The future of food production

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2022 World Food Prize,

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Overview

1. Ag challenge and climate change
2. Climate impact
   a. Temperature stress impact and adaptation
   b. Extremes
3. Alternatives food production systems
4. Summary

Agricultural challenge

Future Food = complex challenge

Food producing systems (crops, livestock & seafood)

- **Increasing demand, food security, quality/nutrition, food safety, health, antimicrobial resistance, hunger-obesity,**
- **Environment (waste, water use & water pollution, overfishing, GHG),**
- **Social inequity (income, women, youth, access to knowledge & technology, …)**

+ Climate change

Paradigm shifts needed.

Asseng et al. 2021 JAS

Agriculture --- Climate Change

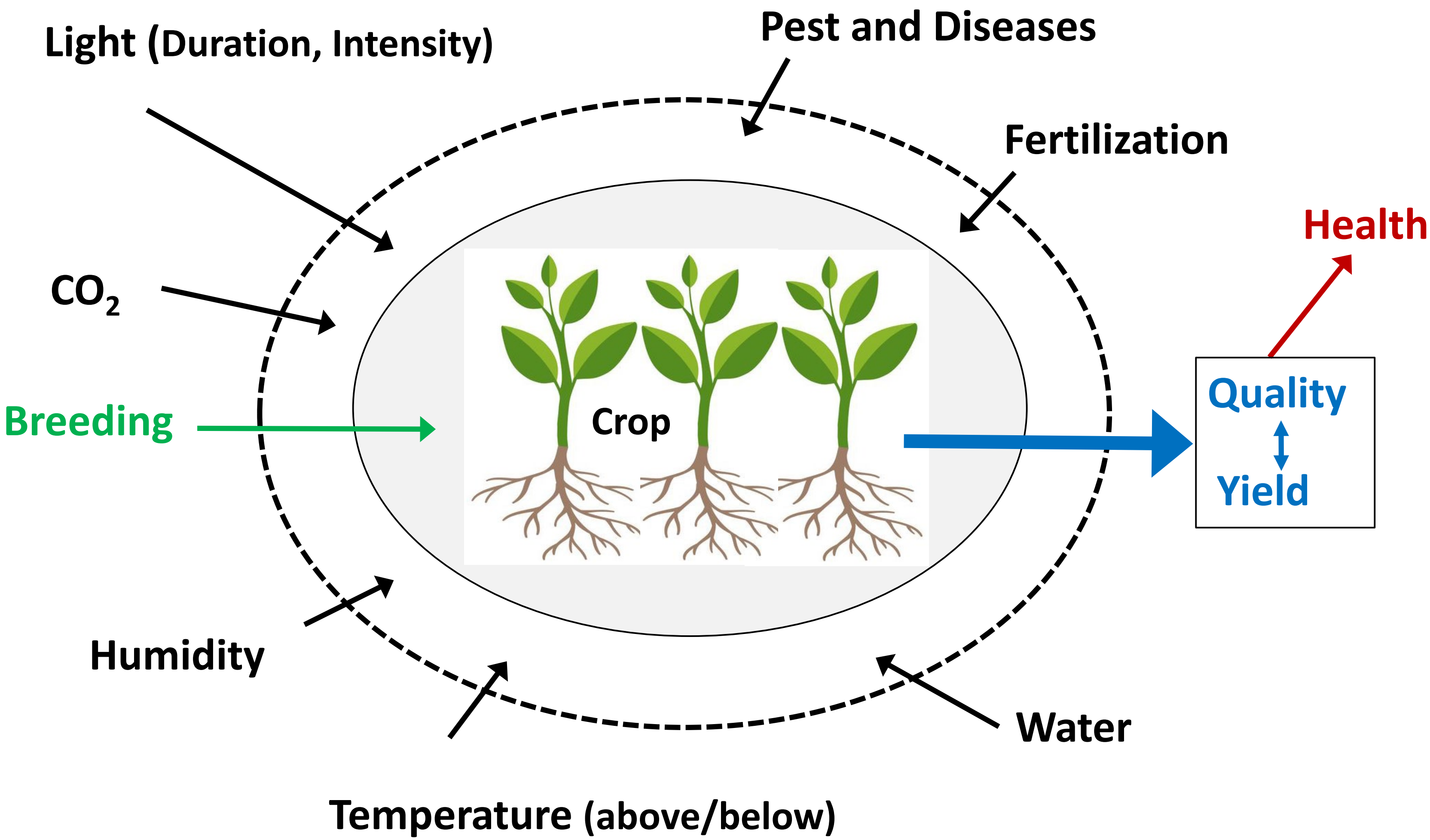
- Produce more food
- Increase nutritional value
- Reduce environmental impact

Climate Change

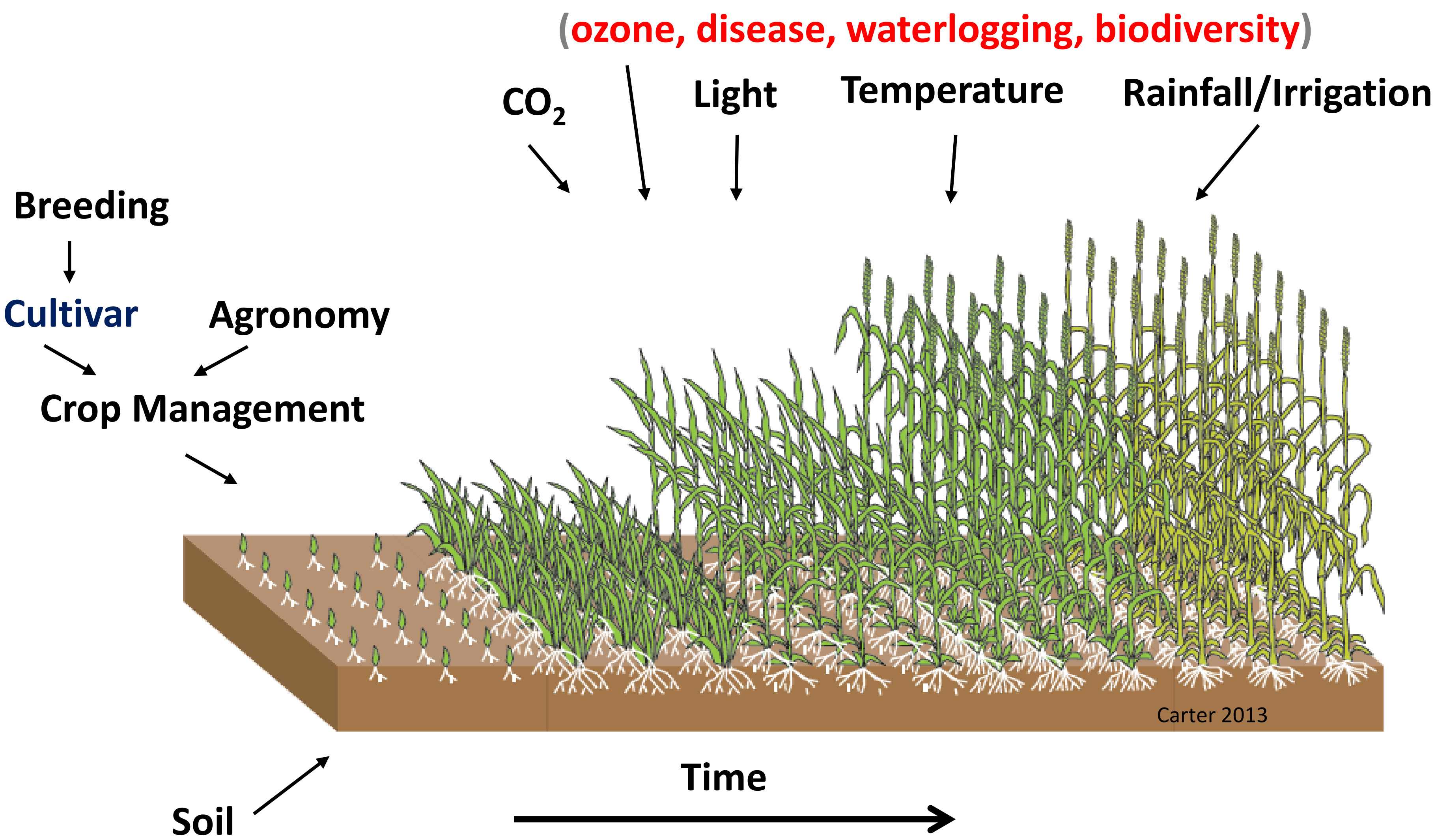
- **Temperature increased by 1.0 ^{o}C**
- **By 2050: Atmospheric CO_2 >500ppm**
- **By 2100:**
  - **Temperature +2 to 4 ^{o}C**
  - **More extremes (heat, droughts, rainfall).**

(IPCC 2015)

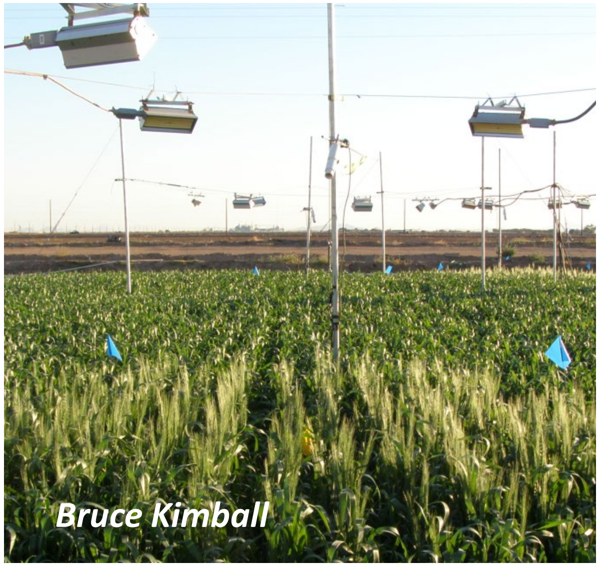
Crop: center of Ag research, basis of food (crop = plant community in the field)

