



Extension

University of Missouri

Hydroponic systems overview

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Topics

- CEA
- Introduction to sustainability
- Advantages and disadvantages
- Organic hydroponic debate
- Systems overview
 - Liquid: NFT, DWC, and Aeroponics
 - Solid: Dutch bucket
- Plant environment control

Controlled Environment Agriculture

- Objective: Keep plants in their comfort zone to maximize productivity



Low



Level of control

High

What is sustainable agriculture?

With sustainable agriculture practices we want to improve the quality of life of farmers and the community by raising profitable crops and livestock while preserving the environment and natural resources.

We want to meet society's food needs and make sure that future generations will have resources to meet their own needs

Pillars of sustainable crop production

3 Pillars of sustainability:

- Profit over the long term
- Stewardship of our nation's land, air and water
- Quality of life for farmers, ranchers and their communities

How can hydroponics be sustainable

Profitable

More produce per square foot
Lower use of pesticides
Efficient water use
Less fertilizer use

Preserving the environment

Less land requirement
Less risk of pesticide drift
Lower use of water
Lower risk of pesticide and fertilizer leaching

Quality of life

Natural areas preservation
Access to safe produce
Urban Agriculture
Access to fresh local food
↑ Profit = more taxes to serve the community

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Advantages: No seasonality

Year round production is possible



Advantages: Short crop cycles

Lettuce ready in 35 to 45 days

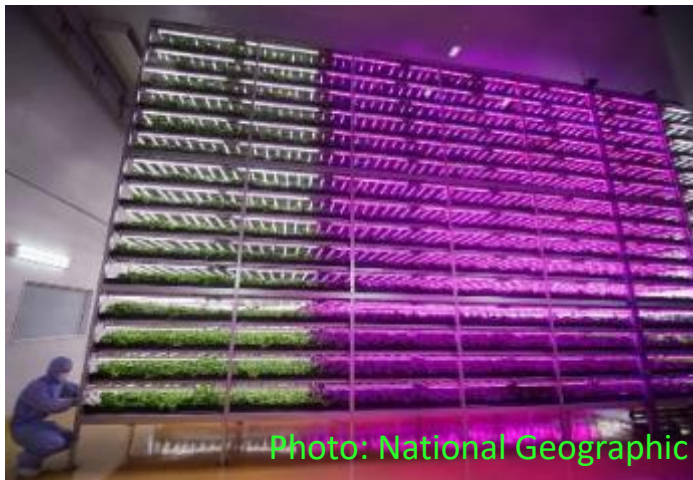


Compared to more than 70 days in the field

Advantages: Food safety

Hydroponic Lettuce

- Lower risk of contamination
- 1 foodborne disease outbreaks from 2014 to 2021



Field Lettuce

- Higher risk of contamination
- 60 foodborne disease outbreaks from 2014 to 2021



[This Photo](#) by Unknown Author is licensed under [CC BY](#)

Advantages: Food access

- Limited land availability in urban areas
 - Development is more profitable
 - Contaminated sites
 - Zoning restrictions
 - Neighbors
- Food quality: beneficial compounds are lost after harvest
- Water use efficiency: Municipal water is expensive
- Food deserts in urban areas

Advantages: High yields

Hydroponic tomato yield

- 1975: 89 Ton/acre/year *
- 1990: 181 Ton/acre/year
- 2005: 300 Ton/acre/year
- Current av: 448 Ton/acre/year

Tomato yield on soil:

- 2012: 3.6 – 6.5 Ton/acre/year
(NASS, 2012)
- 15 to 40 Ton/acre/year (reports)



*Based on a plant density of 10,000 plants per acre.

Why are yields higher?

Higher yields are a result of the combined effects of:

- Varieties (indeterminate tomato)
- High control of the environment and plant nutrition.
- Efficient use of space (vertical farming) and resources

Resources

Hydroponic Lettuce

- Low land requirement
- 166 Ton/acre/year *
- Water: 2.4 gal for each pound per year*
- 11 kWh per pound per year*
- Higher infrastructure costs (\$2.5 to \$5 per sq ft a year)

Field Lettuce

- High land requirement
- 15 Ton/acre/year
- Water: 30 gal for each pound per year
- 0.14 kWh per pound per year
- Lower infrastructure costs (\$0.2 per sq ft per year)

Disadvantages

- High energy use
- Investment: equipment and greenhouse
- Limited crop diversity

HYDROPONIC LETTUCE

Higher infrastructure costs
(\$2.5 to \$5 per sq ft per year)

Greenhouse figure

FIELD LETTUCE

Lower infrastructure costs
(\$0.2 per sq ft per year)

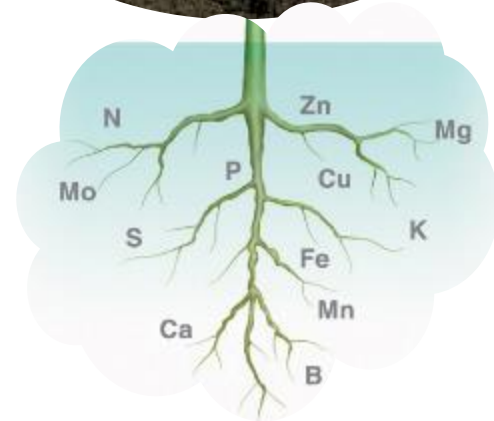
- Steep learning curve

Why is market demand increasing?

- Consumers want produce that uses less resources (water, soil, and fertilizers) while preserving natural ecosystems and biodiversity.
- People want produce grown with less pesticides and with high nutritional value.
- Urban areas want fresh local produce.
- Perceptions about hydroponics are evolving

Environmental impacts

- Preservation of soils and forests (Higher yields)
- Pollution: lower risk of fertilizer and pesticides runoff and infiltration
- Lower use of resources (land, water and fertilizers)
- Lower use of pesticides (no need to control weeds and less disease/insect pressure)
- Able to supply fresh locally sourced food
- High use of energy (renewable sources)
- High dependency on plastics



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Organic hydroponic debate

- Organic Foods Production Act (OFPA)
 - National Organic Program (NOP)
 - National Organics Standards Board (NOSB)
- Since 1995 NOSB made comments about organic hydroponic labeling, but no rule has been made by NOP
- 2017 NOSB voted to remove aeroponics from the labeling, but USDA has yet to act on this recommendation

Organic hydroponic debate

- Arguments against organic hydroponics:
 - They do not build healthy soils
 - They fail to adhere to OFPA's soil fertility requirement
 - They violate OFPA's requirements to improvement of soil quality, management of soil fertility, use of crop rotation practices, conservation of biodiversity, use of other soil management practices, and use of soil samples to measure compliance with OFPA
- March 19, 2021: court ruled to allow organic certification because the OFPA doesn't specifically prohibit hydroponic operations

Steps to organic certification

1. Develop organic system plan (OSP): detail how you will comply with regulations and use of approved substances
<https://www.ecfr.gov/current/title-7/part-205/subpart-g>
2. Have the OSP reviewed by a *certifying agent* and implement it
3. Get inspected
4. Have the certifying agent review the inspection report
5. Receive a decision from certifier
Find an USDA-accredited certifying agency:
<https://www.ams.usda.gov/resources/organic-certifying-agents>
Cost share program:
<https://www.fsa.usda.gov/programs-and-services/occsp/index>

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What is hydroponic?

Crop production system that uses an inert medium and nutrients are provided with a solution.

It is a soilless production system.

