Leibniz Centre for Agricultural Landscape Research (ZALF)

Session: Limits to yield; what does modelling tell us?

Drivers of Crop Yield Variability and Change: Analyses through support of modelling

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UNIVERSITÄT BONN PHENOROB Leibniz-Gemeinschaft Federal Ministry of Food and Agriculture LAND BRANDENBURG Ministry for Science, Research and Culture

Content

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Climate drivers of yield variability

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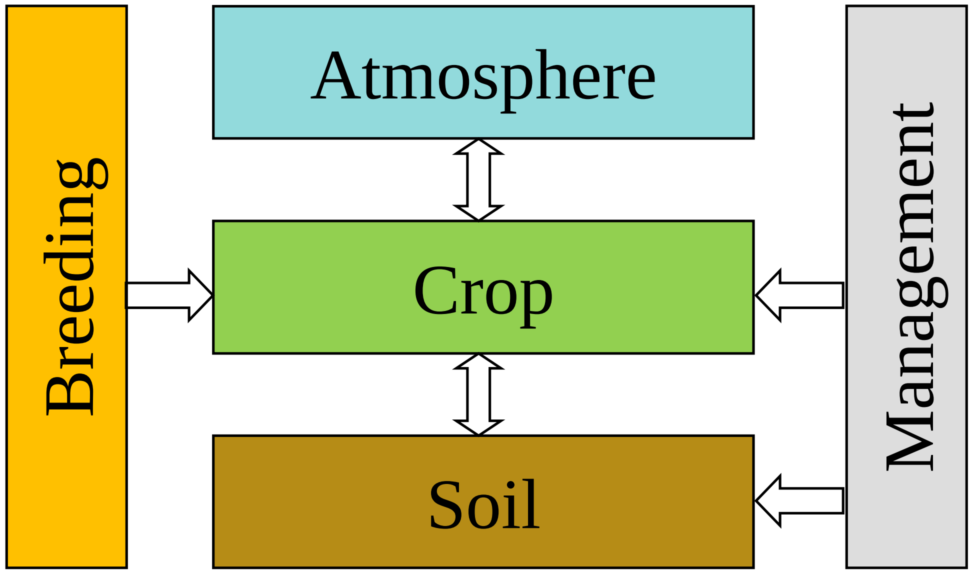
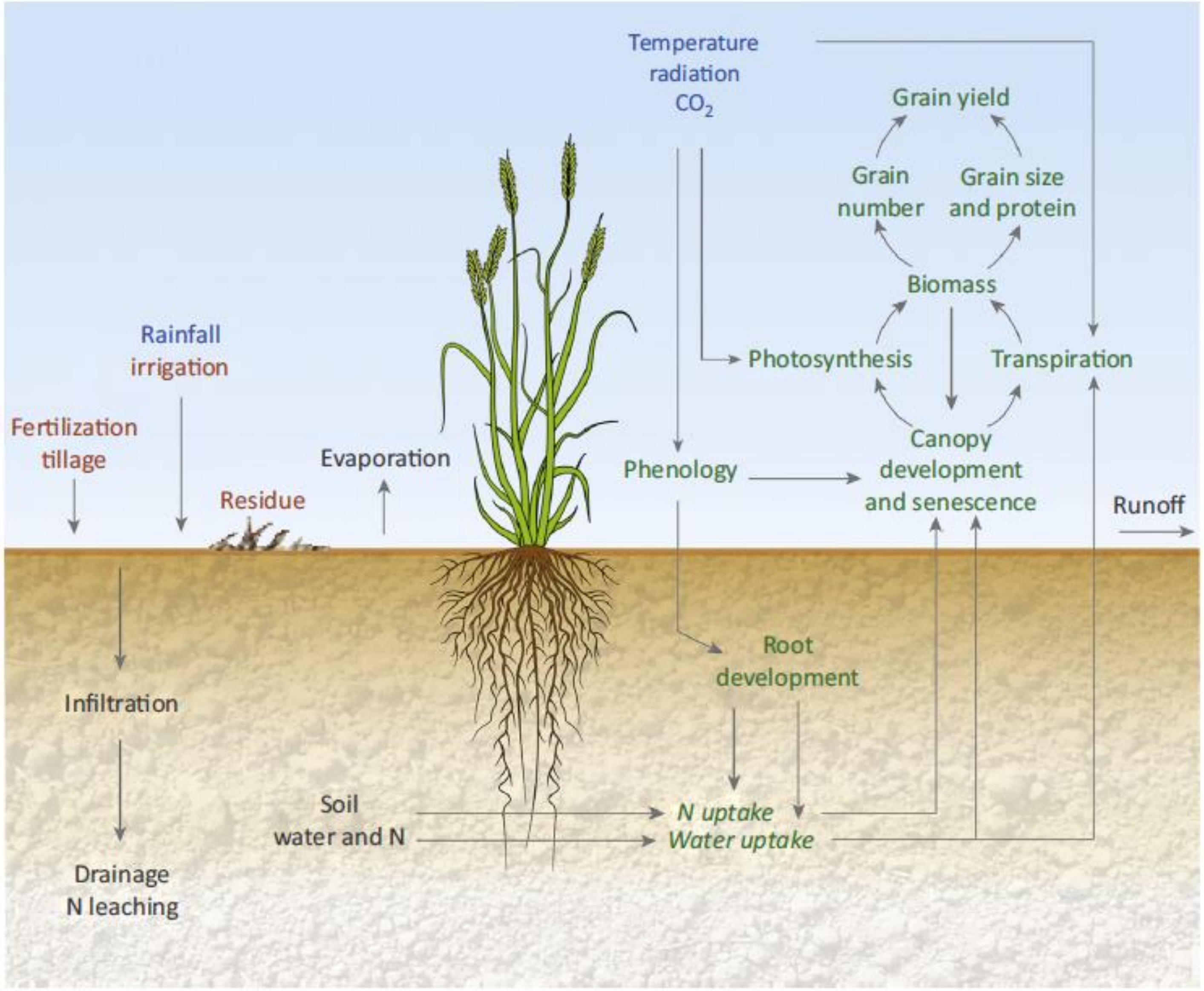
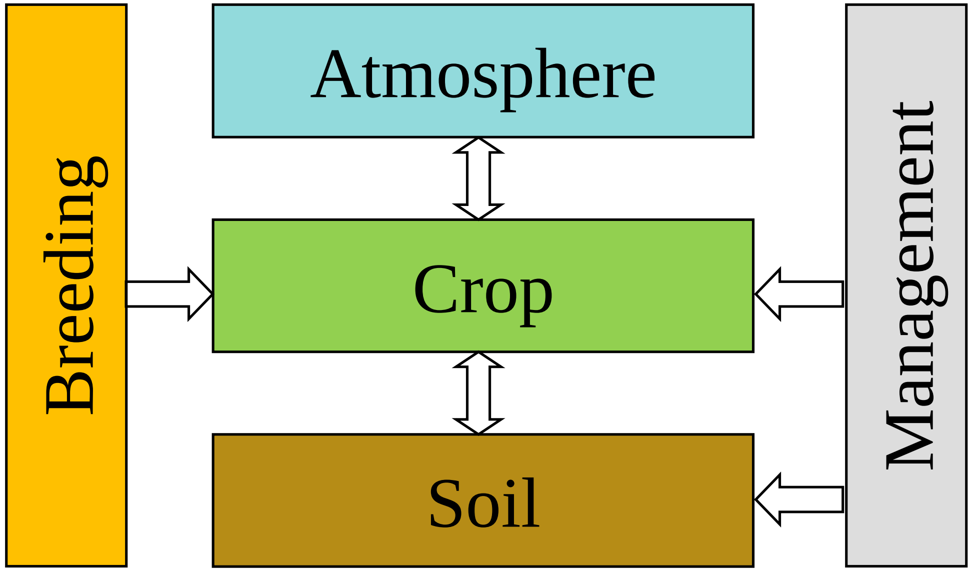


Crop models



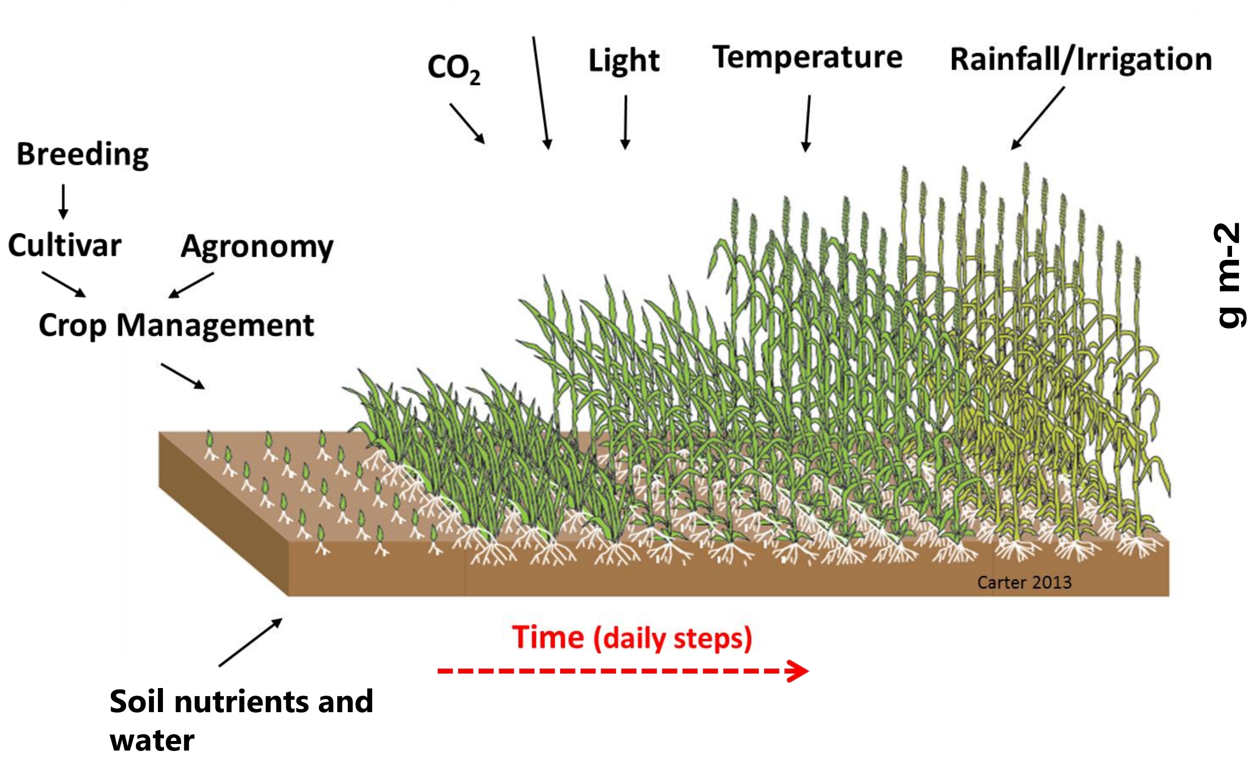
Chenu et al., 2017 Trends in Plant Science

Main factors (drivers)

