Gardening for Home, Profit, and Space: Growing Food on Earth and in Space

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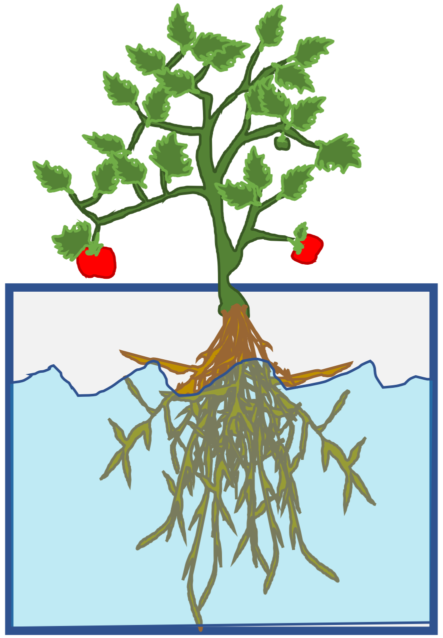
http://www.spacefarms.info
https://www.cyanreact.com
See also: NSS Space Settlement Journal

Overview

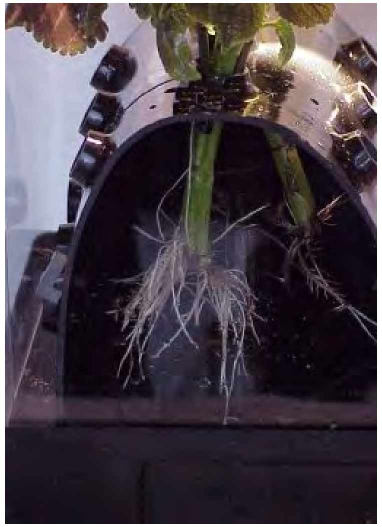
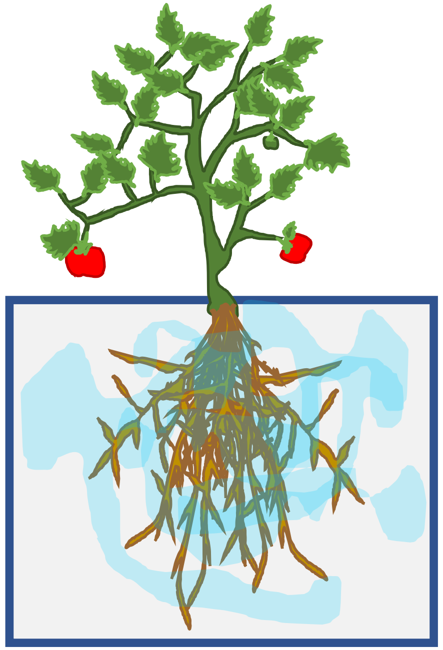
- Can I survive on just hydroponics? (No.) Can I grow a dinner at home, yup.
- Soil vs not soil
  - How much room for dinner in a soil farm?
  - Benefits and costs for soil-less
- Media vs. No Media
- Extra Stuff: All the tanks, pipes, and other stuff beyond the obvious
- What changes in microgravity?
- Getting and starting growth in space
- Scale concerns: Going from a salad to feeding a settlement

Terms

- Hydroponics: use of soilless containers to hold roots and grow plants, with or without media. Water and nutrients flow through or in.
- Media: stuff like rocks, gravel, etc. around the roots that let water flow through
- Aquaponics: combination of hydroponics and a fish or shrimp tank
- Aeroponics: use of sleeves with mists in lieu of flowing liquid water




https://en.wikipedia.org/wiki/Hydroponics

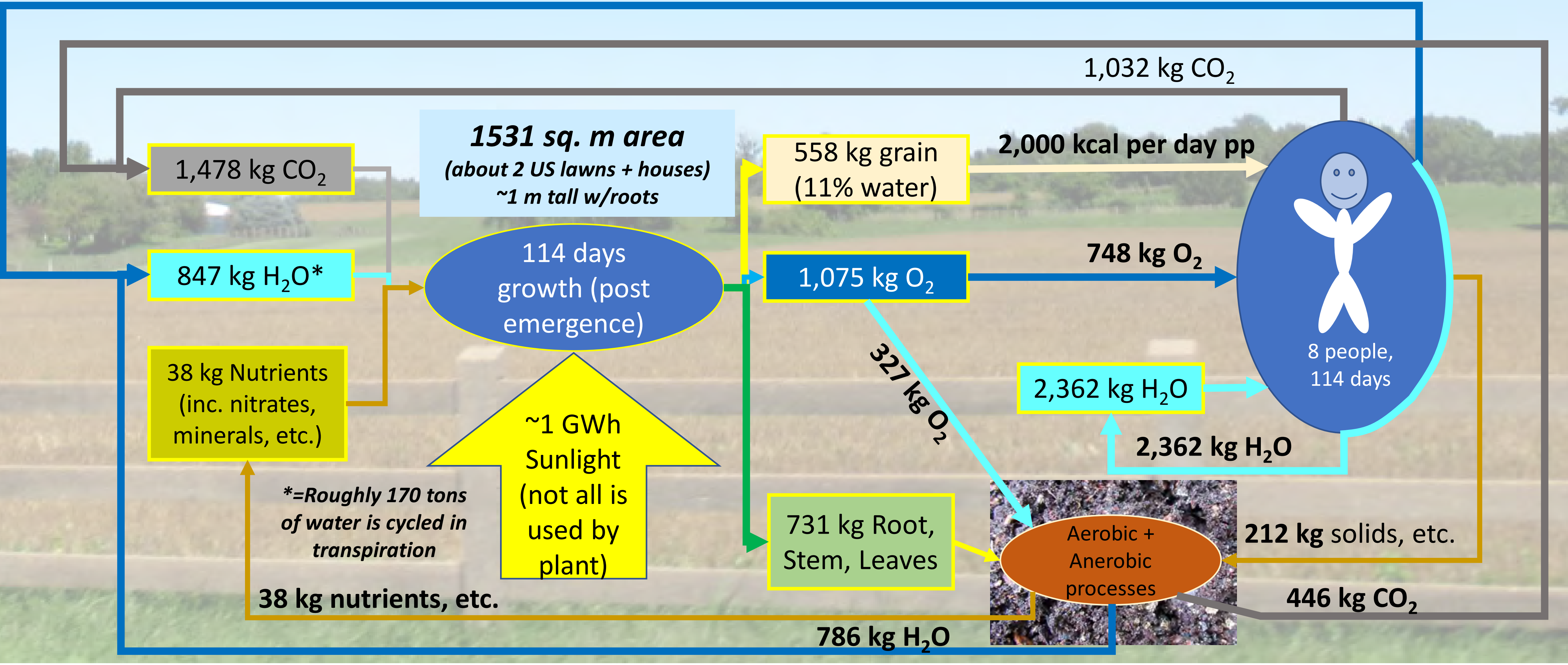



https://en.wikipedia.org/wiki/Aeroponics

Food for 8: Earth Analogy

- On Earth, Farms are soil based and take in things we take for granted:
  - Assume all 8 settlers just eat wheat ("man cannot live on bread alone…" literally in this case) 114 day cycle:

Human values roughly from NASA Handbook, Wheat loosely from MO Dept of Ag.



Plants live in two worlds

- Green parts want CO2 and light
- Roots want O2, H2O, and darkness
- Plants evaporate water from leaves, which pulls water from roots to leaves

Photosynthesis:

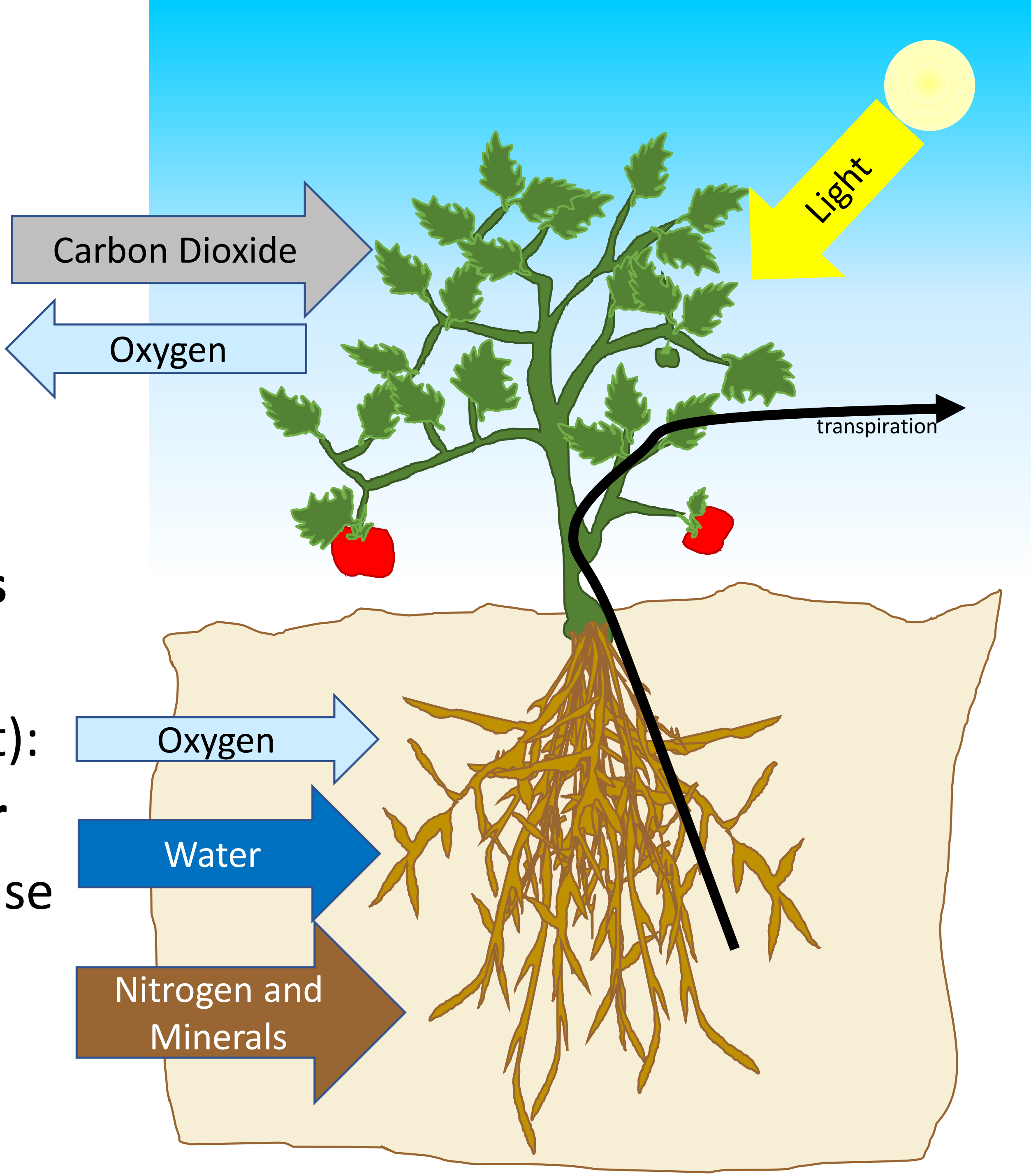
Water + Carbon Dioxide → Oxygen + Sugars

In roots and ***around*** roots (and ripening fruit):

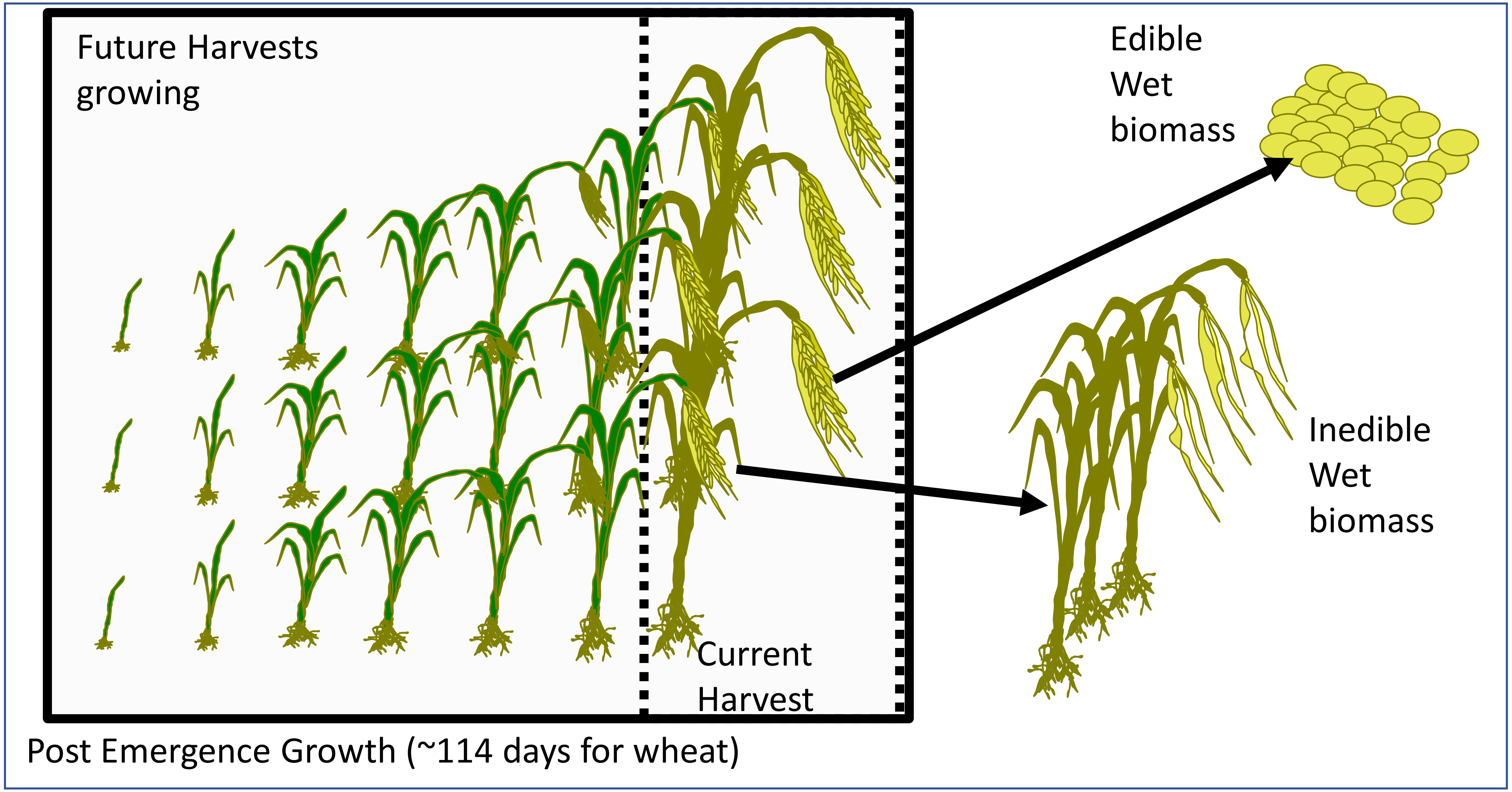
Sugars + Oxygen → Carbon Dioxide + Water

Soil has fungi and bacteria that help plants use nutrients (nitrogen) and manage water.

Photosynthesis produces far more oxygen then roots use.



Growth Cycle/Continuous Harvest



What is Soil?

Soil, i.e. dirt is a living community on particles of various chemicals:

- Living parts:
    - Insects, worms
        - Help break up wood, leaves, dead animals, manure, etc.
        - Aerate the soil
    - Mycorrhizae fungus
        - Aid in water use by plants
    - Bacteria:
        - Decomposers (esp. the ones that digest cellulose!)
        - Nitrogen-fixers (take N2 in atmosphere and fix it into chemicals plants can use)
- Non-living but important:
    - Nitrates and Nitrogen compounds
    - Minerals and salts

https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053862

Earth Soil Crop Table

FYI…
A hectare is 2.47 acres

My house and yard together are 0.12 acres so 1 hectare = 22 houses + yards

If my house and yard were a farm field and I grew potatoes, I could feed 2.4 people for a year after a growing season (180 days+/-),i.e. 1 couple and child.

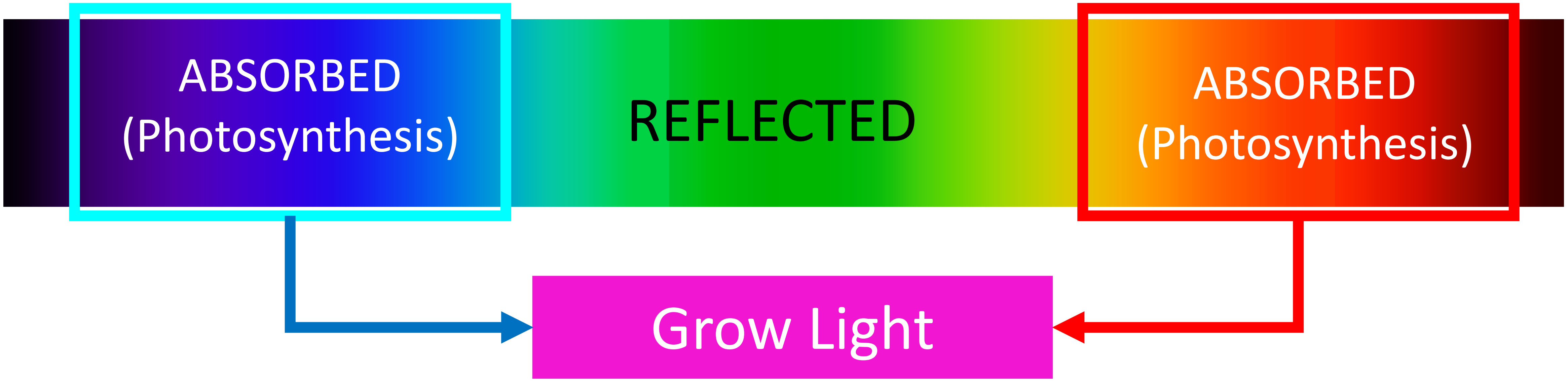
This is why potatoes were so important for Ireland!