Types of hydroponic systems



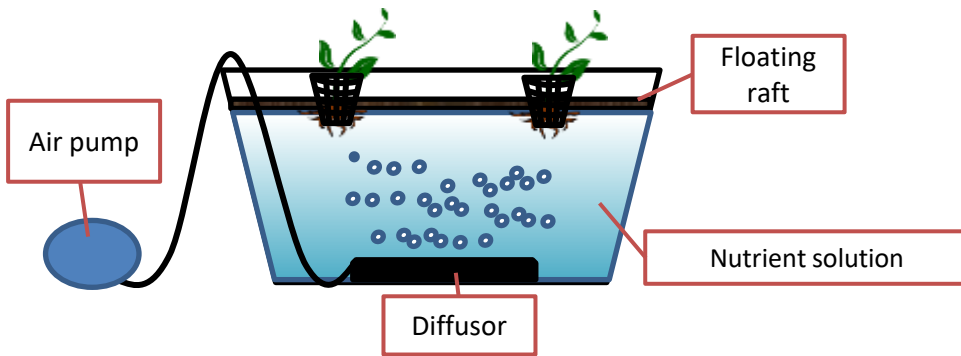
Liquid



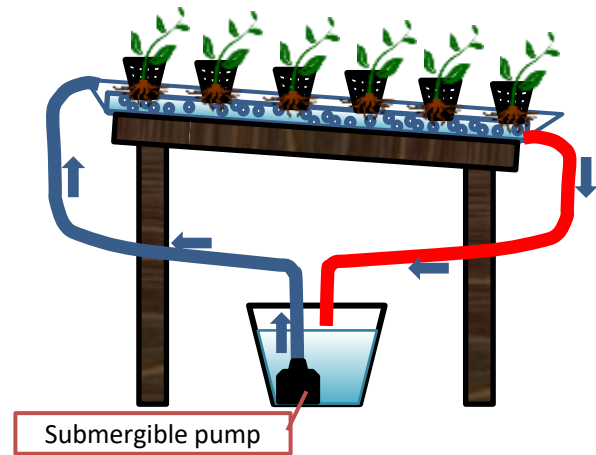
Solid

Liquid systems

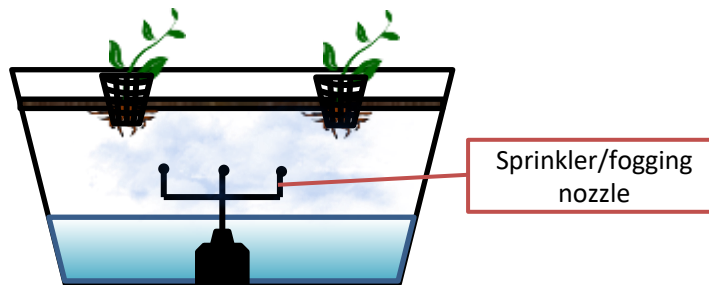
Floating raft/Deep water culture (DWC)