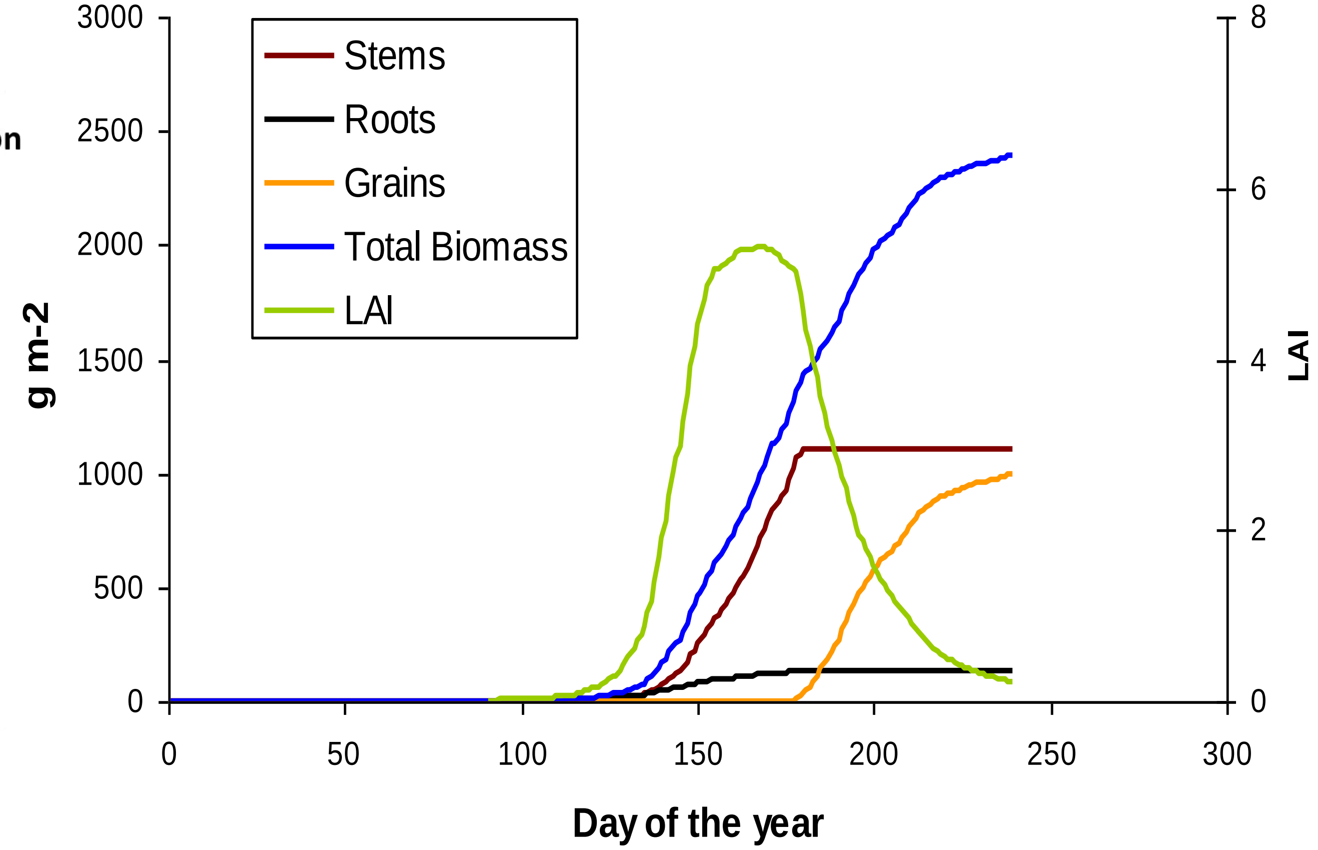


Crop models (simulation of system dynamics)

Selected factors



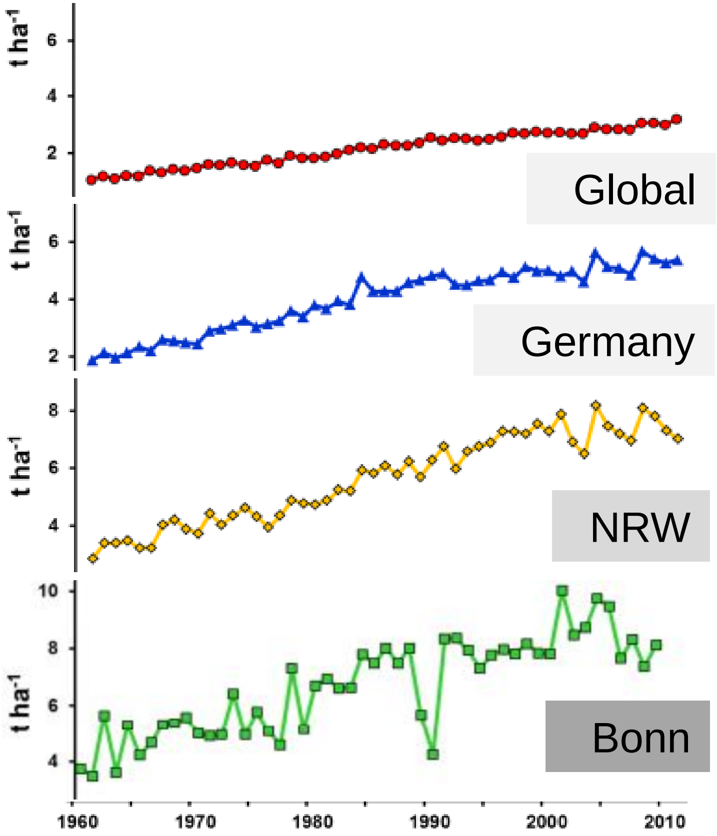
Selected variables



Yield variability (temporal and spatial)