Crop	Footprint (m2 per kg edible wet mass)	How many people a year for 1 crop cycle per hectare? (2000 kcal/day)	Reference Links
Barley	1.34	36	https://www.ag.ndsu.edu/crops/barley
Bell Peppers	0.60	6	https://aggie-horticulture.tamu.edu/smallacreage/crops-guides/vegtables/bell-peppers/
Corn	0.65	74	https://www.ag.ndsu.edu/publications/crops/north-dakota-corn-hybrid-trial-results-for-2017/a793-17.pdf
Lettuce (Arugula)	1.12	3	https://ipmdata.ipmcenters.org/documents/cropprofiles/NJarugula.pdf
Onion	0.28	20	https://coststudyfiles.ucdavis.edu/uploads/cs_public/37/c8/37c88af8-b52e-45eb-bc21-2acd754b0c0a/onionredvs06.pdf
Oats	1.82	29	https://www.ag.ndsu.edu/publications/crops/north-dakota-barley-oat-and-rye-variety-trial-results-for-2018-and-selection-guide/a1049-barley-oat-rye-18.pdf
Peanuts	2.42	32	https://www.farmprogress.com/peanuts/peanut-production-101-rotation-key-bigger-yields
Pinto Beans	0.32	11	https://www.ag.ndsu.edu/publications/crops/pinto-bean-response-to-phosphorus-starter-fertilizer-in-east-central-north-dakota
Potatoes	0.19	54	http://kenoshapotato.com/Potato_Production_USA.htm
Rice	1.01	49	https://www.statista.com/statistics/190832/top-us-states-for-rice-yield-per-harvested-acre/
Soybeans	2.44	8	https://www.ag.ndsu.edu/publications/crops/north-dakota-soybean-variety-trial-results-for-2018-and-selection-guide
Strawberry	0.13	33	https://www.agmrc.org/commodities-products/fruits/strawberries
Tomato	0.24	4	https://extension.uga.edu/publications/detail.html?number=B1312&title=Commercial%20Tomato%20Production%20Handbook
Wheat	2.78	17	https://www.ag.ndsu.edu/publications/crops/browse-by-crop
Rye	3.86	12	https://www.ag.ndsu.edu/publications/crops/north-dakota-barley-oat-and-rye-variety-trial-results-for-2018-and-selection-guide/a1049-barley-oat-rye-18.pdf

Species	Inputs				Outputs				
	H_2O	CO_2	Biomass		O_2	live biomass (edible + inedible) (water + dry mass)	% water in live mass	inedible mass %	notes
			Nitrogen	Minerals,etc.					
Algae	0.944	0.155	0.008	0.004	0.112	1	91%	0%	
Lettuce (Arugula)	0.917	0.101	0.012	0.037	0.066	1	92%	4%	
Onion	0.891	0.172	0.001	0.004	0.068	1	89%	10%	at near maturity
Peanut	0.630	1.430	0.0310	0.0090	1.100	1	34%	55%	at maturity pre-dry. Kernel is 7% water
Pinto Beans	0.530	1.490	0.027	0.038	1.080	1	11%	11%	at near dry maturity
Potatoes	0.670	0.350	0.040	0.190	0.250	1	79%	29%	pre-dry
Rice	0.601	1.450	0.016	0.013	1.080	1	7%	57%	at dry maturity
Soybeans	0.680	0.599	0.020	0.055	0.354	1	34%	78%	at near dry maturity
Strawberry	0.910	0.132	0.048	0.048	0.090	1	91%	63%	assume similar elements in ined and edible
Tomatoes	0.96	0.16	0.00541	0.0046	0.13	1	80%	50%	remaining plant and crops accumulate inedible mass

White Light, maybe. Dark sometimes.

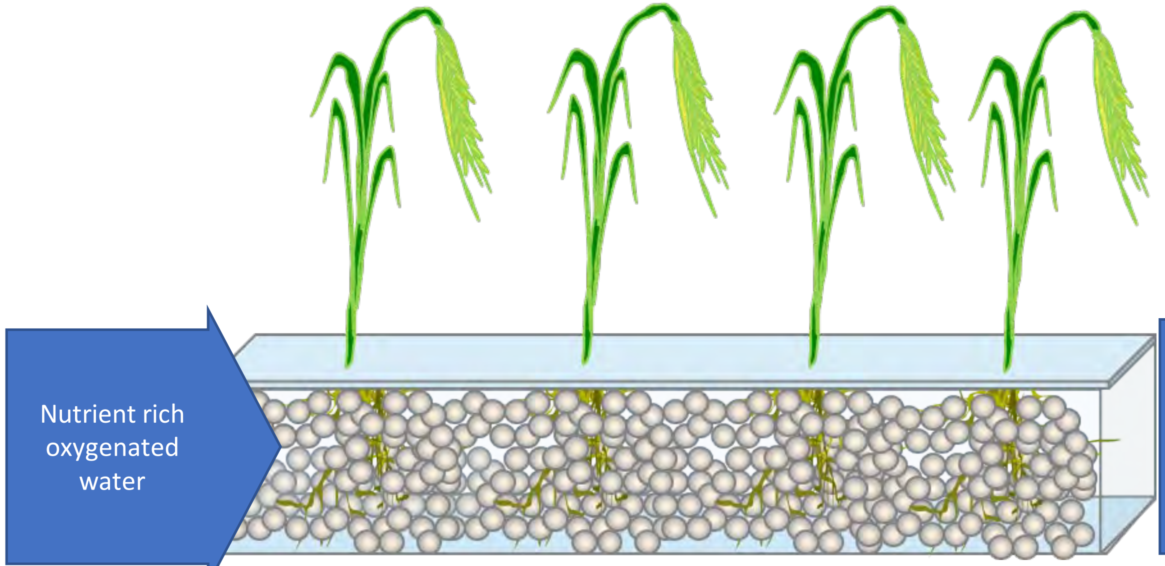
- 'White Light' is a mixture of colors
- Most plants and algae reflect green light and absorb red and blue light.
- Exception: At some times (e.g. flowering), plants also need white light
- Dark: Most plants need some dark time to move around sugars and make chemicals.
- Too much light can overheat (burn) plant leaves!
- Air circulation helps with cooling, and other things.

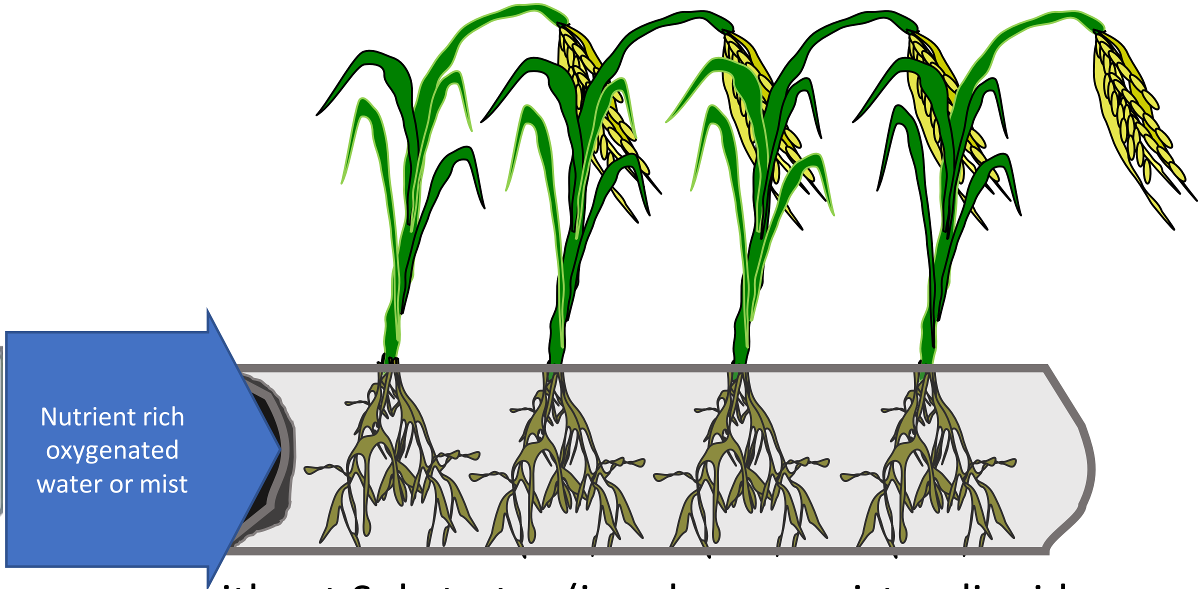


Air circulation, humidity, and fans

- Fans are used in hydroponics to circulate air
  - Controls humidity:
    - Too much humidity=mold, low transpiration
    - Too little = dried out leaves in some kinds of plants
  - Circulates Carbon dioxide for photosynthesis and carries off oxygen produced
- Closed areas will need dehumidifiers to further control humidity
- Closed areas will need added carbon dioxide
  - Burning, fermentation, animals and people.
- NOTE: People do not exhale enough CO2 to feed themselves…..