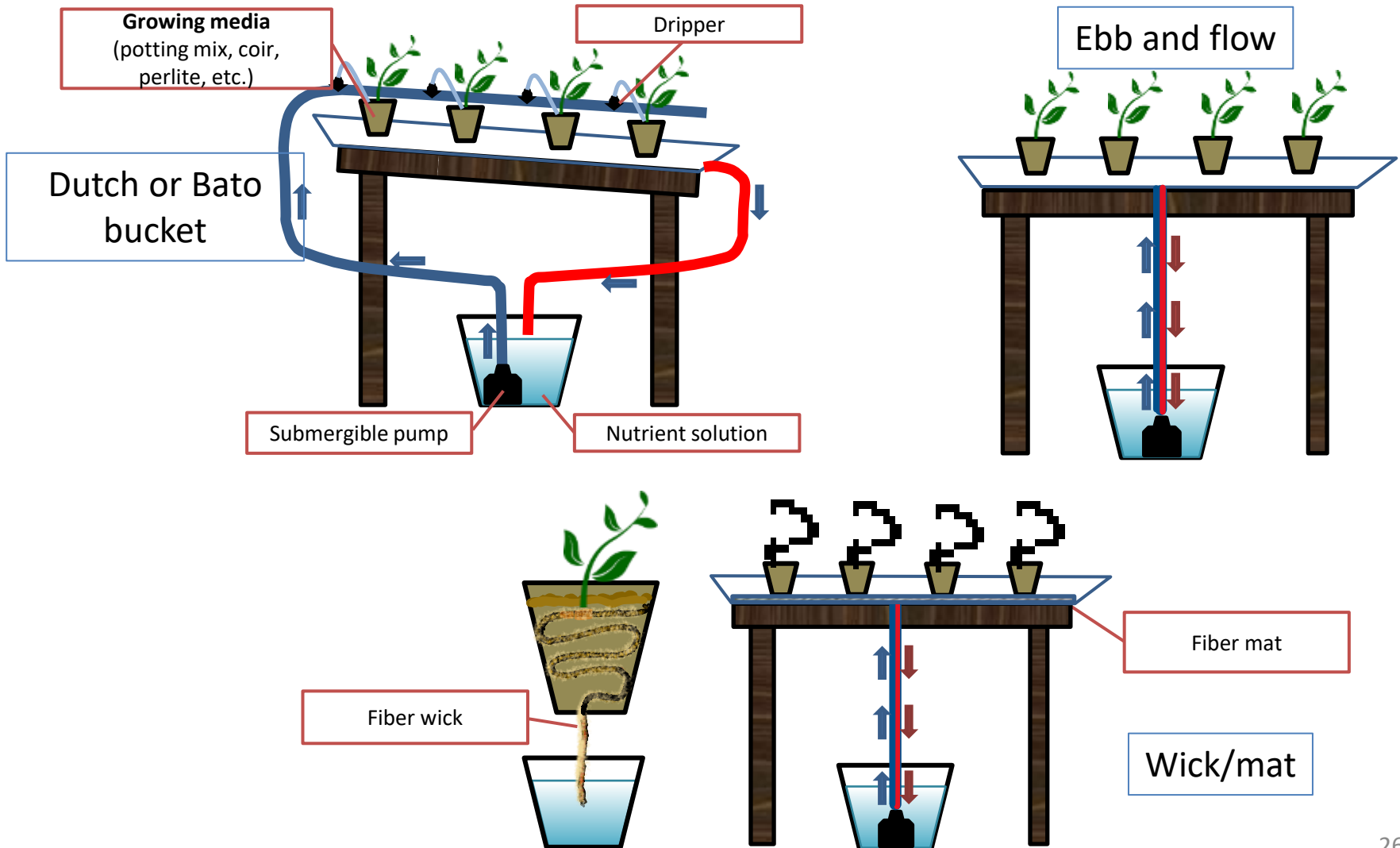
NFT



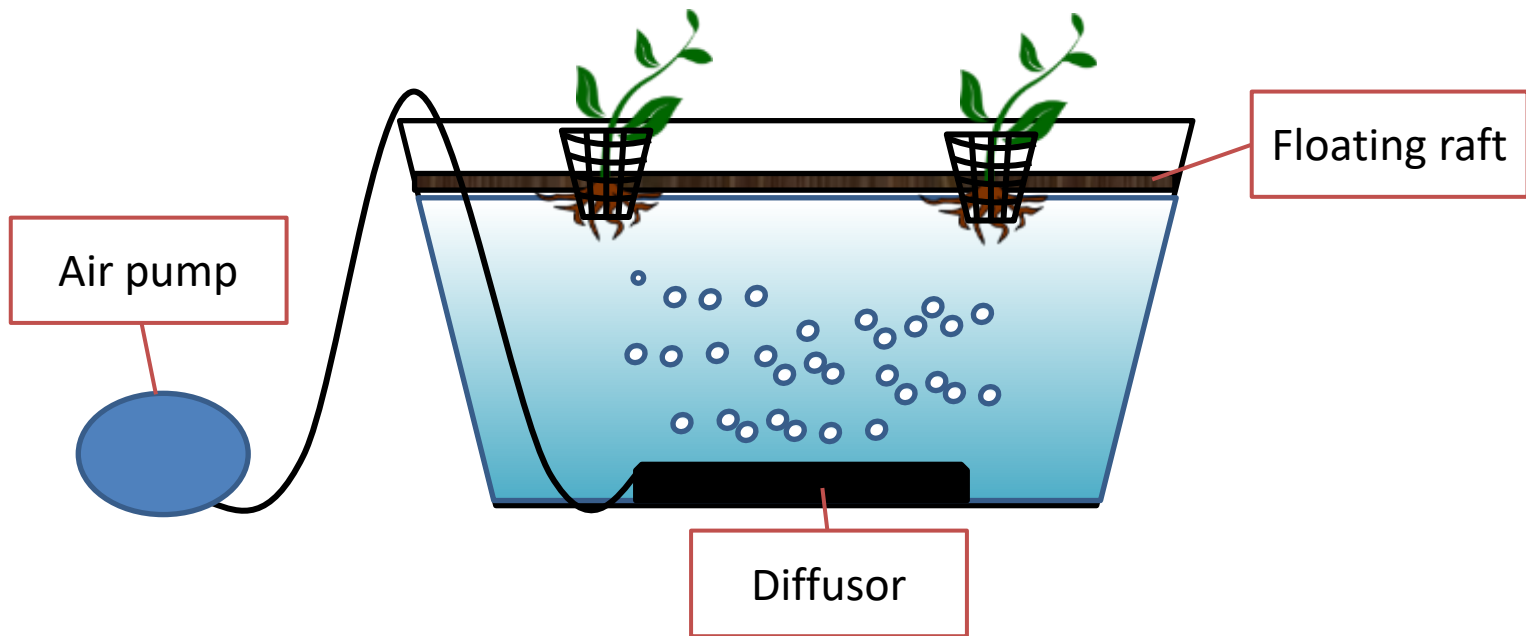
Aeroponic



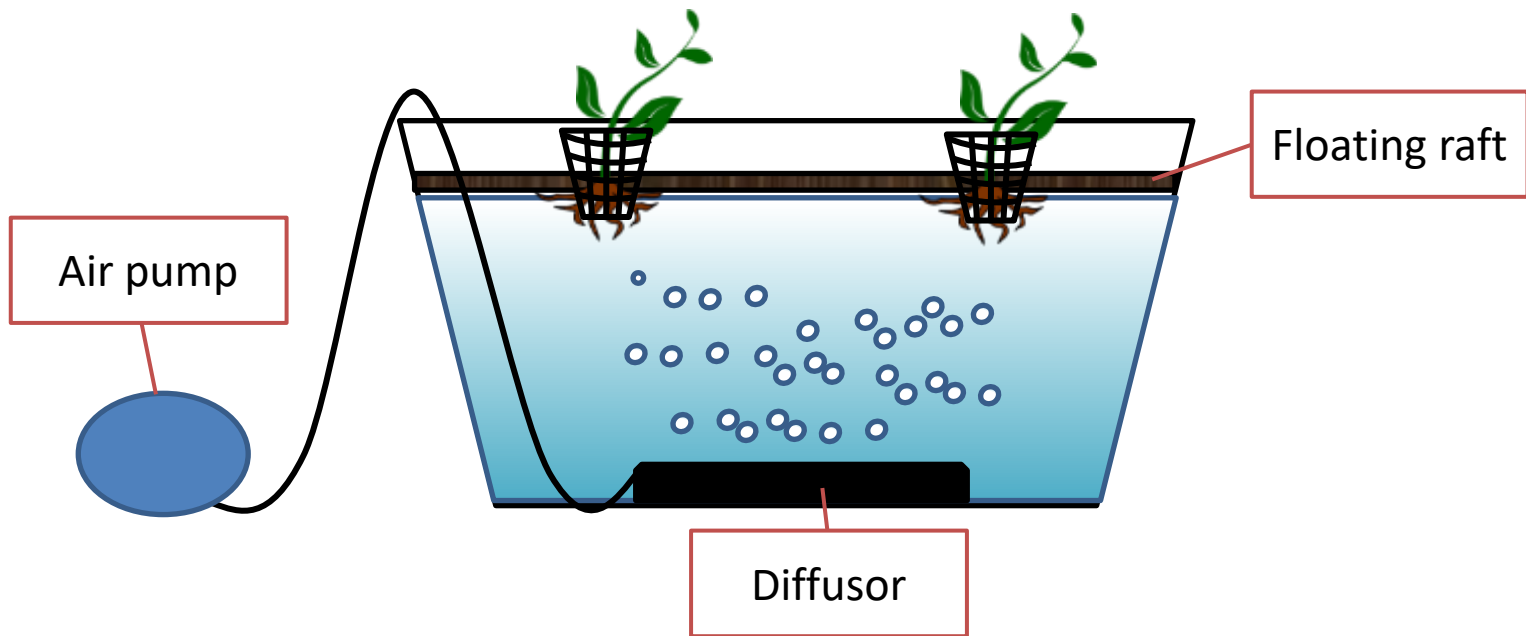
Solid systems



Deep water culture (DWC)



Deep water culture (DWC)