Temporal variability

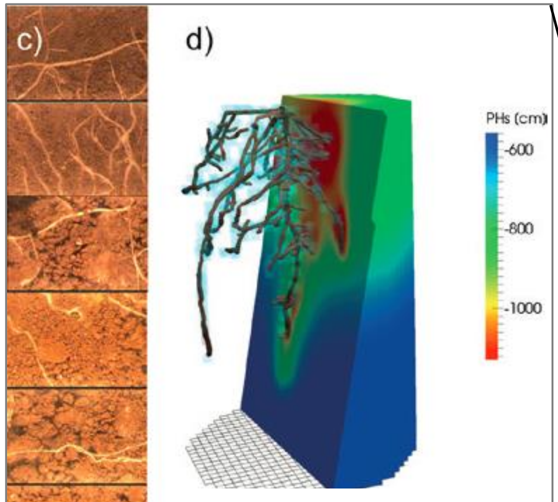
Example, wheat yield



Ewert et al, 2013

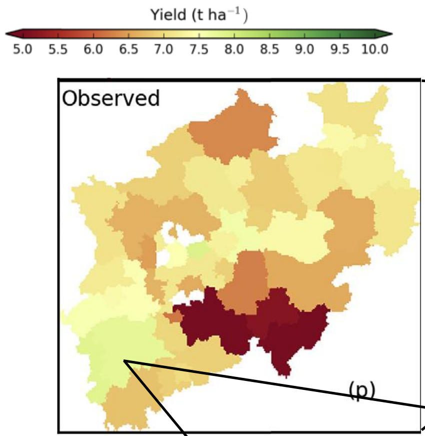
Spatial variability

Wheat roots and root water uptake

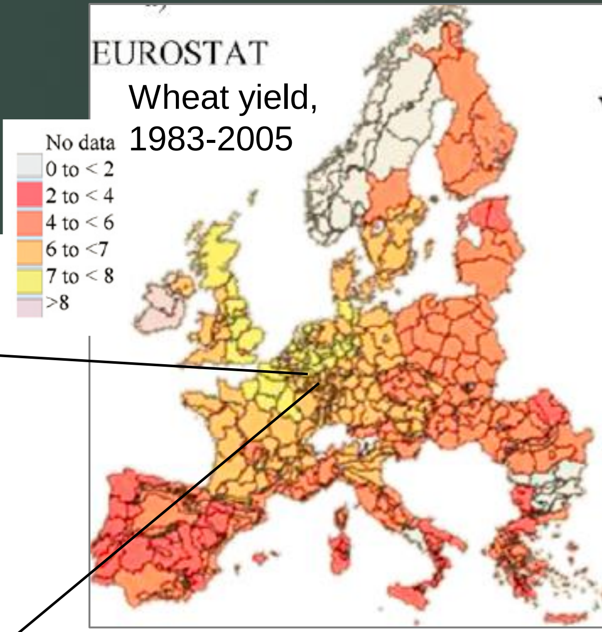


Simmer et al., 2015
Javaux et al., 2008
Cai et al., 2015

Wheat yield , 1999-2011



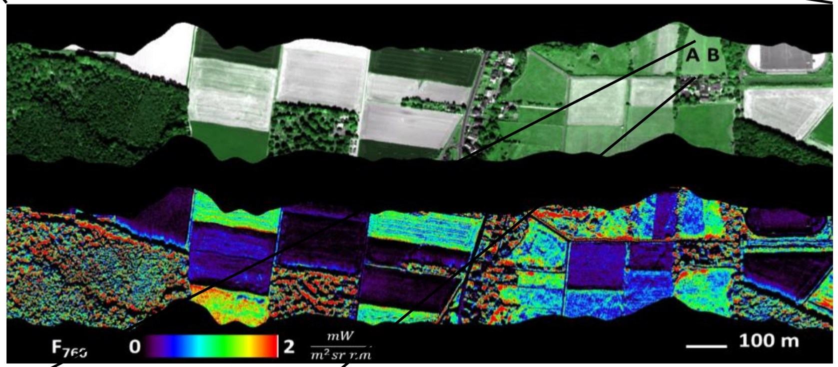
Zhao et al., 2017



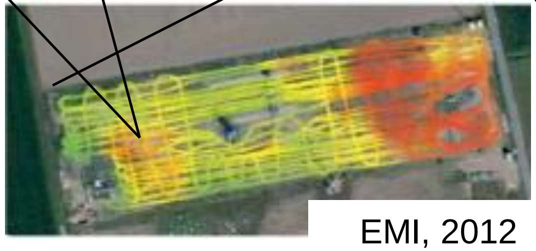
Wheat yield, 1983-2005

Angulo et al., 2013

Fluorescence, 2012



Simmer et al., 2015;
Rascher et al., 2015



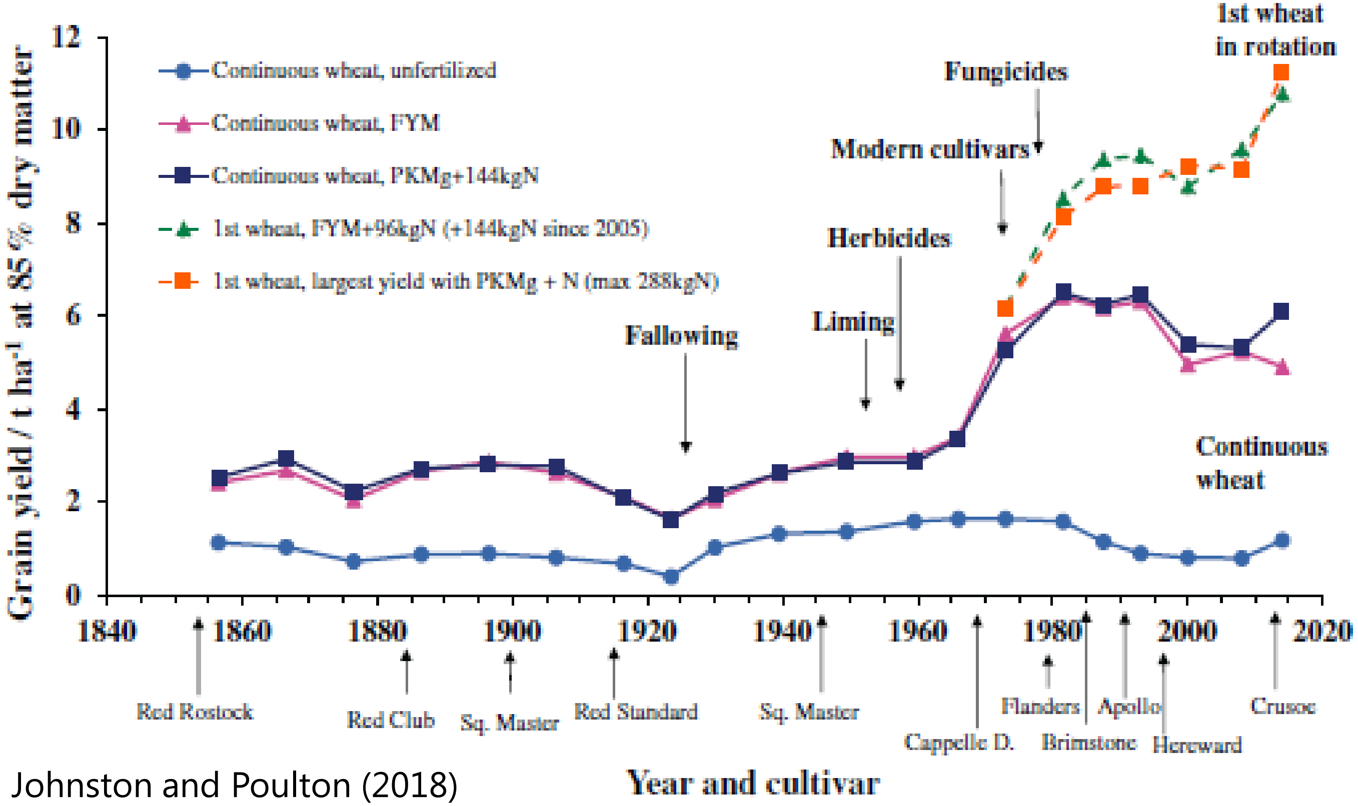
EMI, 2012

Simmer et al., 2013
Stadler et al., 2015

Yield change and gap

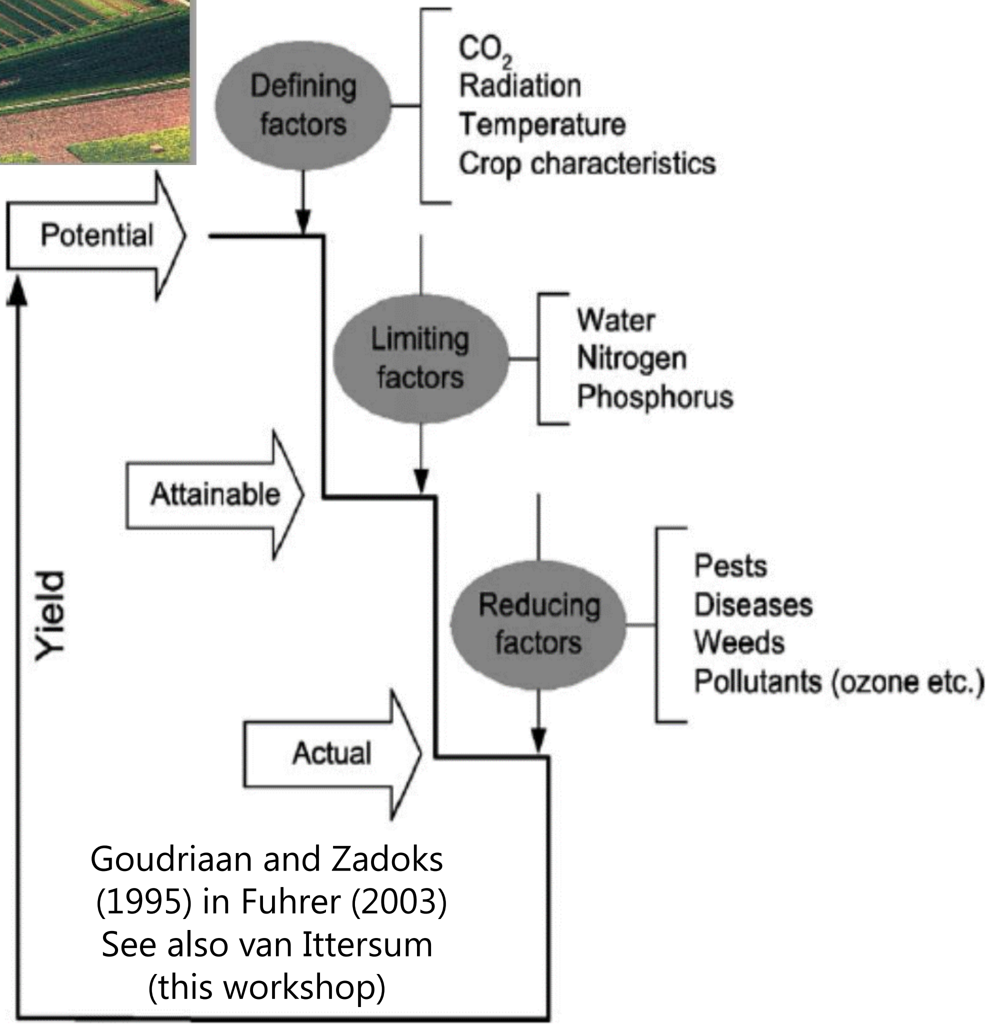
Yield changes over time (long term field experiments, LTE)

Broadbalk Winter Wheat experiment, Rothamsted



Johnston and Poulton (2018)

Yield gap

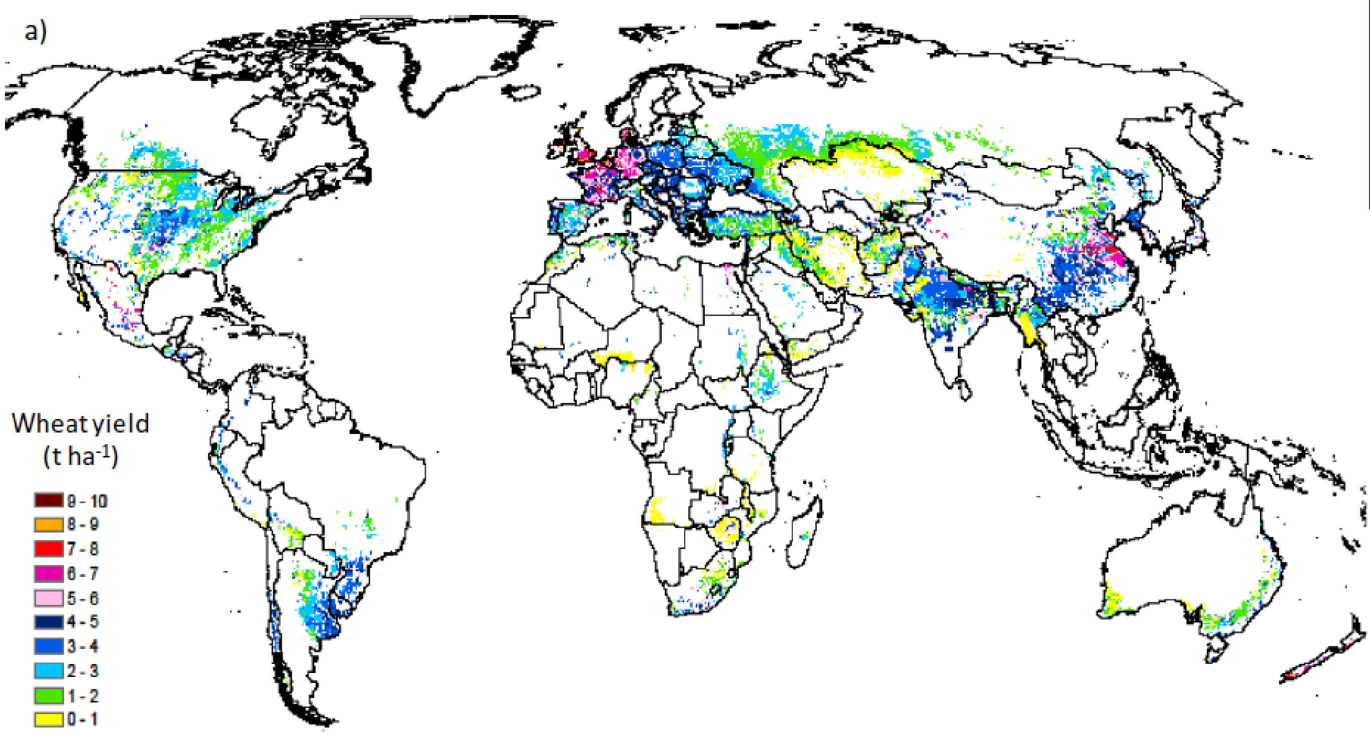


Goudriaan and Zadoks (1995) in Fuhrer (2003)
See also van Ittersum (this workshop)

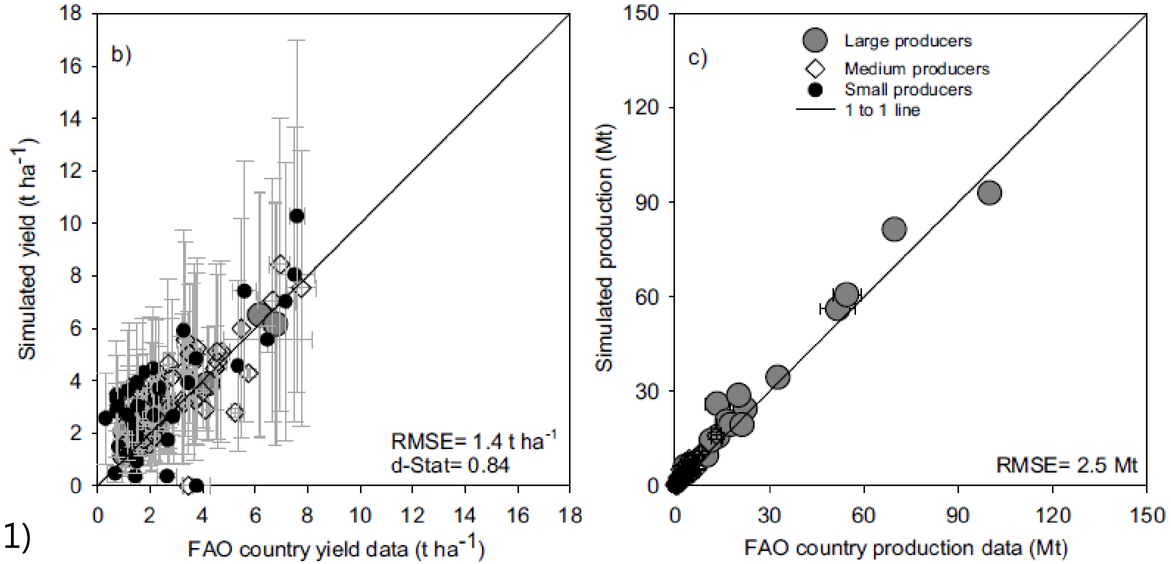
Global wheat yield

- Large spatial variability.
- Sources of variability (space, time)?
- High yields in certain locations indicate large yield potential.
- What conditions and traits explain high yield?

Asseng et al., (2020)



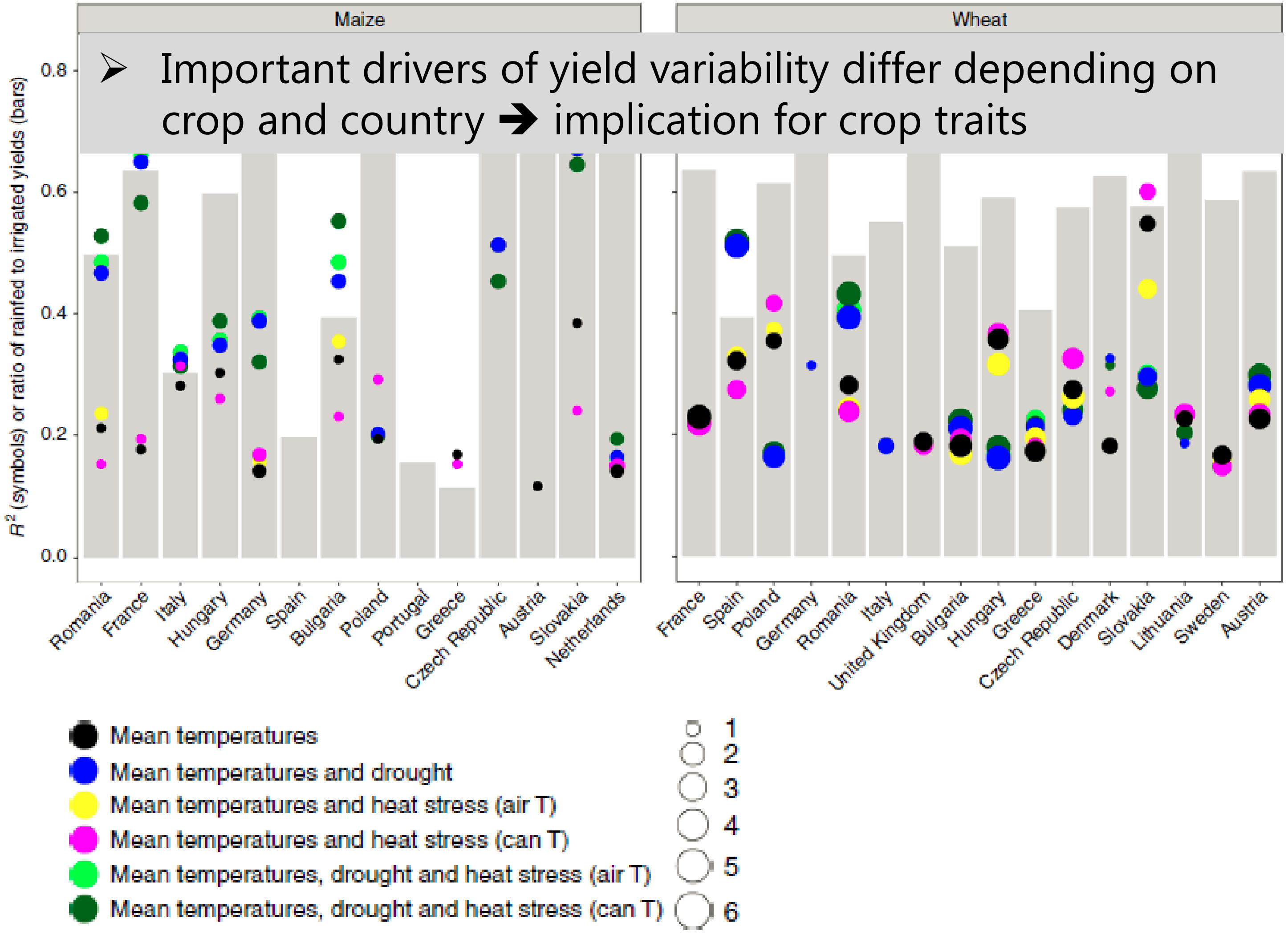
- Crop models reproduce spatial variability relatively well



