Pathways towards Sustainability –
A visionary outlook on future plant production systems

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Organisation

Presentation is available for download:

https://bit.ly/3svrSNL

https://github.com/bpucker/teaching/blob/master/PathwaysTowardsSustainability.pdf

Feel free to ask questions:
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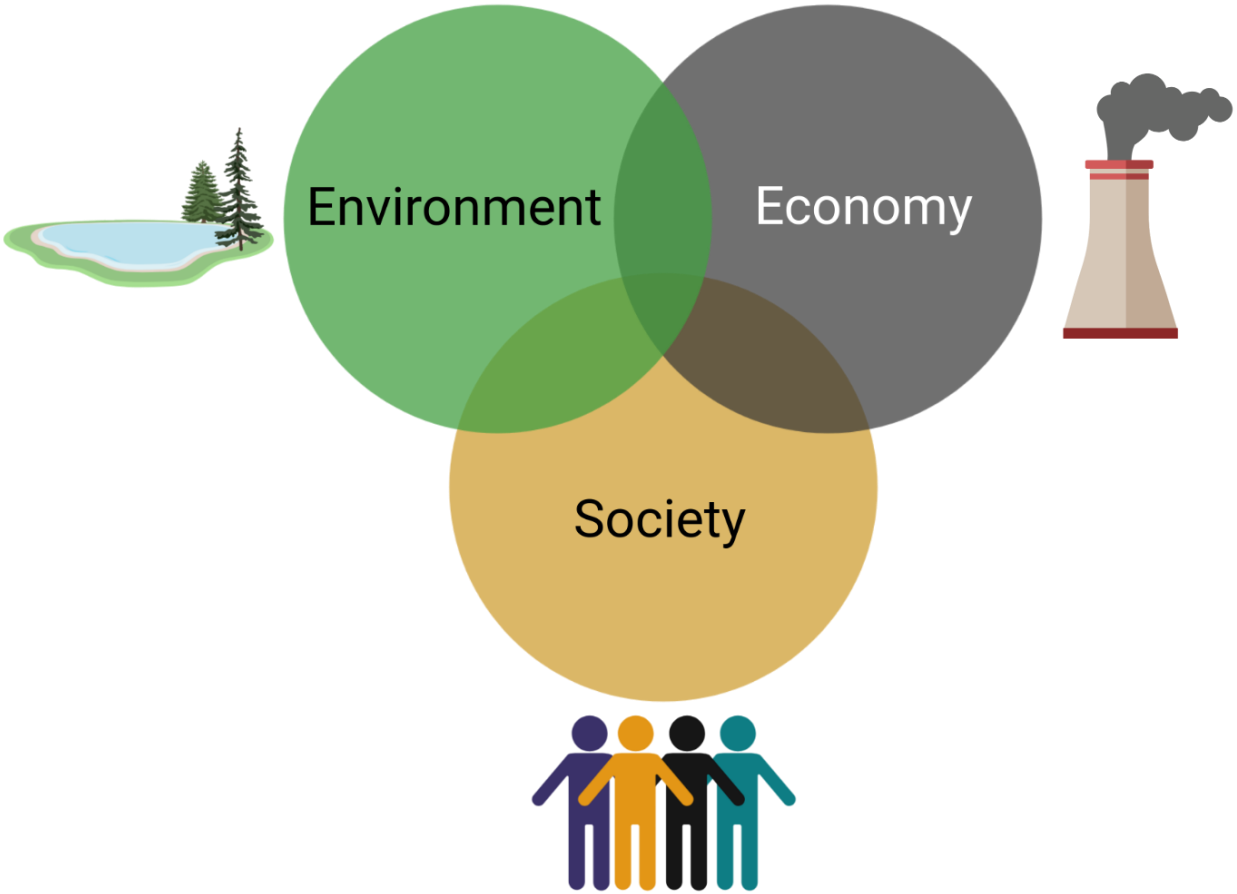
Best spot for video

Future Challenges

- Increase of world population from 7.7 to 9.7 billion by 2050 [1]
- Water scarcity [2]
- Insufficient arable land [3]
- CO_2 neutrality by 2050 [4]
- Increasing global inequality [5]

[1] United Nations
[2] Boretti & Rosa, 2019
[3] ourworldindata.org / FAOstat
[4] European Green Deal / Paris Agreement
[5] UN World Social Report 2020

Sustainability

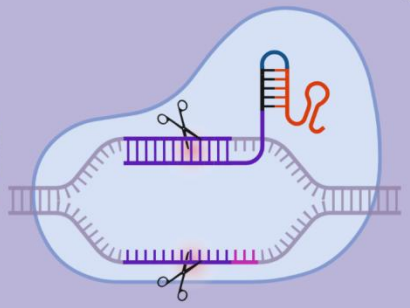


Fullfilling current needs without negative impact on the future ability to continue doing so