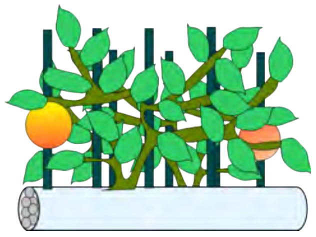
Core Technologies:
Growing Vascular Plants w/o Soil





Using Substrates (i.e. pebbles, fiber, marbles):

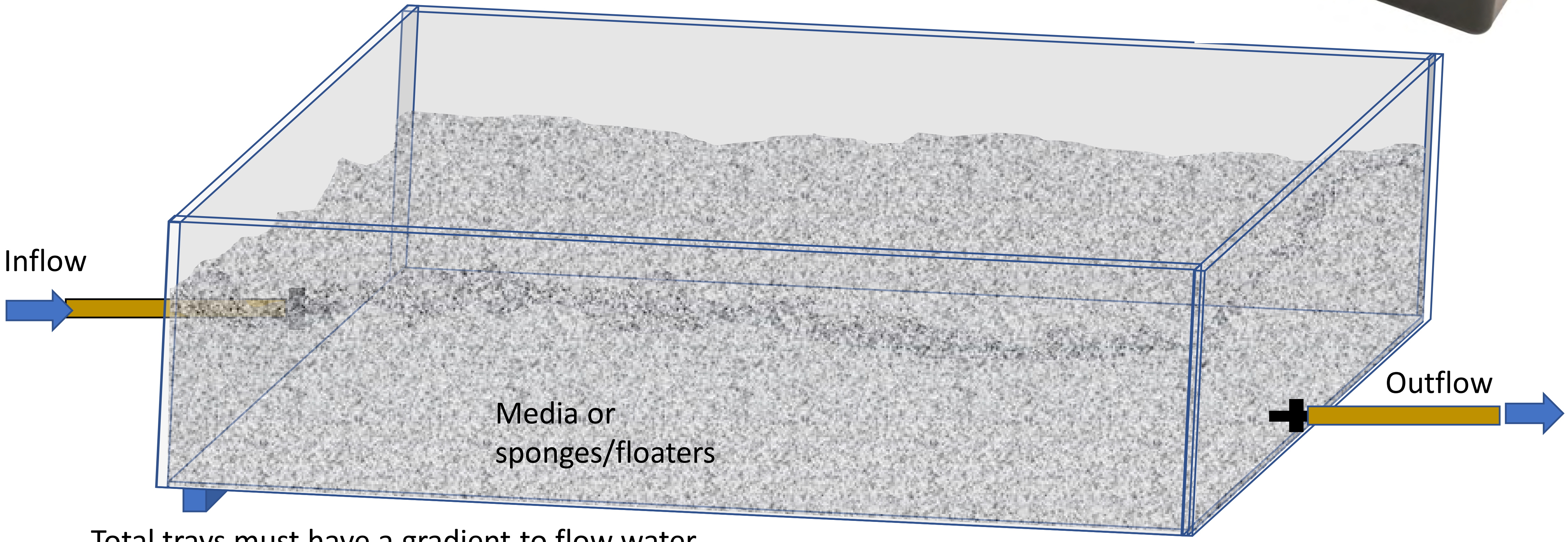
- Costs:
  - Requires mass for substrate (in-situ or shipped)
  - Can clog if flow is not well managed
- Benefits:
  - Allows higher productivity using root fungi and bacteria



without Substrates (i.e. sleeves, mist or liquid systems):

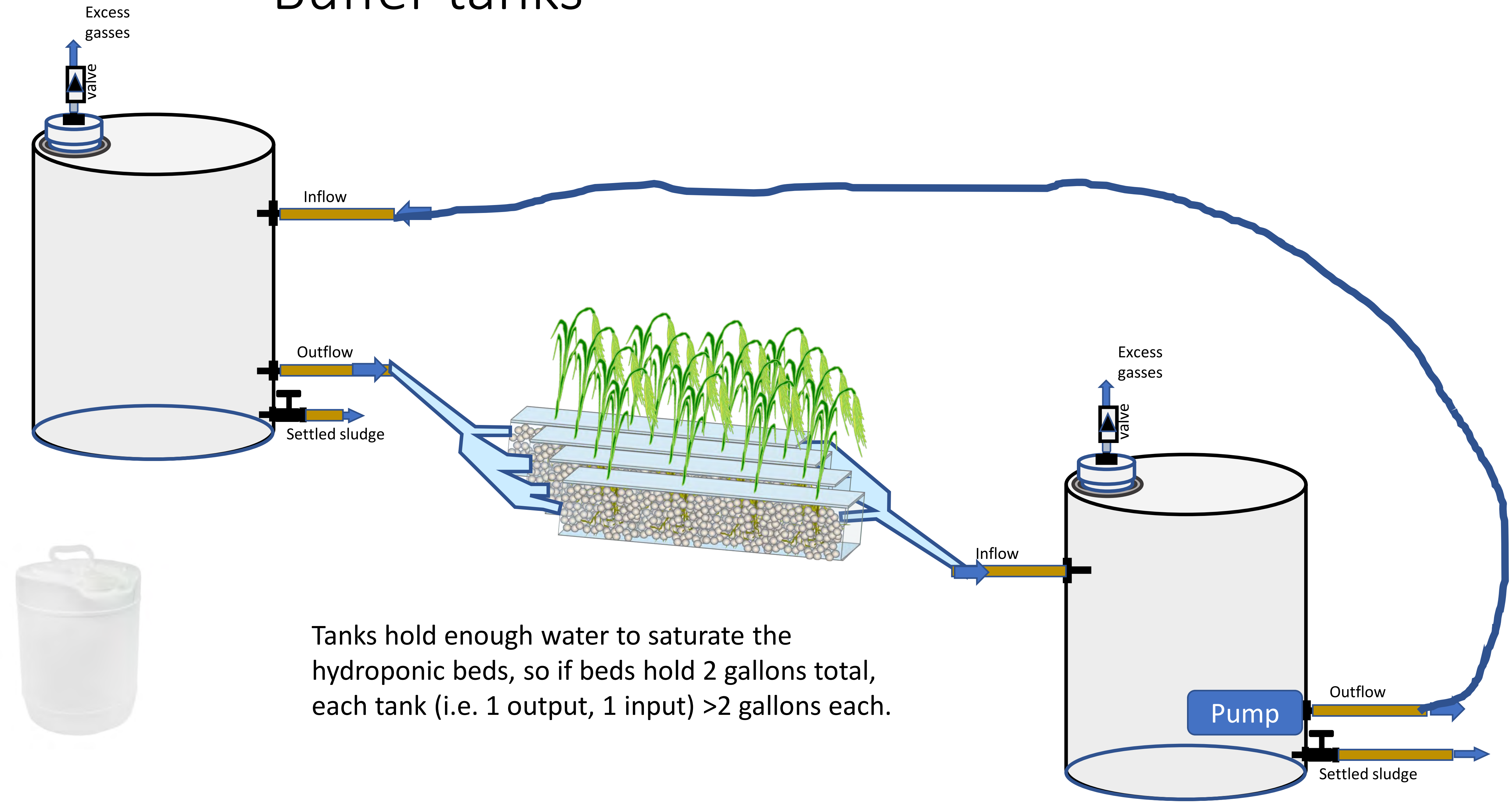
- Costs:
  - Low bacteria and fungi growth in roots
- Benefits:
  - Very low initial mass and volume
  - Well controlled nutrient and root environment