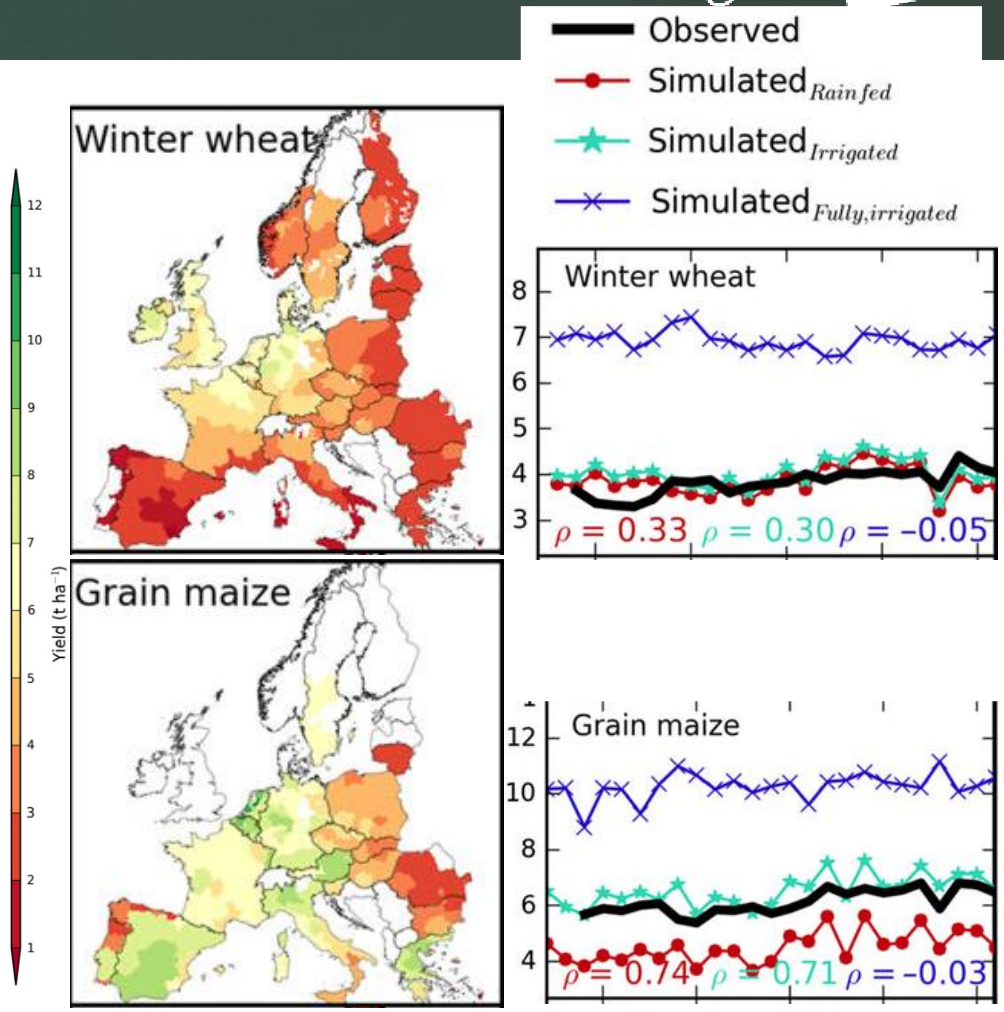
Pequeno et al. (2021)

Climate drivers

- Important drivers of yield variability differ depending on crop and country ➔ implication for crop traits



Climatic variation in historical national crop yields as captured by crop models (1984 and 2009). Webber et al. (2018)

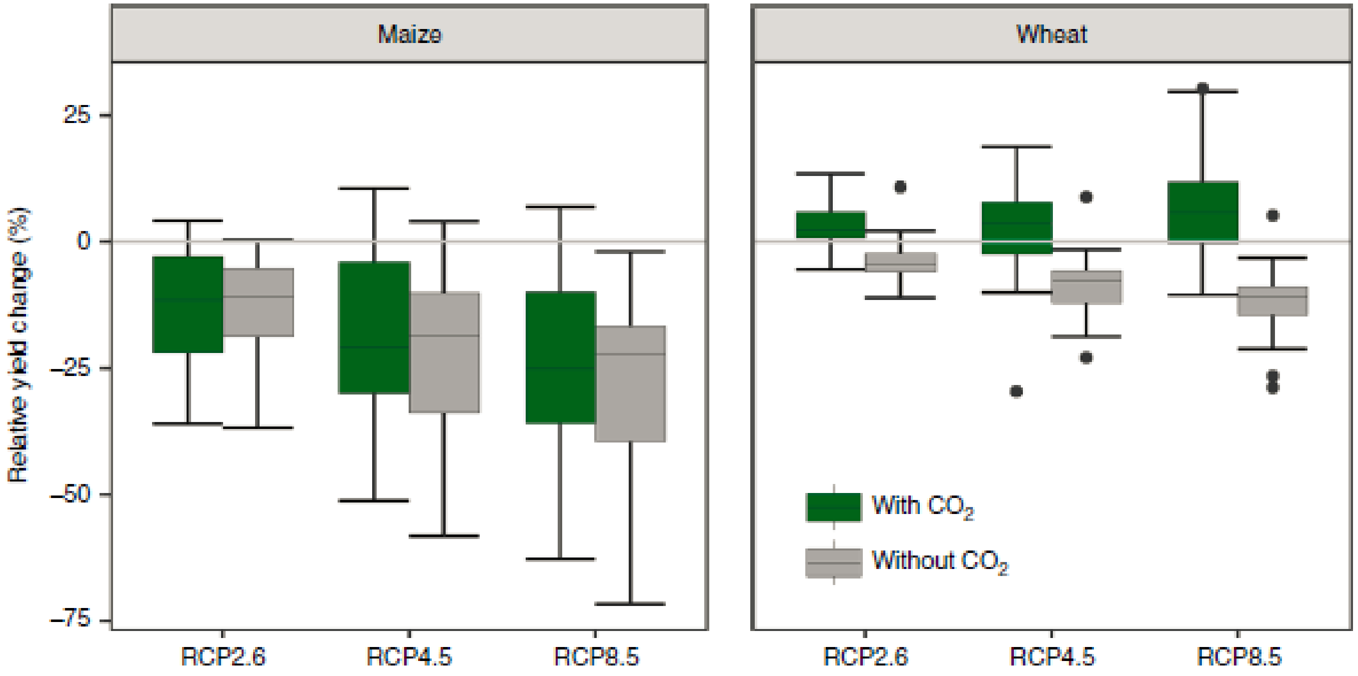


Spatial–temporal variability of observed and simulated rainfed and irrigated yields of maize and wheat (1982-2006), Zhao et al., (2006)

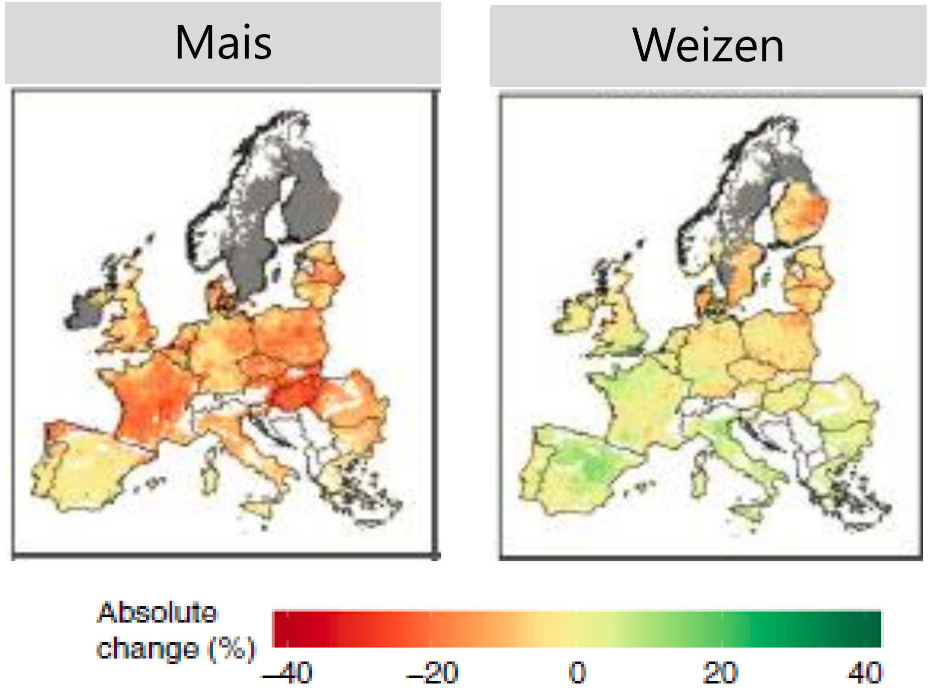
Climate drivers

➢ Severe yield reduction in Maize in south and central Europe; increasing demand for irrigation

Simulated effects of climate change on yield of wheat and maize in Europe (2040-2069 vs. 1981-2010)



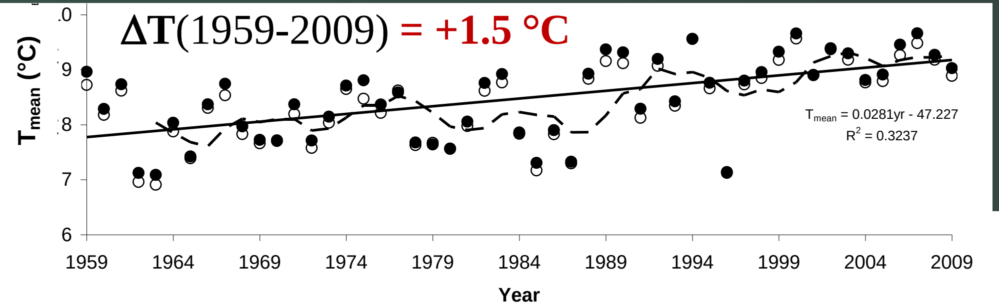
Mean climate change effects for 2040–2069 relative to the baseline period (1981–2010). Model ensemble with six (Maize) and eight (wheat) crop models.