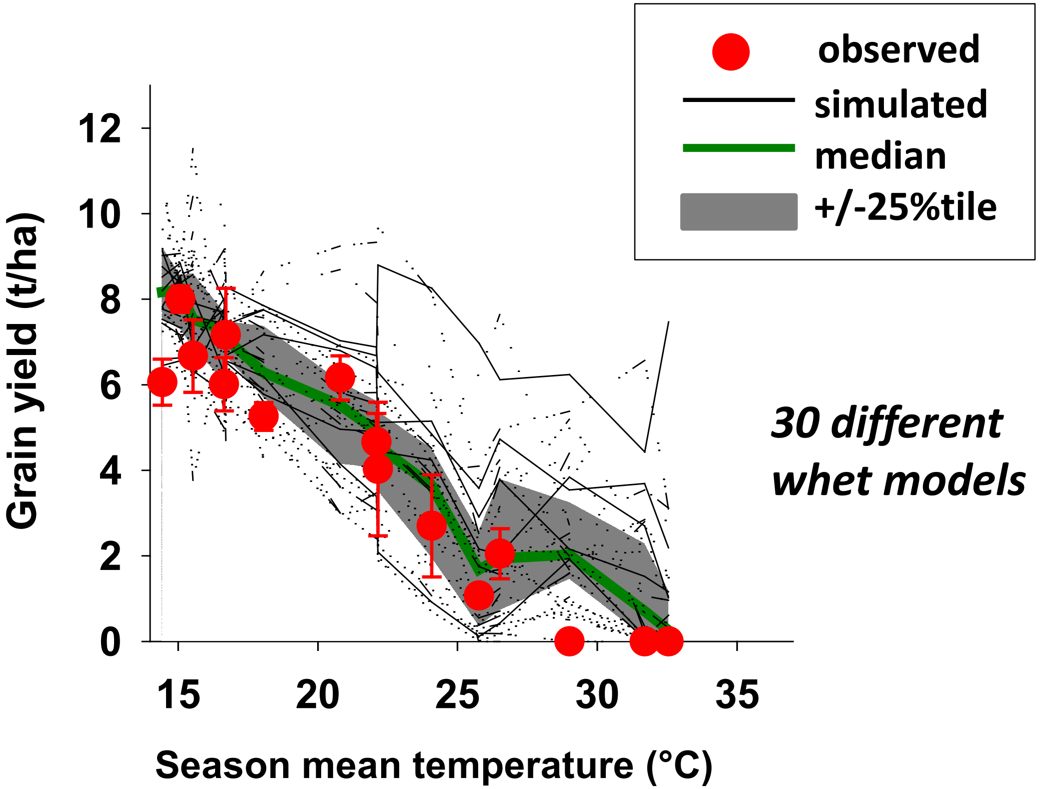


Modeling Wheat Cropping Systems



Multi-model ensembles





30 different whet models

Asseng et al. 2015 Nature CC

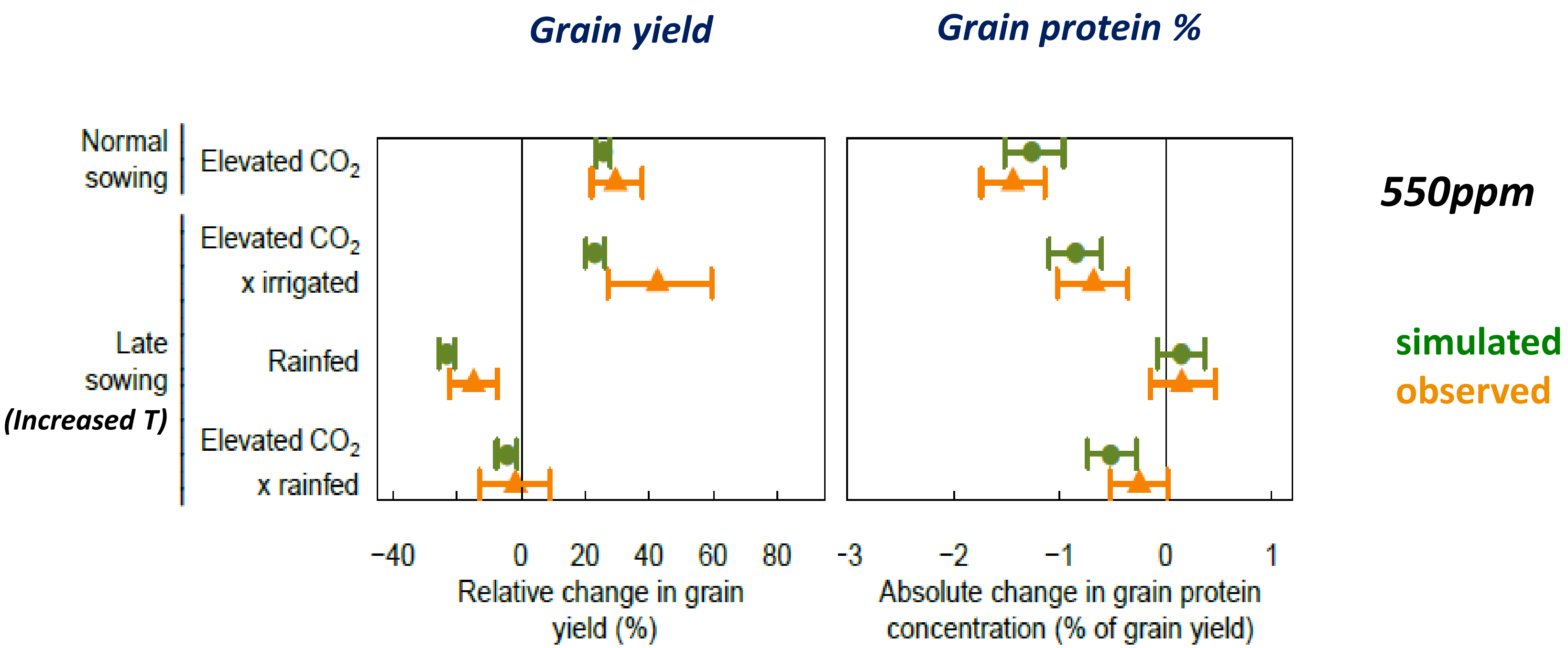
Multi-model ensembles

➢ **Multi-model ensemble median is a better predictor than any single model !**

- **Wheat yields --- *Asseng et al. 2013 Nature CC***
- **Wheat yields (heat stress) --- *Asseng et al. 2015 Nature CC***
- **Wheat variables --- *Martre et al. 2014 GCB***
- **Maize yields --- *Bassu et al. 2014 GCB***
- **Rice yields --- *Li et al. 2014 GCB***
- **Potato yields --- *Fleisher et al. 2016 GCB***
- ***Stats explanation --- Wallach et al. 2018 GCB***

