

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>



Best spot
for video

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

Feel free to ask questions:

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Future Challenges

- Increase of world population from 7.7 to 9.7 billion by 2050 ^[1]
- Water scarcity ^[2]
- Insufficient arable land ^[3]
- CO₂ neutrality by 2050 ^[4]
- Increasing global inequality ^[5]



Data sources: UN mid-year population estimates 2019. This is a visualization from OurWorldInData.org, where you find data and research on how the world is changing.

Licensed under CC-BY by the author Max Roser.

[1] United Nations

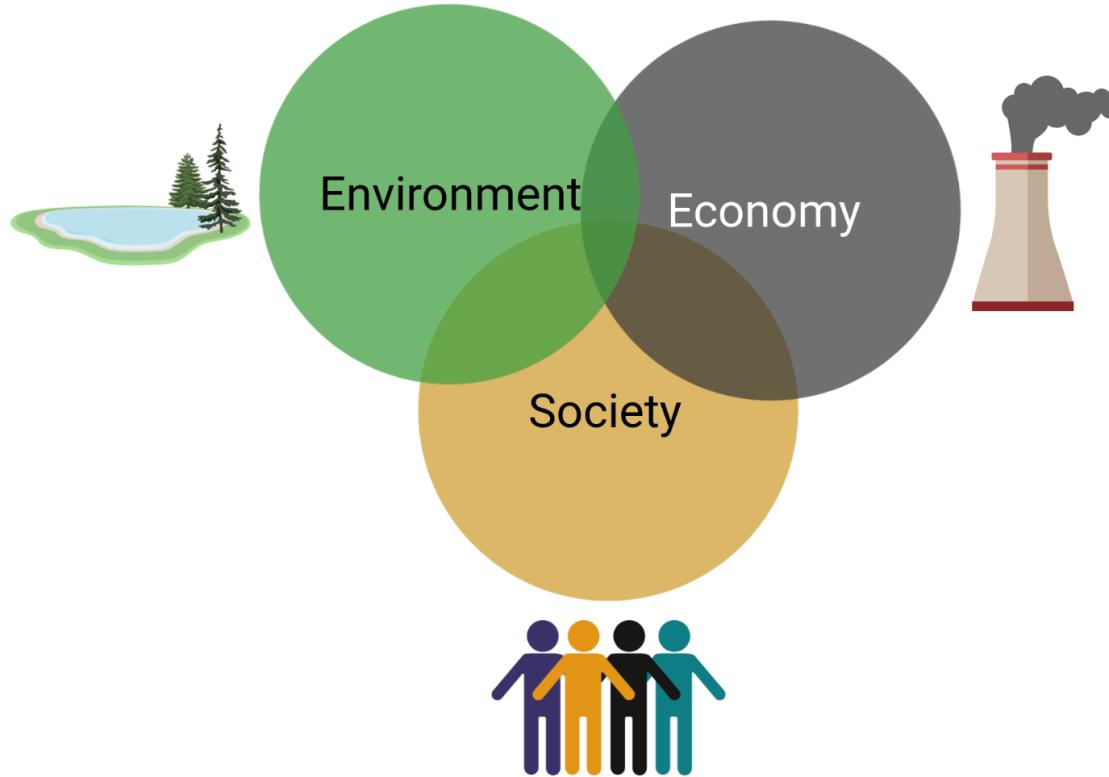
[2] Boretti & Rosa, 2019

[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

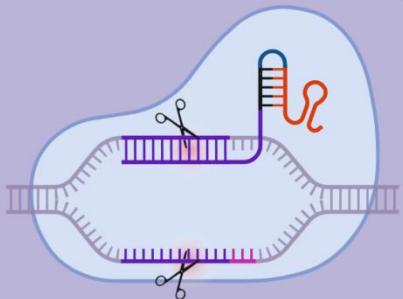


Coping with arable land shortage

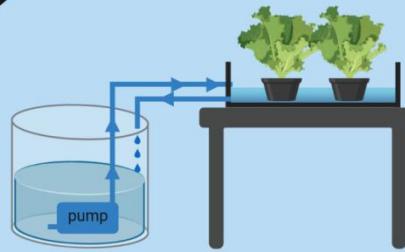


Smart and autonomous farming

Toolbox of sustainable agriculture



Improving plants

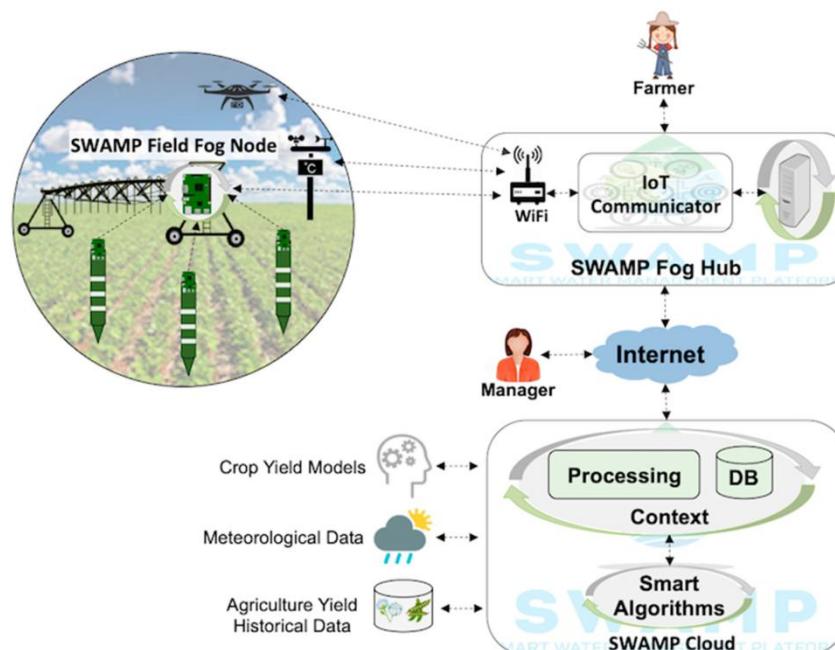


Saving water with hydroponics

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

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

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

Drones

Monitoring



PrecisionHawk Lancaster 5
(drone-zoom.com)