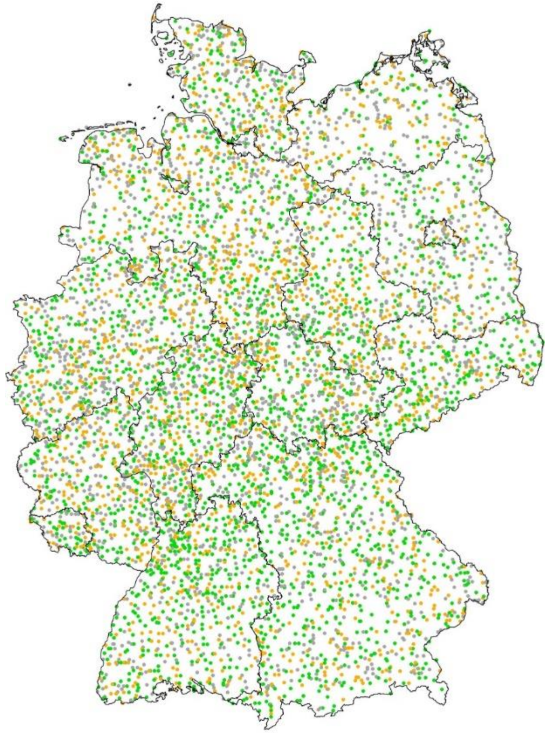
Spatial distribution of changes in yield loss due to drought for 2040–2069 relative to the baseline period (1981–2010), RCP4,5, HadGEM2-ES) and with CO_2 effect.

Webber et al., 2018

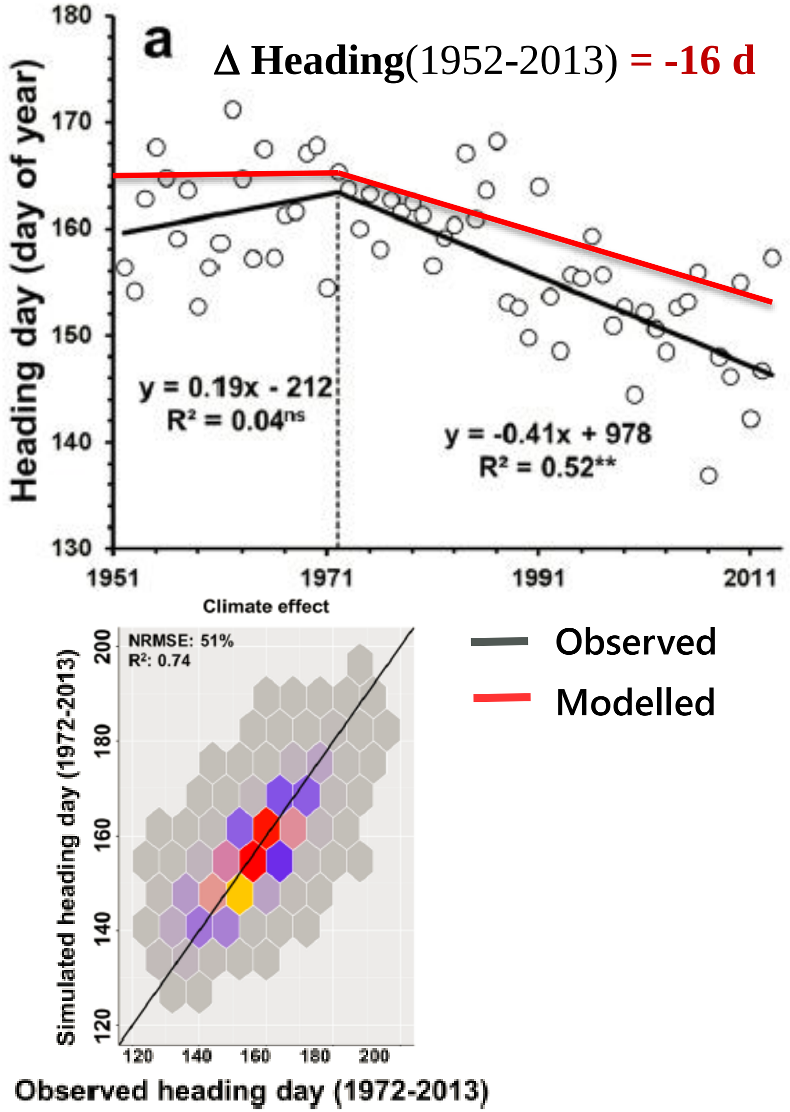
Adaptation (traits and management)

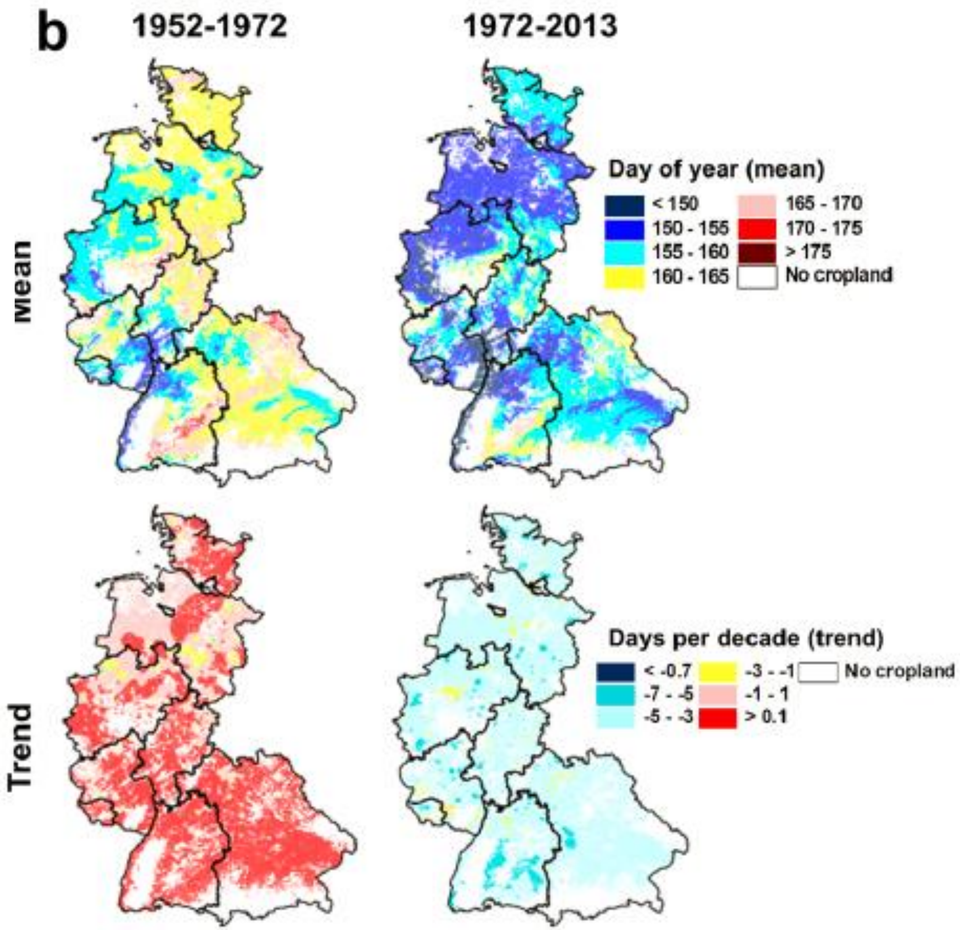


Long term changes of wheat phenology



Weather and phenology observation stations (>6000), 1959-2009

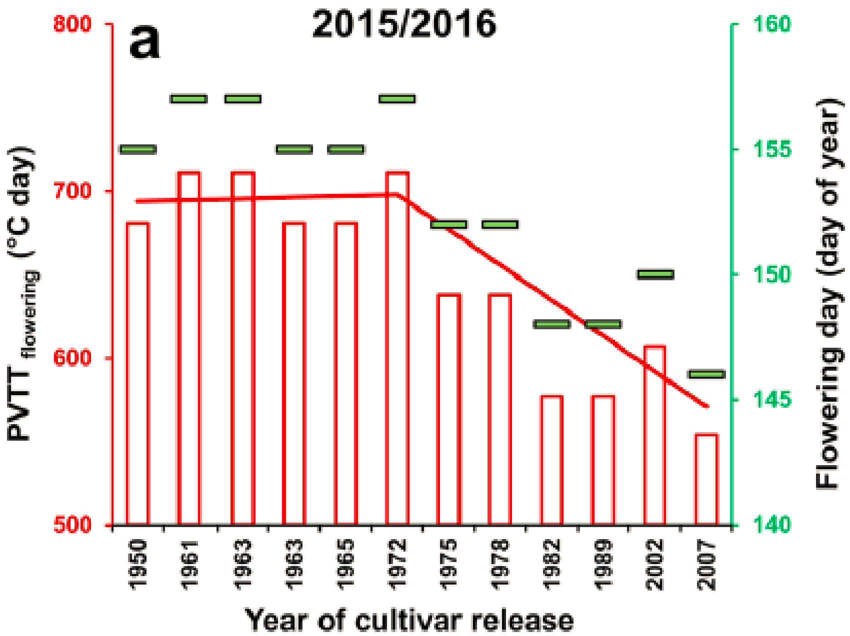


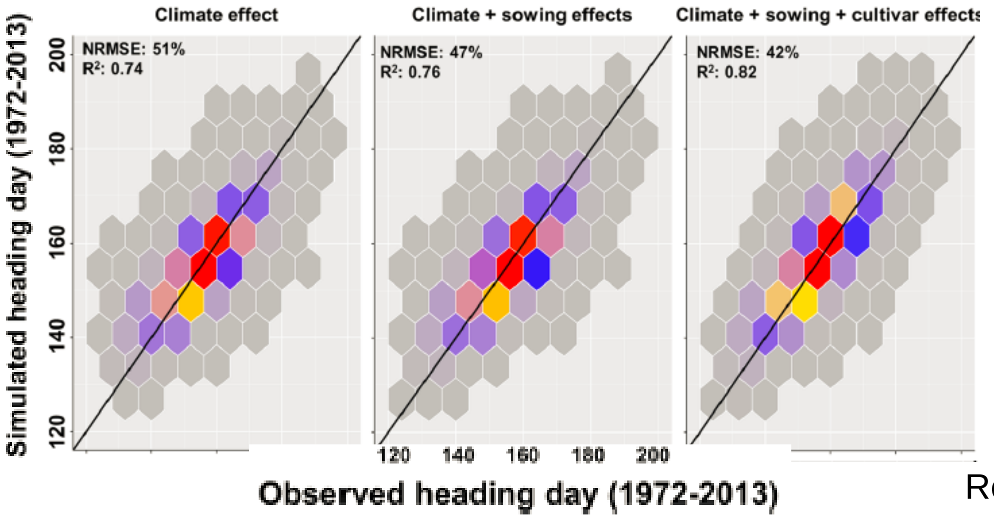


Adaptation (traits and management)

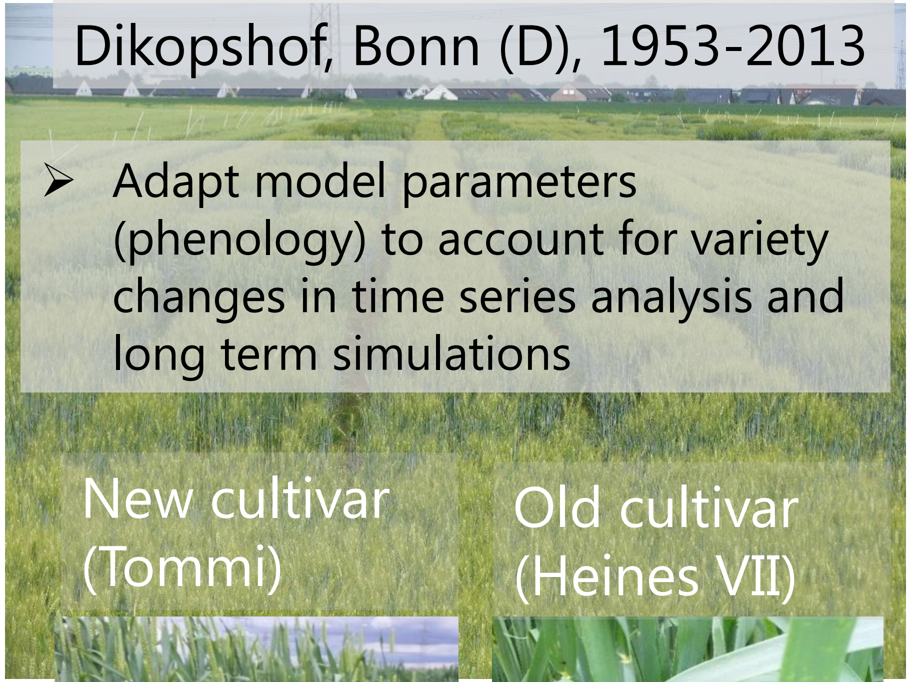
Long term changes of wheat phenology

Direct comparison of winter wheat varieties grown at Dikopshof, Bonn, 1952-2013





Rezaei, et al., (2018)



