UMKC
UNIVERSITY OF MISSOURI
KANSAS CITY

Hydroponic systems overview

Juan Cabrera-Garcia

jcabrera-garcia@missouri.edu

BFRDP Grant #: 2021-70033-35713

1

Topics

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

UMKC

2

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

3

3

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

4

4

How can hydroponics be sustainable

Profitable	Preserving the environment	Quality of life
More produce per square foot	Less land requirement	Natural areas preservation
Lower use of pesticides	Less risk of pesticide drift	Access to safe produce
Efficient water use	Lower use of water	Urban Agriculture
Less fertilizer use	Lower risk of pesticide and fertilizer leaching	Access to fresh local food
		↑Profit=more taxes to serve the community

5

5

Topics

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

UMKC

6

Advantages: No seasonality

Year round production is possible

7

7

Advantages: Short crop cycles

Lettuce ready in 35 to 45 days

Compared to more than 70 days in the field

8

8

Advantages: Food safety

Hydroponic Lettuce

- Lower risk of contamination
- 0 foodborne disease outbreaks from 2014 to 2019

Field Lettuce

- Higher risk of contamination
- 54 foodborne disease outbreaks from 2014 to 2019

https://www.cdc.gov/foodsafety/communication/leafy-greens.html

9

9

Advantages: Food access

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

10

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.

11

11

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)

12

12

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)

*Barbosa et al. 2015. *International Journal of Environmental Research and Public Health* **12(6): 6879-6891**

13

13

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)

FIELD LETTUCE
Lower infrastructure costs
($0.2 per sq ft per year)

Greenhouse figure

- Steep learning curve

14

14

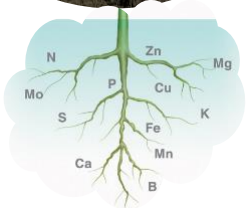
Why is market demand increasing?

- 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

15

15

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

16

Topics

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

UMKC

17

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

18

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

19

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

20

Topics

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

UMKC

21

What is hydroponic?

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

It is a soilless production system.