Model testing with CO_2 x T x Rain

Median of 32 (18 with N) wheat models

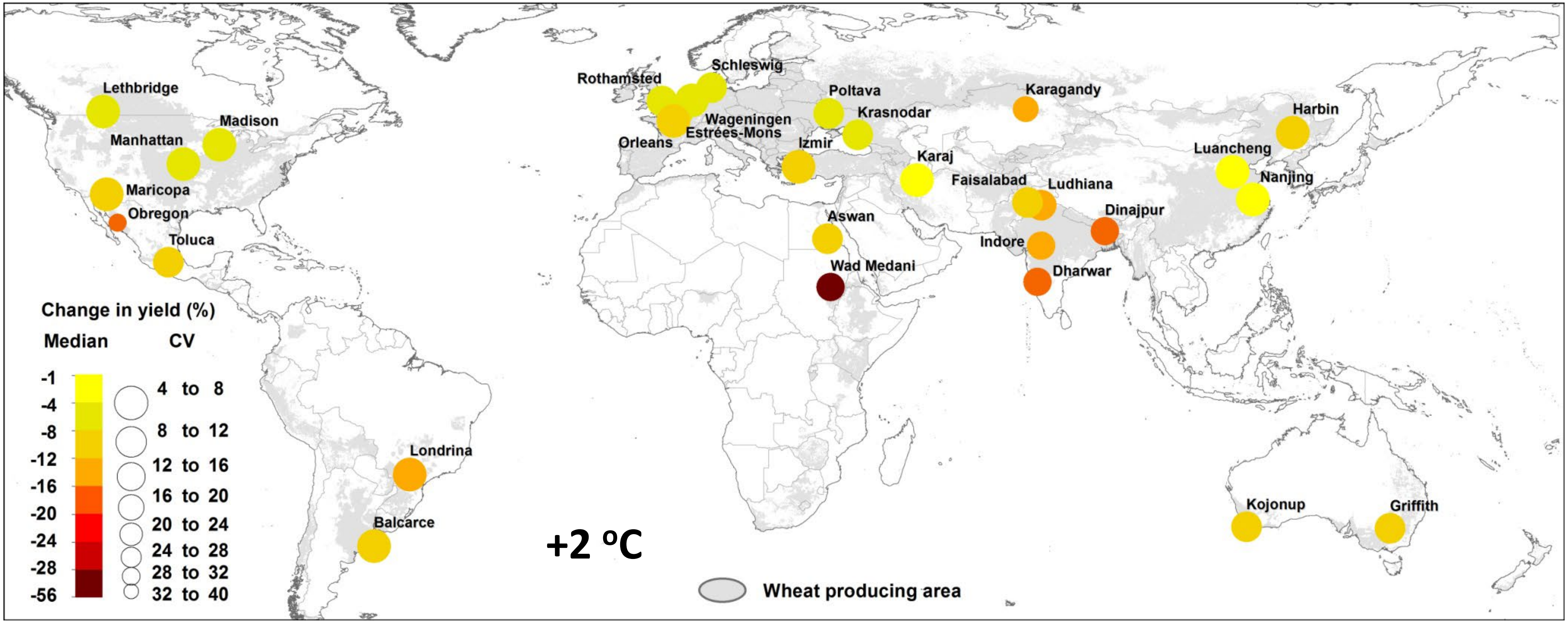


Asseng et al. 2019 GCB

Temperature impact on wheat

Wheat Yield decline with increasing temperature

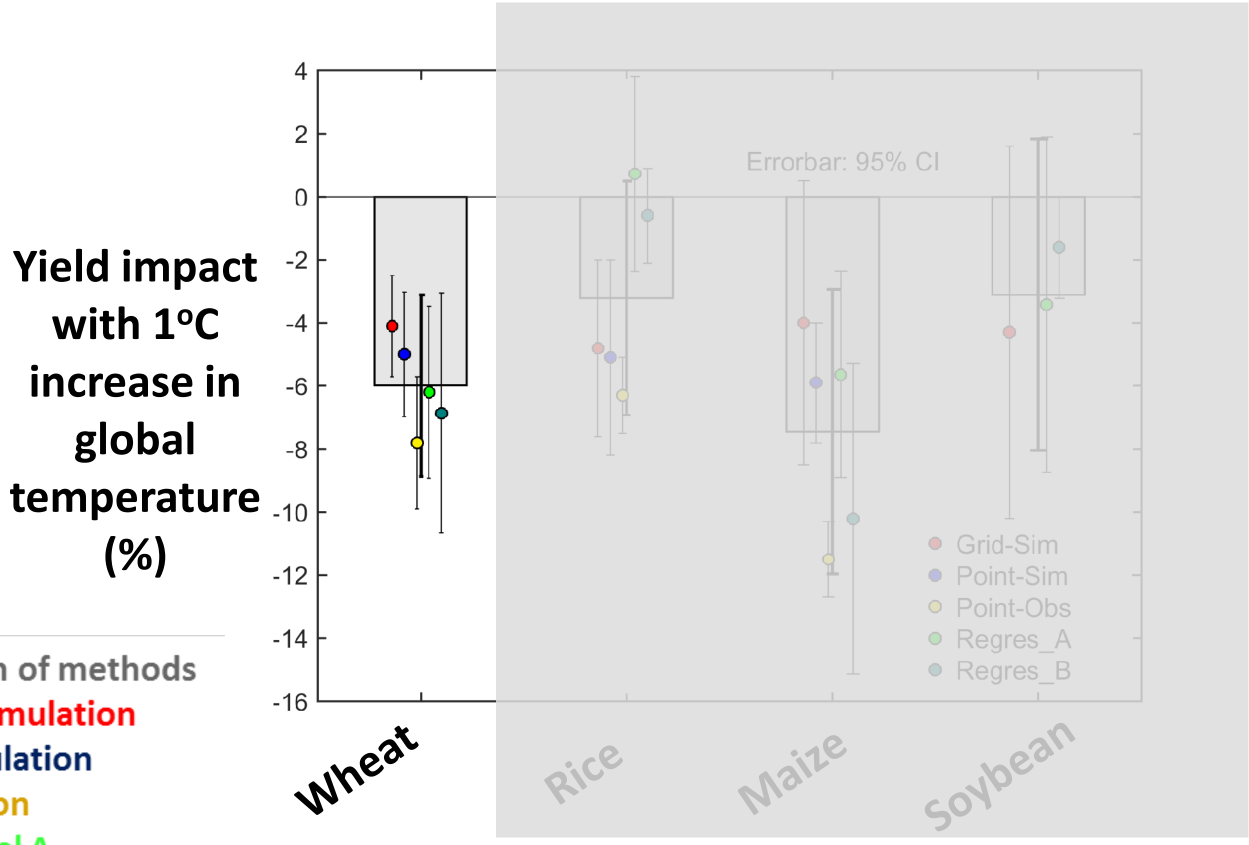
30 model ensemble median (& mean of 30 years)



- ➤ **6% decline in global wheat production for <u>each</u> degree in global warming**

Asseng et al. 2015 Nature CC

Impacts of global temperature increase on global yield estimates for major crops (using 4 methods)



Bar - Mean of methods
Gridded simulation
Point simulation
Observation
Stats model A
Stats model B

(For wheat: *Liu et al. 2016 Nature CC*)

Zhao et al. 2017 PNAS

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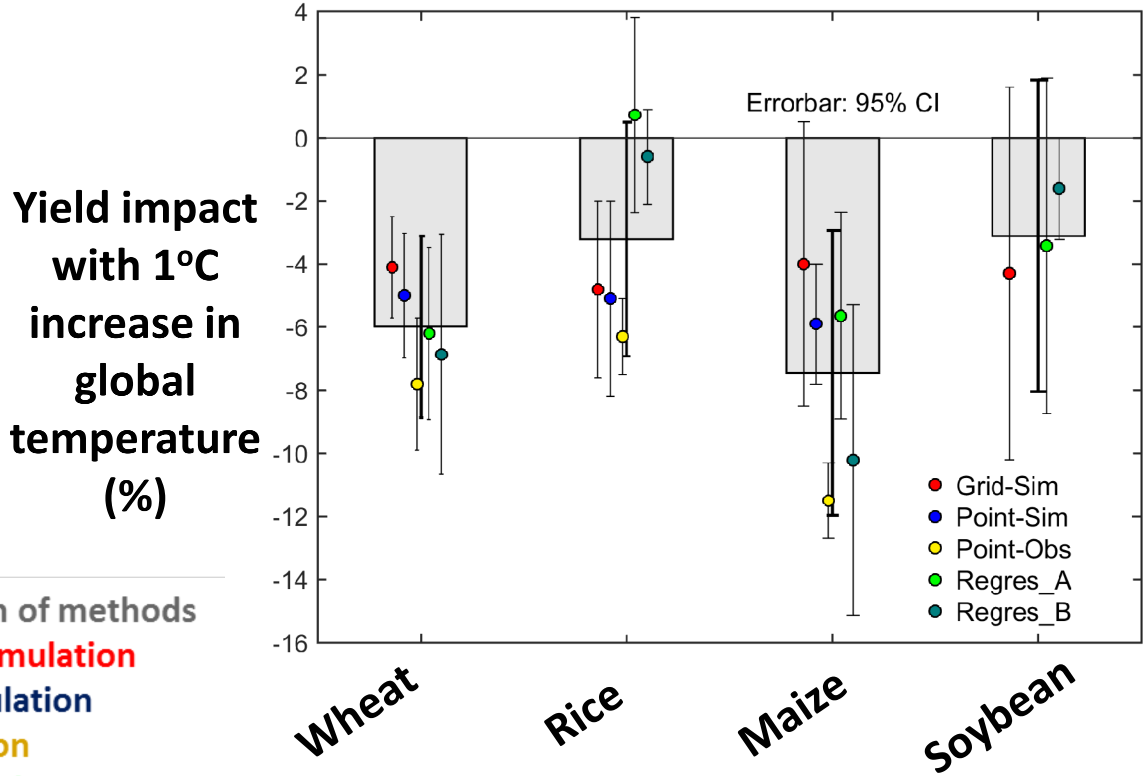

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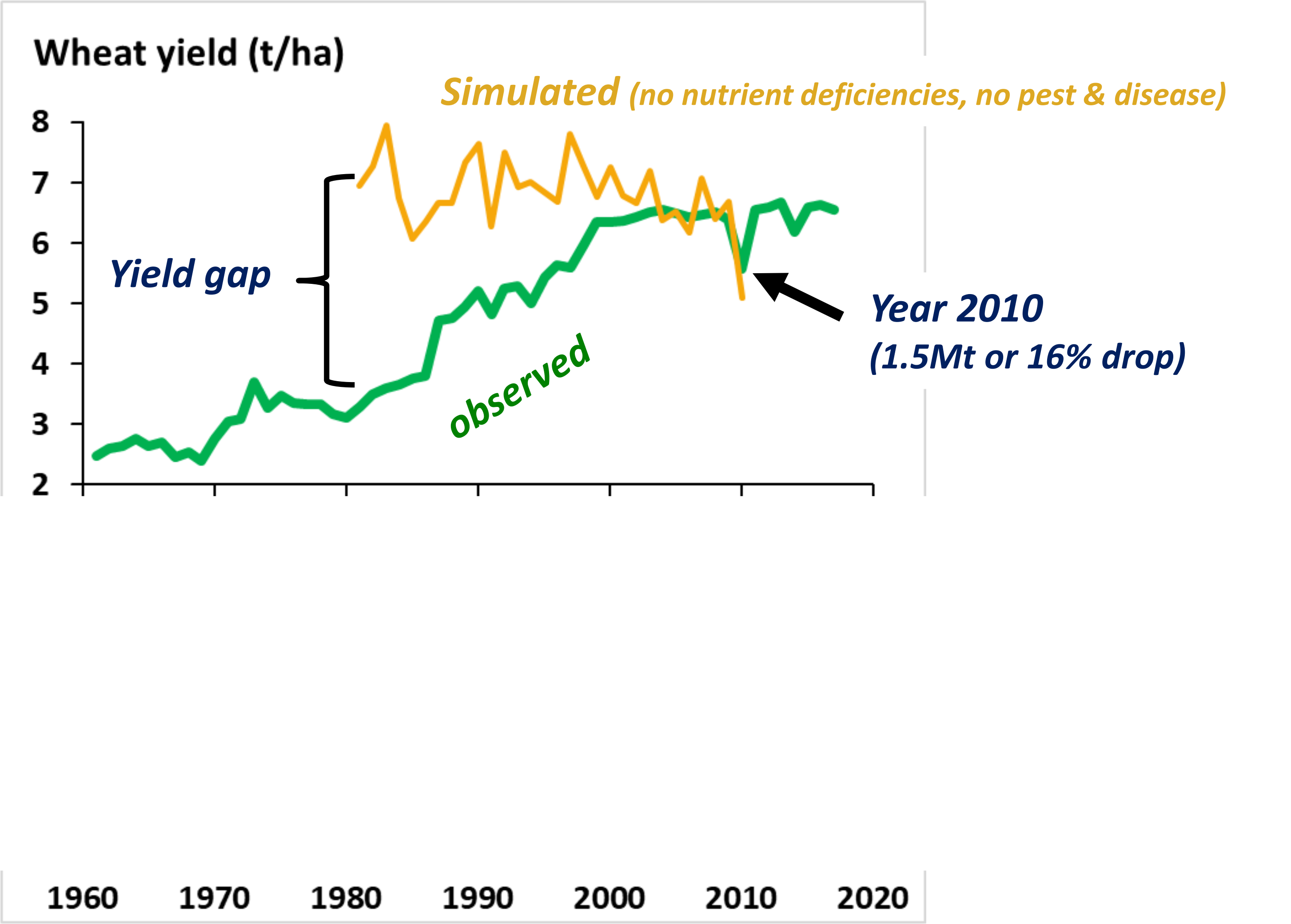
AgMIP The Agricultural Model Intercomparison and Improvement Project