Spraying pesticides



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

Farming and energy production

Advantages

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

Limitations/Issues (in Germany)

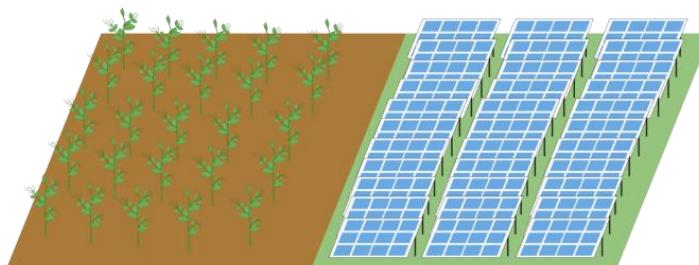
- Subsidies are not granted for agricultural land or produced electricity (not profitable)



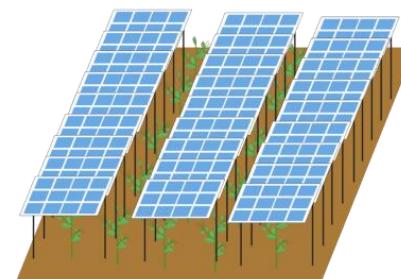
University of Montpellier, France (Christian Dupraz)



Tomatoes under PVs



100% potato & 100 % solar energy



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

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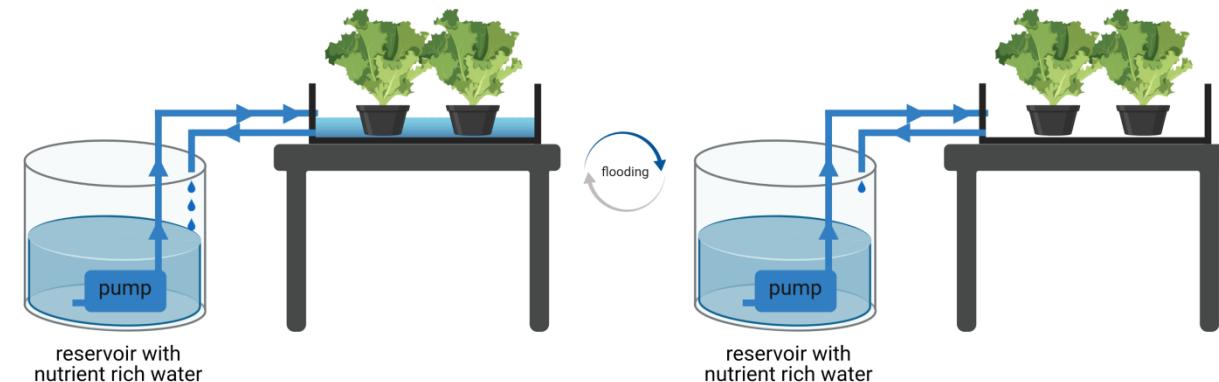
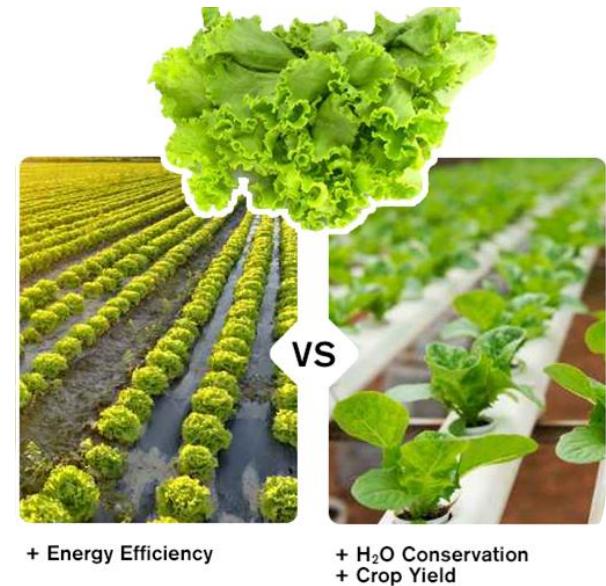
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Hydroponics