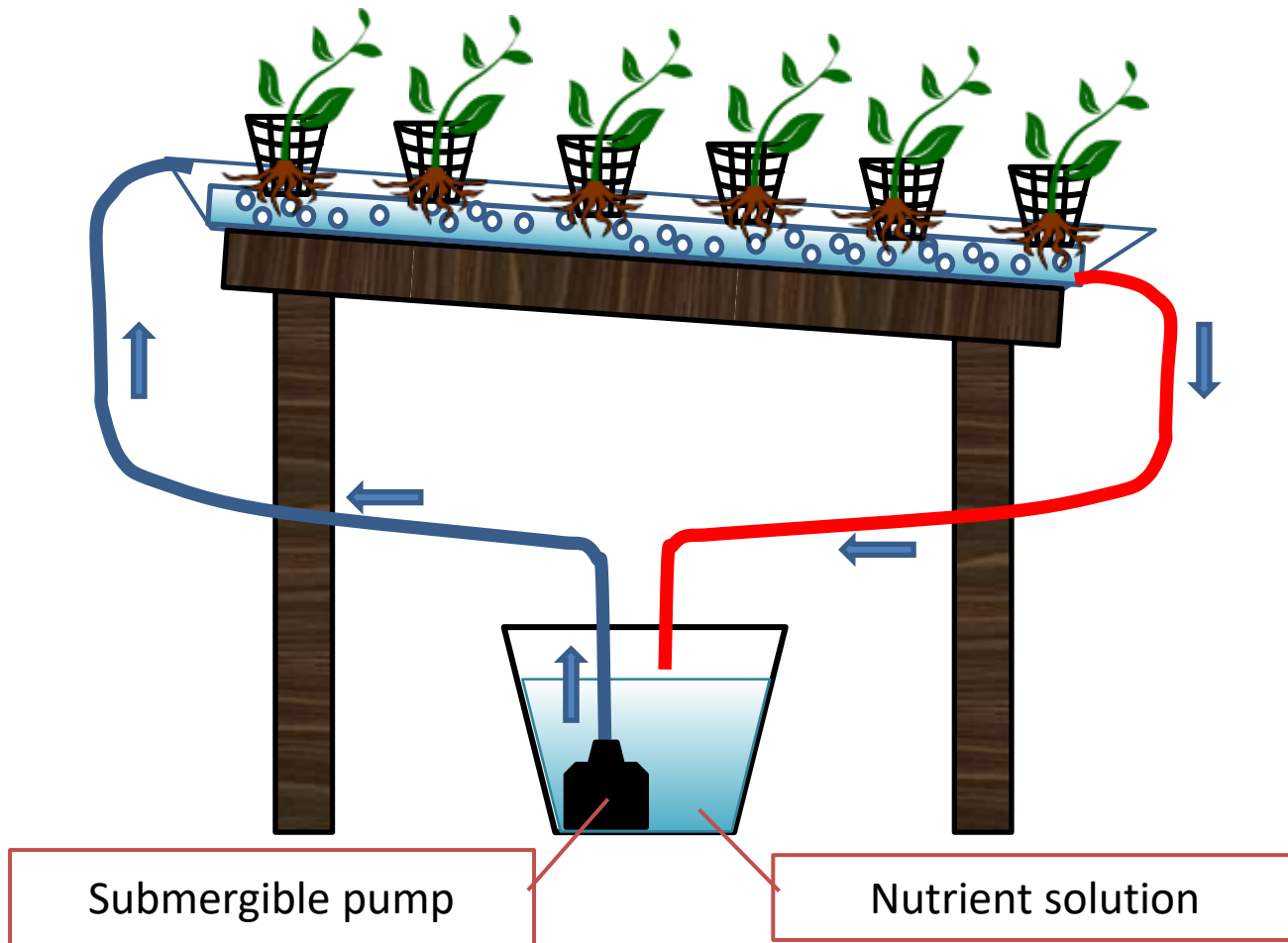


DWC

- ✓ For leafy greens and herbs
- ✓ Plants won't wilt if pump fails
- ✓ Simple construction requires less parts
- ✗ Needs aeration
- ✗ High water and fertilizer use
- ✗ Needs more time and resources to adjust the temperature, pH, and dissolved oxygen



Nutrient Film Technique (NFT)



NFT

- ✓ For leafy greens, herbs, and strawberries
- ✓ No need for aeration
- ✓ Uses less water and fertilizers than DWC
- ✓ Easier to adjust pH and temperature than DWC
- ✗ Susceptible to leakage
- ✗ Driplines can clog
- ✗ Plants wilt immediately if pump fails or if the system clogs



NFT or DWC?

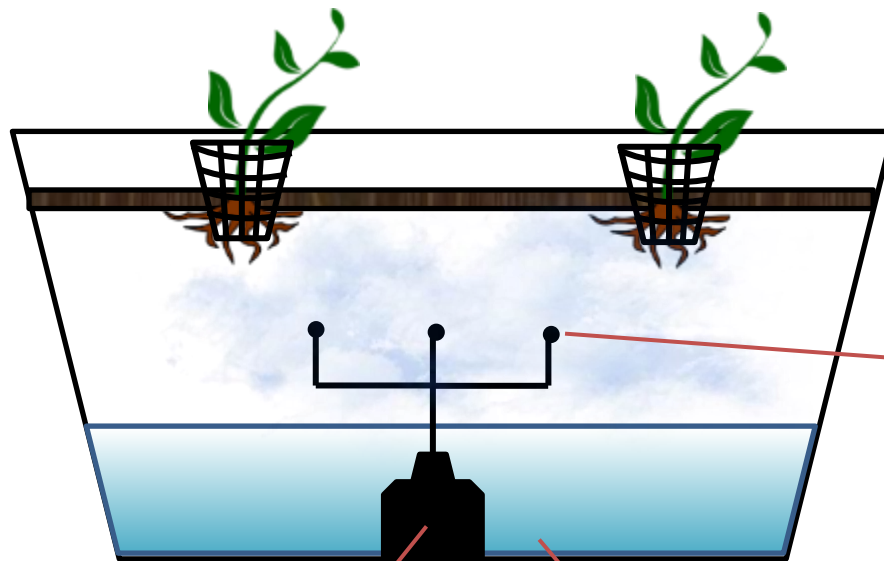
- Hardware & installation cost: ↓DWC \$1.9-\$2.75 per sq ft cheaper than NFT
- Water and fertilizer use: ↓NFT
- Nutrient solution management: easier in NFT
- Risk: ↑NFT

Which one to choose?

DWC will have higher operational costs than NFT but cheaper to build.

The grower must decide what is cheaper and easier to source.

Aeroponics



Micro
sprinkler/fogging
nozzle

Submersible pump

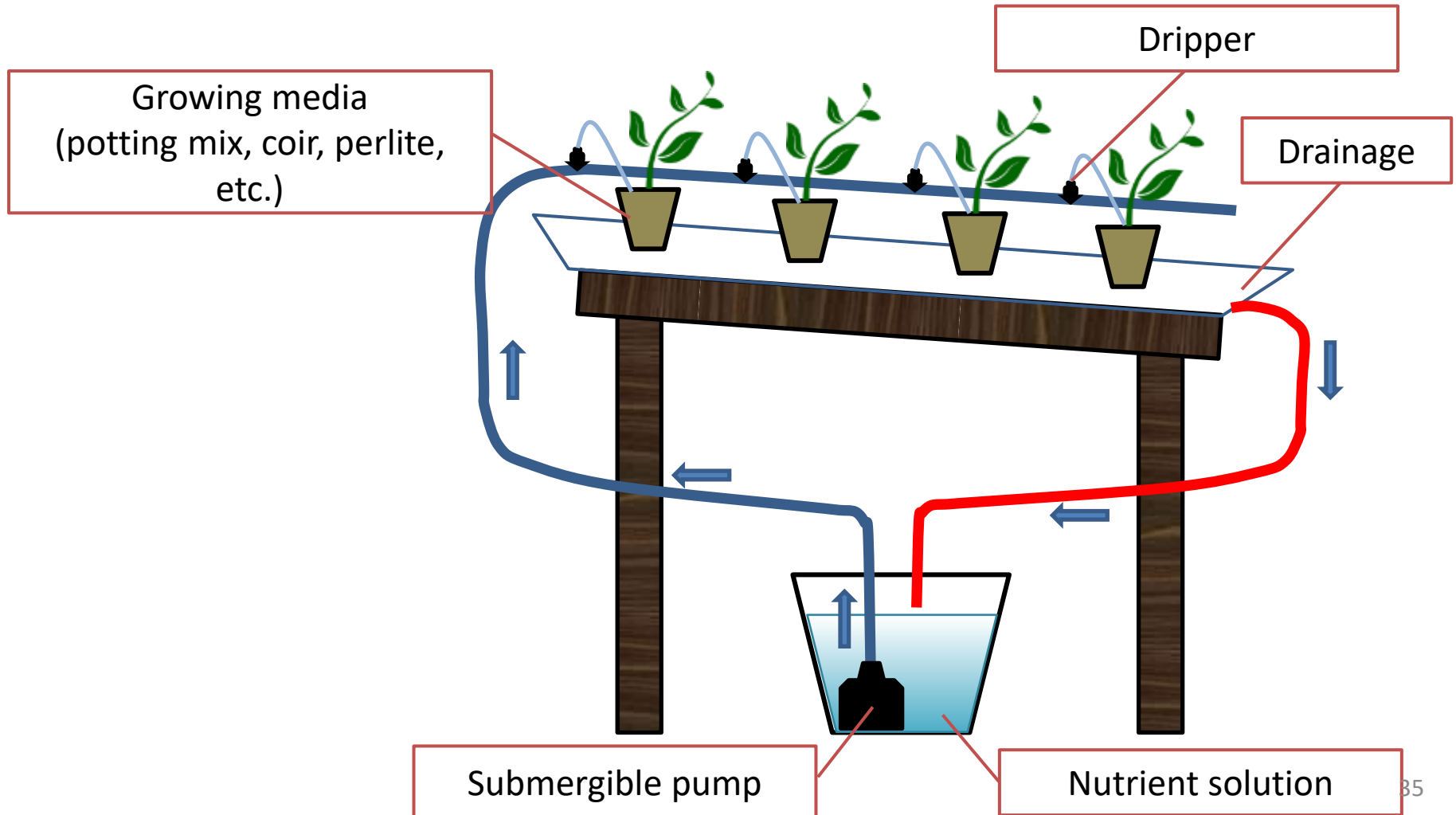
Nutrient solution

Aeroponics

- ✓ For leafy greens, herbs, and strawberries
- ✓ No need for aeration
- ✓ Requires less water than NFT and DWC
- ✓ Adaptable to many designs
- ✗ Requires good water quality to prevent clogging
- ✗ Plants wilt immediately if pump fails or emitters clog
- ✗ Requires a pressurized irrigation system



Dutch/Bato bucket



Dutch/Bato bucket

- Ideal for vines and fruiting crops– tomato, cucumber, cantaloupe
- Needs trellis system to guide plant growth and support weight
- The irrigation frequency and nutrient/water retention will depend on the type of **growing media**





Source: galaku.com

Growing media options



Perlite



Coir



Rockwool



Potting mix



Expanded clay pellets

Any material that can be sourced locally?