Egypt: stagnating yields since 2000 & heat shock

Stagnating yields in many countries
Ray et al. 2012 Nature Comms



Asseng et al. 2018 ERL

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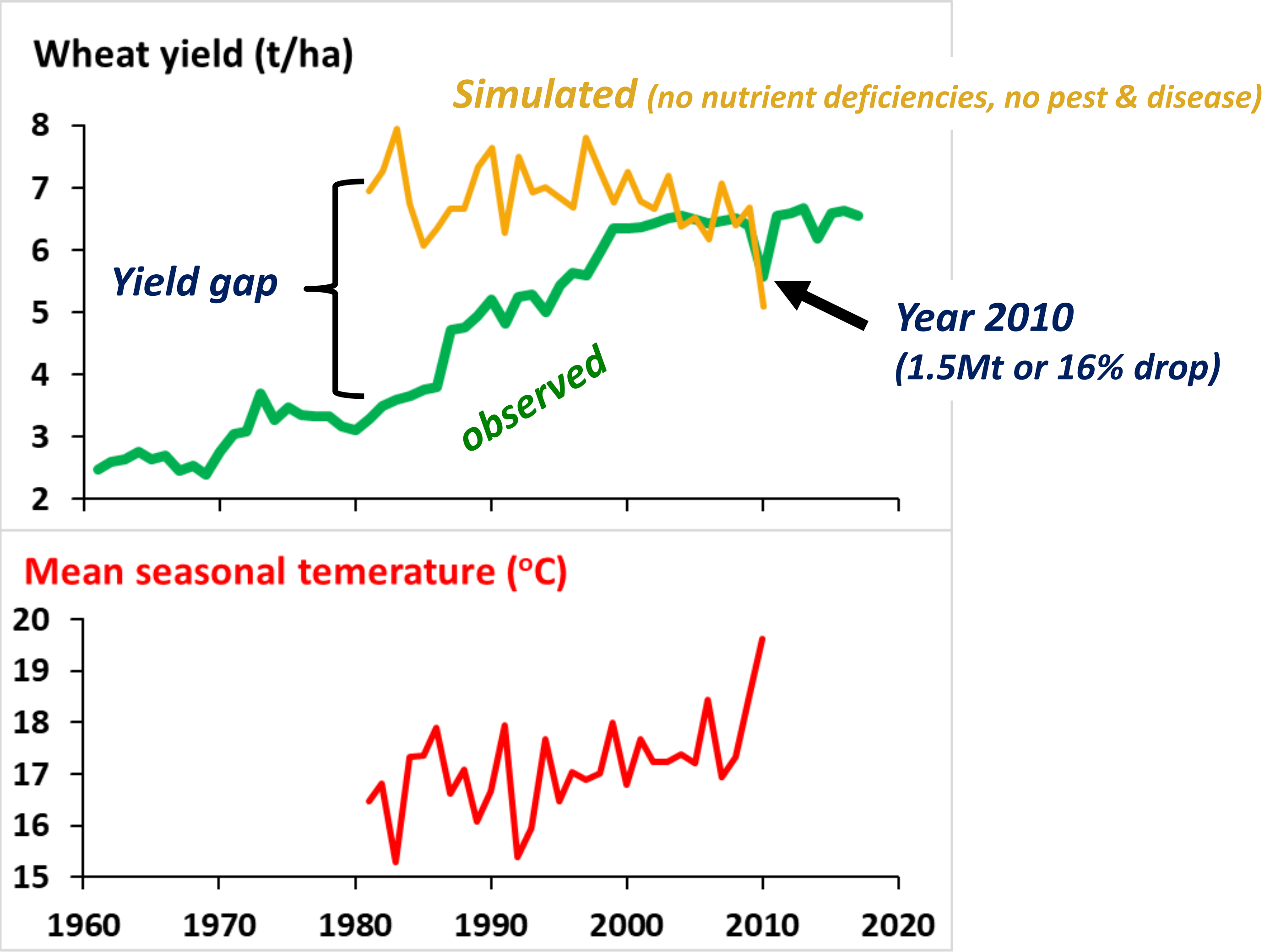


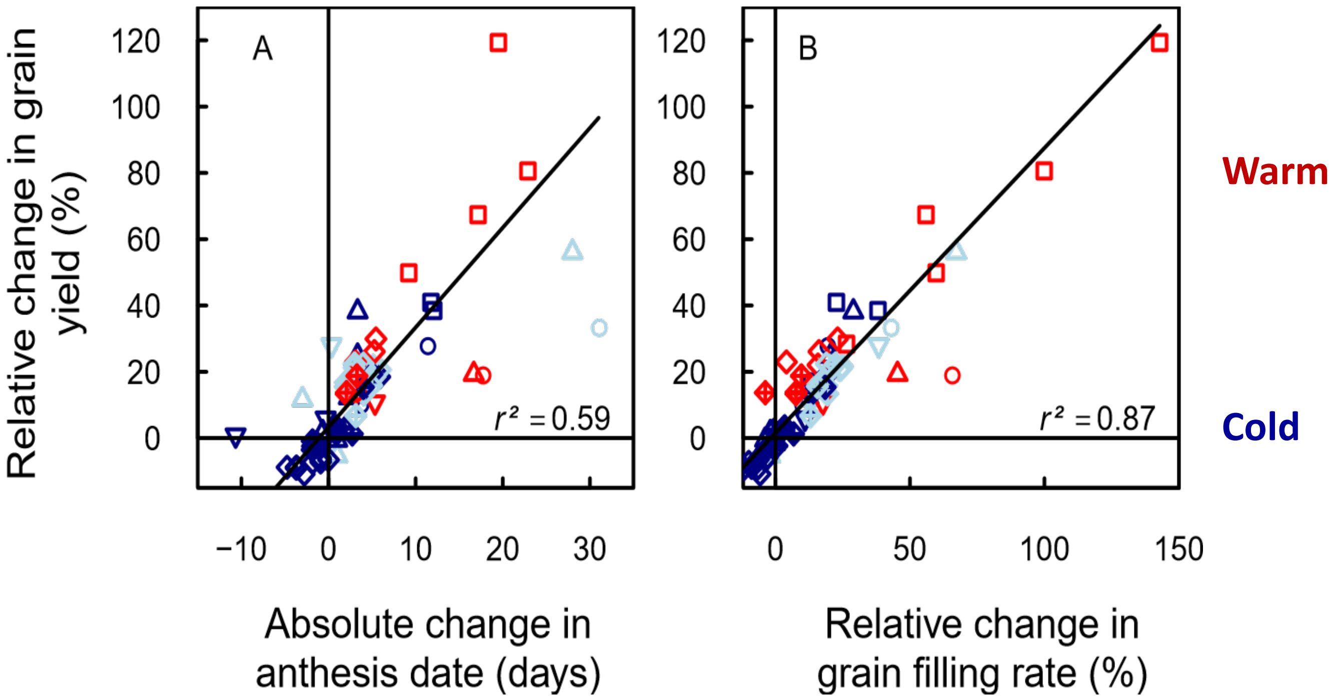
Asseng et al. 2018 ERL

Adaptation to temperature

Field observations from 4 experiments

Proposed adaptation to increased temperature:

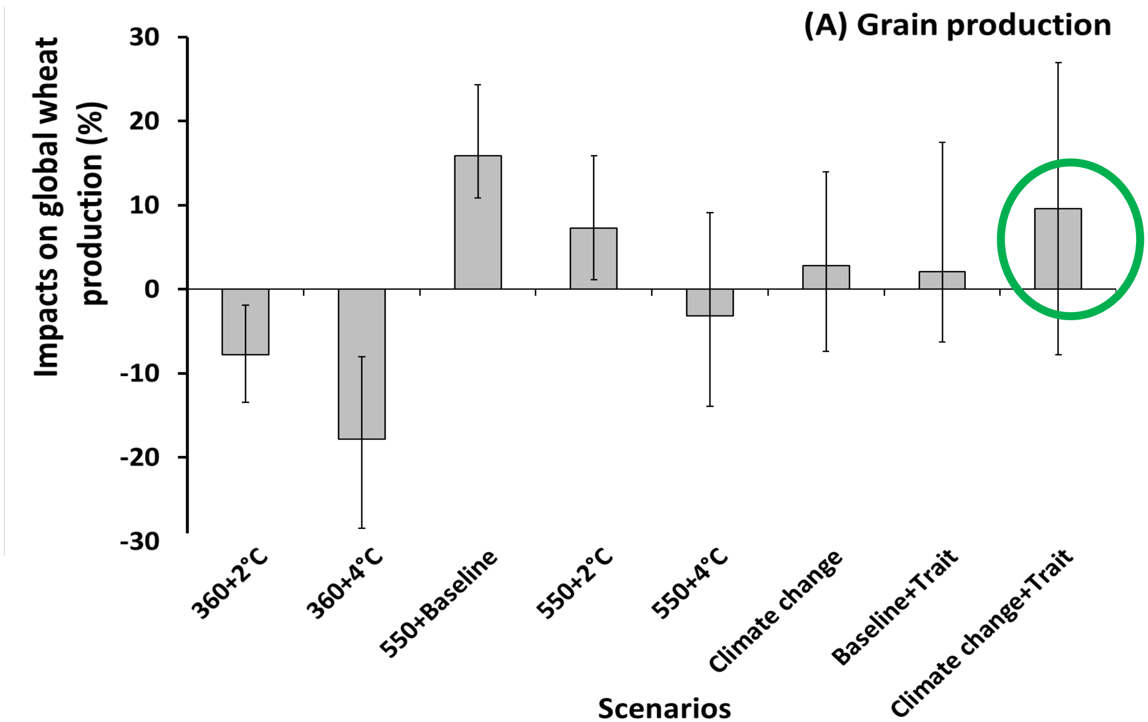
- **Delay anthesis + increase grain filling rate,** ***Asseng et al. 2015 Nature CC***
- **Does exist,** ***Asseng et al. 2019 GCB***



