperature only.
- **Vapor pressure deficit:** VPD=SVP-AVP=SVP × (1-RH/100) – function of both humidity and temperature
- As VPD increases, the plant evaporation rate goes up.



Typical side-by-side fridge volume: 27 $ft^3$ of air.
At 100% RH it contains water:
7.3 ml (¼ Oz) at 50°F (10°C)
30 ml (1 Oz) at 95°F (35°C)

# Environmental science 101: VPD Calculation

- VPD=f(T, RH)
- Countless charts are available online




- SVP can be calculated using various formulas. For plant growing temperature range:

$$SVP=0.61078e^{17.27t/t+237.3}$$ (*Tetens formula,* Wikipedia).

Where temperature *t* is in °C and SVP in kPa

$$VPD=SVP \times (1-RH/100)$$

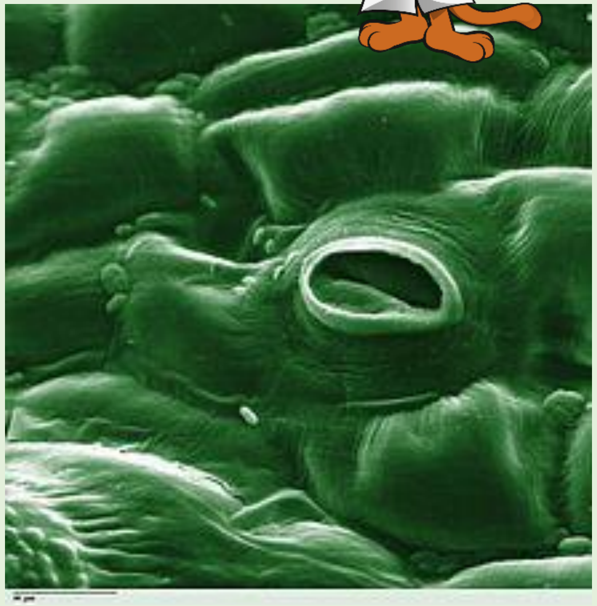
**Very important: the temperature of a healthy transpiring leaf is 1-3 °C lower than ambient air.**

# Environmental science 101: VPD and Plants

Stoma (plural “Stomata”) is a pore in leaves, that provides gas exchange (water vapor, carbon dioxide, oxygen). Plant regulate size of stomatal opening depending on environmental conditions.

VPD increases (RH decreases when temperature is constant):

- Transpiration (evaporation from leaves) rate goes up.
- Stomata get smaller to reduce evaporation.
- $CO_2$ uptake gets reduced.
- Roots have to pull more water.
- More nutrient uptake.
- More stress for the plant. It needs to work harder.



10 µm tomato leaf stoma (Wikipedia)

# Agriculture 101: Optimal VPD

- You don’t want zero VPD (100% RH). Low transpiration, low nutrient uptake, disease and fungus problems.
- Healthy plant transpires 90% of water uptake and uses 10% for its growth (*excluding Arizona desert plants*)
- **Seedlings and small cannabis plants:**
  can’t handle stress and small root system. VPD around 0.8 kPa.
- **Vegetative growth:**
  plants are larger and more robust. Higher VPD increases water and nutrient uptake. Do not increase VPD too much. It reduces $CO_2$ absorption. VPD around 1.0 kPa
- **Flower/Fruit stage:**
  reduce humidity to avoid flower/fruit problem. VPD around 1.2-1.5 kPa

# Precision VPD control

VPD=function(T, RH)

Using formula we can calculate optimal VPD value range

## VPD as function of temperature and RH

Leaf temperature: $T_{leaf}=T_{room}-2$ (°C)