Affordable
Sustainable
Locally sourced



Gravel

Inert

pH of nutrient solution = rootzone pH

Rockwool



- ☑ Water retention, good aeration, adaptable to several systems, and stable over time
- ☒ Requires prolonged saturation, difficult to decompose, not organic, and costly

Coconut coir



- ☑ Retains water and nutrients, good aeration, sustainable, cheap, and compostable
- ☒ Variable quality (depends on supplier) and not stable over time

Growing media materials



Perlite

- ☑ Cheap , aeration
- ☒ Low water retention, dust



Expanded clay pellets

- ☑ Reusable, stable over time
- ☒ Low water retention, \$\$\$, heavy



Gravel

- ☑ Cheap, stable over time
- ☒ Low water retention, heavy



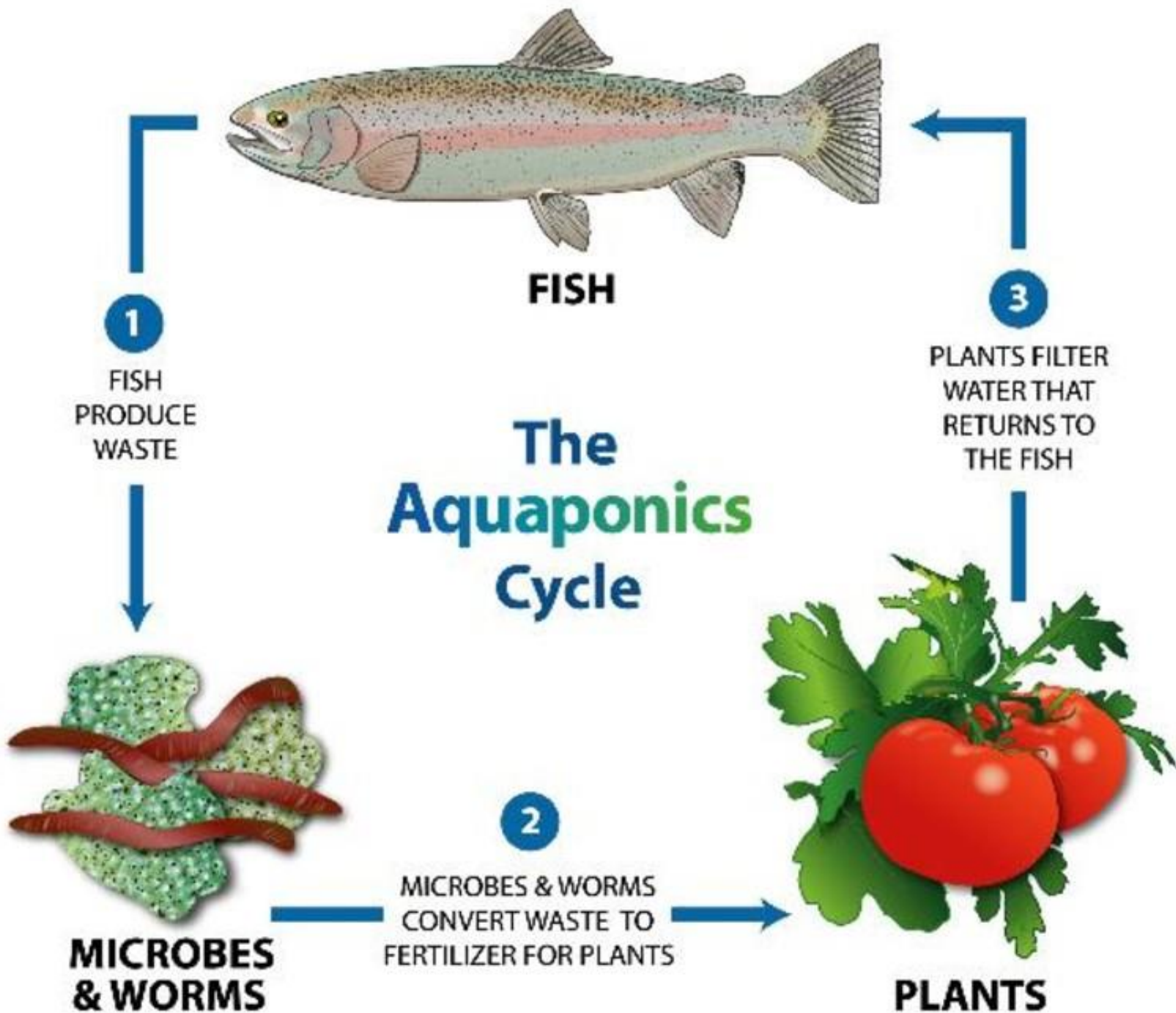
Commercial mixes
Sustainable? (peat)

- ☑ Retains water and nutrients
- ☒ pH changes over time (constant monitoring) not stable over time

Aquaponics



It's not easy. The fish residues may not provide all nutrients and there is a lot of solid residues



Fish:plant Ratio

- Ratio depends on the amount of fish feed used
 - Temperature: fish metabolism
 - Fish species and growth stage
- For DWC systems: 60 – 100 g/m²/day
 - 100 g of feed per day = 1 – 1.6 m²
 - 100 m² of production = 6,000 – 10,000 g/day
 - NFT uses 25% of the requirements for DWC
- On average fishes will consume 1 – 5% of their weight per day
- Ideally measure nitrogen forms and adjust the fish:plant rates
- You might need to supplement plants with added fertilizers

Investment estimates

- Rule of thumb \$15 to \$30 per sq ft*

	Double layer PE tunnel	Arched polycarbonate	Gothic polycarbonate
	Infrastructure cost \$ per sq ft		
Dutch bucket kit	\$18.23	\$21.76	\$29.42
NFT system	\$20.75	\$24.28	\$31.94
DWC	\$19.67	\$23.20	\$30.85
Aquaponic system	\$42.02	\$45.55	\$53.20

- Production costs:

	Tomatoes	Leafy Greens
Field cost (\$/lb)	\$0.59	\$0.62
Greenhouse cost (\$/lb)	\$0.70	\$1.70
Indoor farm cost (\$/lb)	\$1.85	\$4.25

*Estimates for a 30' x 96' production bay

Quick financials

- Dutch Bucket Tomato in greenhouse
 - Capital investment \$21.76: \$3.11 per year 7-year simple depreciation
 - Tomato yield per cycle (15-40 lb/sqft): 20 lb
 - Production cost/sq ft: 20 lb x \$0.7 = \$14
 - Total cost: \$17.11 per sq ft per year ($\approx 43\%$ of gross revenue)
 - Gross revenue: 20lb x \$2 = \$40 per sq ft
 - Net revenue: \$22.89 per sq ft

Quick financials

- DWC lettuce in greenhouse
 - Capital investment \$23.20: \$3.31 per year 7-year simple depreciation
 - Plant yield at 8 inch spacing (28-33 heads/sqft): 30 heads/sqft (18 lb at 0.6 lb per head)
 - Production cost/sq ft: 18 lb x \$1.7 = \$3.06
 - Total cost: \$6.37 per sq ft per year ($\approx 10\%$ of gross revenue)
 - Gross revenue: 30 heads x \$2 = \$60 per sq ft
 - Net revenue: \$53.63 per sq ft