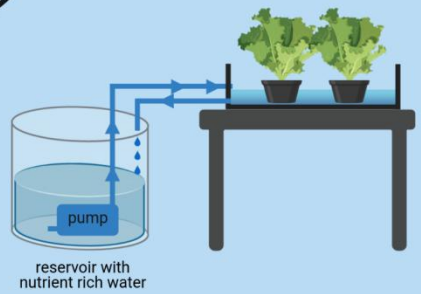
Coping with arable land shortage

Smart and autonomous farming

Toolbox of sustainable agriculture



Improving plants



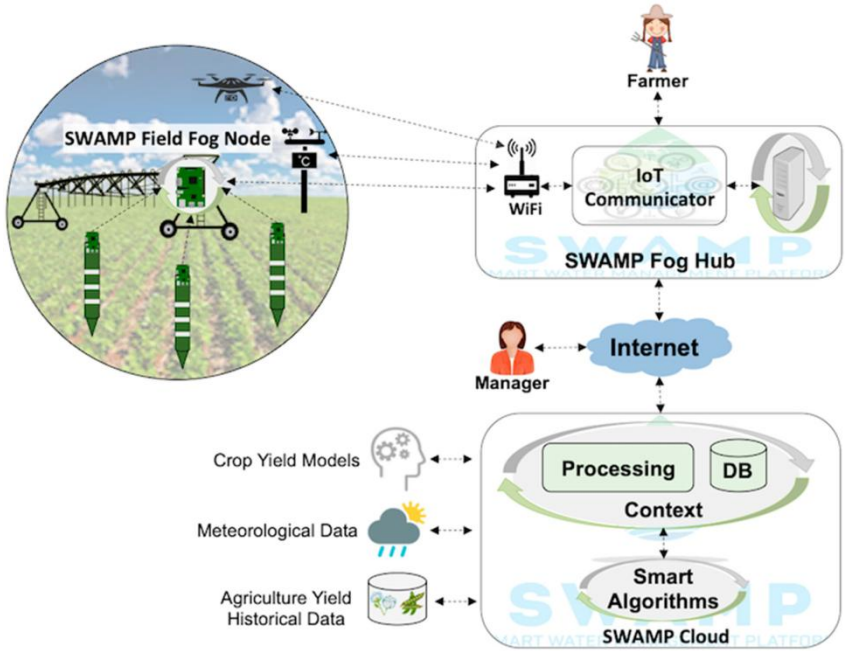
Saving water with hydroponics

See references for image sources

Smart & digital farming

- IoT (Internet of Things): everything is connected
- AI (Artificial Intelligence): recognizing and using patterns

- Advantages: reduced fertilizer, herbicide, and energy use
- Challenges: high startup costs; data security / data protection



Smart farming example: water management

Kamienski et al., 2019; doi: 10.3390/s19020276

Agricultural robots

- Reduces the number of workers required in agriculture
- Advantages: reduced herbicide/fertilizer use; mix cropping
- Limitations: economic relevance

- Tasks:
  - Seeding
  - Monitoring / Phenotyping
  - Weed control (chemical / physical)
  - Thinning/pruning
  - Harvesting
  - Sorting and packaging

PhenoRob:
http://www.phenorob.de/
General overview:
https://www.youtube.com/watch?v=L_IDRGY3YMI

FarmDroid FD20

- One FD20 can manage 20 ha
- Safety mechanisms: cannot leave area and will stop at obstacles
- Solar panels for power (sun light required)
- FD20 stores positions of all plants after seeding
- Weed removal without detecting plant through optical systems

FarmDroid FD20

FarmDroid report:
https://www.youtube.com/watch?v=upzvmpQgJ5E

Drones

Monitoring

Spraying pesticides

Collection of drones:
https://drone-zoom.com/best-drones-for-agriculture-2020/

SWEEPER: automatic fruit picking

- Harvesting sweet pepper in greenhouses
- Camera & machine learning allow to distinguish fruits and leaves
- Only ripe fruits are harvested
- SWEEPER cuts fruits and stores them on tray
- 24 seconds to harvest a fruit

SWEEPER (sweeper-robot.eu)

Arm for harvesting

Identification of fruit

Arad *et al*., 2020; doi: 10.1002/rob.21937

Farming and energy production

Advantages

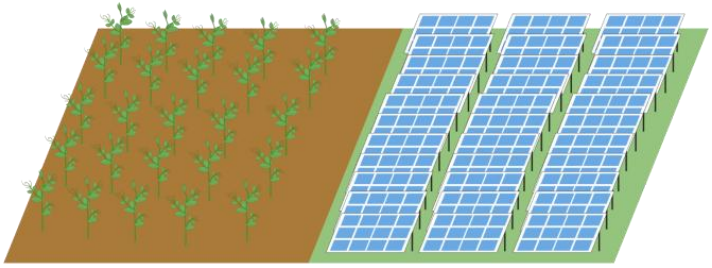
- Avoids land use conflicts
- Suitable for developmental countries
- ‘Adaptation’ to climate change

Limitations/Issues (in Germany)

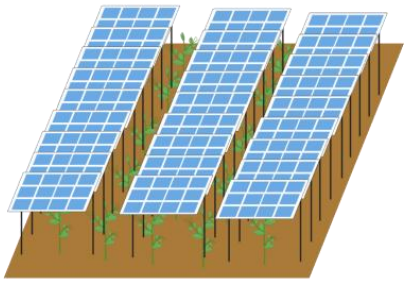
- Subsidies are not granted for agricultural land or produced electricity (not profitable)

University of Montpellier, France (Christian Dupraz)

Tomatoes under PVs



100% potato & 100 % solar energy



103% potato
83% solar energy
>
186% land use efficiency

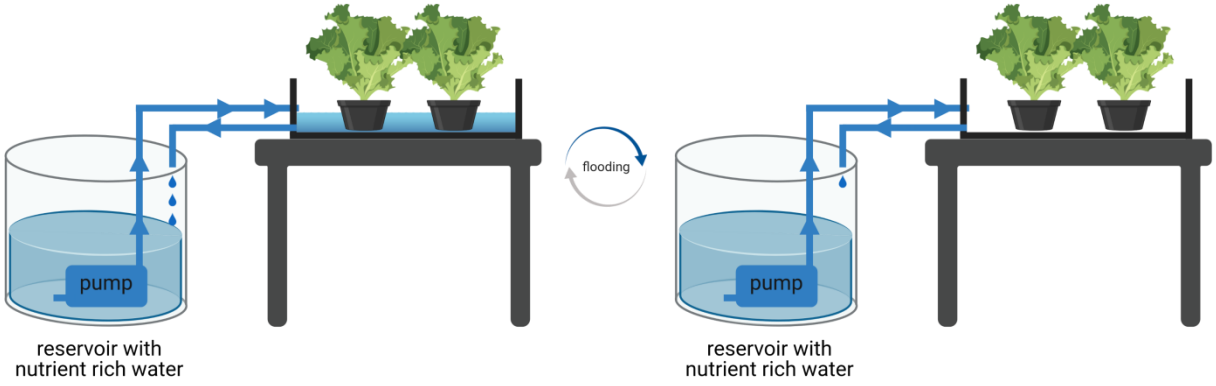
Fraunhofer ISE: Agri-Photovoltaik

Hydroponics

- Soil is replaced by liquids containing macronutrients and trace elements
- Continuous water supply, “flood & drain” system, or batch cultivation
- Root support can be provided by chemically inactive media
- Strawberries, tomatoes, cucumbers, peppers, and cannabis
- Example: lettuce in field vs. Hydroponics
  - 11x increased yield per area in hydroponics
  - 82x higher energy consumption in hydroponics
  - Water consumption is reduced in hydroponics