Young plants / seedlings

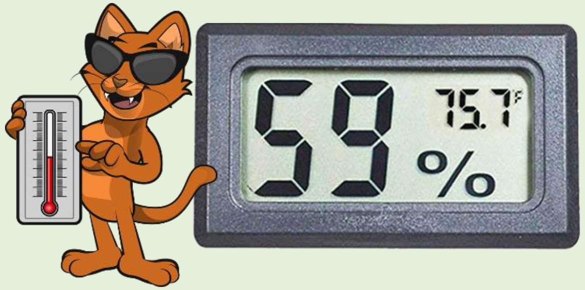
Mature plants

Flowering

| $T_{room}$ | | $T_{leaf}$ | SVP | RH (%) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | °F | °C | kPa | 100 | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 |
| 23 | 73 | 21 | 2.49 | 0.0 | 0.1 | 0.2 | 0.4 | 0.5 | 0.6 | 0.7 | 0.9 | 1.0 | 1.1 | 1.2 | 1.4 | 1.5 | 1.6 |
| 24 | 75 | 22 | 2.64 | 0.0 | 0.1 | 0.3 | 0.4 | 0.5 | 0.7 | 0.8 | 0.9 | 1.1 | 1.2 | 1.3 | 1.5 | 1.6 | 1.7 |
| 25 | 77 | 23 | 2.81 | 0.0 | 0.1 | 0.3 | 0.4 | 0.6 | 0.7 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.5 | 1.7 | 1.8 |
| 26 | 79 | 24 | 2.98 | 0.0 | 0.1 | 0.3 | 0.4 | 0.6 | 0.7 | 0.9 | 1.0 | 1.2 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 |
| 27 | 81 | 25 | 3.17 | 0.0 | 0.2 | 0.3 | 0.5 | 0.6 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.1 |
| 28 | 82 | 26 | 3.36 | 0.0 | 0.2 | 0.3 | 0.5 | 0.7 | 0.8 | 1.0 | 1.2 | 1.3 | 1.5 | 1.7 | 1.8 | 2.0 | 2.2 |
| 29 | 84 | 27 | 3.57 | 0.0 | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.1 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.1 | 2.3 |
| 30 | 86 | 28 | 3.78 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 0.9 | 1.1 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 |
| 31 | 88 | 29 | 4.01 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 |
| 32 | 90 | 30 | 4.25 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.1 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 | 2.8 |
| 33 | 91 | 31 | 4.49 | 0.0 | 0.2 | 0.4 | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 1.8 | 2.0 | 2.2 | 2.5 | 2.7 | 2.9 |
| 34 | 93 | 32 | 4.76 | 0.0 | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | 2.1 | 2.4 | 2.6 | 2.9 | 3.1 |
| 35 | 95 | 33 | 5.03 | 0.0 | 0.3 | 0.5 | 0.8 | 1.0 | 1.3 | 1.5 | 1.8 | 2.0 | 2.3 | 2.5 | 2.8 | 3.0 | 3.3 |
| 36 | 97 | 34 | 5.32 | 0.0 | 0.3 | 0.5 | 0.8 | 1.1 | 1.3 | 1.6 | 1.9 | 2.1 | 2.4 | 2.7 | 2.9 | 3.2 | 3.5 |
| 37 | 99 | 35 | 5.63 | 0.0 | 0.3 | 0.6 | 0.8 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | 2.5 | 2.8 | 3.1 | 3.4 | 3.7 |

Next: Change RH and temperature to maintain optimal VPD…

# Precision VPD control




- Both temperature and humidity should be controlled – manually or **using smart controller**
- **Slowly** bring (T, RH) point into optimal area
- Automatic control makes task much easier
- During night time reduce humidity
- Air movement is essential

## VPD as function of temperature and RH

Leaf temperature: $T_{leaf}=T_{room}-2$ (°C)

Young plants / seedlings
Mature plants
Flowering

| $T_{room}$ | | $T_{leaf}$ | SVP | RH (%) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | °F | °C | kPa | 100 | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 |
| 23 | 73 | 21 | 2.49 | 0.0 | 0.1 | 0.2 | 0.4 | 0.5 | 0.6 | 0.7 | 0.9 | 1.0 | 1.1 | 1.2 | 1.4 | 1.5 | 1.6 |
| 24 | 75 | 22 | 2.64 | 0.0 | 0.1 | 0.3 | 0.4 | 0.5 | 0.7 | 0.8 | 0.9 | 1.1 | 1.2 | 1.3 | 1.5 | 1.6 | 1.7 |
| 25 | 77 | 23 | 2.81 | 0.0 | 0.1 | 0.3 | 0.4 | 0.6 | 0.7 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.5 | 1.7 | 1.8 |
| 26 | 79 | 24 | 2.98 | 0.0 | 0.1 | 0.3 | 0.4 | [illegible] | [illegible] | [illegible] | 1.0 | 1.2 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 |
| 27 | 81 | 25 | 3.17 | 0.0 | 0.2 | 0.3 | 0.5 | 0.6 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.1 |
| 28 | 82 | 26 | 3.36 | 0.0 | 0.2 | 0.3 | 0.5 | 0.7 | 0.8 | 1.0 | 1.2 | 1.3 | 1.5 | 1.7 | 1.8 | 2.0 | 2.2 |
| 29 | 84 | 27 | 3.57 | 0.0 | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | [illegible] | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.1 | 2.3 |
| 30 | 86 | 28 | 3.78 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 0.9 | 1.1 | [illegible] | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 |
| 31 | 88 | 29 | 4.01 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | [illegible] | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 |
| 32 | 90 | 30 | 4.25 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.1 | 1.3 | 1.5 | 1.7 | [illegible] | 2.1 | 2.3 | 2.5 | 2.8 |
| 33 | 91 | 31 | 4.49 | 0.0 | 0.2 | 0.4 | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 1.8 | 2.0 | 2.2 | 2.5 | 2.7 | 2.9 |
| 34 | 93 | 32 | 4.76 | 0.0 | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | 2.1 | 2.4 | 2.6 | 2.9 | 3.1 |
| 35 | 95 | 33 | 5.03 | 0.0 | 0.3 | 0.5 | 0.8 | 1.0 | 1.3 | 1.5 | 1.8 | 2.0 | 2.3 | 2.5 | 2.8 | 3.0 | 3.3 |
| 36 | 97 | 34 | 5.32 | 0.0 | 0.3 | 0.5 | 0.8 | 1.1 | 1.3 | 1.6 | 1.9 | 2.1 | 2.4 | 2.7 | 2.9 | 3.2 | 3.5 |
| 37 | 99 | 35 | 5.63 | 0.0 | 0.3 | 0.6 | 0.8 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | 2.5 | 2.8 | 3.1 | 3.4 | 3.7 |