- 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



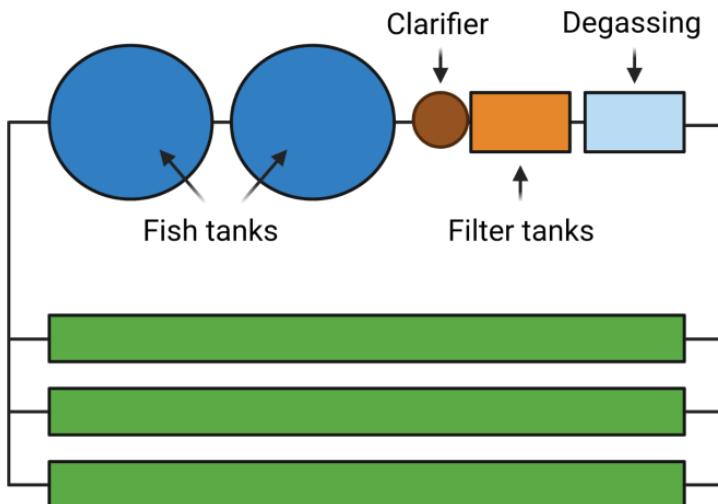
Expanded clay aggregate Rock wool



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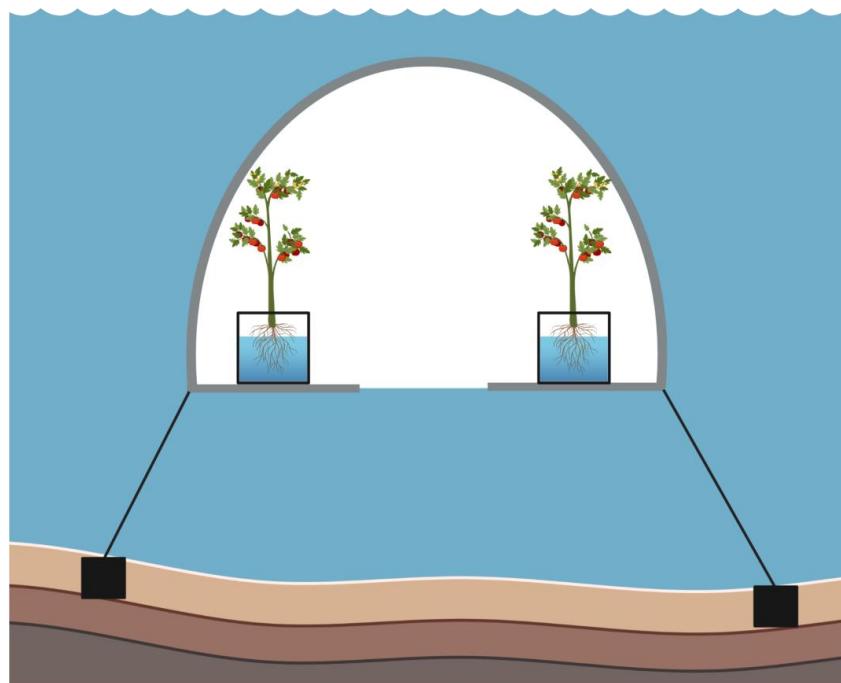
Aquaponics

- Next level hydroponics: combining fish farming (aquaculture) and hydroponics
- Closed loop(N and CO₂):
 - 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



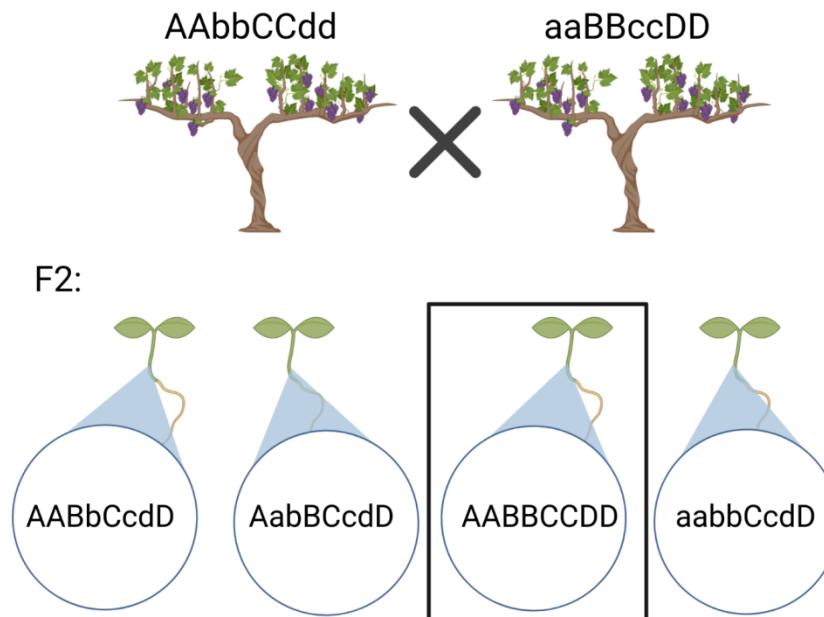
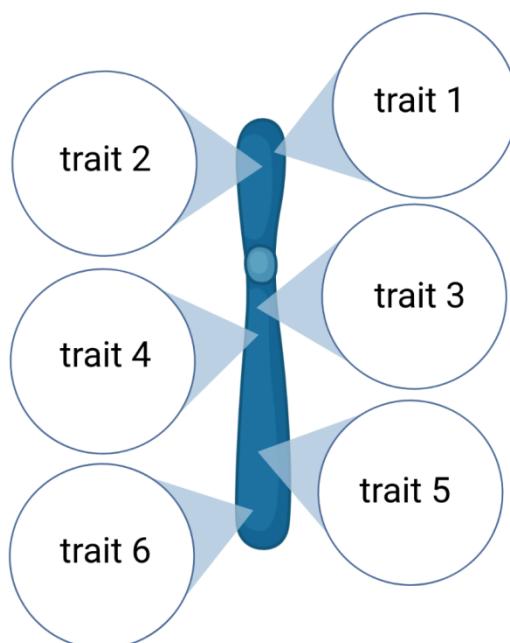
Underwater farming: Nemo's Garden Project