Topics

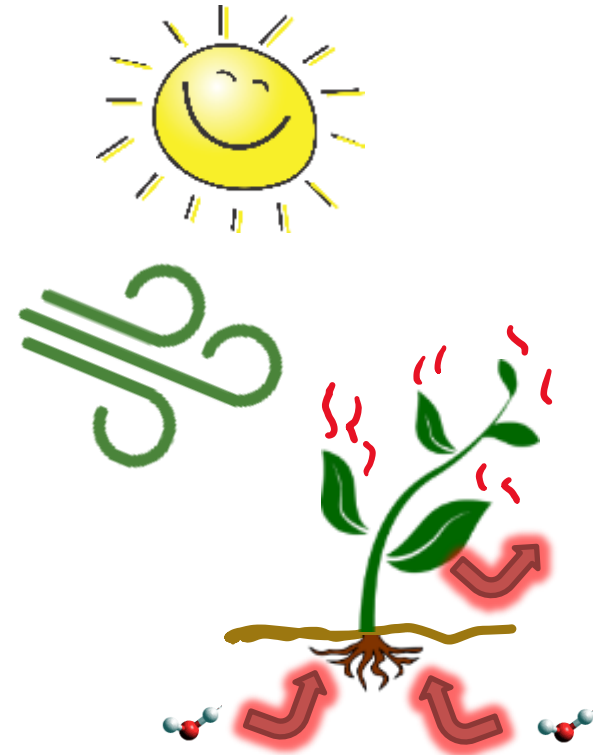
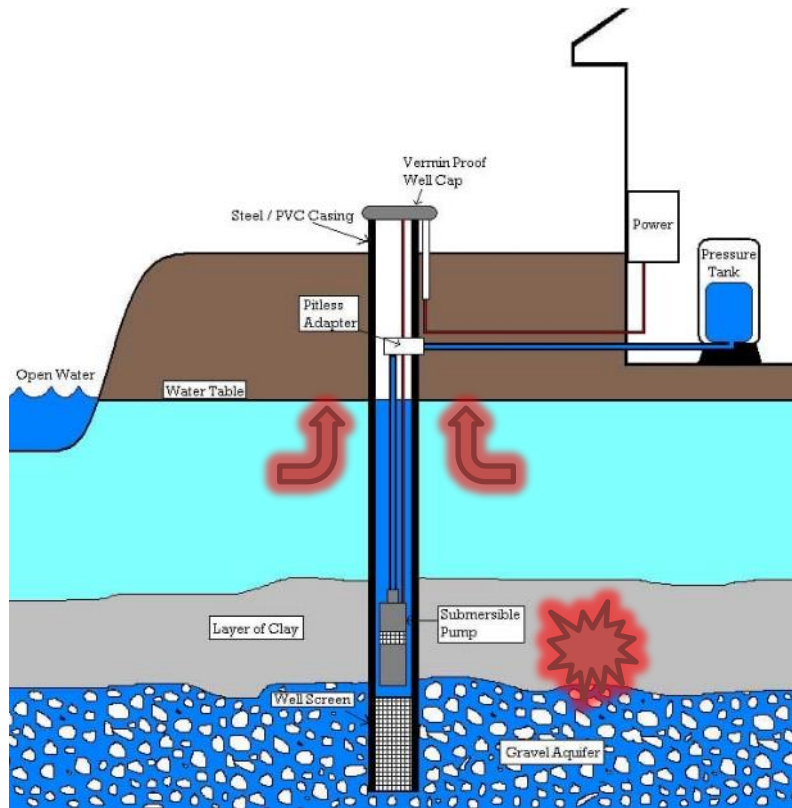
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Environment monitoring systems

- Temperature: air and water
- Relative humidity
- Solar radiation
- Nutrient solution
 - pH
 - Electrical conductivity
 - Dissolved oxygen
 - Nitrogen: nitrate, nitrites, ammoniacal nitrogen



Air flow and water absorption



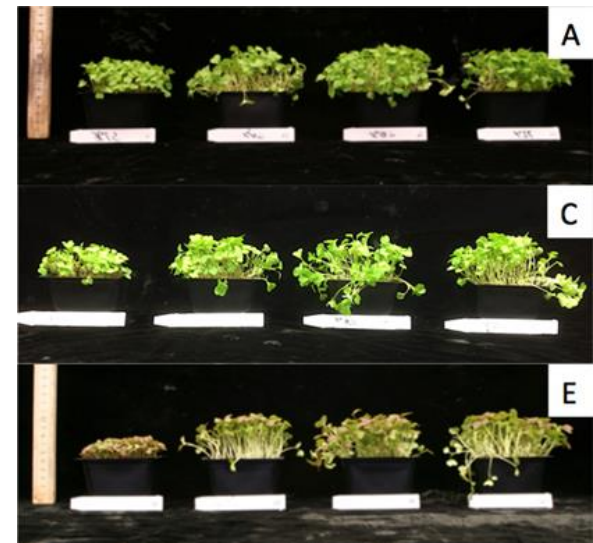
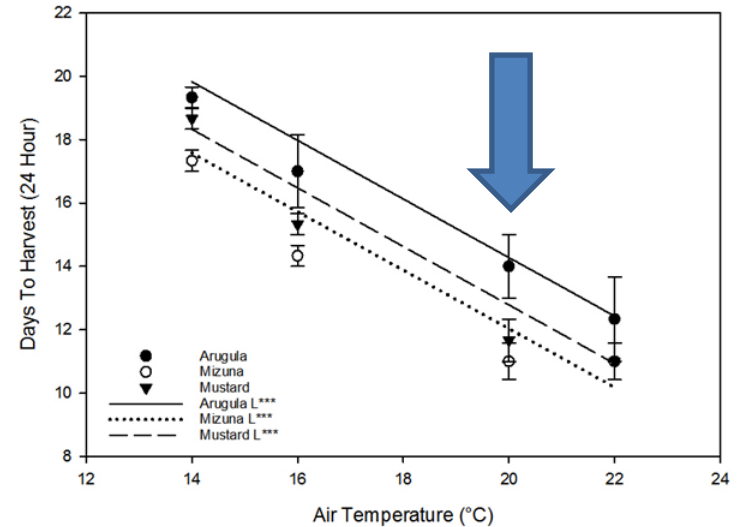
Air flow and water absorption



Brendan Morrison and Allayana Darrow. The Planet Magazine.
<https://theplanetmagazine.net/a-vertical-horizon-586ff6f67e98>

Temperature

- Cool temperatures slow down germination and growth, increasing time to harvest.
- Avoid temperatures below 68°F (20°C)
- Maximum temperature 85°F (29°C). Increases disease pressure and inhibit germination in some varieties
- Rule of thumb over 68°F and under 75°F



Lighting considerations

- Cost: Natural sunlight is free!
- Distance from plants
 - Low heat emitting lights: LED and Fluorescent lamps
- Light coverage
 - Fixtures that spread light
- Quantity and Quality