Cheap Plant Growth Trays



Total trays must have a gradient to flow water

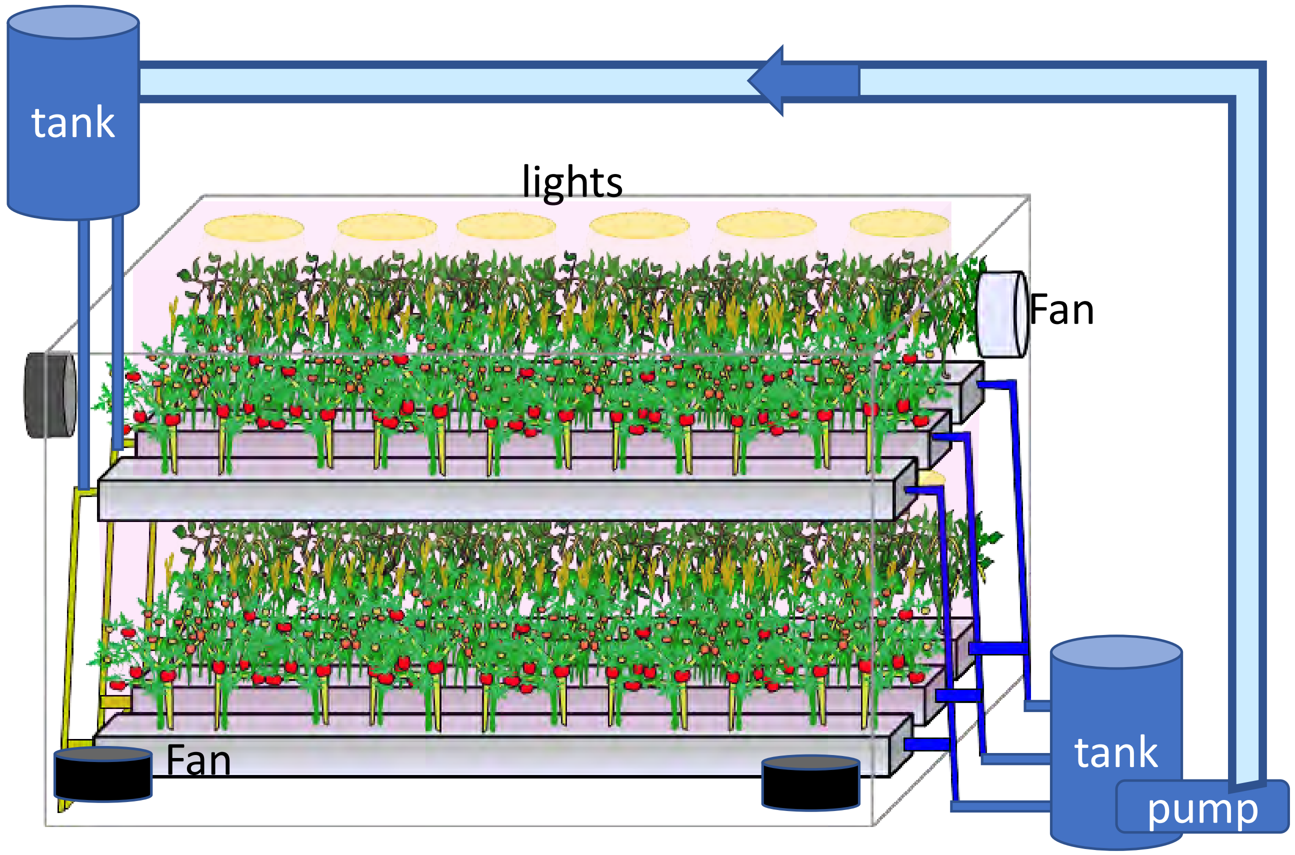
Buffer tanks



Tanks hold enough water to saturate the hydroponic beds, so if beds hold 2 gallons total, each tank (i.e. 1 output, 1 input) >2 gallons each.

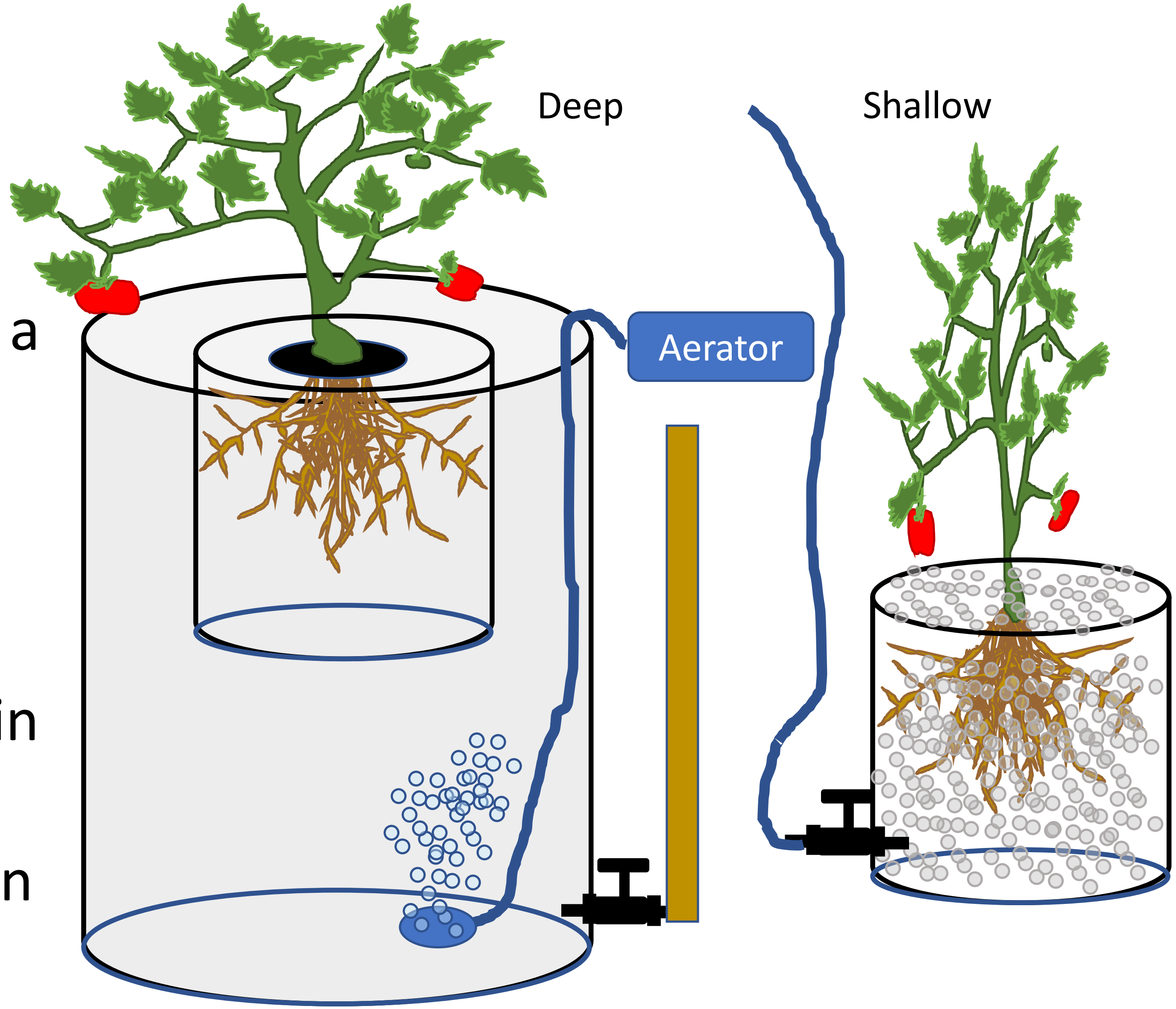
Hydroponics: Trays and Shelves

- Hydroponic Stage uses:
  - Lighting above and around
  - pumps to push and pull liquids or mists through trays
  - oxygen injectors and nutrient mixers for root bed (or complex pump cycle to oxygenate roots)
  - Fans to move air around plants
  - Condensers to collect transpired water
  - Sensor arrays to monitor roots, plants, with complex control systems, filters to protect pumps.
  - Pumps/Fans to manage heat level and rejection
- Human Labor: Pollination, pruning, watching sensor arrays and control systems, filter changes, etc.
- Most of the structure can be built using in-situ materials
- Initial load: seeds, sensor/control systems, pumps, lights.