Dikopshof, Bonn (D), 1953-2013

- ➢ Adapt model parameters (phenology) to account for variety changes in time series analysis and long term simulations

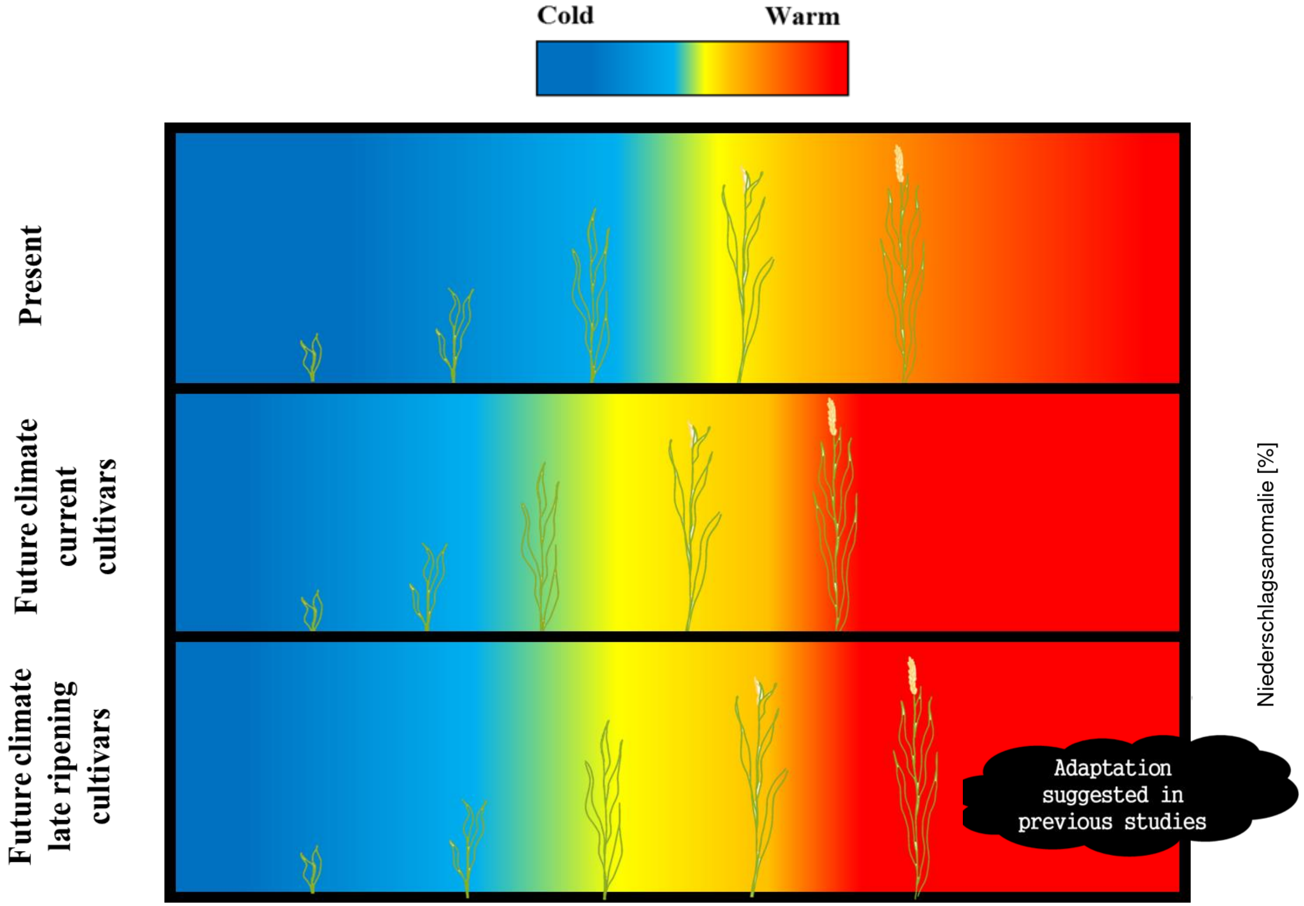
New cultivar (Tommi)

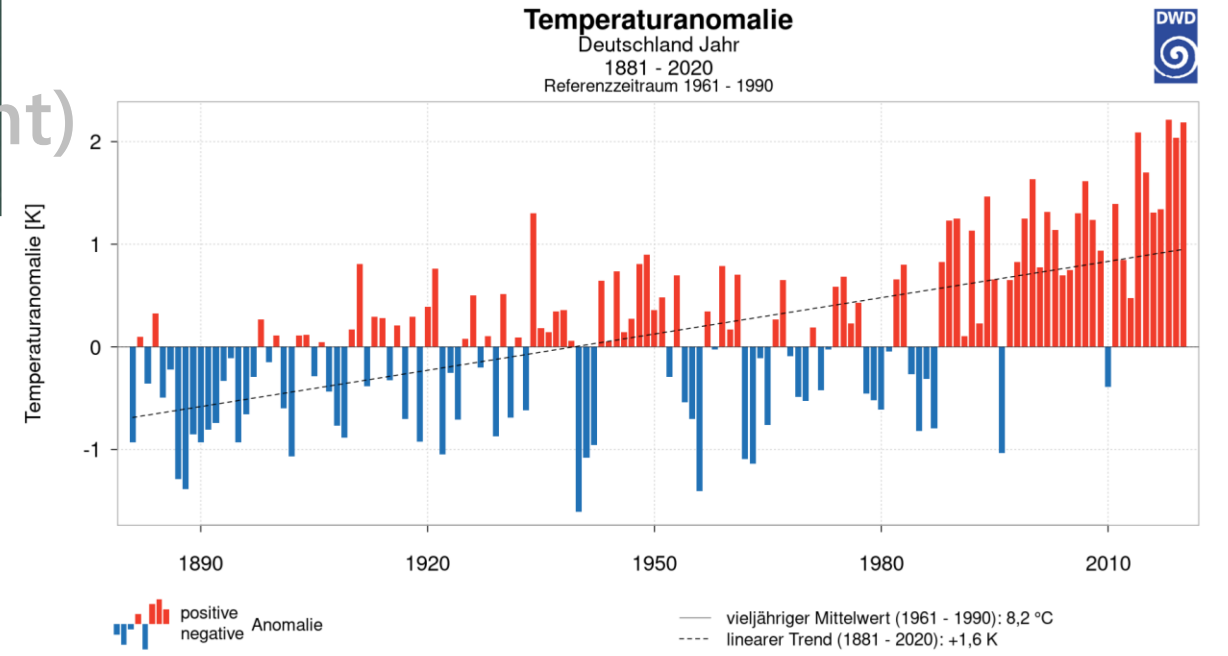
Old cultivar (Heines VII)

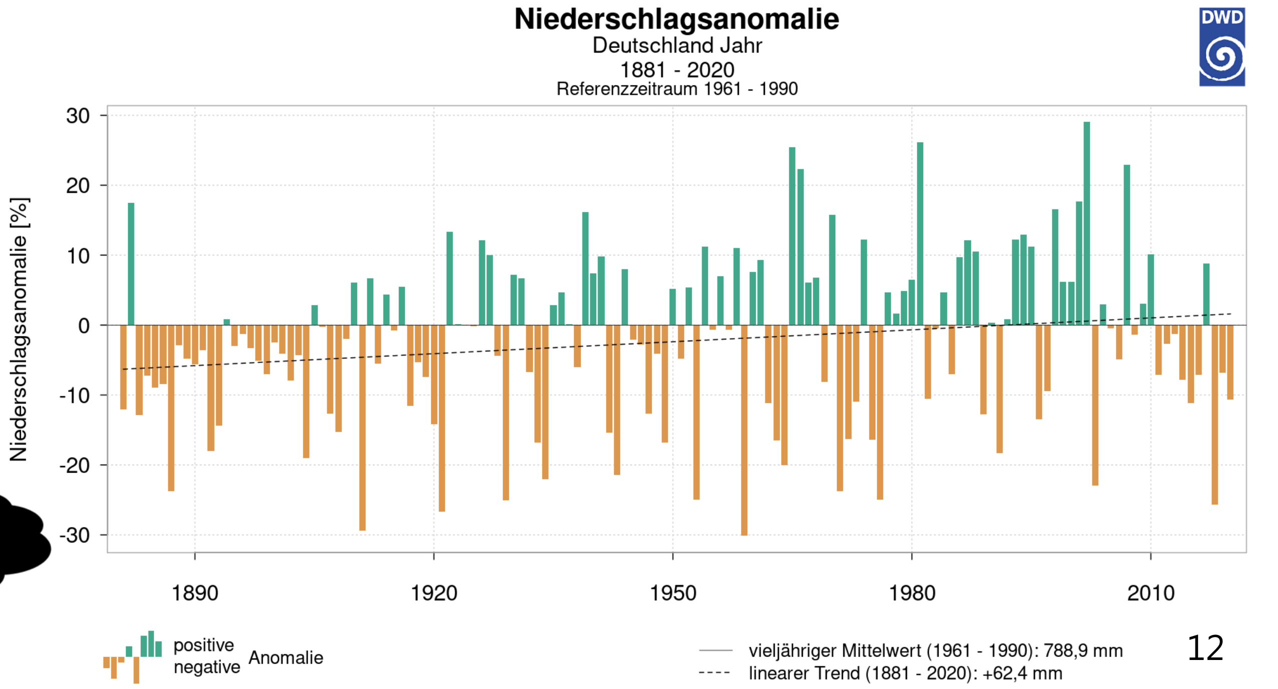
31 May 2016

Adaptation (traits and management)