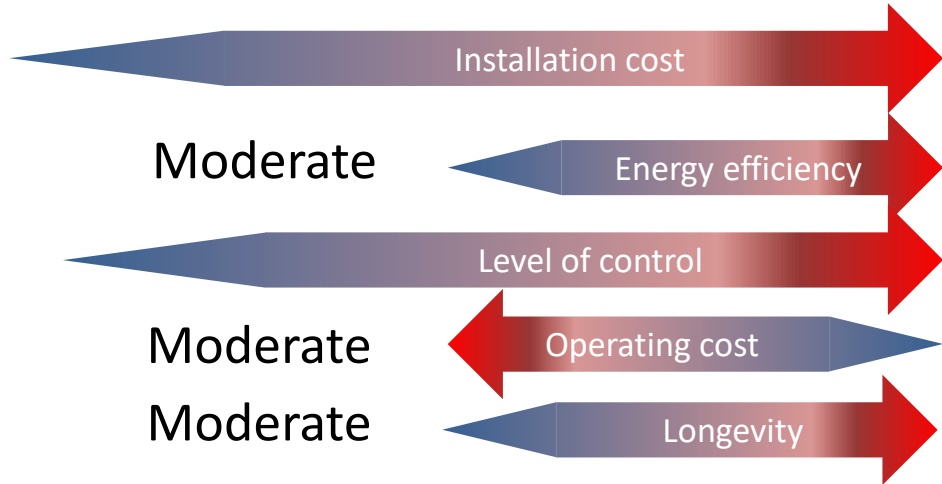
Image from: thekitchn.com

Sunlight vs Fluorescent vs LED



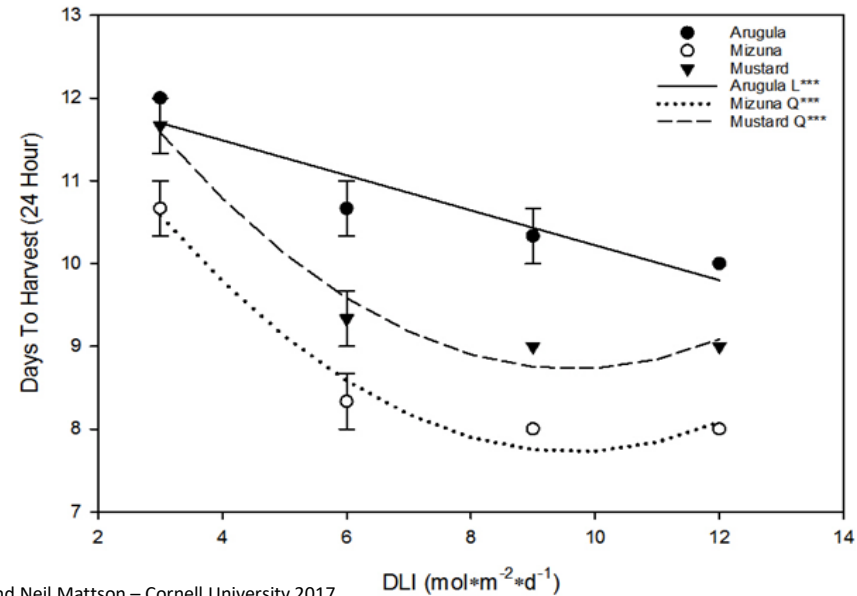
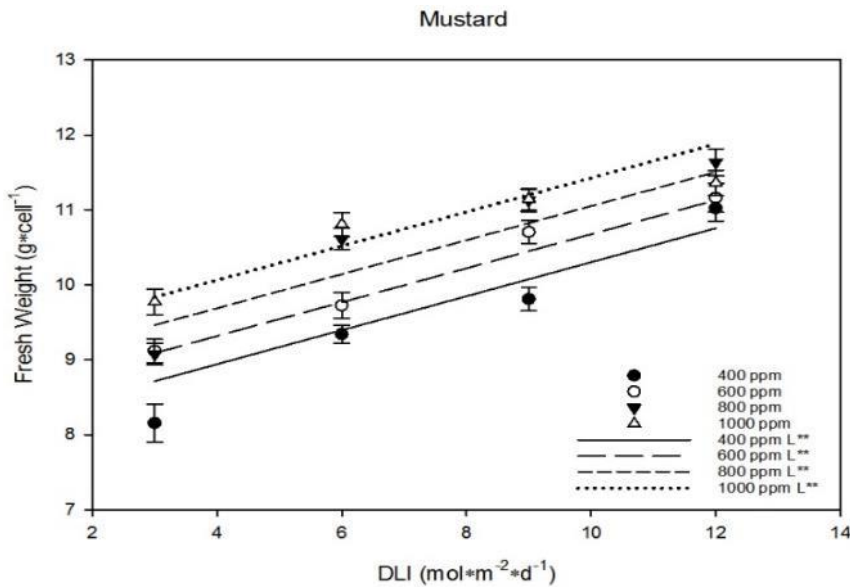
FREE!

\$\$\$



Light quantity and growth

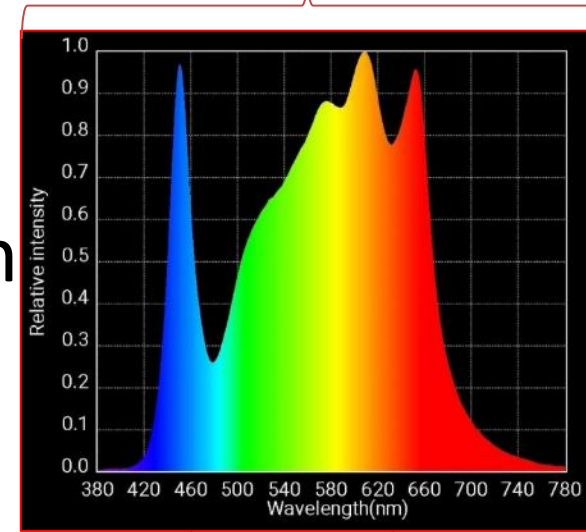
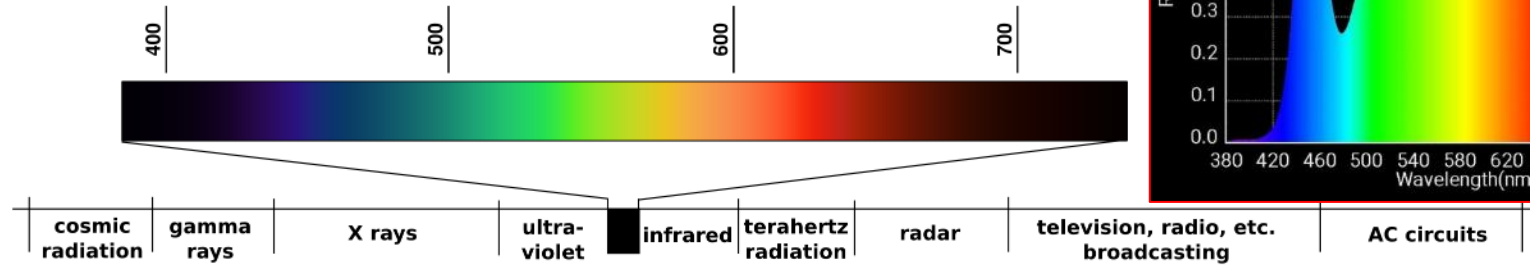
- Decreases days to harvest
- Increases weight
- Provide 12 to 16 hours per day