Bucket Hydroponics

- May or may not use media or a basket
- Roots immersed in a oxygenated nutrient solution
- Transpiration pulls water out, and water is added to maintain water level in bucket
- Shallow bucket: Most common type for a certain pharmaceutical

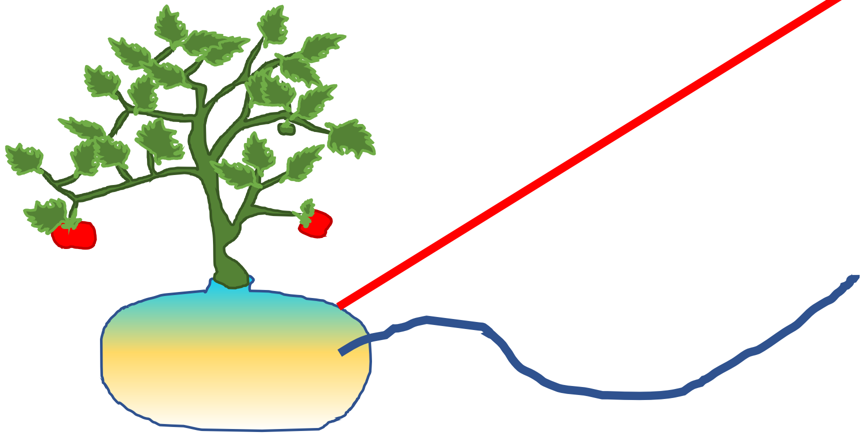


https://www.homedepot.com/p/Viagrow-Hydroponic-Deep-Water-Culture-Vegetative-System-4-Site-V4DWCV/203124373?mtc=Shopping-B-F_Brand-G-Multi-NA-Multi-NA-Feed-PLA-NA-NA-Catchall_PLA&cm_mmc=Shopping-B-F_Brand-G-Multi-NA-Multi-NA-Feed-PLA-NA-NA-Catchall_PLA-71700000014585962-58700001236285396-92700010802552454&gclid=EAIaIQobChMIuN_mq4e56AIVd___jBx3l1gsZEAQYASABEgJ54_D_BwE&gclsrc=aw.ds

Zero G concerns

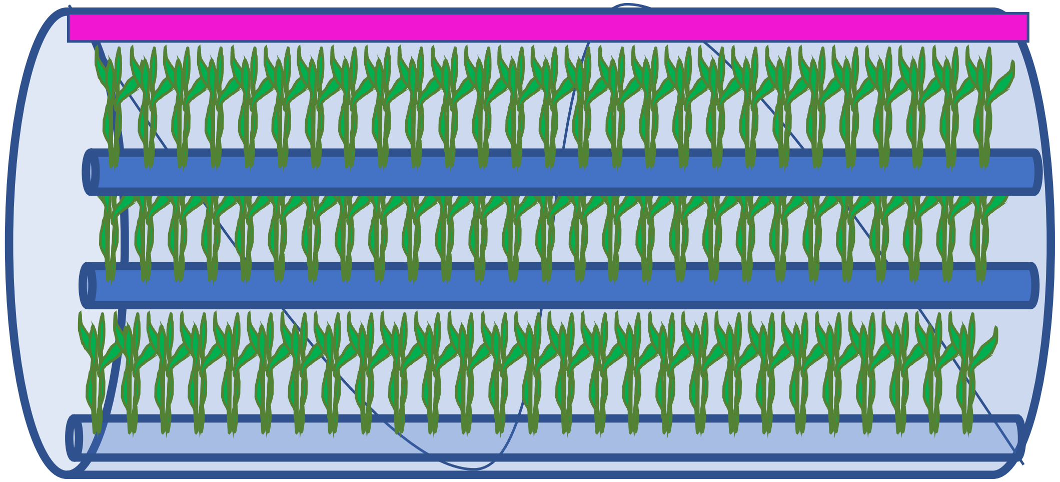
- Water flow slowly by capillary action
- Air must be moved with fans
- Condensers(Dehumidifiers) actively collect water from air and pump into root bed/media
- Water added slowly to roots (in bag or fiber diaper or container)

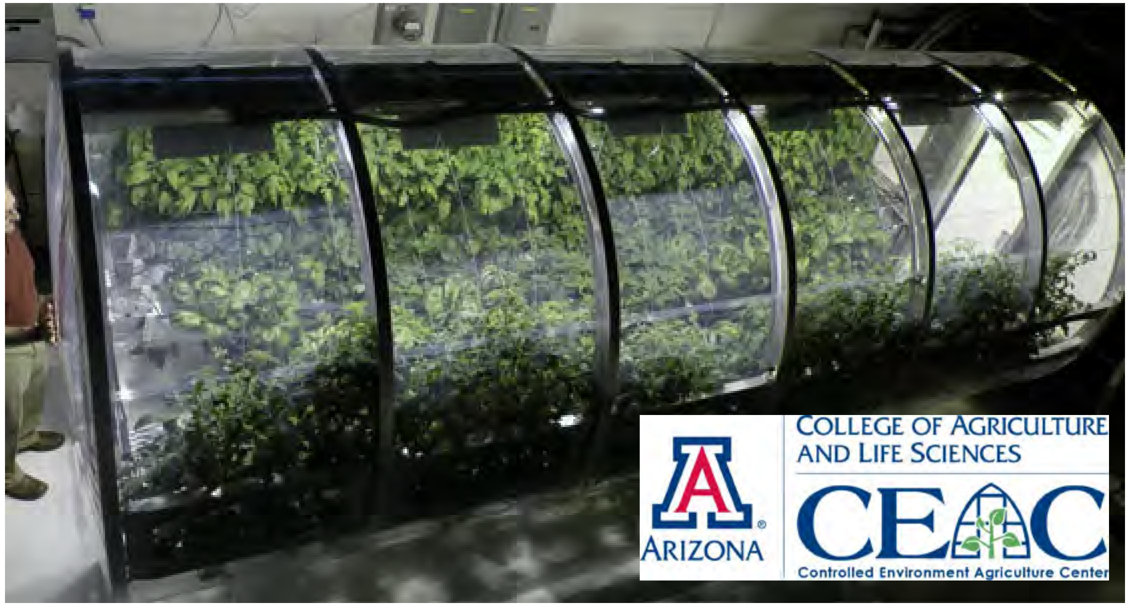
https://www.nasa.gov/content/growing-plants-in-space



Antarctica to the Moon

- University of Arizona has developed:
  - Packing Media garden for the South Pole
  - a sleeve system and enclosed expanding hydroponic garden



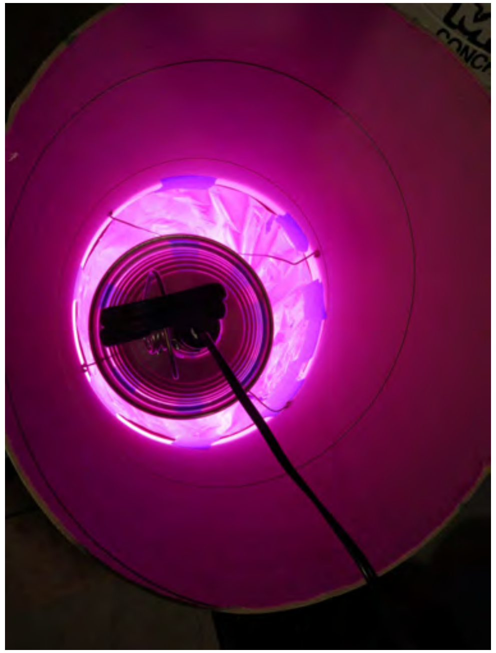


https://ceac.arizona.edu/research/south-pole-growing-chamber

https://cals.arizona.edu/lunargreenhouse/

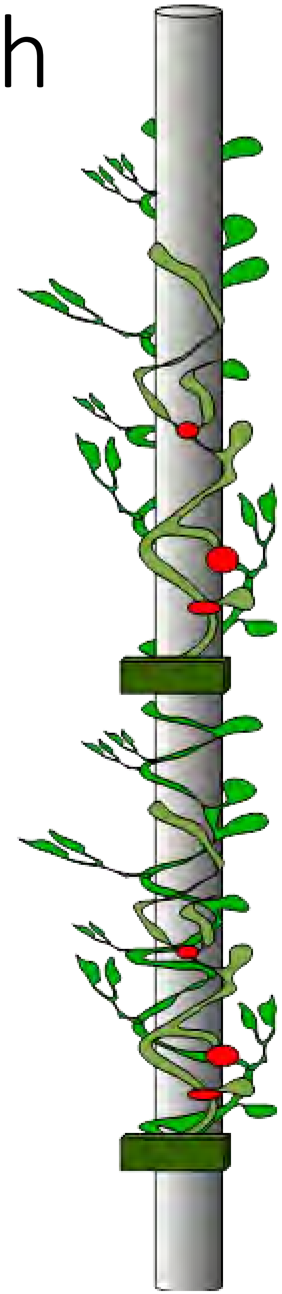
My (Current) hydroponic experiment

- Time intervals for ISS sunlight
- Media based hydroponics
- LED grow lights on timers
- Pump on timer
- 2 tanks:
  - Output tank receives water from pots via gravity
  - Input delivers water to pots via gravity
  - Pump moves water from output tank to input tank at a few intervals per day
  - Uses flood and flow method to aerate
  - Current state: waiting for germination



In Habitat Growth

- Corners, tabletops, hallways, walls inside habitats can all be added to food production and oxygen recycling, especially for spices, herbs, and dwarf fruit and coffee plants.
- Can use grey water from showers, sinks, food prep.