Optimal Temperature

Optimal RH

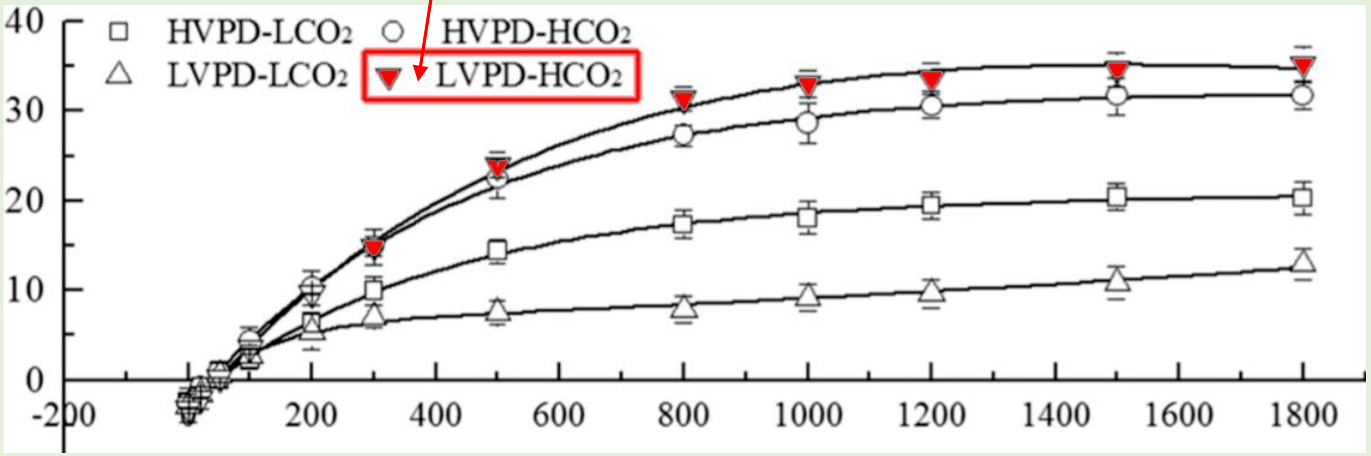
Next: Another component of optimal mix - $CO_2$ ...

# Agriculture 101: Optimal VPD and $CO_2$

| Condition | Stomatal density ($mm^{-2}$) | Stomatal area ($\mu m^2$) |
|---|---|---|
| High VPD-Low $CO_2$ (natural growth conditions) | 167.2 | 562 |
| High VPD-High $CO_2$ (enriched $CO_2$) | 174.9 | 570 |
| Low VPD-Low $CO_2$ (greenhouse conditions) | 208.7 | 715 |
| Low VPD-High $CO_2$ (greenhouse conditions, enriched $CO_2$) | 239.0 | 624 |

More stomata → more $CO_2$ absorbed → higher photosynthesis rate

Photosynthesis rate




PPFD (μmol · $m^{-2}$ · $s^{-1}$)

Greenhouse tomato plants. High VPD=4.44 kPa, Low VPD=1.90 kPa, High $CO_2$=800 ppm, Low $CO_2$=400 ppm

PPFD – Photosynthetic Photon Flux Density. Amount of PAR light arriving at the plant surface each second.

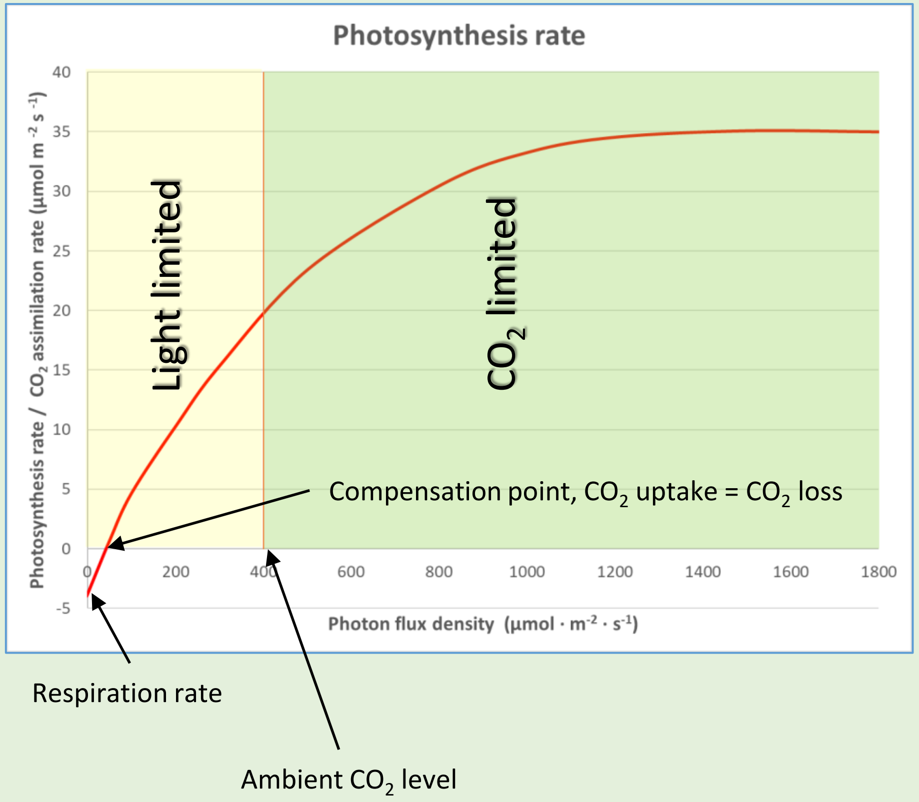
X-C Jiao, X-M Song, D-L Zhang, Q-J Du, & J-M Li. (2019) Coordination between vapor pressure deficit and CO2 on the regulation of photosynthesis and productivity in greenhouse tomato production. *Nature. Scientific Reports*.