Asseng et al. 2019 GCB

Climate change impact (2050) at global scale (temperature, CO_2, rain)

Median of 32 (18 with N) models



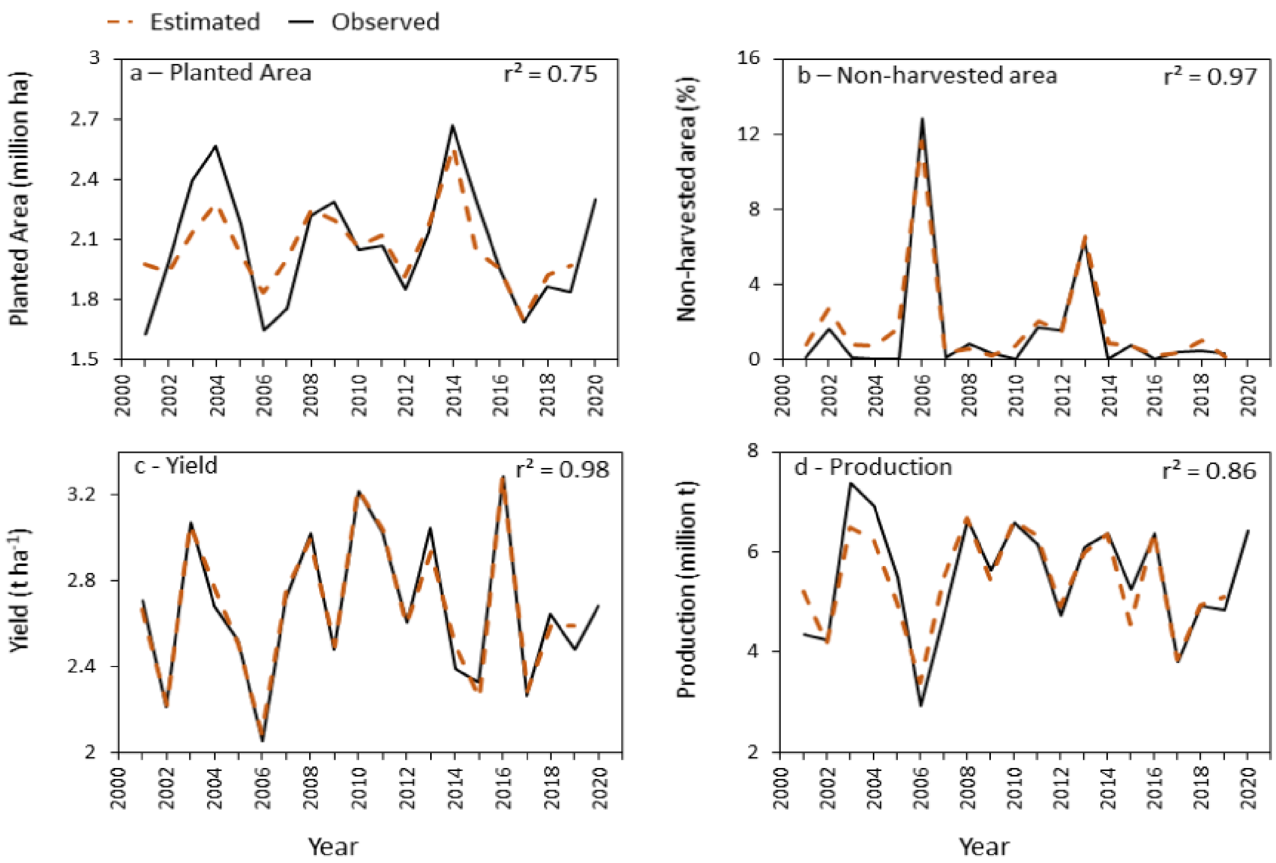
Delay anthesis + increase grain filling rate

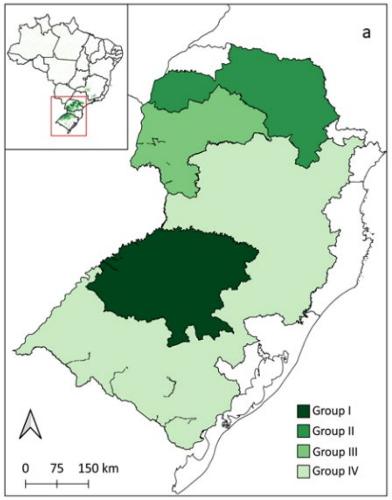
Asseng et al. 2019 GCB

Climate change and extreme events

Wheat grain production extremes, Brazil

Multiple linear regression models, built with regional data



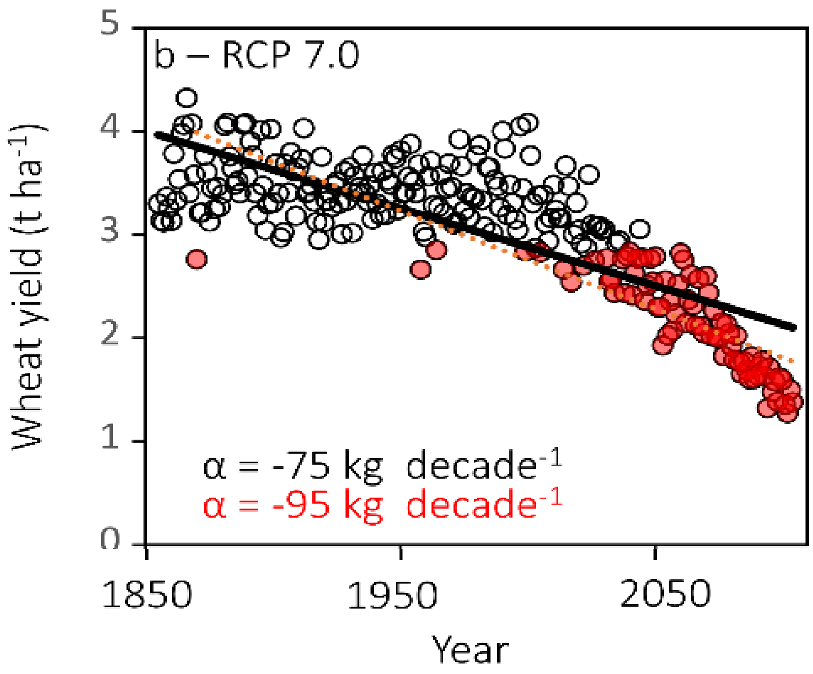


de Souza Nóia Júnior et al. 2021 ERL

Wheat grain yield extremes, Brazil

Brazil, estimated national wheat yield

(5 CIMP6 climate data)



extreme low production

Extreme: 5th percentile of occurrence of simulated wheat production during 1850-2020

de Souza Nóia Júnior et al. 2021 ERL

Alternative food production systems

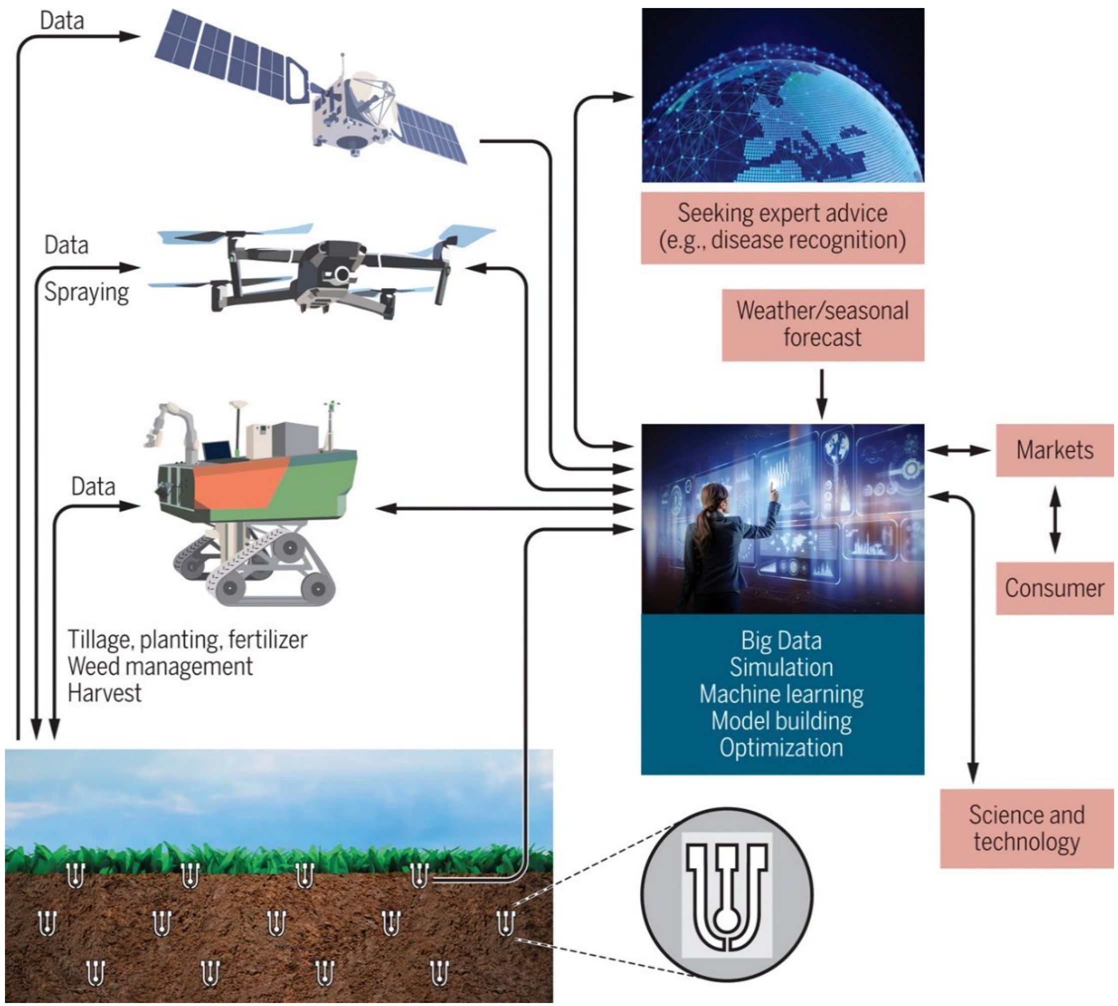
Promising technology

1. **Robots/drones replacing labor – declining labor force, fewer young people**
2. Large scale aquaculture – produce fish on land! conserve wild fish
3. One-Health concept – dynamic systems
4. **Connectivity & 'Big data'** to optimize systems.
5. **Indoor (control growing conditions crops**/fish)
6. Tailored genes for crops/livestock & fisheries
7. Meat from plants/petri dish --- other novel sources of food?
8. **Minimize environmental degradation** (e.g. GHG neutral, livestock/seafood, recycle water, zero losses), circularity.