22

22

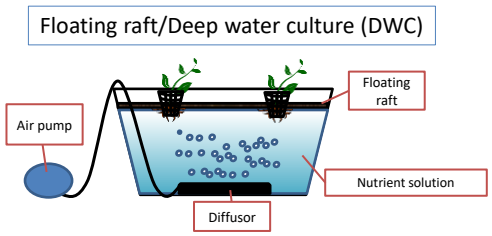
Types of hydroponic systems

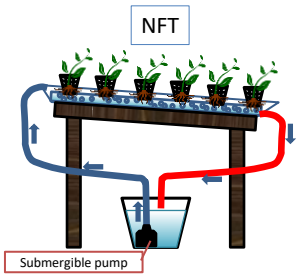
Liquid

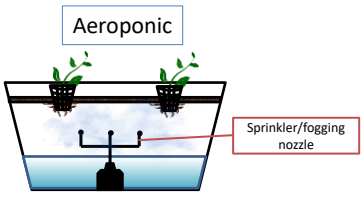
Solid

23

Liquid systems

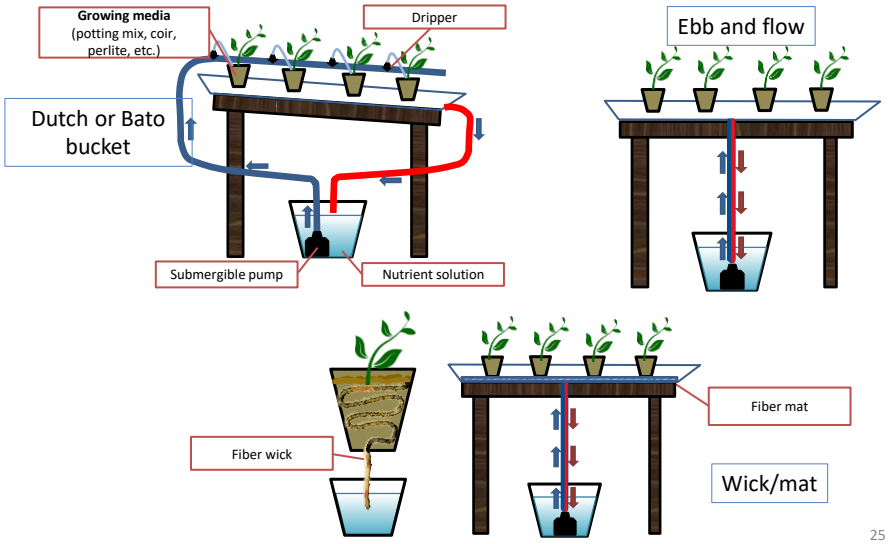






24

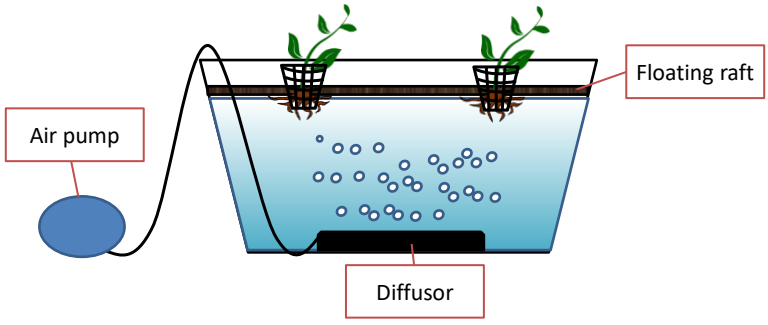
Solid systems



25

25

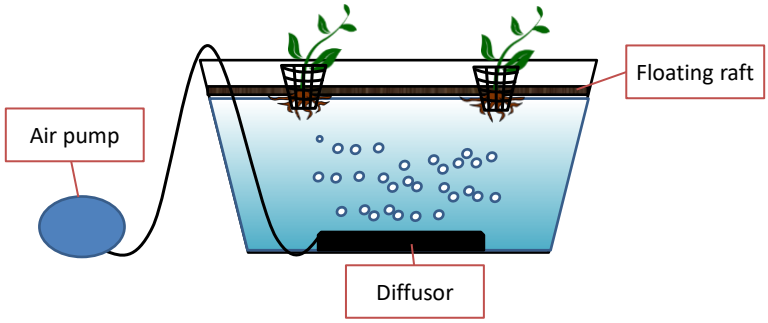
Deep water culture (DWC)



26

26

Deep water culture (DWC)



27

27

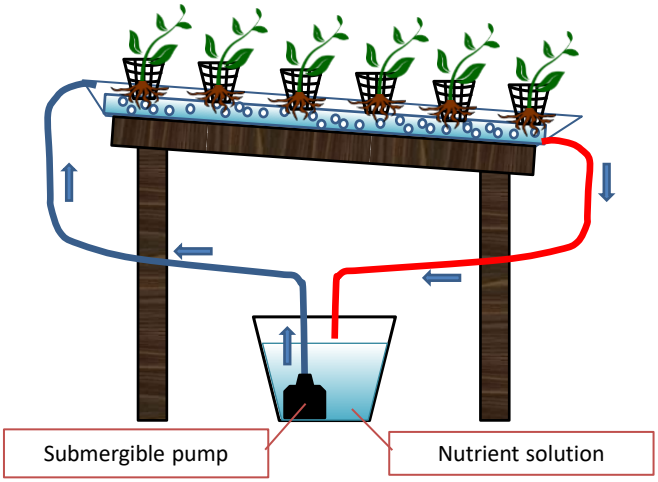
DWC

- ✓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

28

28

Nutrient Film Technique (NFT)



29

29

NFT

- ✓ For leafy greens and herbs
- ✓ No need for aeration
- ✓ Use 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

30

30

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

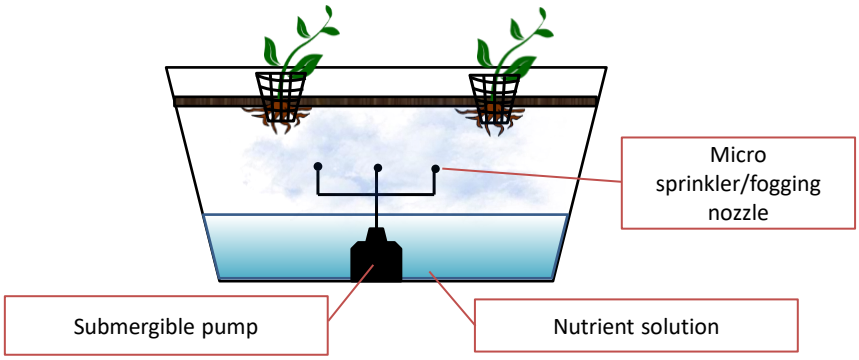
Which one to choose?