Combining optimal VPD with elevated $CO_2$ level increases photosynthesis rate → bigger and healthier plants, higher yield.

# $CO_2$ in growing environment

$CO_2$ injection can double growth rate


**Liebig's barrel: Light level, temperature, RH and $CO_2$ level must be balanced for the plant to utilize resources most efficiently**




- $CO_2$ compensation point: 100 ppm (350-400 ppm with Mycorrhizae). Respiration and photosynthesis are equal so there is no net loss or gain
- Between 400 ppm (ambient level) and 800 ppm photosynthesis increases very quickly as the $CO_2$ levels climb
- The increase is less, but significant between $CO_2$ concentration of 800 to 1200 ppm
- $CO_2$ saturation for cannabis cultivation is 1,300 ppm
- $CO_2$ concentration above 2000-3,000 ppm may cause leaf burn
- Air circulation is critical for $CO_2$ enrichment

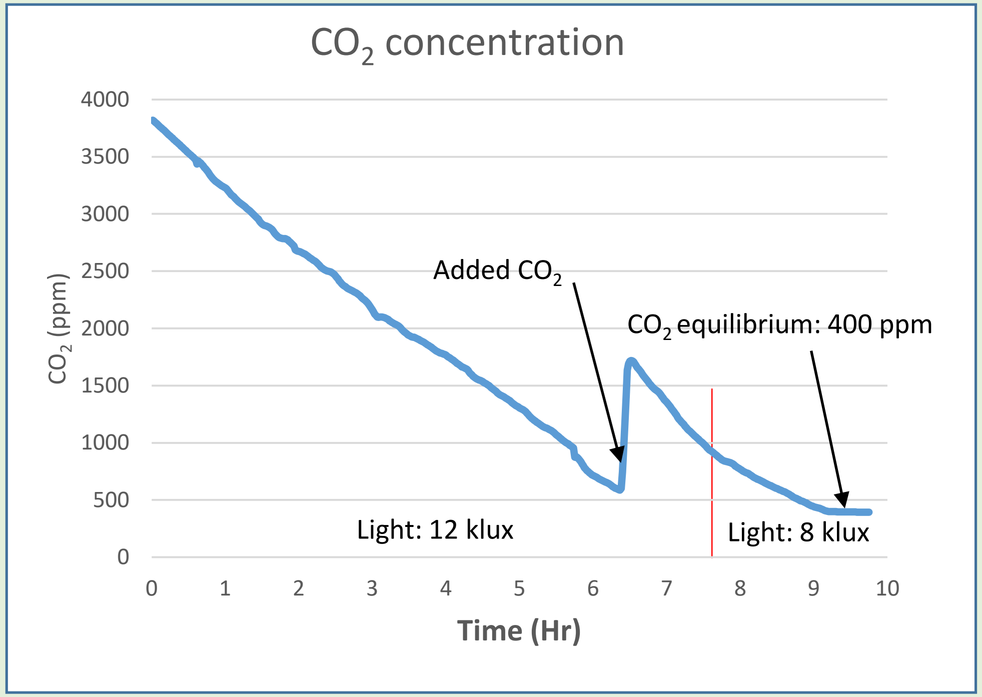
Safety - $CO_2$ human exposure:

- 400 – 1,000 ppm: typical level found in occupied spaces with good air exchange
- 1,000 – 2,000 ppm: level associated with complaints of drowsiness and poor air
- 5,000 ppm: maximal permissible exposure limit for daily workplace exposures
- 40,000 ppm: this level is immediately harmful due to oxygen deprivation.

Chandra, S., Lata, H., Khan, I. A., & Elsohly, M. A. (2008). Photosynthetic response of *Cannabis sativa* L. to variations in photosynthetic photon flux densities, temperature and CO2 conditions. *Physiology and molecular biology of plants : an international journal of functional plant biology*, 14(4), 299–306.