- Isolated biospheres underwater are free of pests
- Might withstand earth quake and tsunami
- Next step: using saltwater for agriculture (Red Sea Farms project)

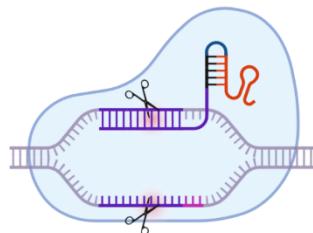


SMART breeding

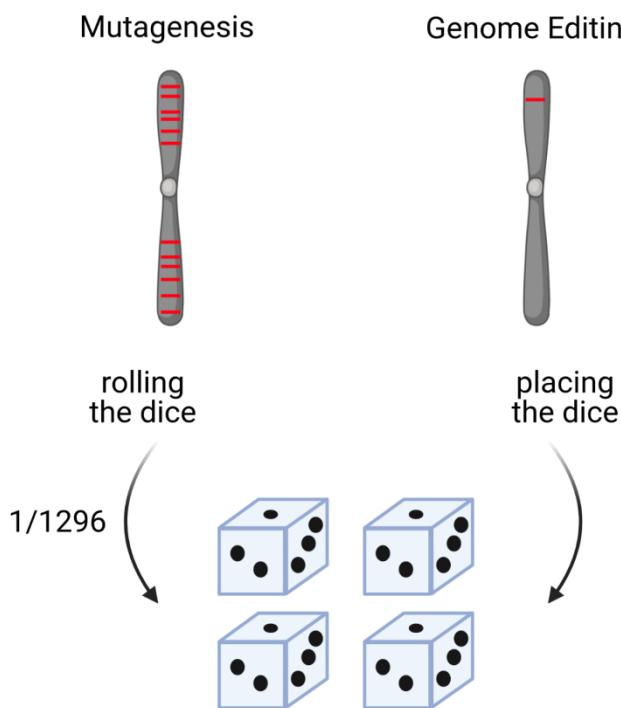
- SMART = Selection with Markers and Advanced Reproductive Technologies
- No genetic engineering; just selection of desired trait combinations
- Knowledge about genes underlying a trait is beneficial for optimal marker design
- Methods: marker-assisted selection (MAS) and mutation breeding



Genome Editing via CRISPR/Cas9



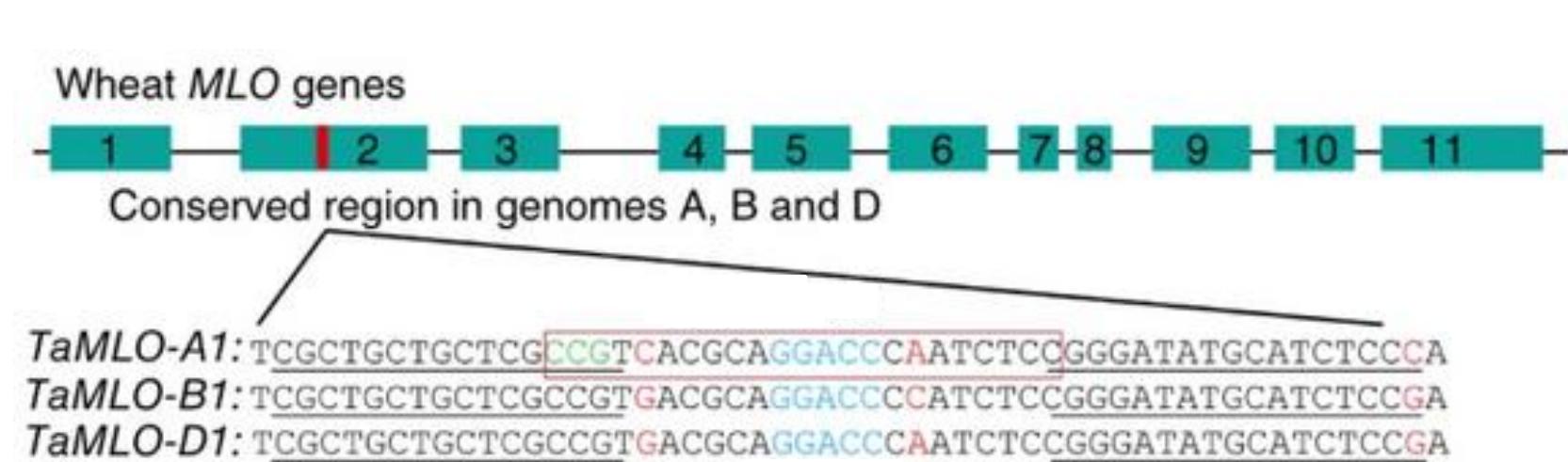
Jennifer Doudna & Emmanuelle Charpentier
(Nobel Prize for Chemistry 2020)