Expanded clay aggregate


Rock wool



reservoir with nutrient rich water

reservoir with nutrient rich water

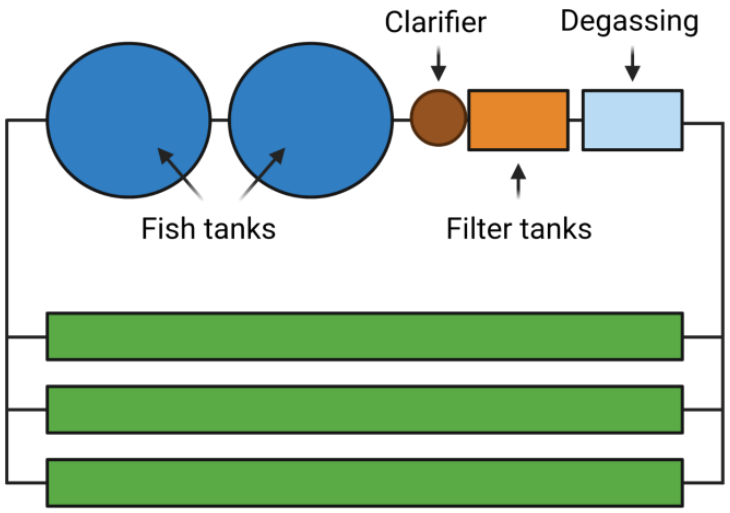
+ Energy Efficiency

+ H_2O Conservation
+ Crop Yield

Barbosa *et al*., 2015; doi:10.3390/ijerph120606879

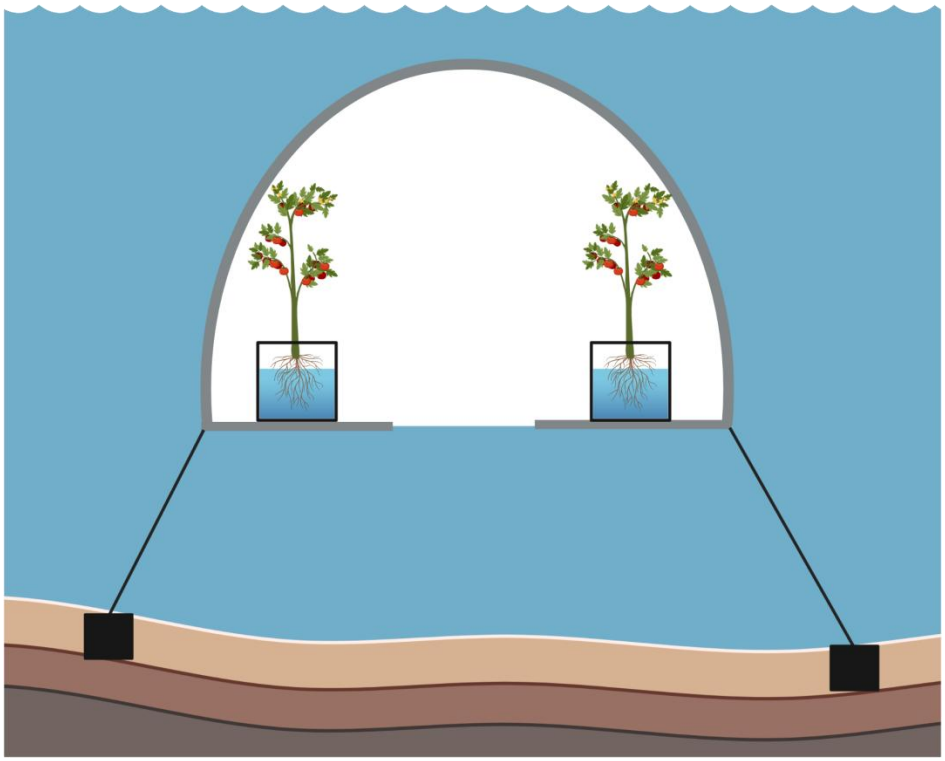
Aquaponics

- Next level hydroponics: combining fish farming (aquaculture) and hydroponics
- Closed loop(N and CO_2):
  - Rearing tank: fish cultivation
  - Biofilter: bacteria convert ammonia to nitrate
  - Hydroponics: Plants take up nutrients
- Water helps to maintain temperature in the greenhouse at night



Underwater farming: Nemo's Garden Project

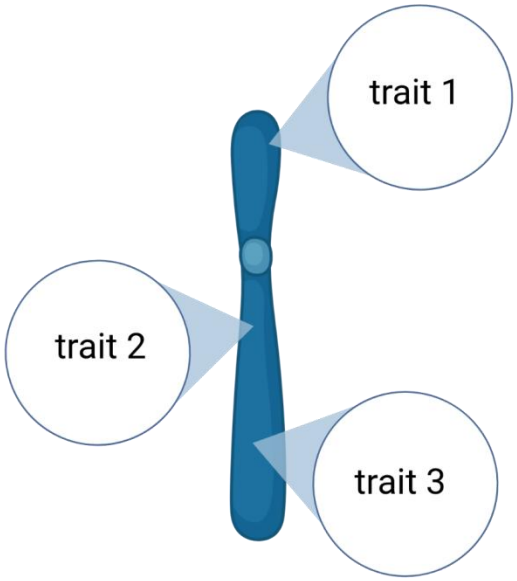
- Isolated biospheres underwater are free of pests
- Might withstand earth quake and tsunami