Jonathan Allred and Neil Mattson – Cornell University 2017

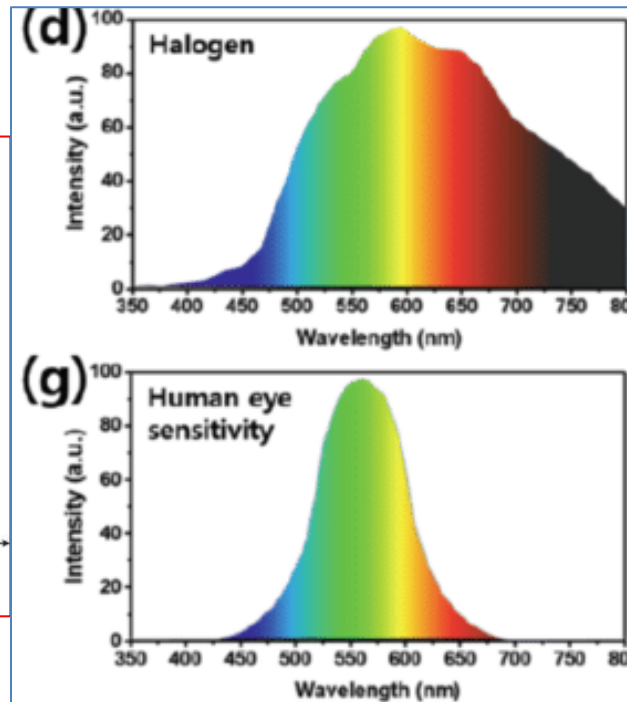
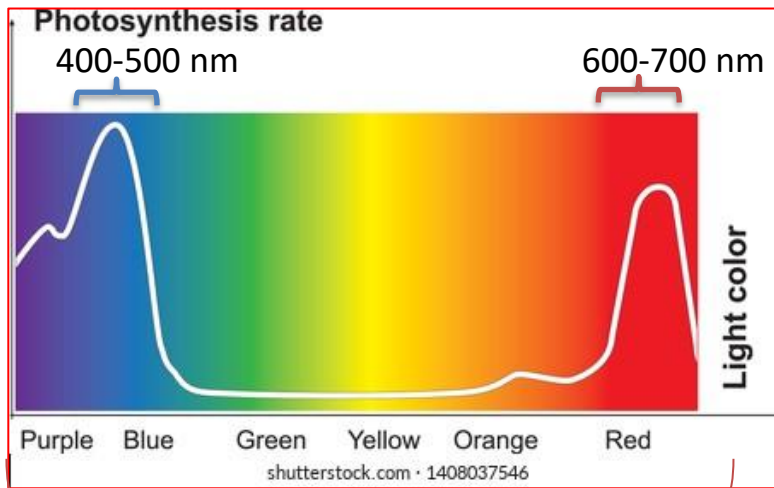
Light quality

- Light used by plants: 400-700 nm



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- Peak photosynthesis:

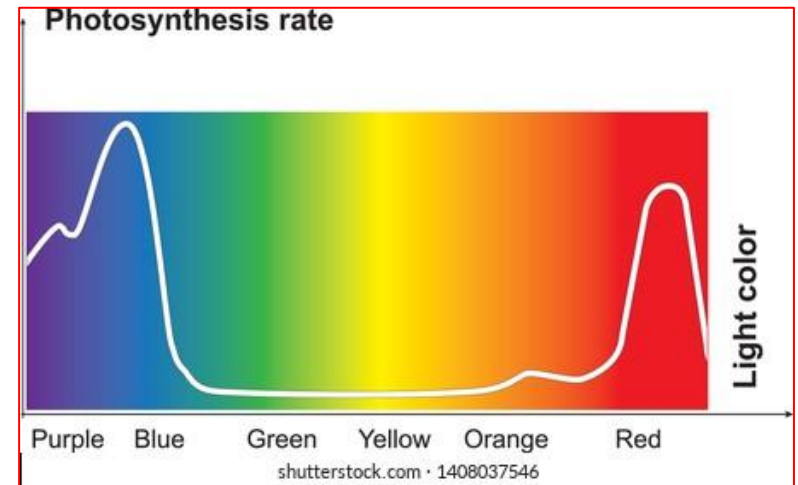
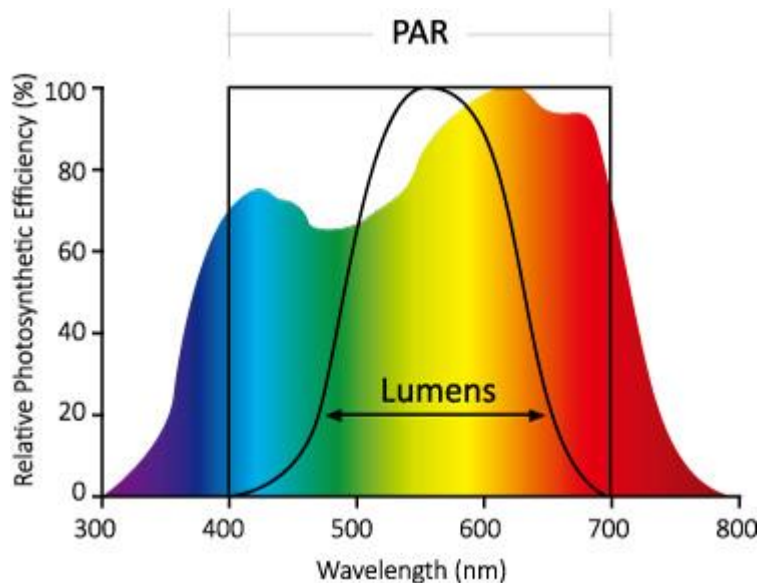


For plants

For human eyes

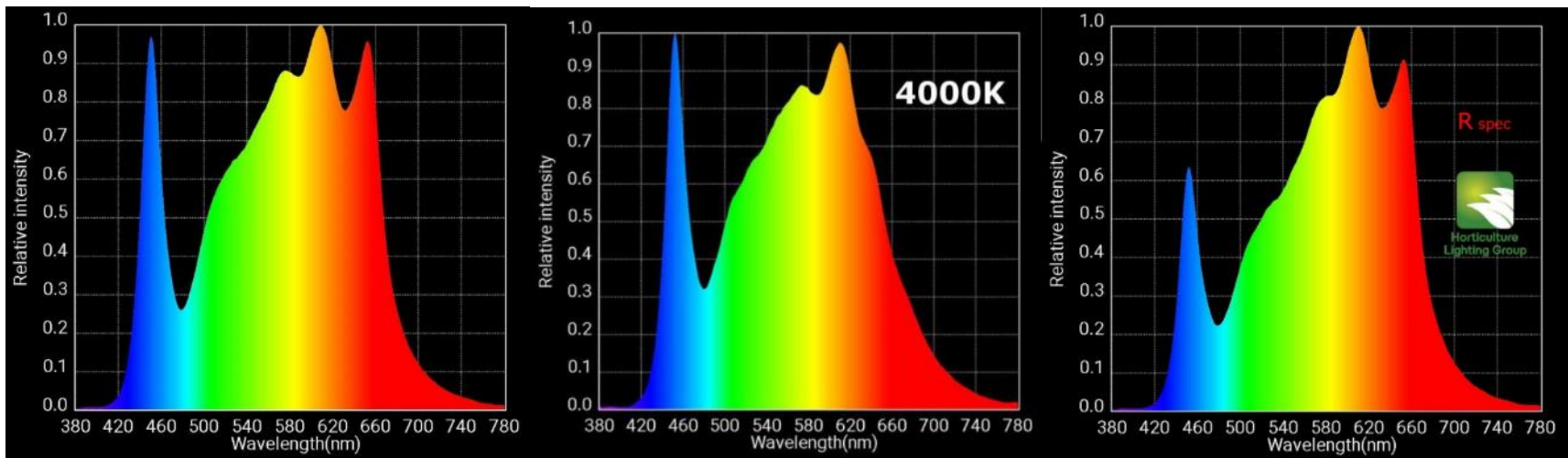
Light quality

- **Avoid:** candela, foot candles, lumens, lux
- **Proper units:**
 - Photosynthetically active radiation (PAR) 400-700nm
 - Photosynthetic Photon Flux (PPPF)
 - Photosynthetic Photon Flux Density PPPFD



Light quality

- Red light: Promote growth, flowering in tomatoes
- Blue light: Promote accumulation of nutrients (anthocyanin), too much stunts growth
- Growers apply light treatment throughout the season or at the end of the season



Keeping plants in their comfort zone

1. Air flow: 55 to 60% relative humidity (dehumidifier/air flow)
2. Adequate lighting: 14 hours per day (LED lights)
3. Keep proper temperature (HVAC)
4. Provide adequate amounts of essential nutrients
 - Prepare nutrient solution
 - Electrical conductivity (EC)
5. Monitor and adjust the pH of the nutrient solution
 - Affects availability and absorption of nutrients
6. Manage the water temperature and dissolved oxygen