- Adaptation to variable climate and extremes?
- Assessment of risks

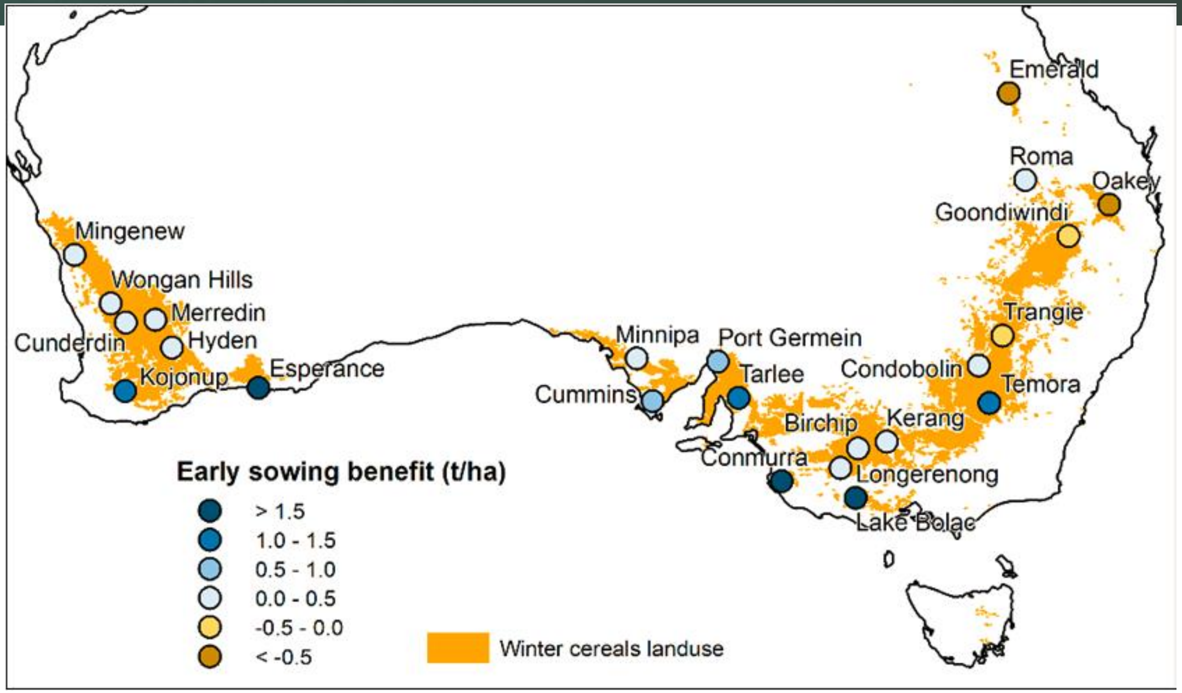




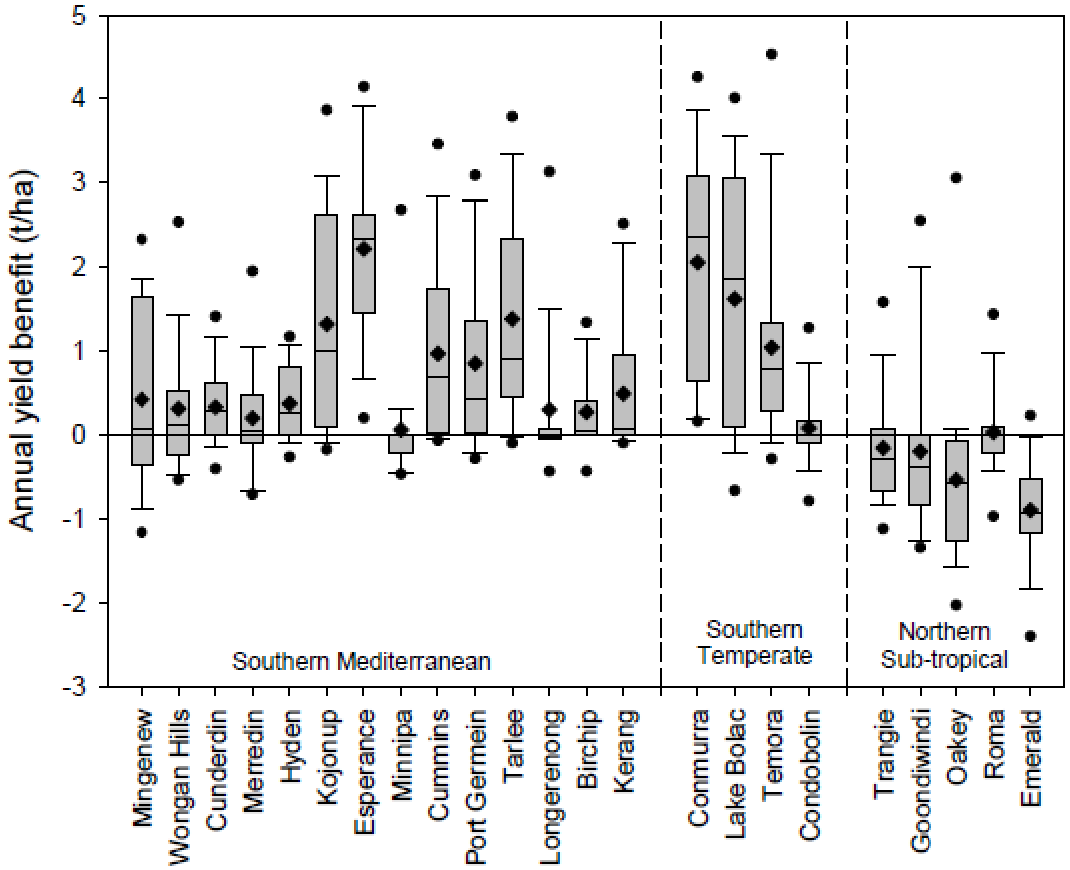


Adaptation (traits and management)

- Adaptation to drought ad heat by improved management and crops (**G** x E x **M**)
- Example, wheat in Australia (combined modelling and experimental study)



Locations of the 23 simulated sites relative to Australian winter cereal production, and the magnitude of the mean yield cost or benefit of the early sowing strategy.

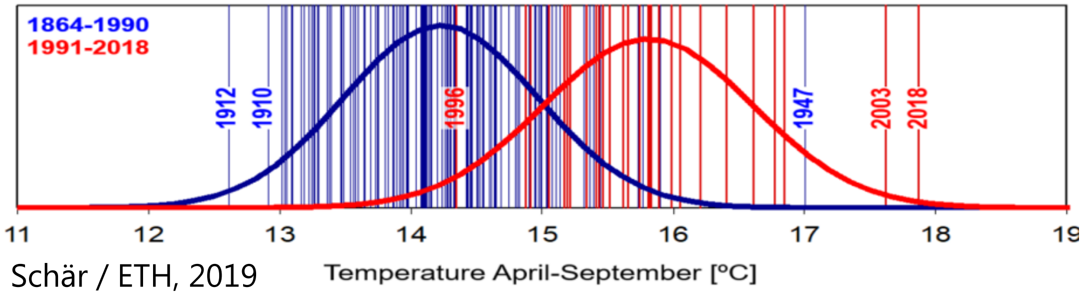


Box plot showing variability between 1996 and 2015 in the simulated annual yield benefit^(t/ha) achieved by sowing wheat earlier using a novel, slower-developing cultivar

Hunt et al., 2019

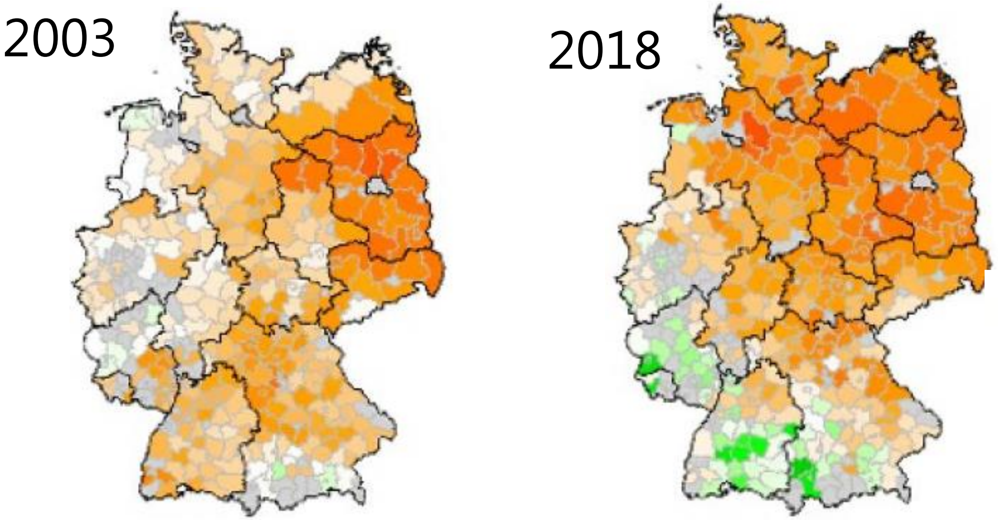
Divers crop responses

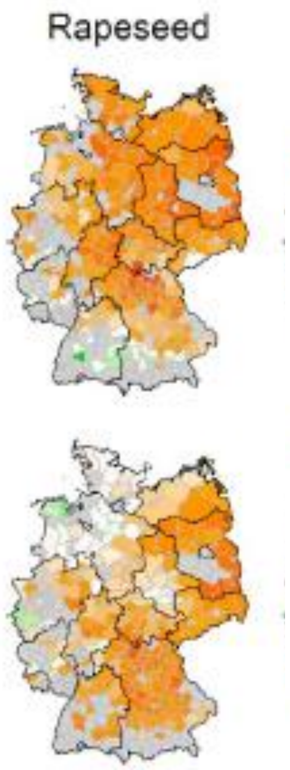
- Increasing climate variability and extrems
- Diversification of crops (and cultivars)

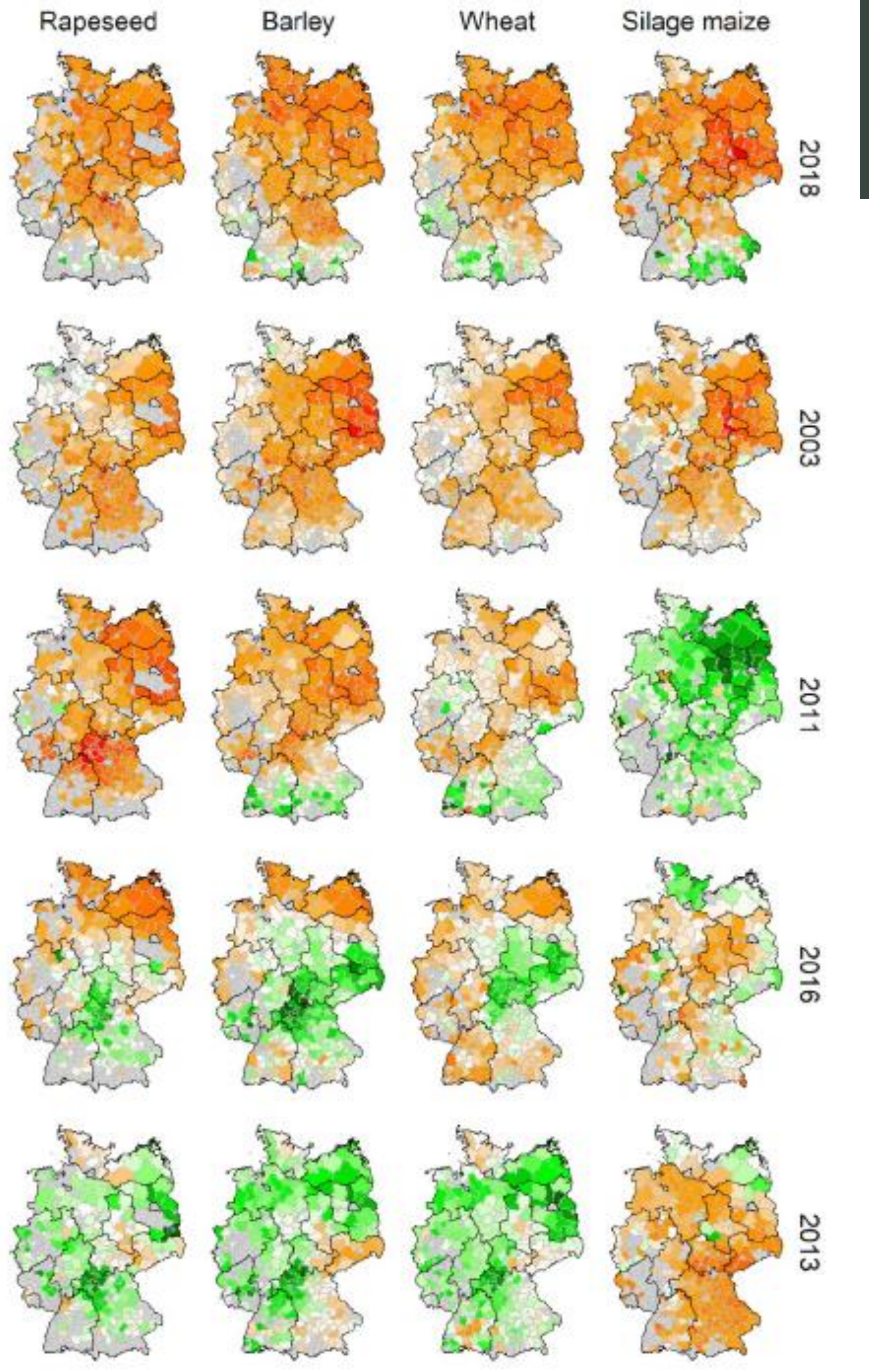


Schär / ETH, 2019

Yield change (wheat)