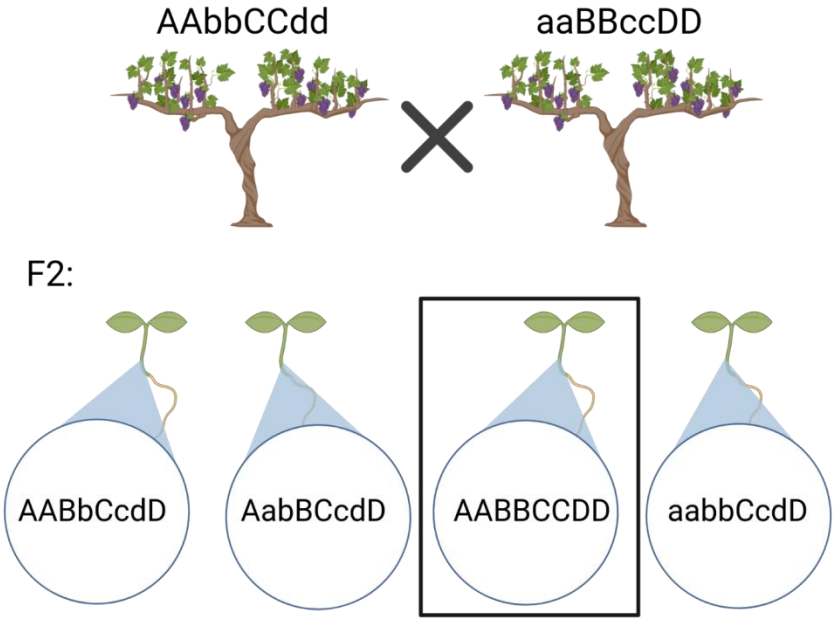


Underwater farming:
http://www.nemosgarden.com/the-project/

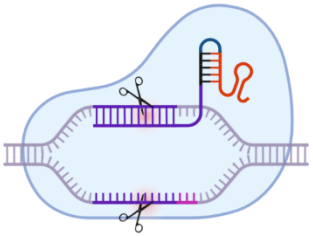
SMART breeding

- SMART = Selection with Markers and Advanced Reproductive Technologies
- Knowledge about genes underlying a trait is beneficial for optimal marker design
- Methods: marker-assisted selection (MAS) and mutation breeding

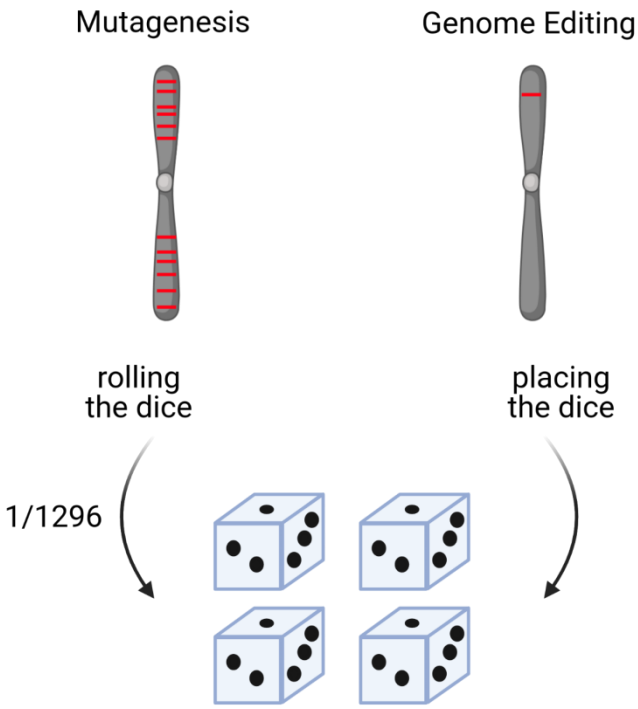




Genome Editing via CRISPR/Cas9



Jennifer Doudna & Emmanuelle Charpentier
(Nobel Prize for Chemistry 2020)

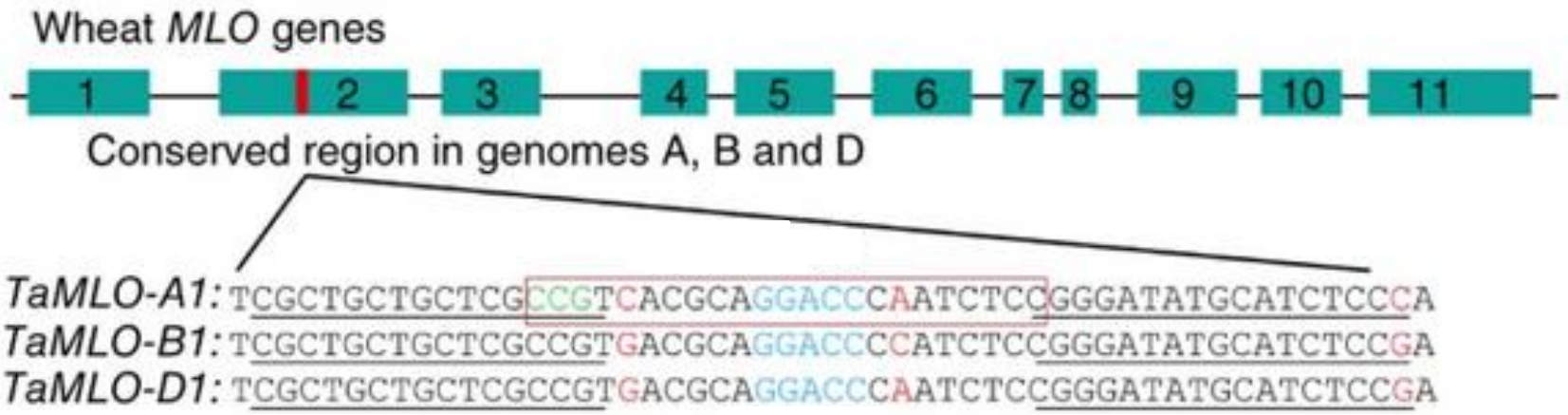


- Point mutations cannot be differentiated from natural variations
- EU is currently re-evaluating the GMO status of gene edited plants
- Process-based regulation vs. product-based regulation
- Small companies could afford genome editing to boost their breeding programs