- **Youth will drive, Governance is critical.**

Asseng et al. 2021 JAS

Future farms without farmers ?



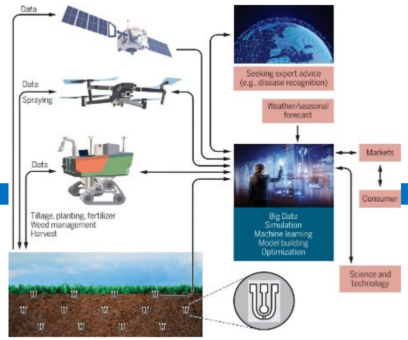
Asseng & Asche, Science Robotics 2019

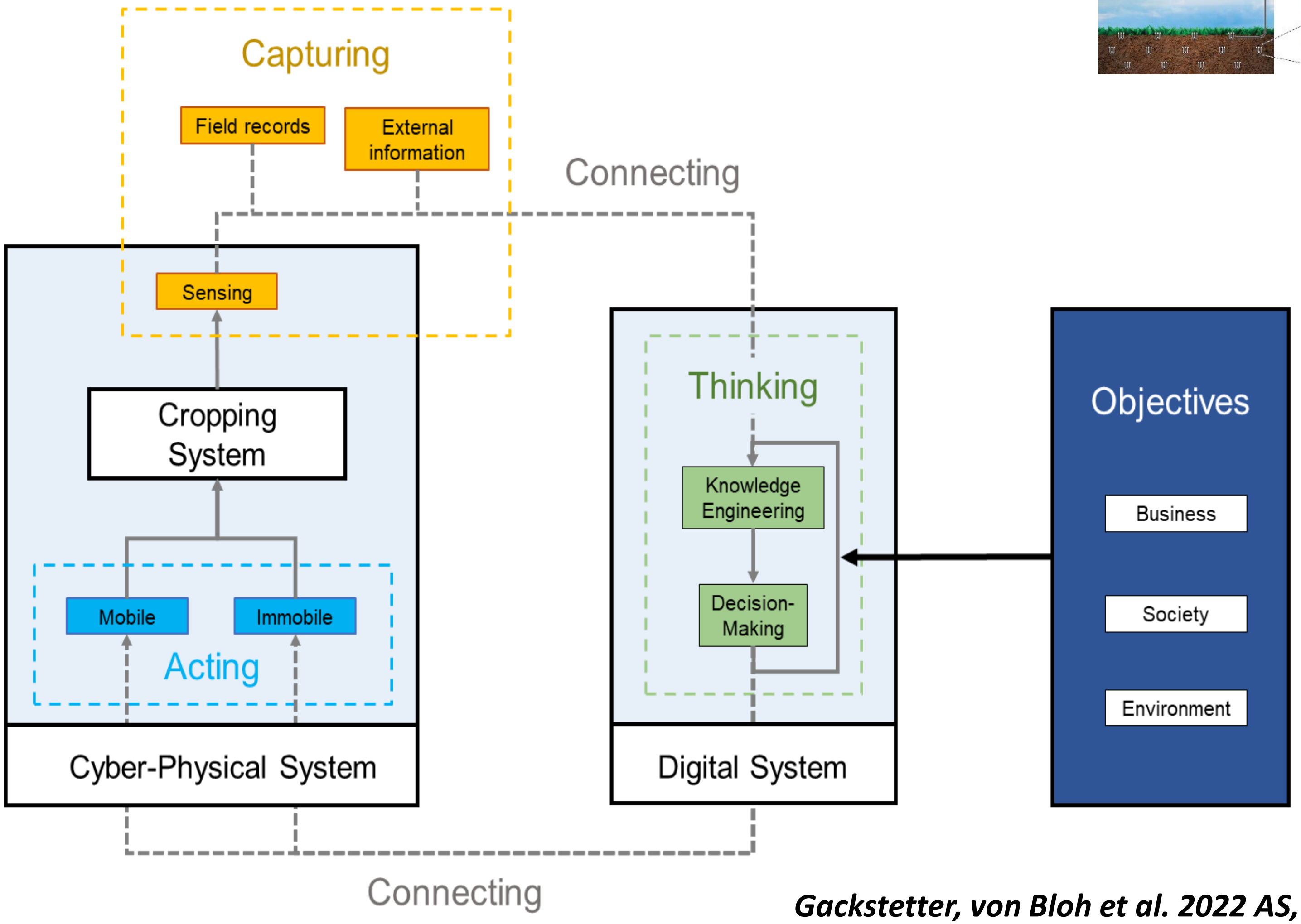
Increased productivity and sustainability
- breaking trend of increasing field/farm size

Conventionell cropping system | Future cropping system

Gackstetter, von Bloh et al. 2022 AS under review

Autonomous farming





Gackstetter, von Bloh et al. 2022 AS, under review

Alternative food production systems

Promising technology solutions

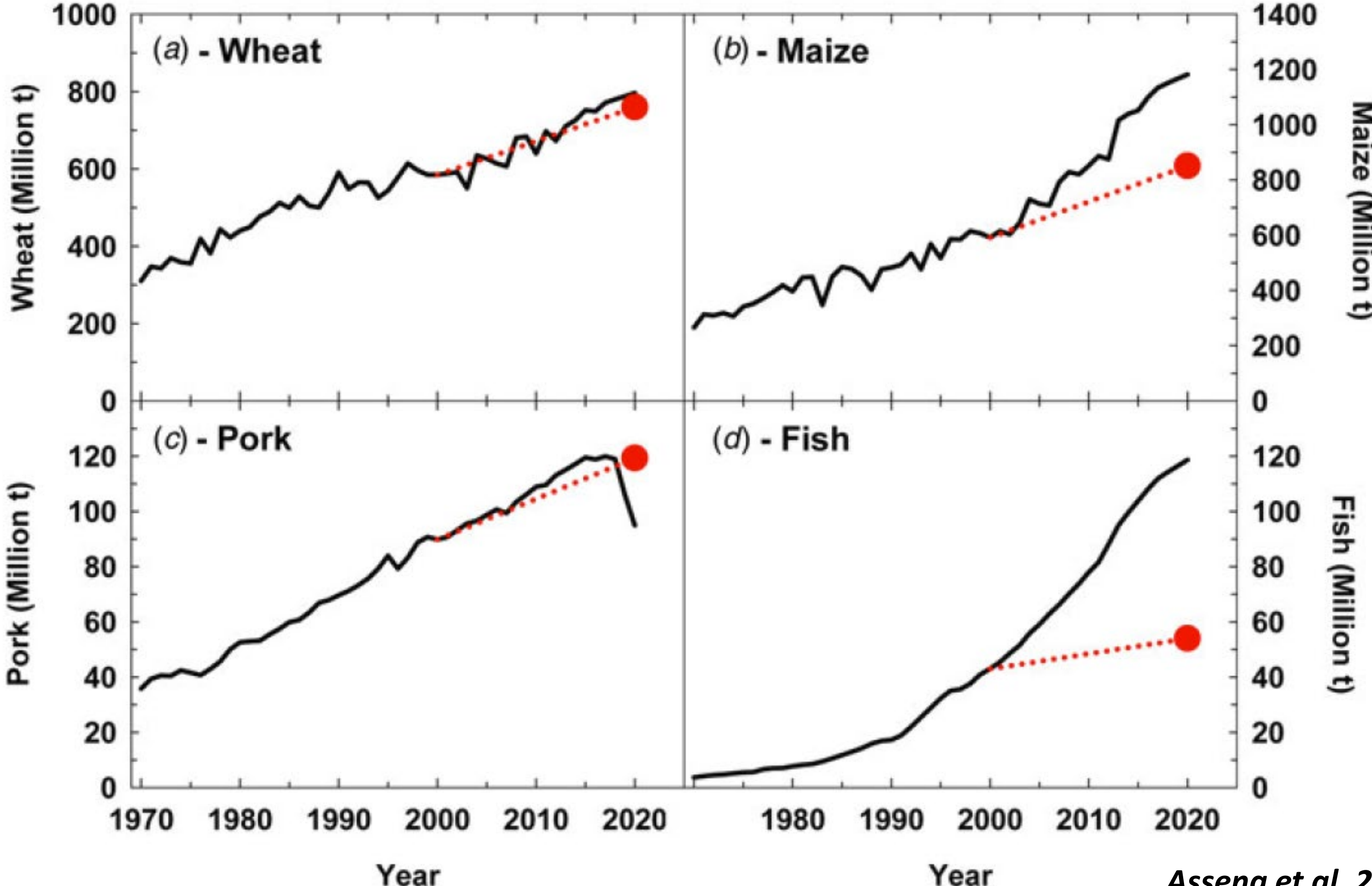
- ➢ **But what about Africa ? (can it leapfrog?)**

- ➢ **Are these sustainable ?**

Asseng et al. 2021 JAS

Projecting food production ?