- 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

Genome Editing Applications: *MLO* in bread wheat

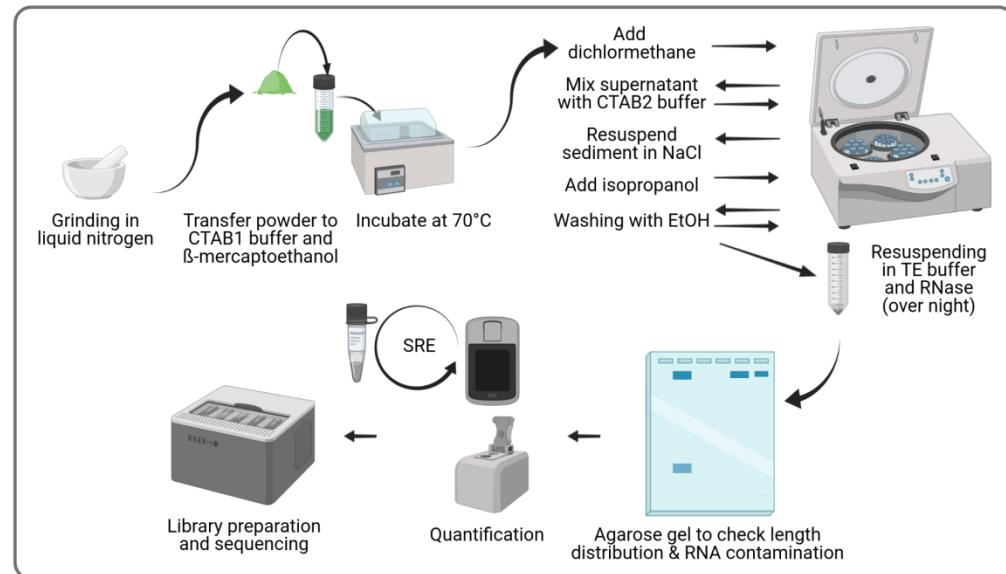
- Editing of 3 homoeoalleles of *MILDEW-RESISTANCE LOCUS (MLO)* in bread wheat confers resistance against powdery mildew
- Trait is not found in natural population due to genetic redundancy
- Broad spectrum inheritable resistance



Establishing orphan crops



Yams become inedible shortly after harvest



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 Viehöver², Dirk C. Albach¹ and Bernd Weisshaar^{2,*}



Identification of causal genes is first step towards modification



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 [†]



Vertical farming

- Plants are grown in stacked layers to save space
- Combined with hydroponics or aquaponics
- Re-using existing structure e.g. old buildings
- Challenges:
 - High start-up and maintenance costs
 - Energy requirements
 - Water and light pollution
- Vertical farming directly in the supermarket (microgreens)



Dickson Despommier
(made vertical farming popular)



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?