Talk by Thomas Jacobs:
https://www.youtube.com/watch?v=O1Ysc_jmLpA

Genome Editing Applications: *MLO* in bread wheat

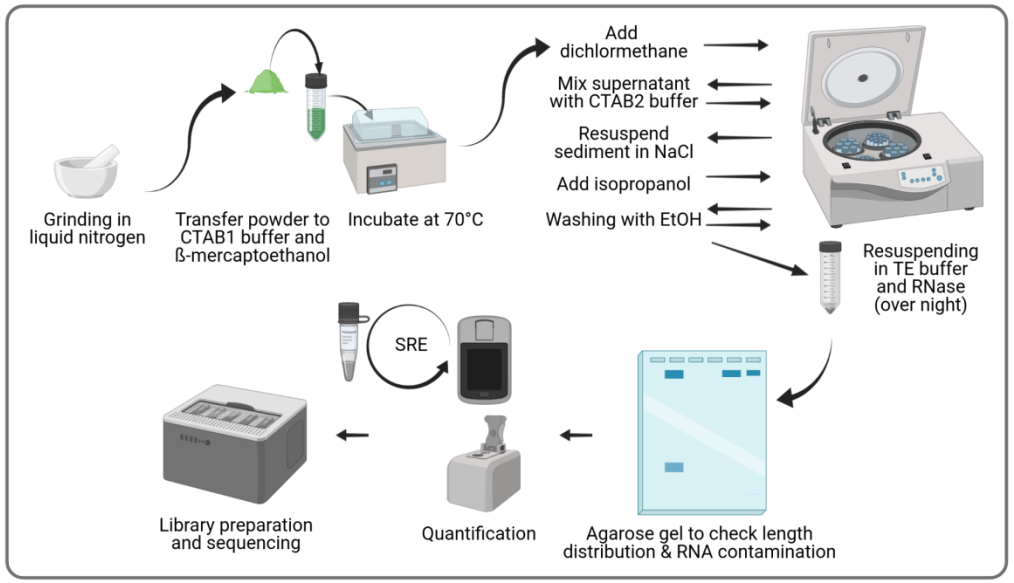
- Editing of 3 homoeoalleles of *MILDEW-RESISTANCE LOCUS* (*MLO*) in bread wheat confers resistance against powdery mildew
- Trait is not found in natural population due to genetic redundancy
- Broad spectrum inheritable resistance



Wang *et al*., 2014; doi:10.1038/nbt.2969

Establishing orphan crops

Yams become inedible shortly after harvest



genes

MDPI

Article

High Contiguity *de novo* Genome Sequence Assembly of Trifoliate Yam (*Dioscorea dumetorum*) Using Long Read Sequencing

Christian Siadjeu [1,2,†], Boas Pucker [2,3,†], Prisca Viehöver [2], Dirk C. Albach [1] and Bernd Weisshaar [2,*]

Identification of causal genes is first step towards modification

plants

MDPI

Article

Transcriptome Sequence Reveals Candidate Genes Involving in the Post-Harvest Hardening of Trifoliate Yam *Dioscorea dumetorum*

Christian Siadjeu *, Eike Mayland-Quellhorst, Shruti Pande, Sascha Laubinger and Dirk C. Albach

Siadjeu & Pucker *et al.*, 2020; doi:10.3390/genes11030274

Vertical farming

- Plants are grown in stacked layers to save space
- Combined with hydroponics or aquaponics
- Re-using existing structure e.g. old buildings

Dickson Despommier
(made vertical farming popular)

- Challenges:
  - High start-up and maintenance costs
  - Energy requirements
  - Water and light pollution

- Vertical farming directly in the supermarket (microgreens)

Urban farming & Foodscaping

- Foodscaping = growing edible plants between horticultural plants

- Advantages:
  - Increasing food security, accessibility, and availability
  - Local production reduces packaging and transport
  - Could increase quality of nutrition and health

- Risks:
  - No quality control and spread of pests
  - Contamination with emission
  - Social inequality?