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

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

31

Aeroponics



32

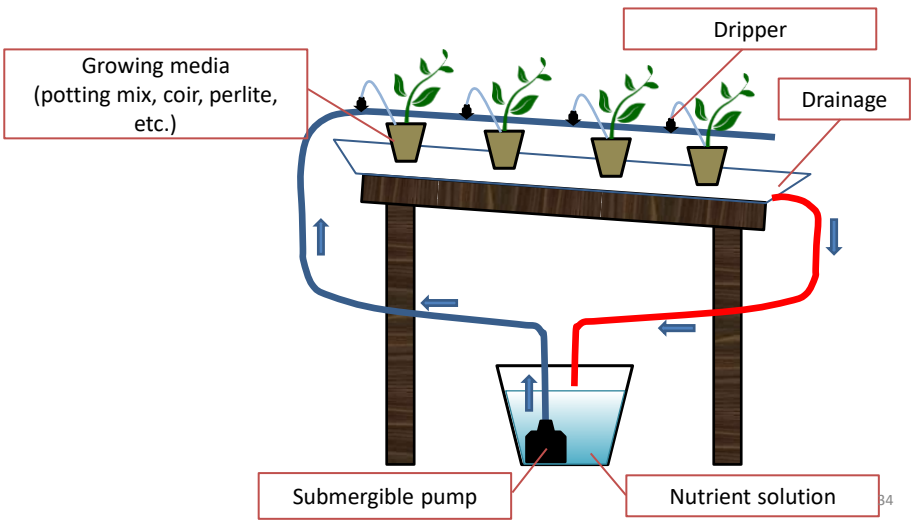
32

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

33

Dutch/Bato bucket



34

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**

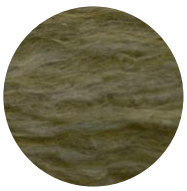
35

35

Growing media options

Perlite

Coir



Rockwool

Potting mix

Expanded clay pellets

Any material that can be sourced locally?

Affordable
Sustainable
Locally sourced

Gravel

36

36

Rockwool

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

37

Coconut coir

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

38

38

Other 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

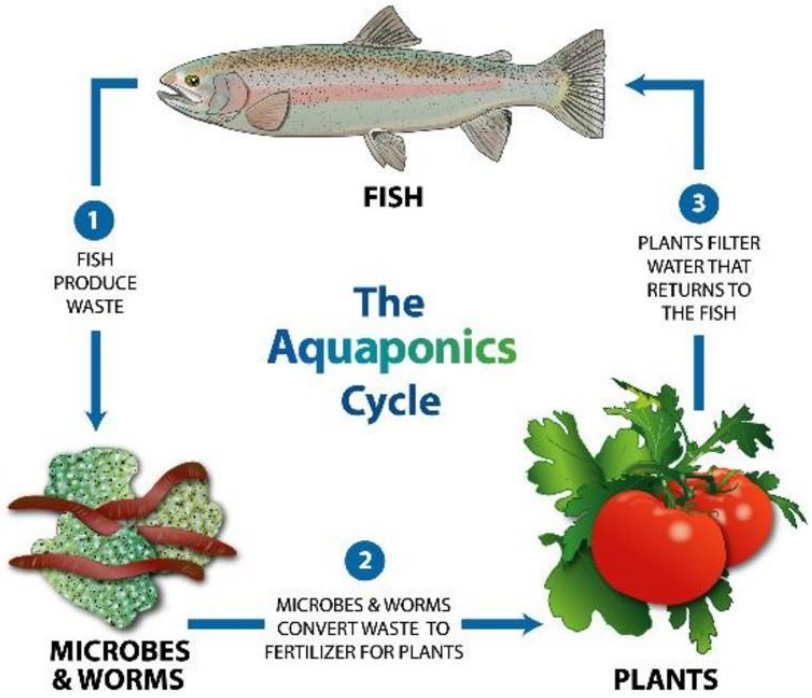
☒ pH changes over time (constant monitoring) not stable over time

39

Aquaponics

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

40



41

41

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/m^2/day
  - 100 g of feed per day = 1 – 1.6 m^2
  - 100 m^2 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 ajust the fish:plant rates
- You might need to supplement plants with added fertilizers