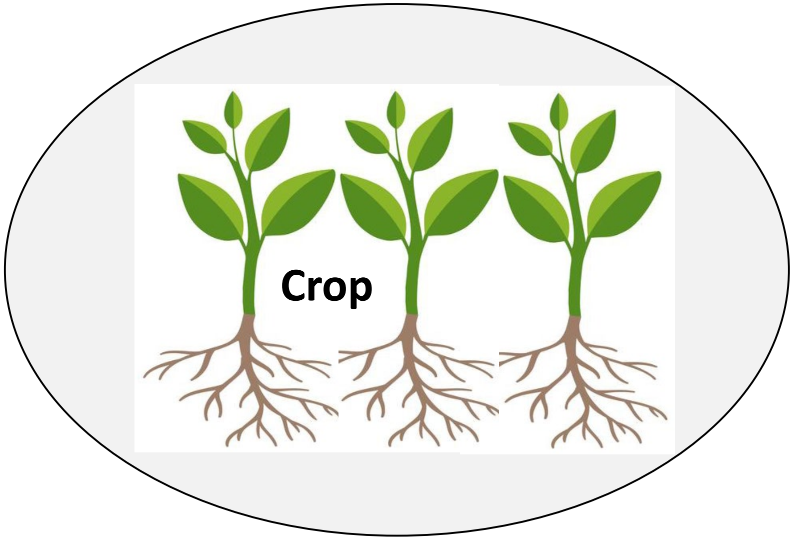
IFPRI projections from 2000 for 2020



Asseng et al. 2021 JAS

AgMIP The Agricultural Model Intercomparison and Improvement Project

From field to Vertical Farming

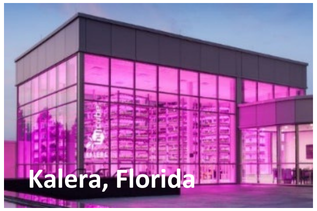


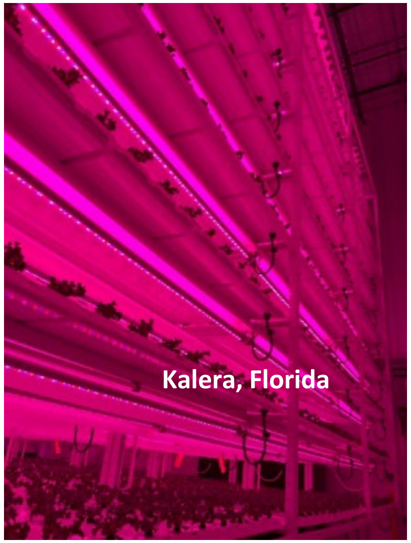
All factors controlled
Many ‘fields‘ stacked above each other

Light
weather
soil

Controlled weather
(supplementary light)
Soil: y/n

Vertical Farming: from small to big


Kalera, Florida


Kalera, Florida


infarm, Berlin


z.B. HSWT


infarm


Plantcube


Fraunhofer-Institut, Aachen


AeroFarms


Nordic Harvest

Indoor wheat at TUM

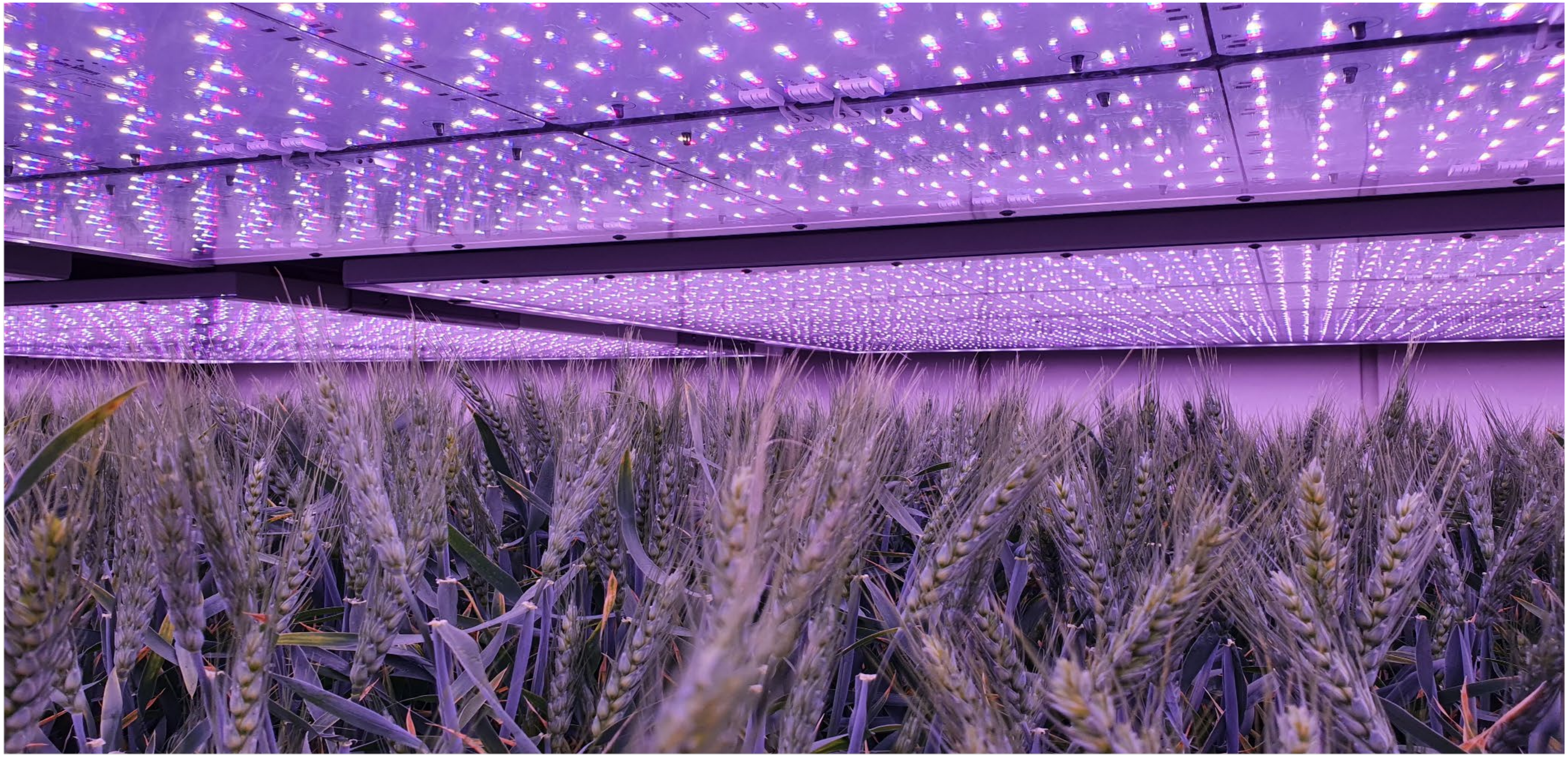
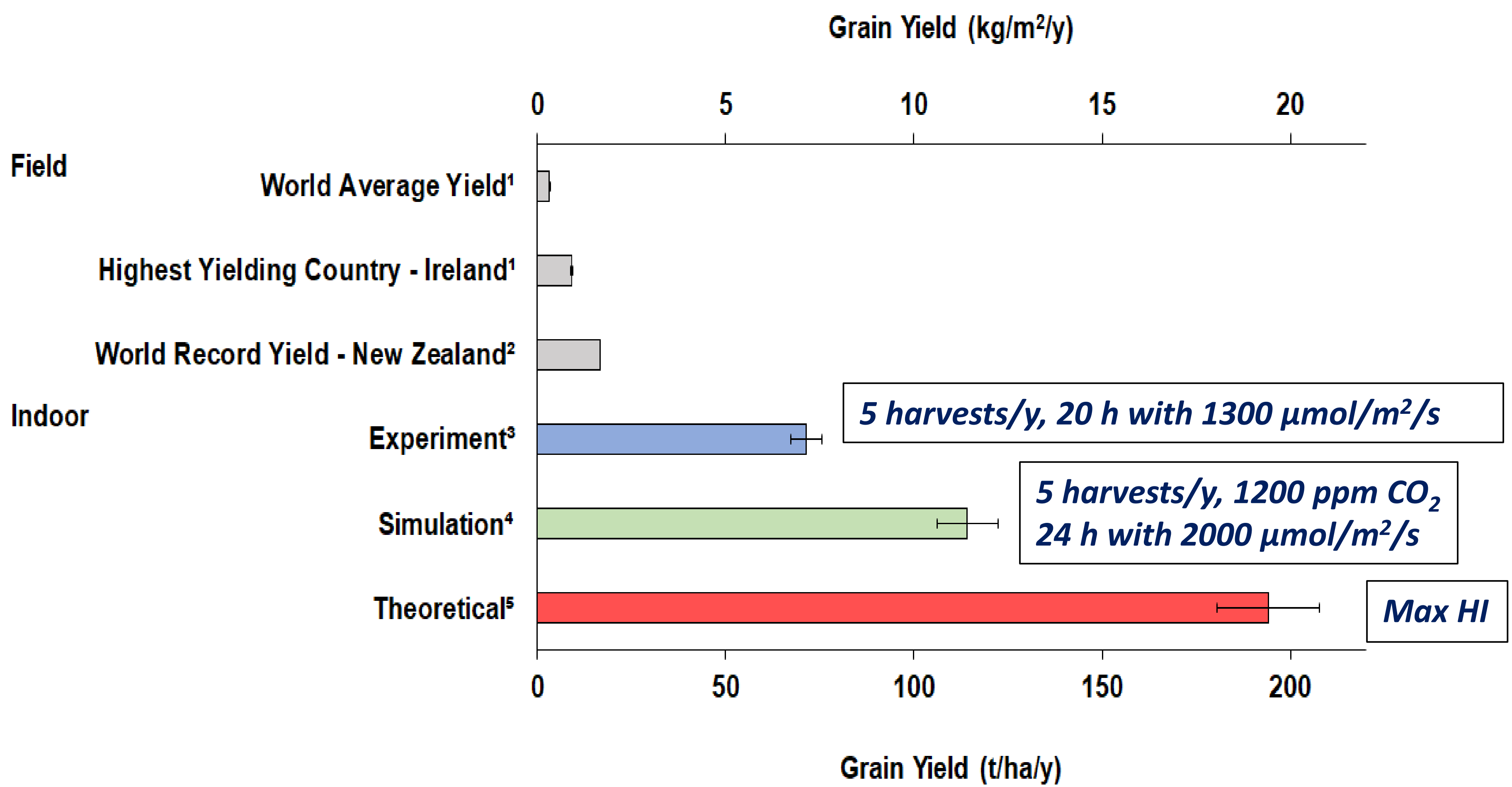


Fig.1 Wheat (*Triticum aestivum* cv. Apogee) at 30 days, grown at 23°C and 24h light.