# $CO_2$ absorption

Combined CO2 / RH / Temperature / Light sensor prototype


Courtesy of TopTropicals.com

- Dwarf tomato plants planted in Sunshine Abundance mix with Mycorrhizae added
- Plant weight: 150-200 g
- Light: neutral white LED light strip
- Temperature: 24-30°C. Humidity: RH=98%
- $CO_2$ equilibrium – 400 ppm. Small plant size and large amount of substrate (mycorrhiza and bacteria) produces extra $CO_2$
- At high concentration $CO_2$ consumption is linear:
  - at 10-12 klux light level: 10 ppm/min for a small plant
  - Below 10 klux: around 5 ppm/min

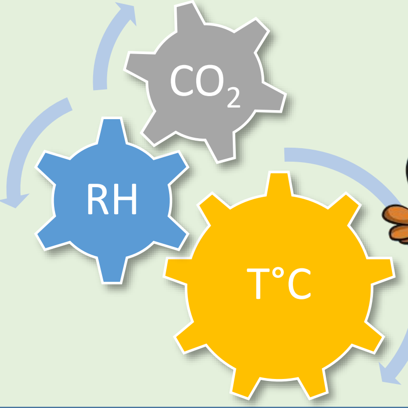
# $CO_2$ during dark period

- In complete darkness, the plant releases $CO_2$
- Concentration increases linearly, approximately 4 ppm/min per small plant **(2,000 ppm per 8 hours)**
- **There is no $CO_2$ saturation point – dangerous.** The maximum in the experiments received 4,000 ppm
- Water and high $CO_2$ concentration → carbonic acid → burn plants
- 3,000 ppm during 2 hours resulted in burn of 30% of leaves. Not reversible
- <u>**Turn off $CO_2$ during dark periods**</u>

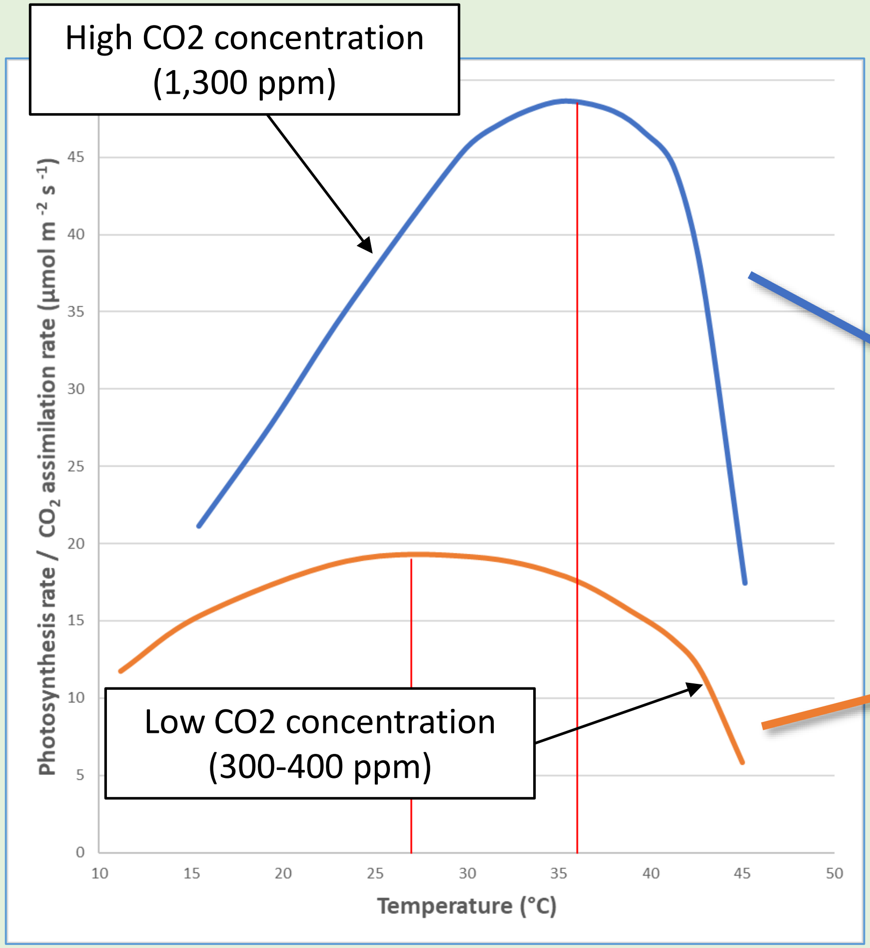
Excess of $CO_2$ during night time caused leaf burn

# $CO_2$ / Temperature / RH / VPD

- Photosynthesis maximum shifts from 27°C (81°F) to 33-36°C (91-97°F)
- RH must be adjusted to maintain optimal VPD
- **Optimal balance is key to success**








## VPD as function of temperature and RH

Leaf temperature: $T_{leaf}=T_{room}-2$ (°C)