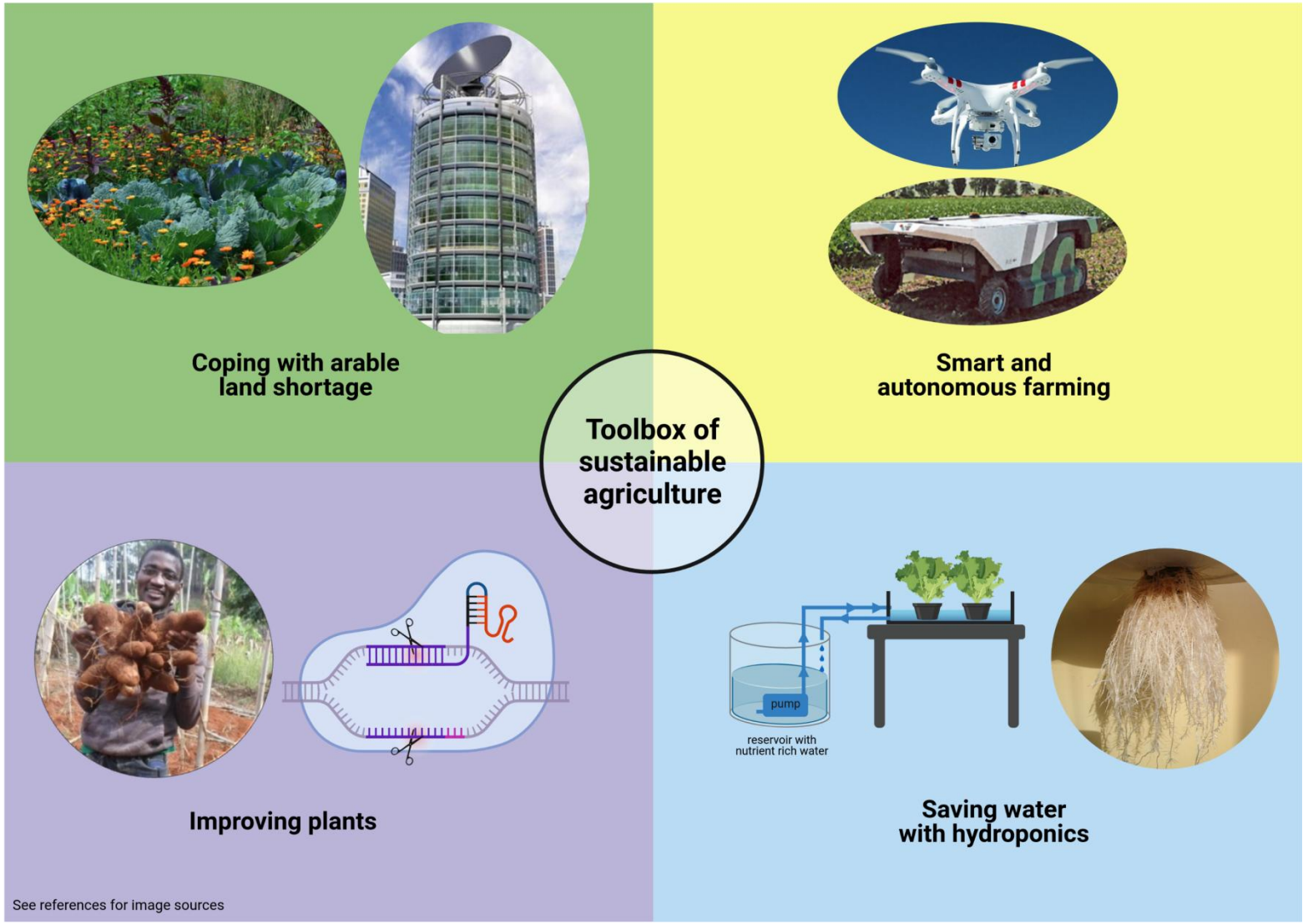
Integration through urban farming

- “Sieker-Gärten” supports integration of migrants through gardening/farming
- 2500 m^2; 40 families (200 persons)
- Children learn concepts of biodiversity, ecology, and economy

Urban farming project ‘Sieker-Gärten’

Garten-Kultur-Verein(t)-Sieker e.v.

Summary


Coping with arable land shortage
Smart and autonomous farming
Toolbox of sustainable agriculture
Improving plants
pump
reservoir with nutrient rich water
Saving water with hydroponics
See references for image sources

Questions?

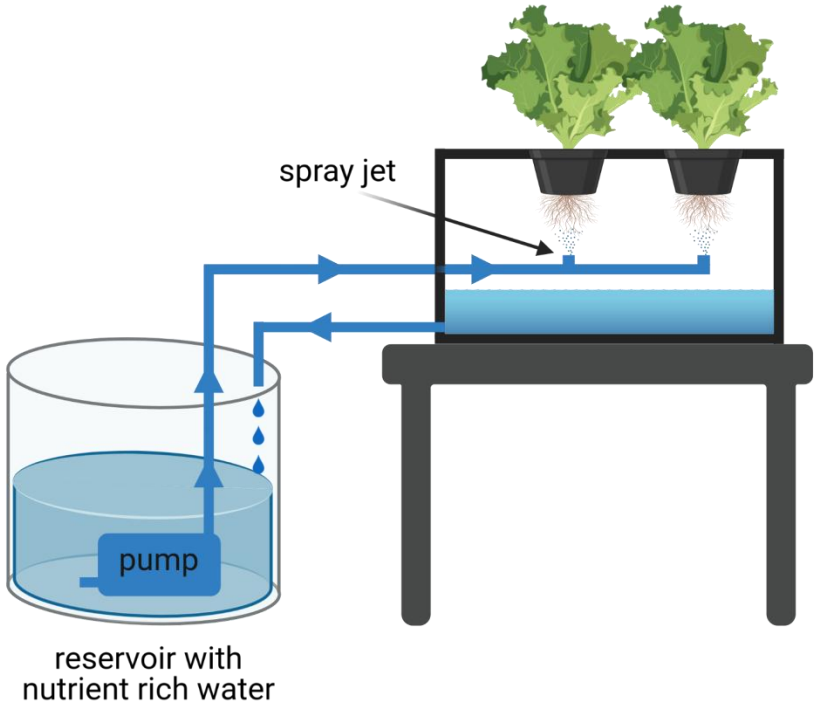
Literature and References

- https://www.un.org/en/global-issues/population
- http://www.fao.org/faostat/en/#data/RL/visualize
- https://ec.europa.eu/clima/policies/eu-climate-action_en
- https://www.ise.fraunhofer.de/de/leitthemen/integrierte-photovoltaik/agri-photovoltaik-agri-pv.html

Outtakes

Aeroponics & Fogponics

- Spraying liquid with nutrients
- Substantially reduced water consumption; more energy needed
- Tuber yield per plant was increased by 70% for potato compared to hydroponics (Ritter et al., 2000)



Polyculture / Intercropping

- Advantages: pest management, harnessing resources
- Challenge: efficiency
- Structural types: Mixed, row, temporal
- Functional types: pest trap or repellant intercropping