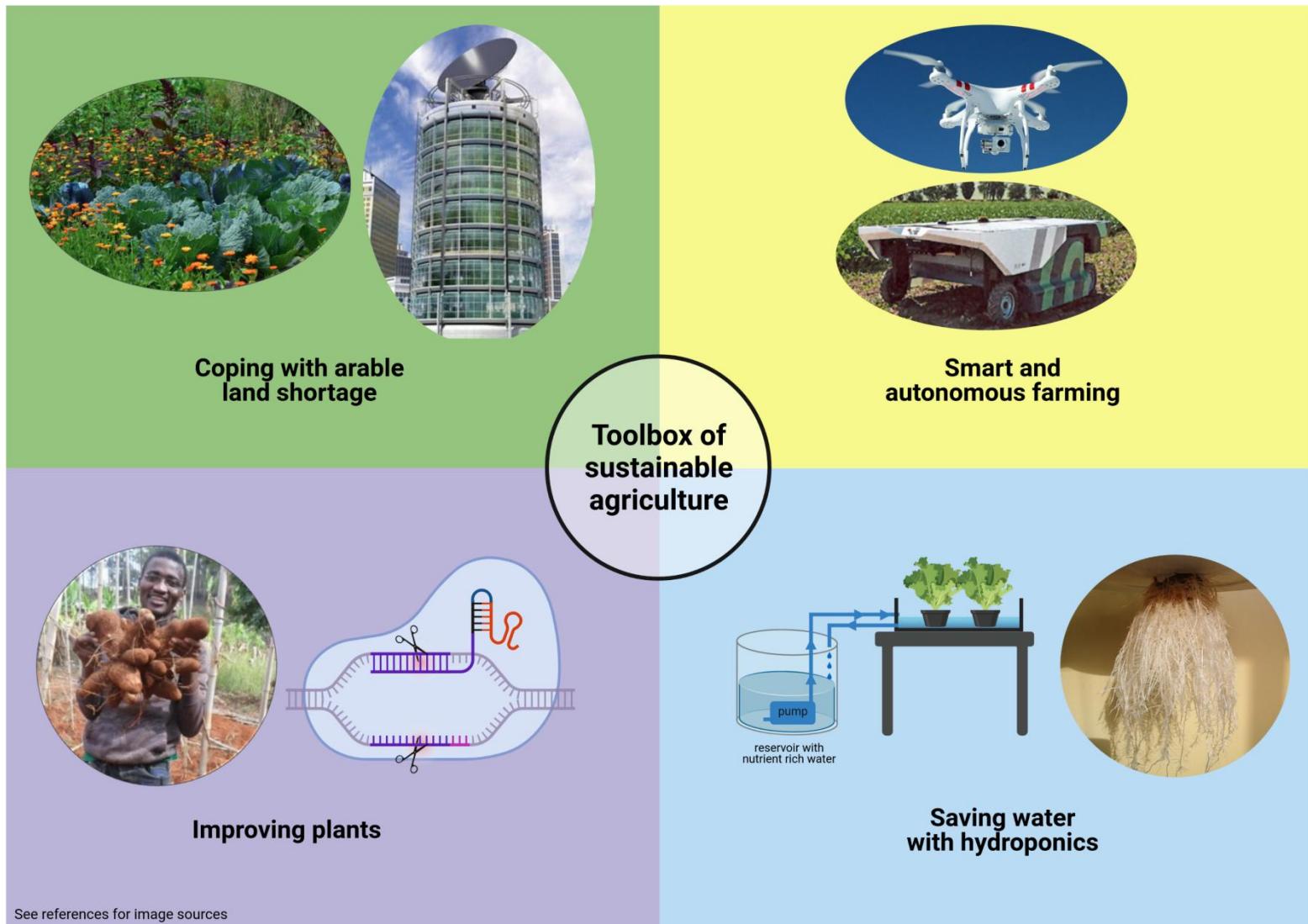
Integration through urban farming

- “Sieker-Gärten” supports integration of migrants through gardening/farming
- 2500 m²; 40 families (200 persons)
- Children learn concepts of biodiversity, ecology, and economy



Urban farming project ‘Sieker-Gärten’

Summary



Questions?



Literature and References

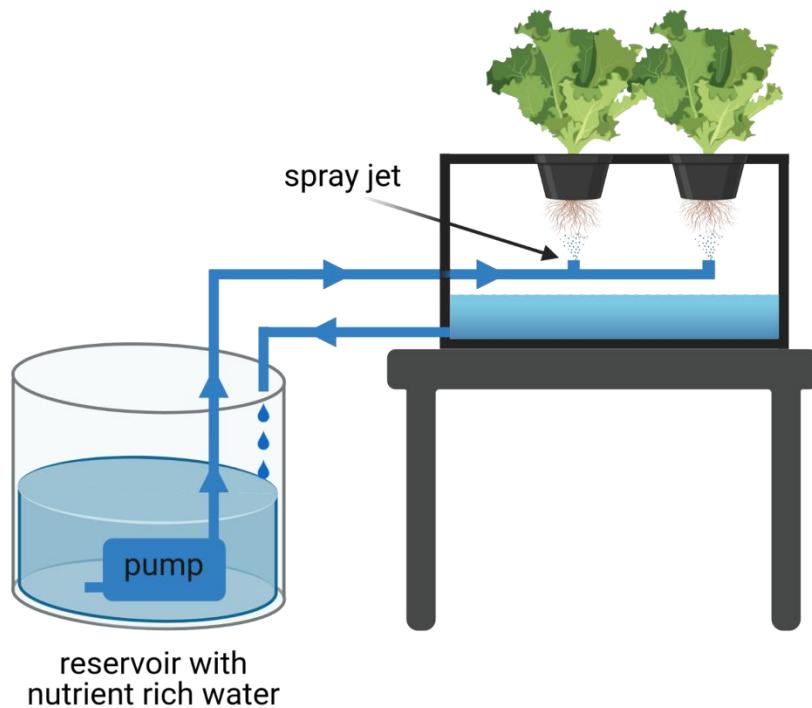
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- <http://www.fao.org/faostat/en/#data/RL/visualize>
- https://ec.europa.eu/clima/policies/eu-climate-action_en
- <https://www.ise.fraunhofer.de/de/leitthemen/integrierte-photovoltaik/agri-photovoltaik-agri-pv.html>