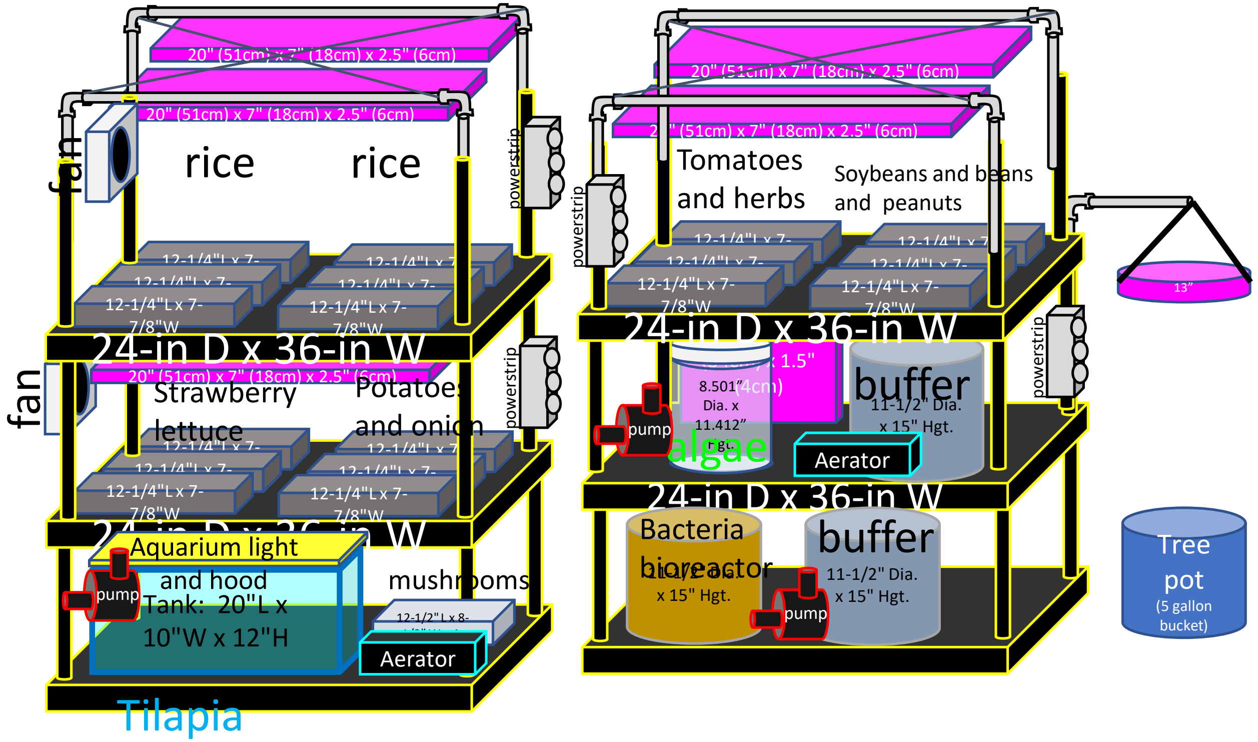


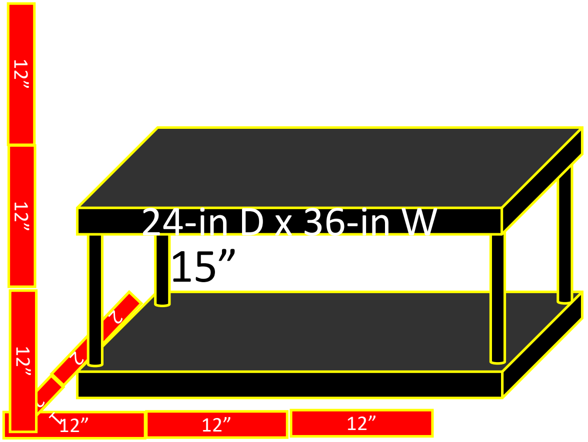
Spice	Time to First Harvest (wiki)
Basil	75 days
Cilantro	30 days
Dill	90 days
Fennel	100 days
Mustard	95 days
Chives	60 days
Marigold (Candula)	70 days
Mint	90 days
Tarragon	60 days
Oregano	120 days
Cumin	120 days
Ginger	200 days
Serrano Peppers*	120 days
Paprika*	150 days
Saffron	180 days
Chili Peppers*	120 days
Coriander	100 days
Garlic	180 days
Turmeric	300 days
Thyme	1 year
Rosemary	1 year
Hops	2-3 Years
Coffee**	2-3 Years
Tea**	2-3 Years
* = Same species as bell peppers	
** = large enough to require space and possibly a hydroponic stage, good for export!	

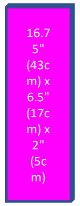
Nutrients

Species	Kcal per kg wet	wet mass						
		Carbohydrate**	Fats	Proteins	Fiber	Ash	Water	dry%
Chlorella (algae)	383	2.27%	0.91%	5.71%	0.03%	4.40%	86.68%	13.32%
Peanuts	5630	8.04%	48.75%	25.19%	8.50%	2.61%	6.91%	93.09%
Pinto Beans	3470	47.05%	1.23%	21.42%	15.50%	3.90%	10.90%	89.10%
Potatoes	770	15.46%	0.09%	2.05%	2.03%	5.35%	75.02%	24.98%
Rice	3570	71.00%	1.02%	13.29%	5.88%	1.57%	7.24%	92.76%
Soybeans	1470	6.85%	6.80%	12.95%	4.20%	5.23%	63.97%	36.03%
Tilapia	960	0.00%	1.70%	19.87%	0.00%	4.13%	74.30%	25.70%
Tomato	180	2.63%	0.20%	0.88%	1.26%	9.14%	85.89%	14.11%
Mushroom	220	2.26%	0.34%	3.09%	1.00%	0.86%	92.45%	7.55%
Lettuce (Arugula)	250	2.05%	0.66%	2.58%	1.60%	1.40%	91.71%	8.29%
Onion	400	8.99%	0.10%	1.10%	1.70%	0.35%	89.11%	12.24%
Strawberry	320	5.68%	0.30%	0.67%	2.00%	0.40%	90.95%	9.05%
Yeast from Yeast-Bacteria Reactor	774	3.59%	1.91%	10.14%	6.74%	5.95%	71.66%	28.34%
**= minus fiber								