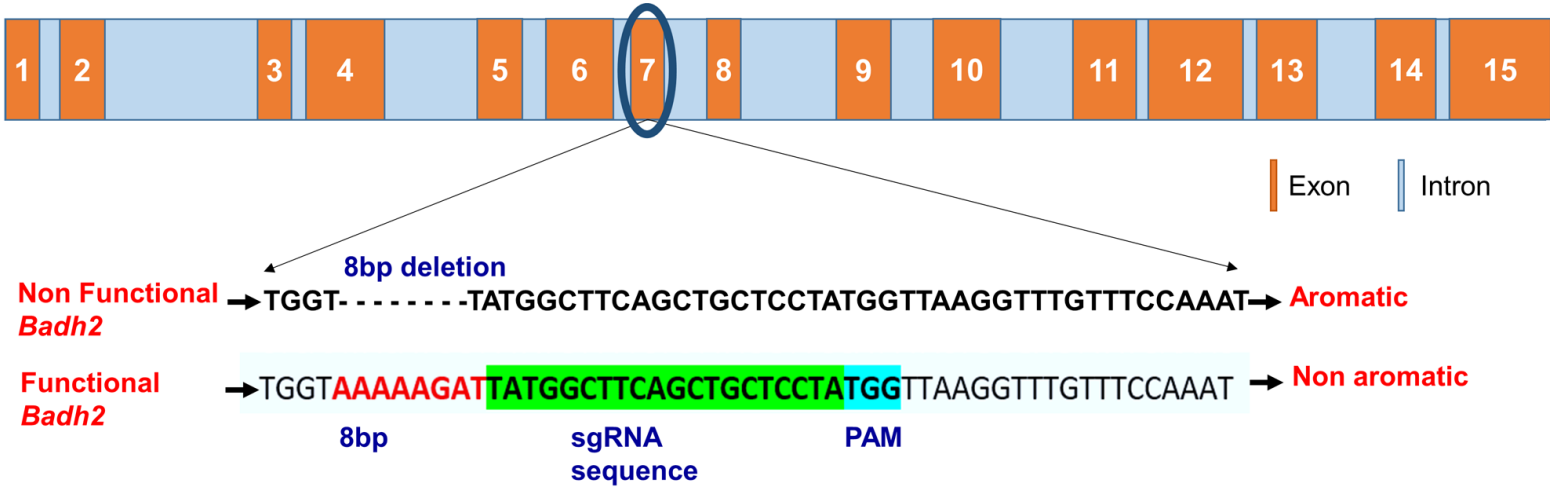
carrots & onions

cereals & peas

strawberries & onions

Genome Editing Applications: BADH2 in rice

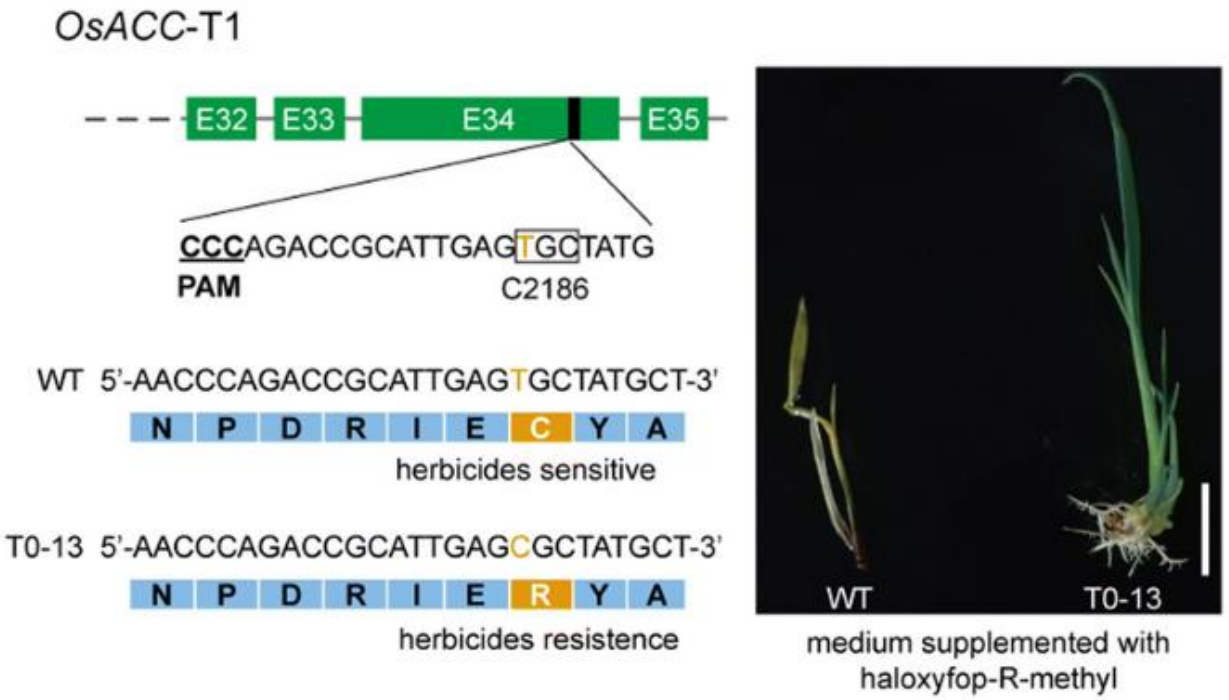
- Editing BADH2 in rice leads to formation of aroma (2-acetyl-1-pyrroline)
- BADH = betaine aldehyde dehydrogenase
- Introduction of new trait into elite varieties



Ashokkumar *et al.*, 2020; doi: 10.1371/journal.pone.0237018

Genome Editing Applications: herbicide tolerant rice

- tRNA adenosine deaminase is fused to Cas – enabling A-T to G-C conversion
- Gain of function point mutation in *ACC* confers herbicide resistance (C2186R)
- *Lolium rigidum* plants with this amino acid substitution showed resistance



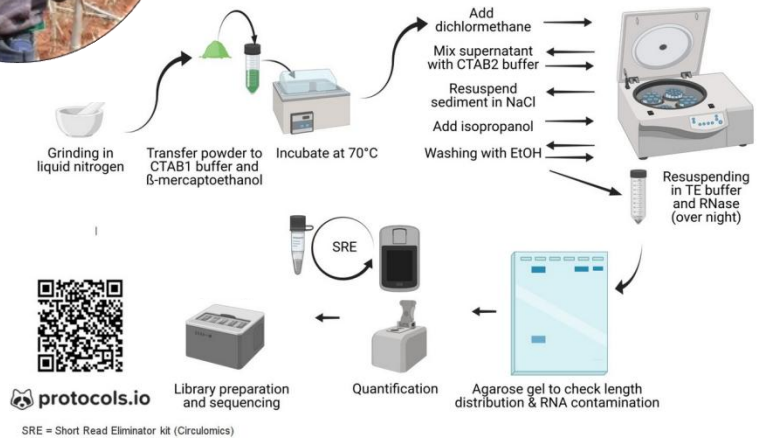
Li *et al.*, 2018; doi:10.1186/s13059-018-1443-z

Additional Genome Editing Applications

- Rice CDC48 gene (Zong Nature Biotech 2017)
- Wheat LOX2 (Zong Nature Biotech 2017)
- ACC in rice confers herbicide resistance (Li, Genome Biology 2018)