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 repellent intercropping



cereals & peas



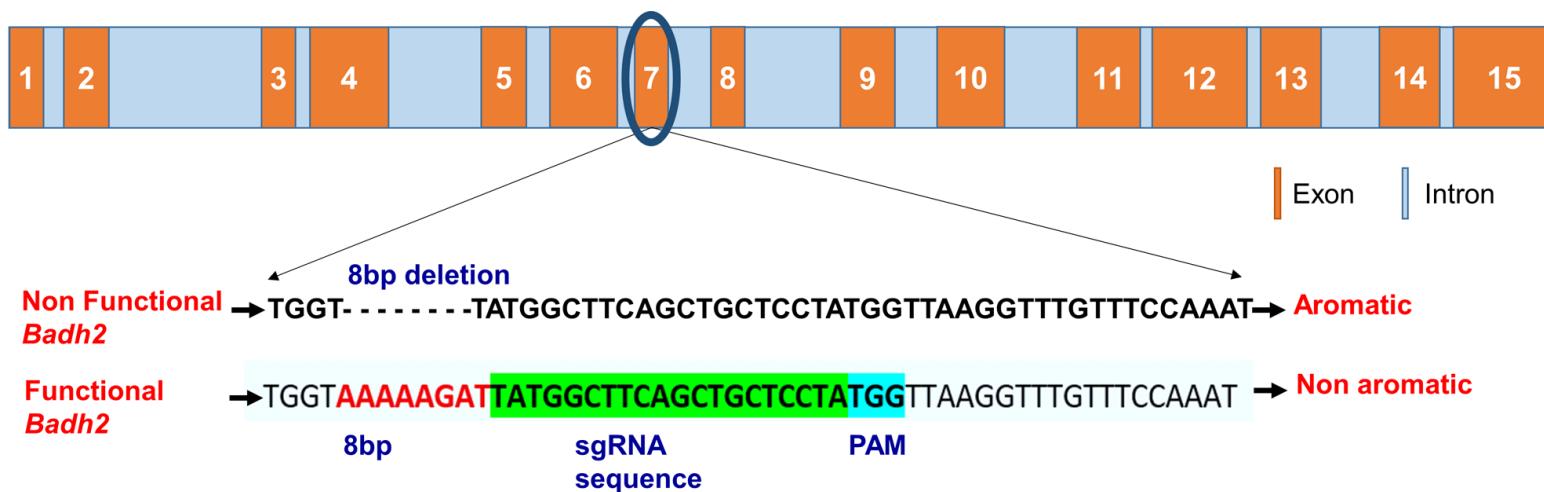
carrots & onions



strawberries & onions

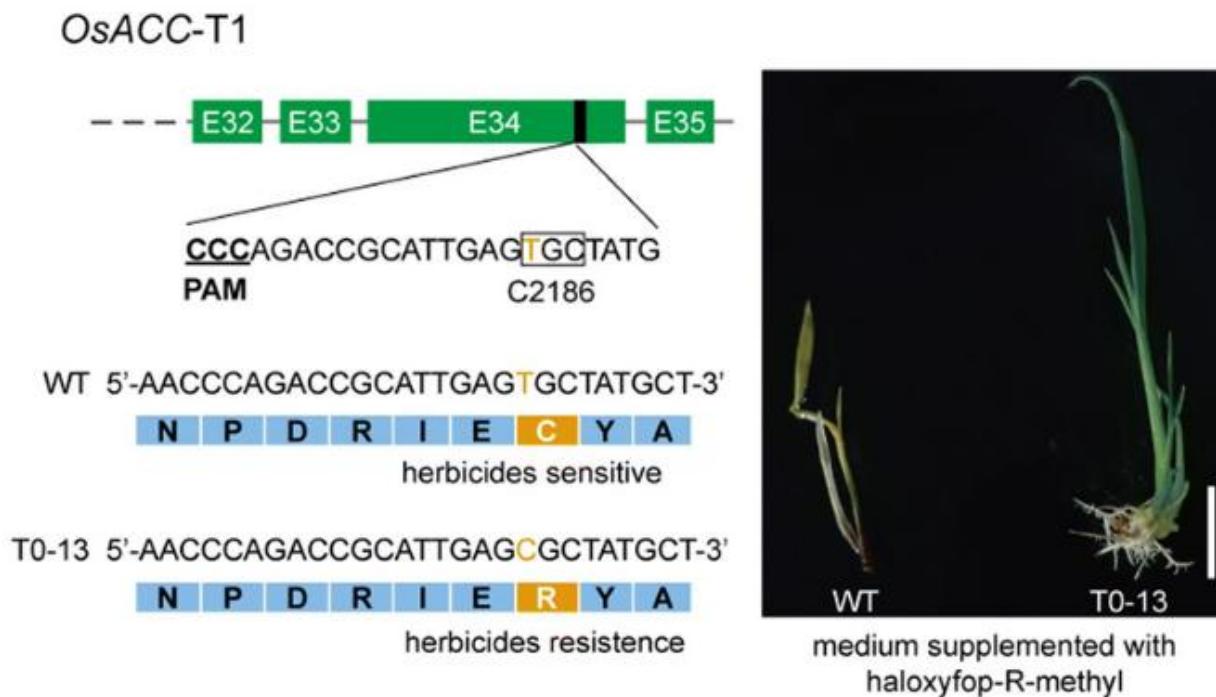
Genome Editing Applications: BADH2 in rice

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



Genome Editing Applications: herbicide tolerant rice

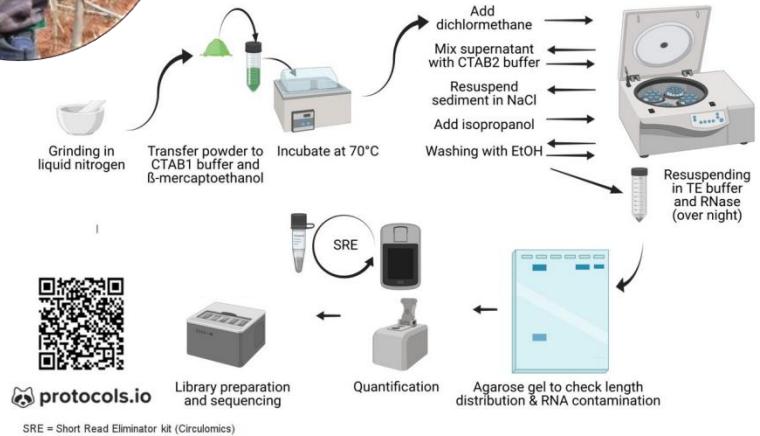
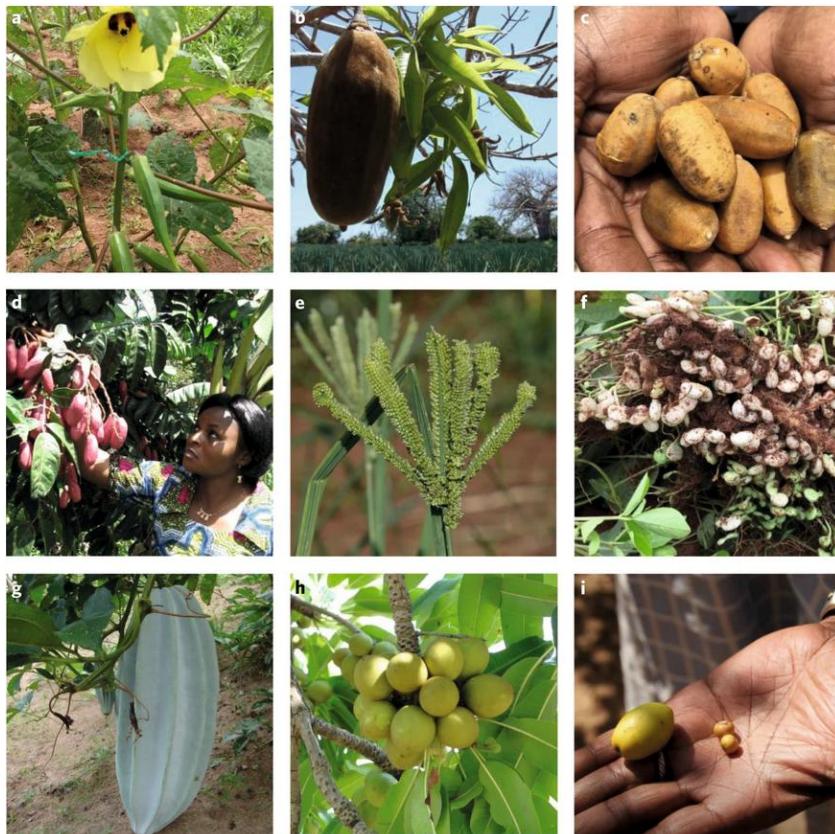
- tRNA adenosine deaminase is fused to Cas – enabling A-T to G-C conversion
- Gain of function point mutation in ACC confers herbicide resistance (C2186R)
- *Lolium rigidum* plants with this amino acid substitution showed resistance