42

42

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

43

Topics

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

UMKC

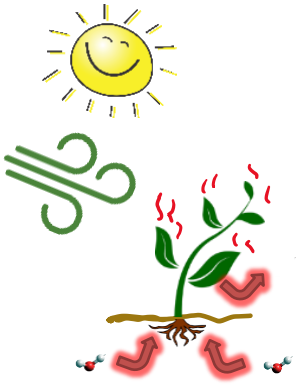
44

Environment monitoring systems

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

45

Air flow and water absorption



46

46

Air flow and water absorption

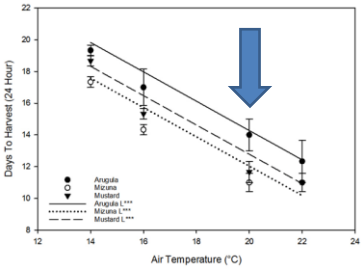
Brendan Morrison and Allayana Darrow. The Planet Magazine. https://theplanetmagazine.net/a-vertical-horizon-586ff6f67e98

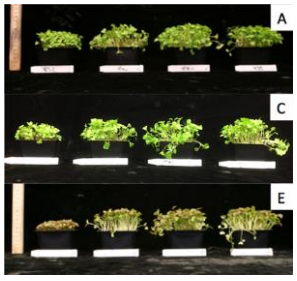
47

47

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





48

Jonathan Allred and Neil Mattson – Cornell University 2017

48

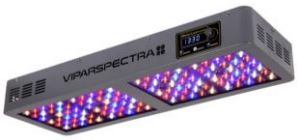
Lighting considerations

- 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

49

Sunlight vs Fluorescent vs LED

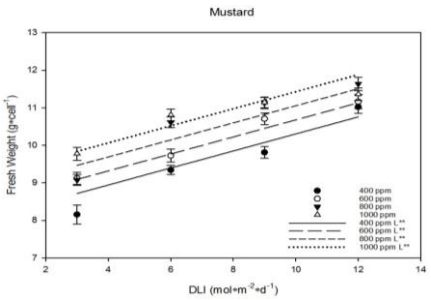


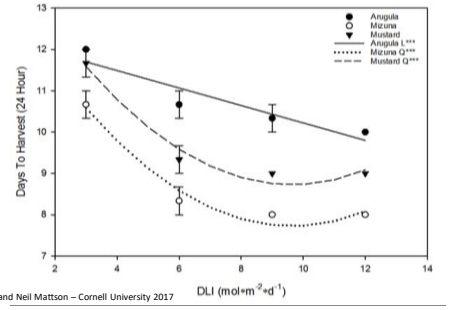
FREE!	Installation cost	$$$
Moderate	Energy efficiency	High
Low	Level of control	High
Moderate	Operating cost	Low
Moderate	Longevity	High

50

Light quantity and growth

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



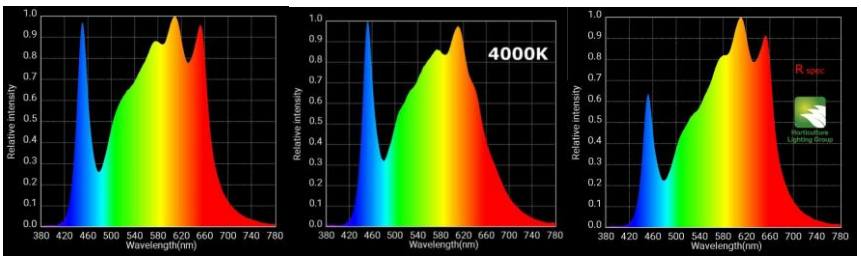


Jonathan Allred and Neil Mattson – Cornell University 2017

51

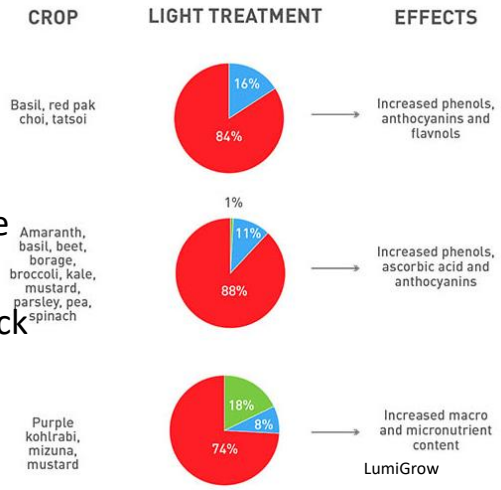
Light quality

- Red light: Promote growth
- Blue light: Promote accumulation of nutrients (anthocyanin)
- Growers apply light treatment throughout the season or at the end of the season



52

- Rules of thumb for basil:
  - 3 times more red than blue plus some green
  - 12 to 16 hours (check plant growth: it can be more or less depending on the light)



53

53

Keeping plants in their comfort zone

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

54

54