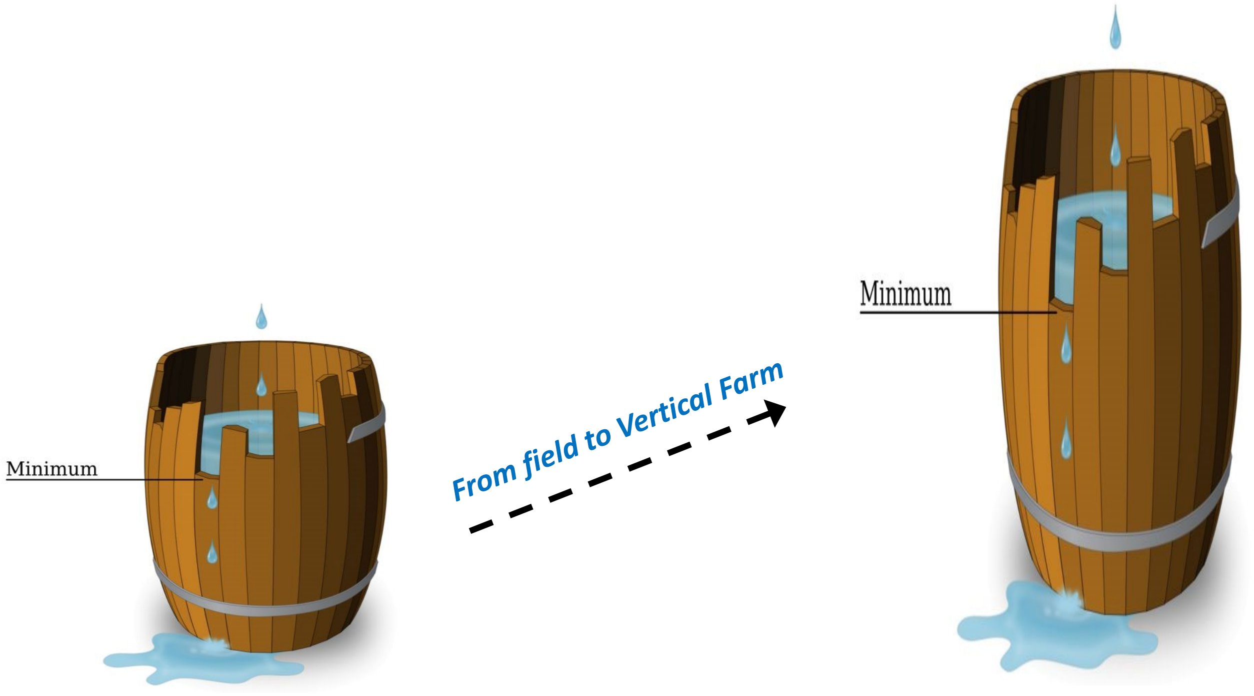
Indoor wheat farming (1 layer)



Asseng et al. 2020 PNAS

What are the limits of crop growth and yield in a Vertical Farm ?

(all growth factors can be controlled)

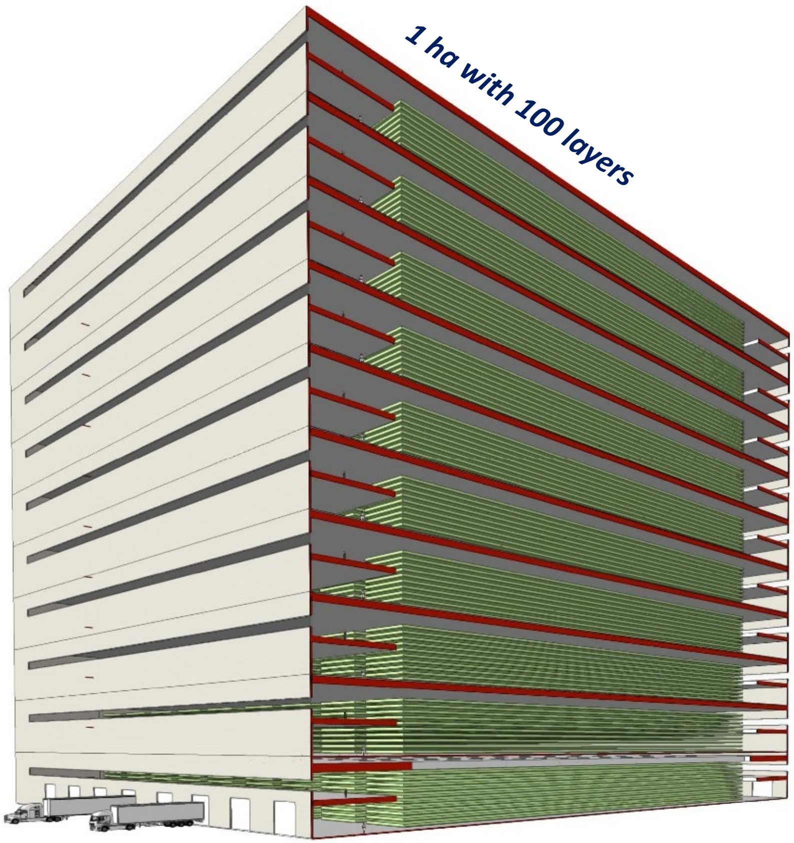


Minimum Law (Sprengel/Liebig, 1839/1855)

Indoor Wheat (100 layers)

(100m x 100m = 1 ha; 100 layers = 100 ha = 1.000.000 m^2)

- **6000 x Global average wheat yield /ha/year** (18,000 t/ha/year)
- **Quality ?**
- **>50% cost of energy**
- **VF for wheat not economical**



Asseng et al. 2020 PNAS

BUT

- **$528,000,000,000 / year global Ag subsidies** *(OEDC Report 2019)*
- **Pollution not accounted for**
- **Food security / national security - 'Food as a weapon'**
- **'Bitcoin mining' uses 0.5% of annual global energy** *(The New York Times, Sep 2021)*

Potential food system ‘game-changers’

(1) **Artificial intelligence linked with Big Data, sensors and food systems knowledge to increase productivity, optimize resource use and minimize externalities in food supply chains,**

(2) **Autonomous acting technologies including robots and drones** throughout the food supply chain,

(3) Tailored genes for specific food production, nutritional and environmental outcomes,

(4) Large-scale aquaculture both on-land and in the ocean,

(5) Novel food and feed from farmed single-cell organisms, algae and insects, and designed food using synthetic biology, and

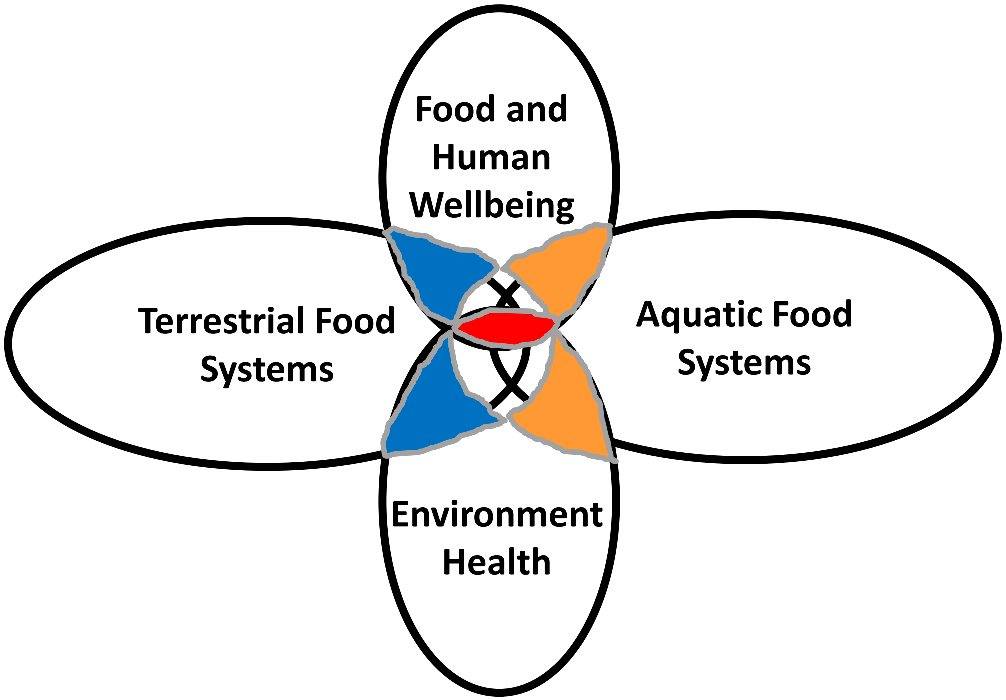
(6) **Vertical farming with controlled-environment production** of **crops**, livestock and seafood.

Asseng et al. 2021 JAS

Future of Food

Way forward 2050

- Technology **Revolution** in Food
- Huge opportunity for society to produce healthy, nutritional & environmentally-friendly food for all
- Think/act systems
- Role of universities, industry, governance & society.



Asseng et al. 2021 JAS