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



Yam genome sequence



Article

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

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Food loss

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

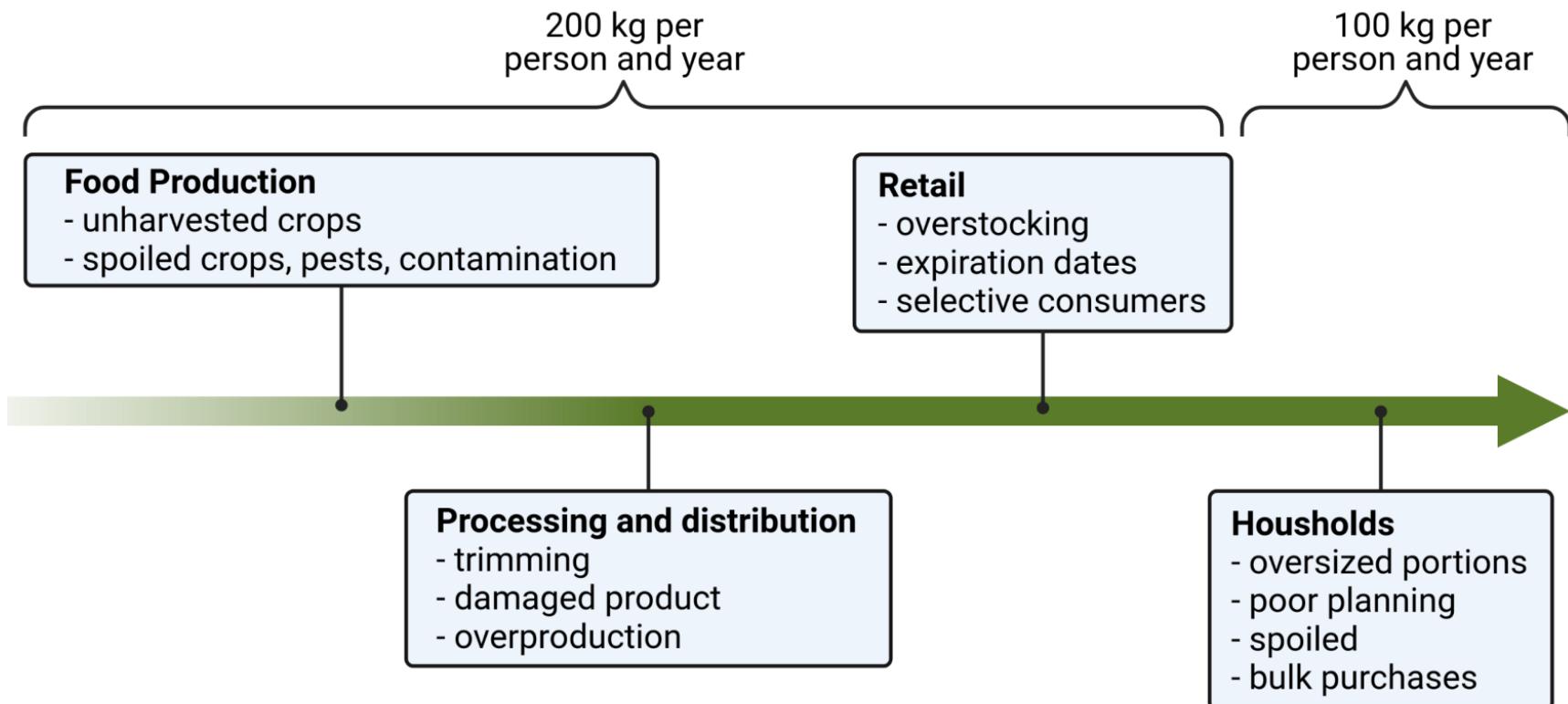


Image References

- Drone: [https://commons.wikimedia.org/wiki/File:DJI_Phantom_2_Vision%2B_V3_howering_over_Weissfluhjoch_\(cropped\).jpg](https://commons.wikimedia.org/wiki/File:DJI_Phantom_2_Vision%2B_V3_howering_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
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- 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