Establishing orphan crops

African (orphan) crop species



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Yam genome sequence

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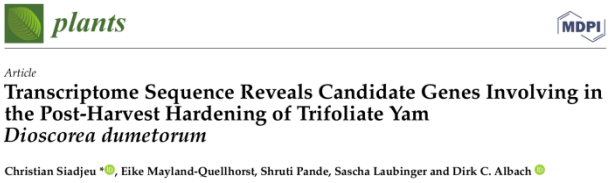
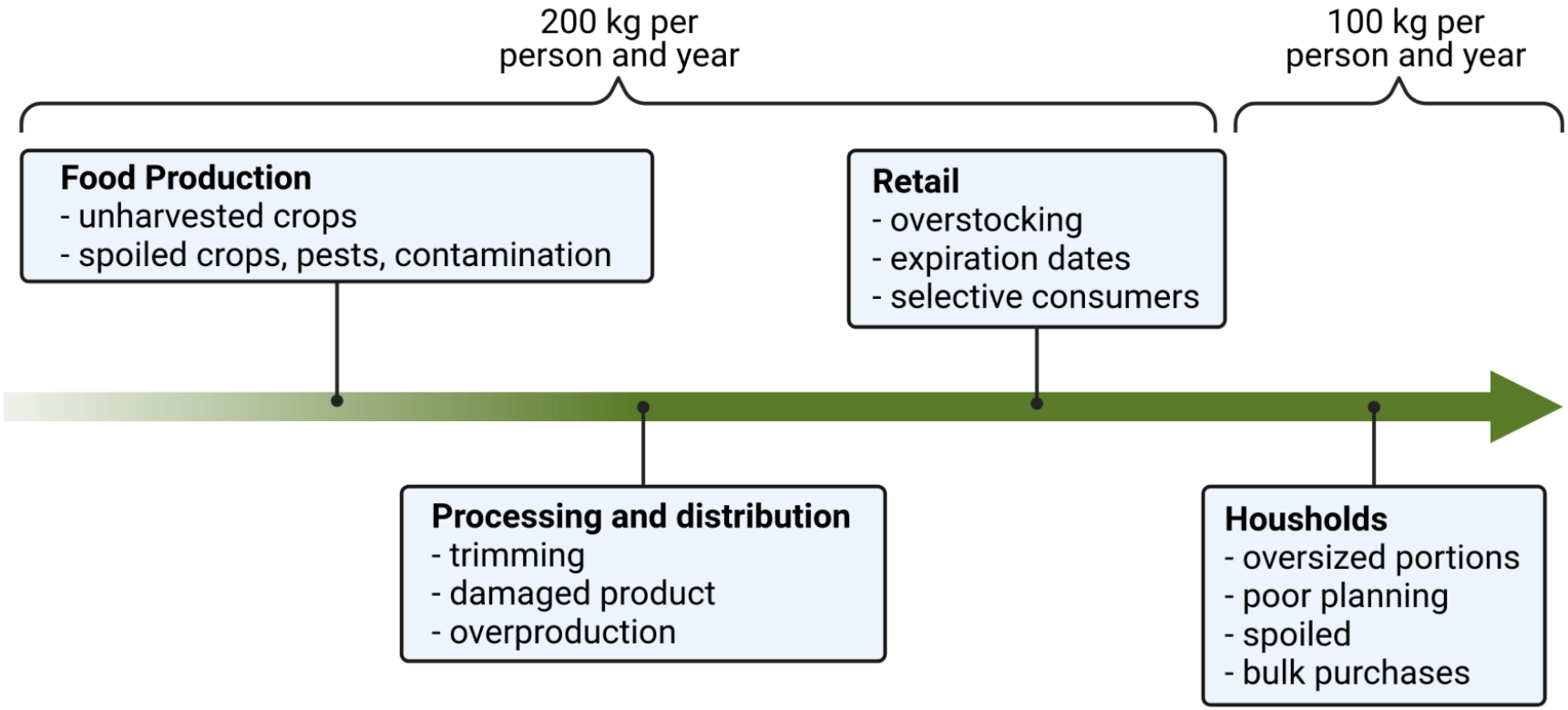


Jamnadass *et al*., 2020; doi:10.1038/s41588-020-0601-x
Siadjeu & Pucker *et al*., 2020; doi:10.3390/genes11030274

Food loss

- Food loss is only an estimation; true extend is unknown
- Start-ups and NGOs are mitigating food loss



FAO, 2011

Image References

- Drone: https://commons.wikimedia.org/wiki/File:DJI_Phantom_2_Vision%2B_V3_hovering_over_Weissfluhjoch_(cropped).jpg
- Vertical farming: https://commons.wikimedia.org/wiki/File:Vertical_farm2.jpg
- Urban farming: https://de.wikipedia.org/wiki/Urbane_Landwirtschaft#/media/Datei:New_crops-Chicago_urban_farm.jpg
- Hydroponics: https://de.wikipedia.org/wiki/Hydrokultur#/media/Datei:Roots_of_a_hydroponically-grown_plant.jpg
- Farming under PVs: https://de.wikipedia.org/wiki/Photovoltaik-Freifl%C3%A4chenanlage#/media/Datei:Ernte_Agrophotovoltaikanlage.jpg
- Robots: https://www.agrarheute.com
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- Greenhouse robot: https://en.wikipedia.org/wiki/Harvest_Automation#/media/File:OmniVeyor_HV-100_Image_1.jpg
- Vertical farming: https://commons.wikimedia.org/wiki/File:Sgverticalfarming2.png
- Clay aggregates: https://commons.wikimedia.org/wiki/File:Hydroton.jpg
- Aquaponics: https://en.wikipedia.org/wiki/File:Aquaponics_with_catfish.jpg
- Dickson Despommier: https://commons.wikimedia.org/wiki/File:Dickson_Despommier_underground.JPG
- Foodscaping: https://en.wikipedia.org/wiki/Foodscaping#/media/File:White_cabbage_garden.jpg
- Rock wool: https://en.wikipedia.org/wiki/File:Rockwool_4lbs_per_ft3_fibrex5.jpg
- Aquaponics 2: https://en.wikipedia.org/wiki/File:Aquaponics_at_Growing_Power,_Milwaukee.jpg
- Aeroponics: https://en.wikipedia.org/wiki/Aeroponics#/media/File:Aeroponic_roots_nepal.jpg
- PrecisionHawk Lancaster 5: https://drone-zoom.com/best-drones-for-agriculture-2020/
- Agri-PV: https://en.wikipedia.org/wiki/Agrivoltaic#/media/File:Dornbirn-Montfortstrasse_19-Gardening-Photovoltaik-01ASD.jpg
- Desertification: https://de.wikipedia.org/wiki/Desertifikation#/media/Datei:Erosion_Lesotho.jpg
- Some figures generated with BioRender.com