Young plants / seedlings

Mature plants

Flowering

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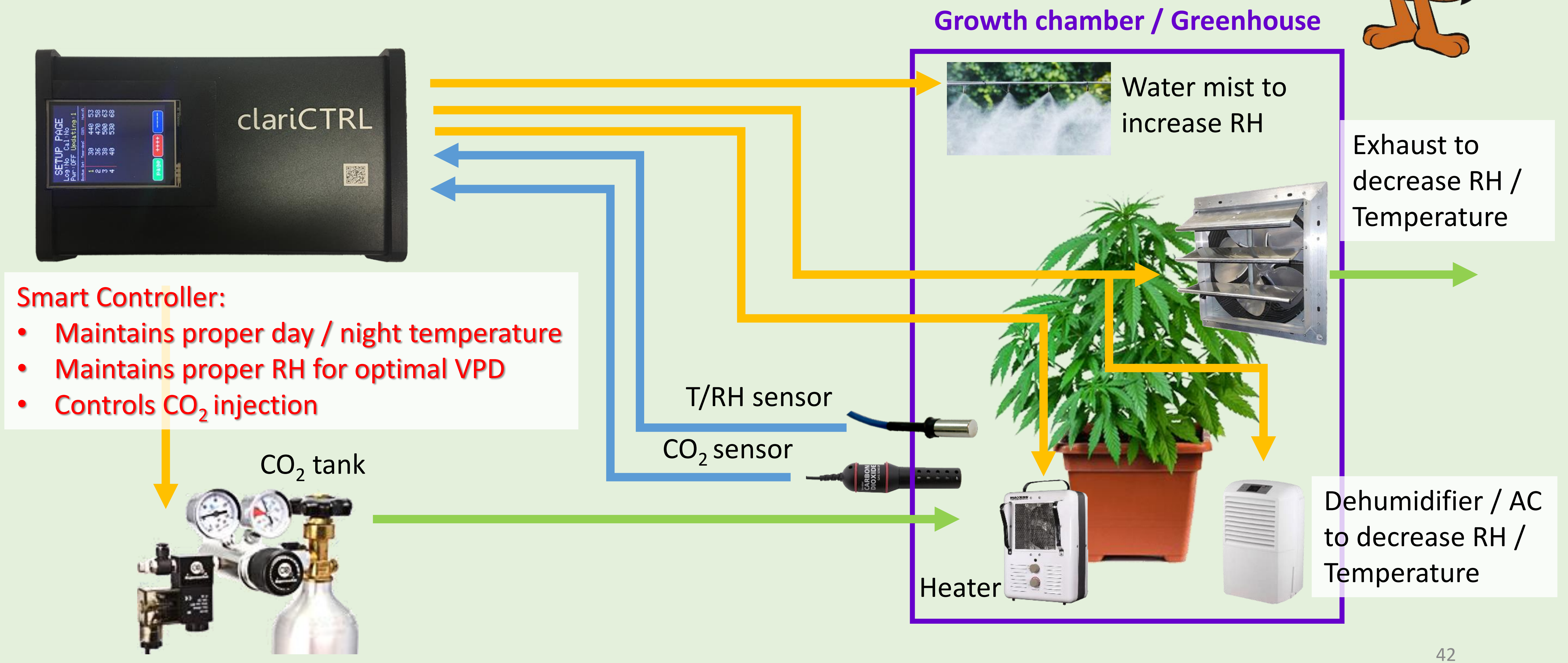
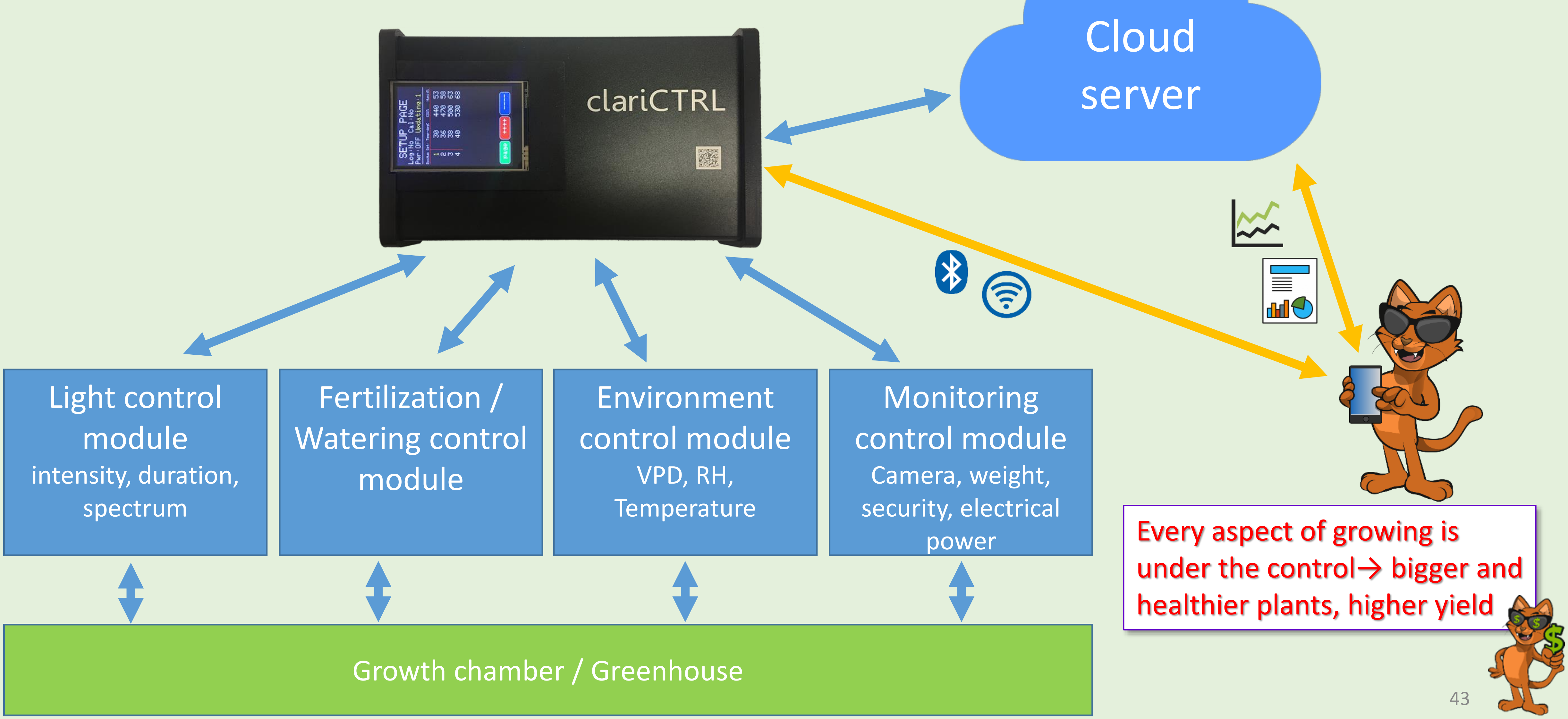
| 24 | 75 | 22 | 2.64 | 0.0 | 0.1 | 0.3 | 0.4 | 0.5 | 0.7 | 0.8 | 0.9 | 1.1 | 1.2 | 1.3 | 1.5 | 1.6 | 1.7 |
| 25 | 77 | 23 | 2.81 | 0.0 | 0.1 | 0.3 | 0.4 | 0.6 | 0.7 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.5 | 1.7 | 1.8 |
| 26 | 79 | 24 | 2.98 | 0.0 | 0.1 | 0.3 | 0.4 | 0.6 | 0.7 | 0.9 | 1.0 | 1.2 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 |
| 27 | 81 | 25 | 3.17 | 0.0 | 0.2 | 0.3 | 0.5 | 0.6 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.1 |
| 28 | 82 | 26 | 3.36 | 0.0 | 0.2 | 0.3 | 0.5 | 0.7 | 0.8 | 1.0 | 1.2 | 1.3 | 1.5 | 1.7 | 1.8 | 2.0 | 2.2 |
| 29 | 84 | 27 | 3.57 | 0.0 | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.1 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.1 | 2.3 |