Schematic: opt 2

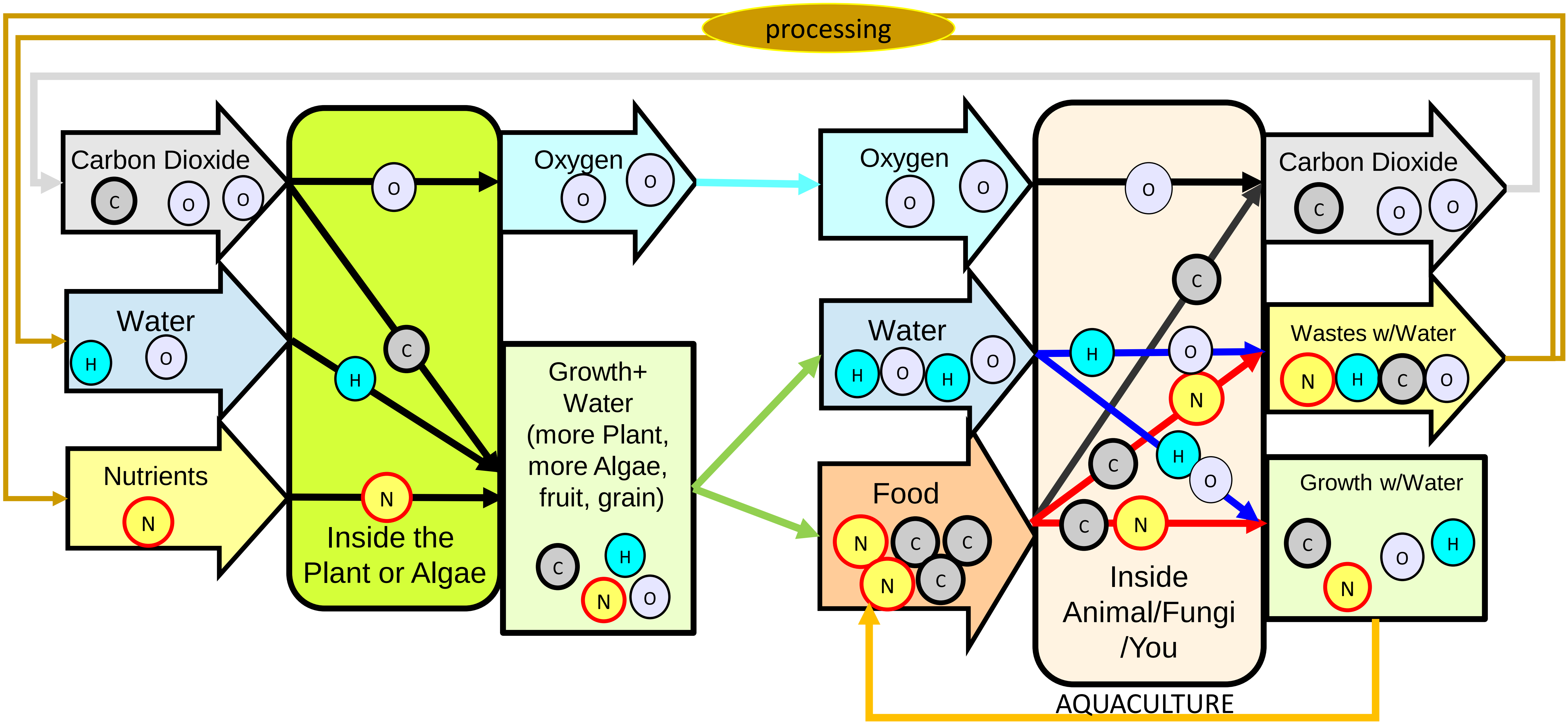






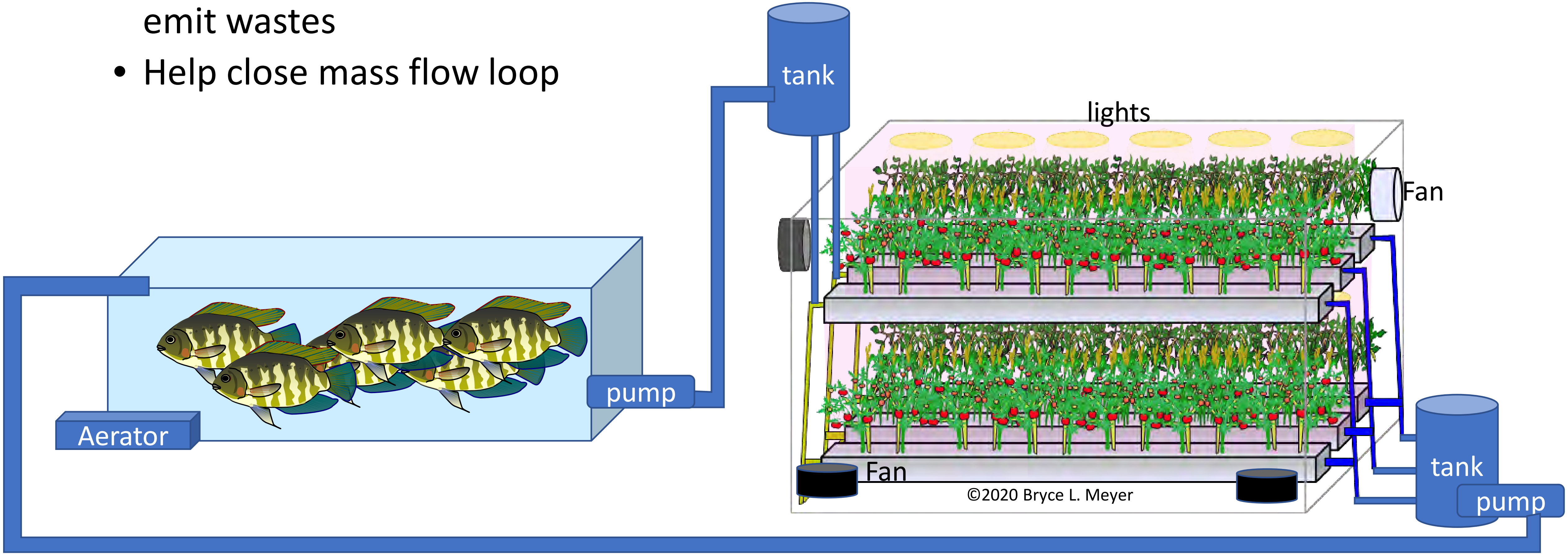
CATEGORY	INGREDIENT
Grains	Rice
Meat	Tilapia
Herbs	Herbs
Starch	Potatoes
Mushroom	Mushroom
Oil & Nuts	Peanut & soy oil
Salad	Lettuce, tomato, onion
Legumes	Kidney beans
Tree	Tangerine
Berry	Strawberry
“Dairy”	Soy milk

Simplified Biochemistry



Aquaponics

- Combine plants and fish or shrimp
  - Plants use waste water circulated to roots, fish eat plant left overs and food and emit wastes
  - Help close mass flow loop



https://www.theaquaponicsource.com/what-is-aquaponics/

Scale

- The larger a hydroponic farm the more active fluid movement and control must be:
  - More pumps
  - More heat control and rejection, CO_2 control, humidity:
    - More fans
    - More condensers
    - More Sensors and controls
    - More CO_2 sources
    - More nutrients and pH control
  - Possibly controlling parts for particular species
- Pollination:
  - Might need robots, people, or bees!
    - Kids with a paint brush…..

NET-NET: As the farm grows in size, more automation, pumping, sensing, air moving, and regulation is required to get optimum production, though there are some economies of scale as well.

Scales in Space

Settlement Level / Resort Level	Space Equivalent	Earth Analog (Resort)	Earth Analog (Settlement)	Food Source	Recycling and Farming
0/0	ISS as of 2017, all space outposts to 2017.	Everest Base Camp	Remote Outpost	All from Earth	Minimal Chemical Recycling of gases and water. A few ornamental plants. Requires extensive resupply.
0/1	Inflatable or Basic Orbital Unit/Hotel	Oil Rig, Antarctica Bases.	Remote Outpost	All from Earth	Minimal Chemical Recycling of gases and water. Plants as ornamental compliment to diet. Requires extensive Resupply
0/2	Beginning Space Resort	Hotel with amenities	Camp/ Hotel with Garden (no families)	Most from Earth, some local	Some biological recycling of solids, and full recycling (biological/mechanical) of gases and water. Some hydroponic growth. Minimal bioreactors. Requires import for Complex menus.
3-Jan	Next Level Space Resort	Major Hotel/ Resort (Cruise Ship destination)	Farming Transient Town (few families).	Some items Earth, though staples and spice items local.	Complete recycling of solids, liquids, gases. Hydroponics and bioreactors, minimal animal (aquatic or insect). Complex menus combining local sources, with luxury items from off-site
2/4A	Full Space Resort as part of a small settlement.	All inclusive luxury resort as part of a community.	Permanent Growing Town	Majority of foods local. Self Sufficient for all but guests and children. Access to some in-situ or local supplies.	Complete recycling of solids, liquids, gases, very efficiently. Hydroponics, some in-soil in Habitat growth, and bioreactors, many aquatic species (fish, shrimp). Complex menus from local sources, though some re- supply for luxury items and inefficiencies.
3/4B	Full Space Resort as part of a growing settlement	All inclusive luxury resort as part of a community and city. Many off resort options.	Permanent Large Growing Town/ City with food exports.	Self Sufficient for all but guests and extra pop growth and export. Access to re-sources for excess production. Part of a trade web.	Complex farms (either staged or 'open' air) with diverse species, including crop species for export. Mass flow is efficient for the productive farm. Parks with extensive in-soil planting, including limited tree and bush crops and ornamental plants.

Conclusions

- Hydroponics/Aeroponics are growth methods
  - No Media: nutrient/water in contact with roots directly
  - Aeroponics=mist to roots
  - Hydroponic=liquid over roots, with out without media, bucket or tray.
  - Media can hold bacteria and fungi that can aid resiliency of plants
  - Tanks and pumps regulate flow, sensors make sure all is well
  - Lights can be blue-red grow-lights most of the time, white light sometimes
  - CO_2 to green parts, O_2 to roots.
- Aquaponics: Combining fish or shrimp aquaculture with hydroponics to optimize total production and mass balance
- Scale: The more crops and bigger the farm, the more active (pumps, condensers, fans) it must be to work well
- Gravity: The lower the gravity, the more pumps, condensers, and fans are required.

Synopsis
Zoom Meeting - Growing Food on Earth and in Space

- https://www.meetup.com/Saint-Louis-Space-Frontier-Meetup/events/269575040/

At Home Photobioreactor and aerobic bioreactor