| 30 | 86 | 28 | 3.78 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 0.9 | 1.1 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 |
| 31 | 88 | 29 | 4.01 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 |
| 32 | 90 | 30 | 4.25 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.1 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 | 2.8 |
| 33 | 91 | 31 | 4.49 | 0.0 | 0.2 | 0.4 | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 1.8 | 2.0 | 2.2 | 2.5 | 2.7 | 2.9 |
| 34 | 93 | 32 | 4.76 | 0.0 | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | 2.1 | 2.4 | 2.6 | 2.9 | 3.1 |
| 35 | 95 | 33 | 5.03 | 0.0 | 0.3 | 0.5 | 0.8 | 1.0 | 1.3 | 1.5 | 1.8 | 2.0 | 2.3 | 2.5 | 2.8 | 3.0 | 3.3 |
| 36 | 97 | 34 | 5.32 | 0.0 | 0.3 | 0.5 | 0.8 | 1.1 | 1.3 | 1.6 | 1.9 | 2.1 | 2.4 | 2.7 | 2.9 | 3.2 | 3.5 |
| 37 | 99 | 35 | 5.63 | 0.0 | 0.3 | 0.6 | 0.8 | 1.1 | 1.4 | 1.7 | 2.0 | 2.3 | 2.5 | 2.8 | 3.1 | 3.4 | 3.7 |

# Precision VPD/T/RH/$CO_2$ control



# Smart controller for precision plant growth



# What is smart controller for precision growing?

- Highly accurate and flexible, combined with ease of use
- High-reliability is essential: high-value crop (sometimes irreplaceable)
- Works with high $CO_2$ concentration, very high humidity, temperature, tight pH range
- Controls dosing and sampling, long-term, flexible, responsive sequencing
  - One-button setup, even for complex multi-stage data-driven growth cycles
- Accurate and detailed logging over time periods from seconds to months
- Easily reconfigurable communications
  - Email and text alerts, Wi-Fi, Ethernet, USB, Bluetooth
  - Remote and standalone control and monitoring (smartphone / PC / tablet)

**Advanced plant growth controller is invaluable tool for plant growing success**

# Scientifically designed plant boosters and fertilizers

Tomato seedlings


2 weeks after treatment


4 weeks after treatment


Different concentration

SUNSHINE BOOSTERS

TopTropicals.com
We Grow Happiness

# Scientifically designed plant boosters and fertilizers


3 weeks after treatment
Cabbage (*Brassica sp.*)


3 weeks after treatment
Tomato seedlings

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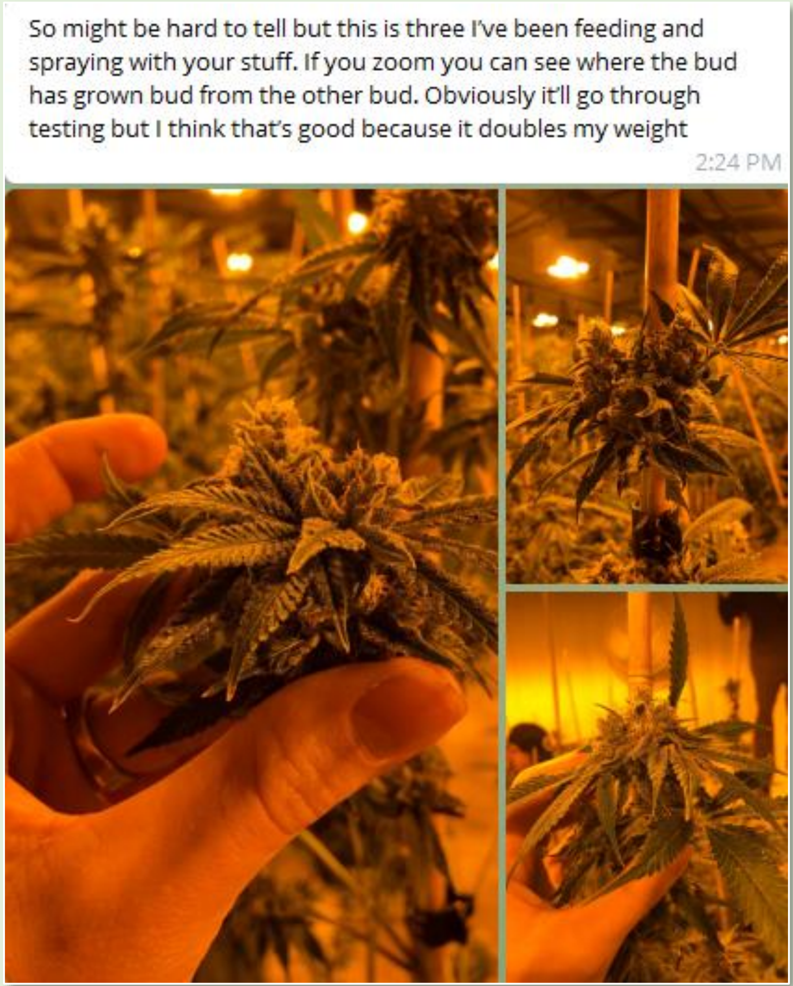
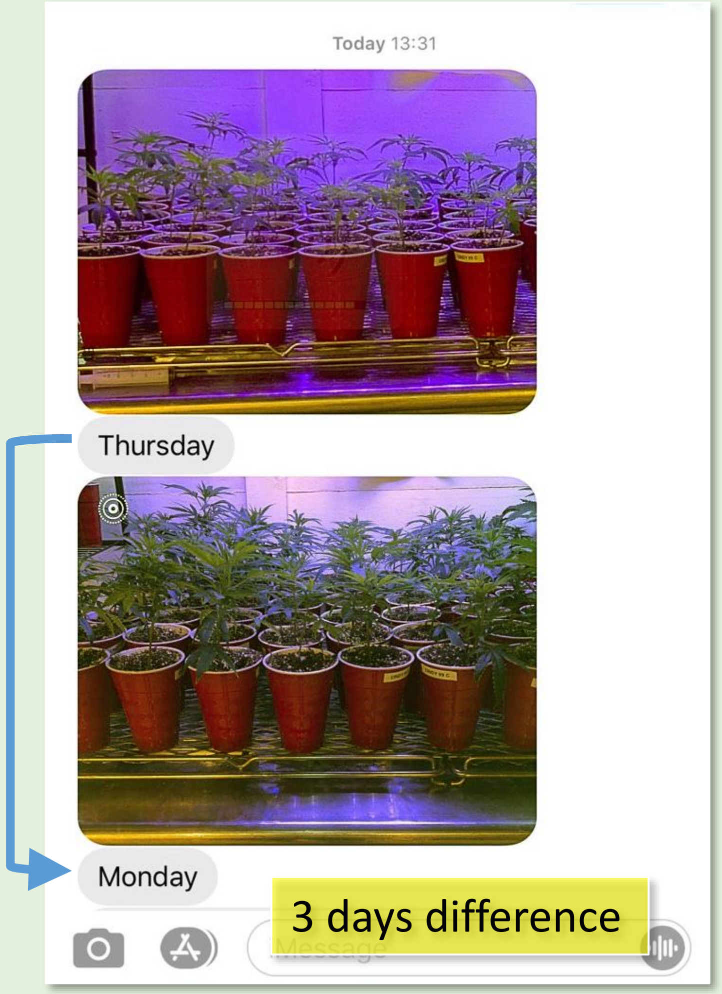
# Scientifically designed plant boosters and fertilizers




SUNSHINE BOOSTERS

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# Take away home:

- Precision growing allows greatly increasing plant yield
- Components for success:
  - Substrate
  - Fertilizers
  - Environment: $CO_2$ / VPD / RH / T
  - Smart controller
  - Lighting – **we'll cover it next time**
- Balance of essential elements is key to success ("Liebig's barrel")
- Smart controller makes balancing easier

# Visit us:


- Our booth at the show
- Our website: SunshineBoosters.com

Learn more about:

- Our patent pending smart nutrient system
- Our patent pending smart controlled growing environment
- Soon: Growing chamber at Kickstarter

Contact us:

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# Thanks everyone helping us

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