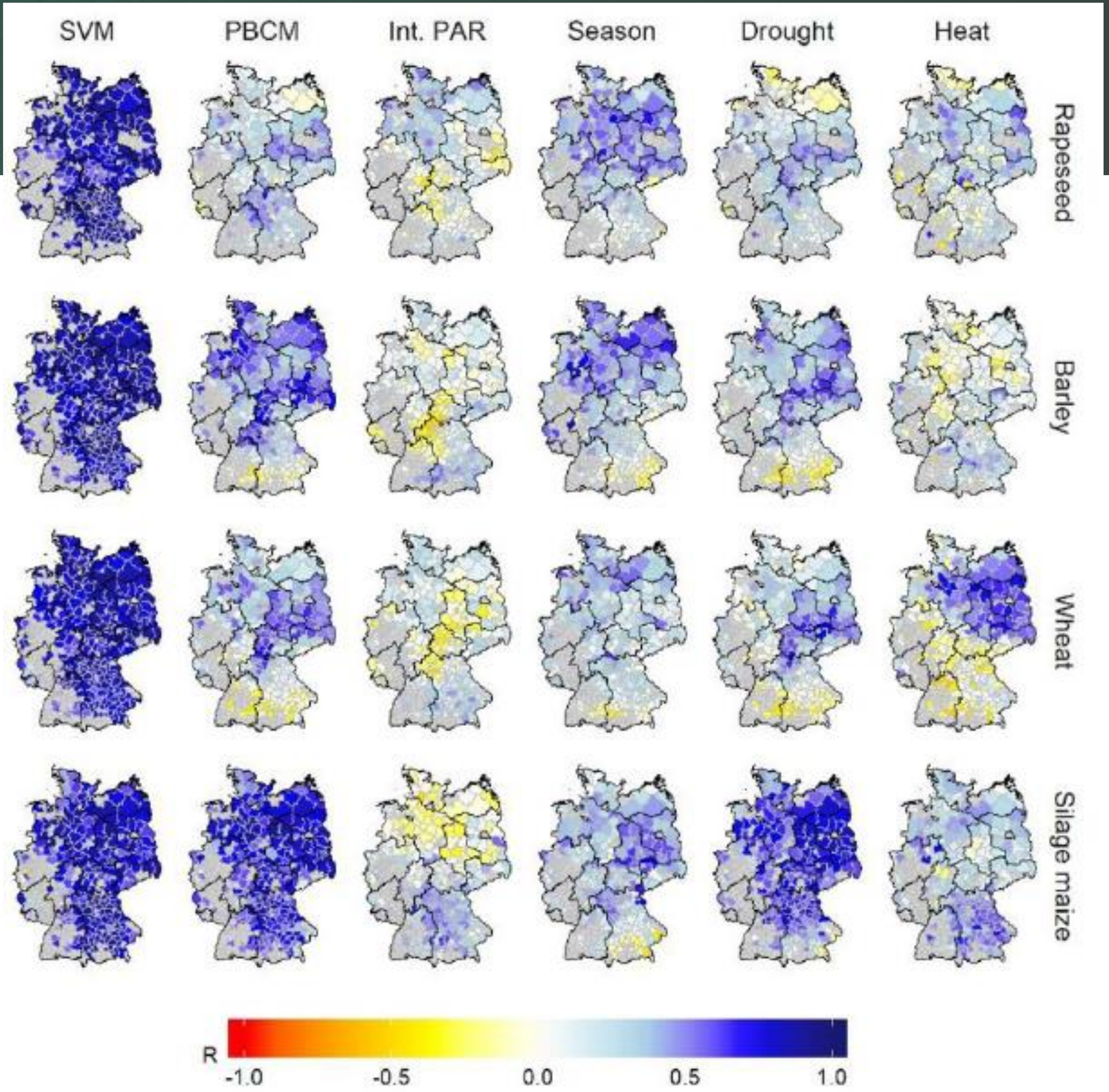
Relative yield changes of selected crops in extreme years between 1998-2018

(Webber et al., 2020).

Divers crop responses

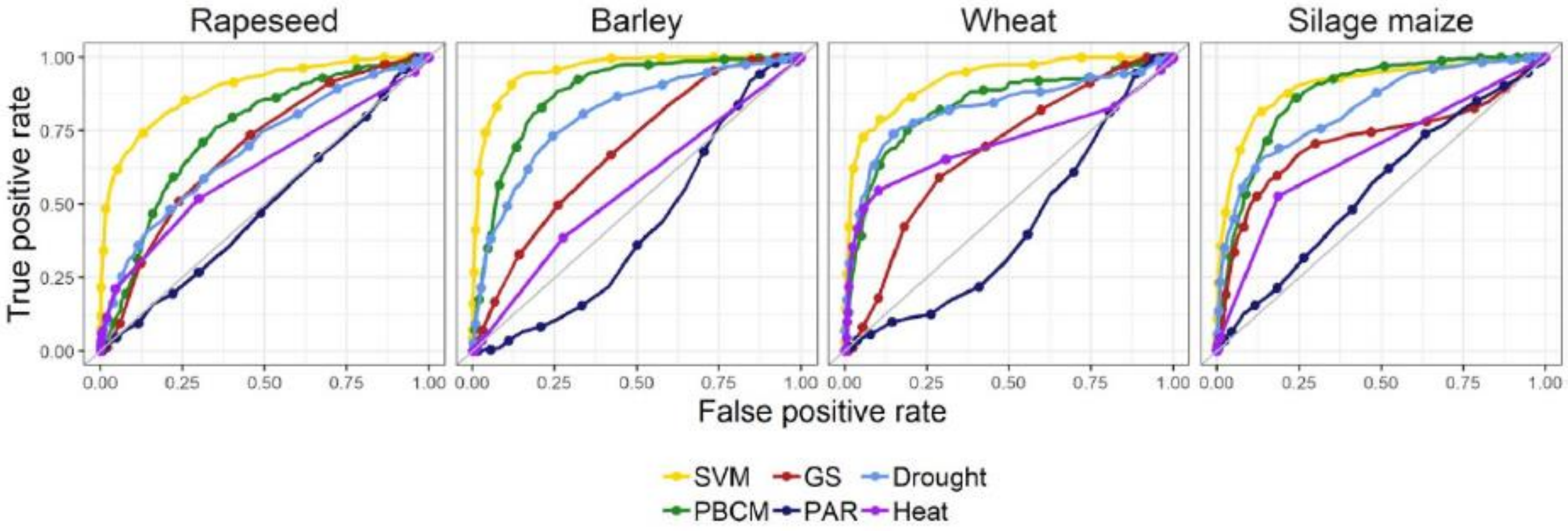
- ➢ Crop models support the analysis of important drivers of yield variability due to extreme events
- ➢ Combination with SVM is promising

Spatial patterns of the temporal correlation coefficient (r) between relative change in observed yield and the relative change in the SVM and the process-based crop model (PBCM); and simulated processes: intercepted PAR; growing season duration (Season); seasonal drought stress; and seasonal heat stress. All correlations were assessed on the relative to the Olympic average of the 5 previous years for the rapeseed, winter barley, winter wheat and silage maize crops considering data from 1998 to 2018. Webber et al. (2020)



Divers crop responses

- Crop models support the analysis of important drivers of yield failue due to extreme events

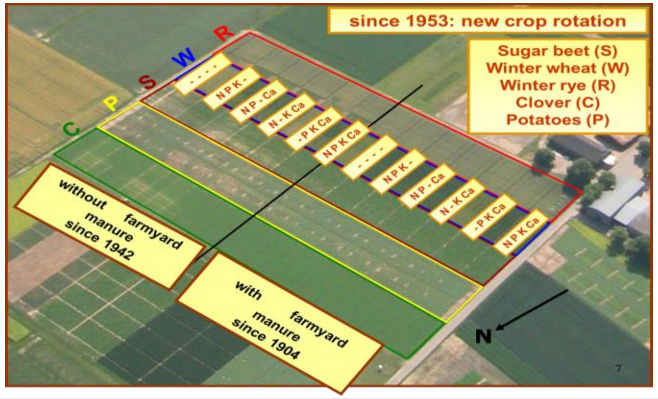


ROC (Receiver operating characteristic) curves to depicting the prediction accuracy of the relative yields in each of support vector machine (SVM), process-based crop model (PBCM, green) and its simulated processes: growing season duration (GS), intercepted photosynthetically active radiation (PAR), heat and the severity of drought in classifying yield failures at the 20% loss level for different crops across Germany between 1998 and 2018. Webber et al. (2020).

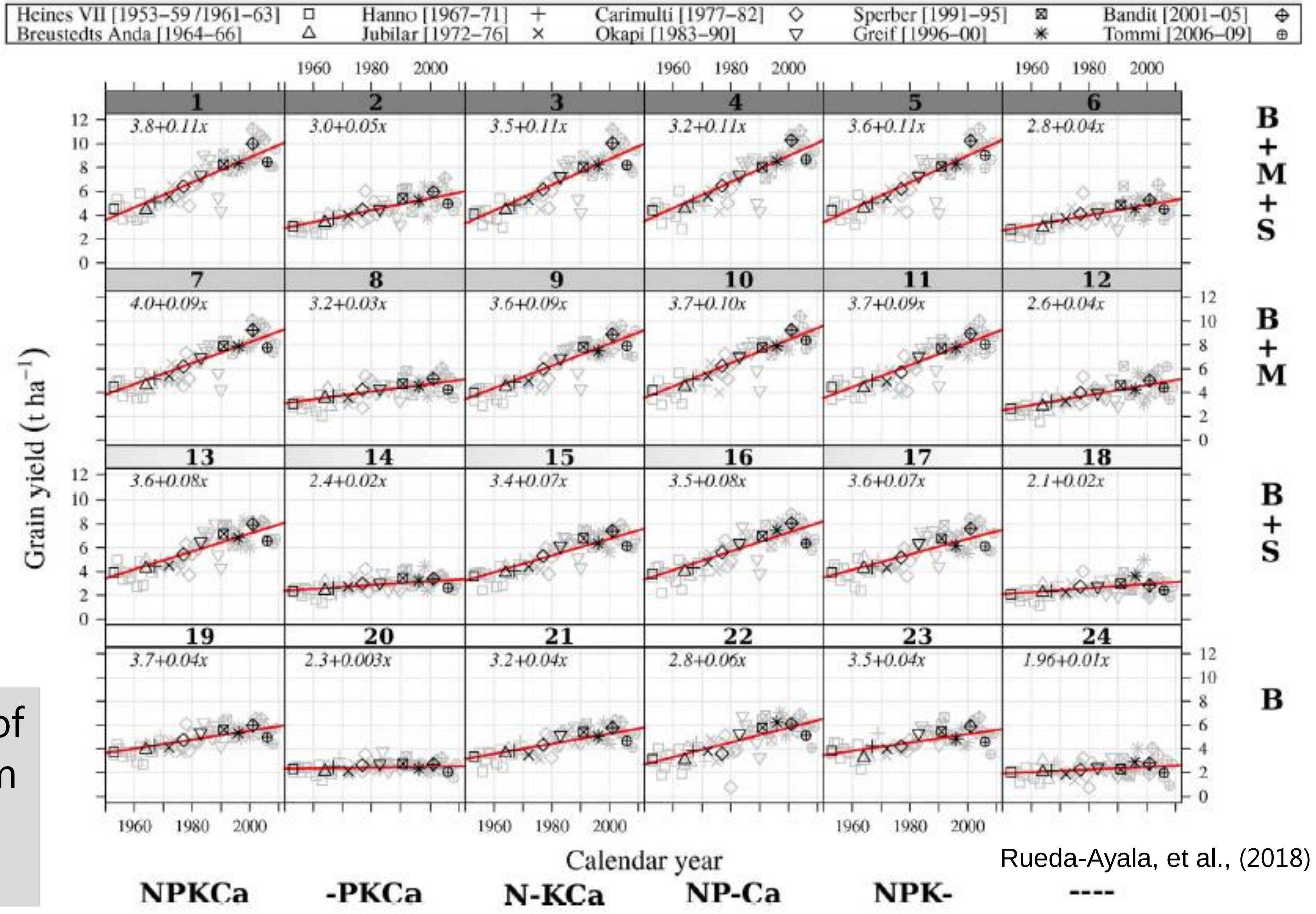
Resource limited conditions

? Modelling long time series of crop and soil variables

?? Parameterisation for changing varieties?



Yield change and variability of winter wheat in the long term fertilization experiment, Dikopshof, Bonn, 1953-2013



Rueda-Ayala, et al., (2018)

Resource limited conditions ➔ divers production systems

- Most production under limited resource supply
- Future production systems need to meet multiple targets

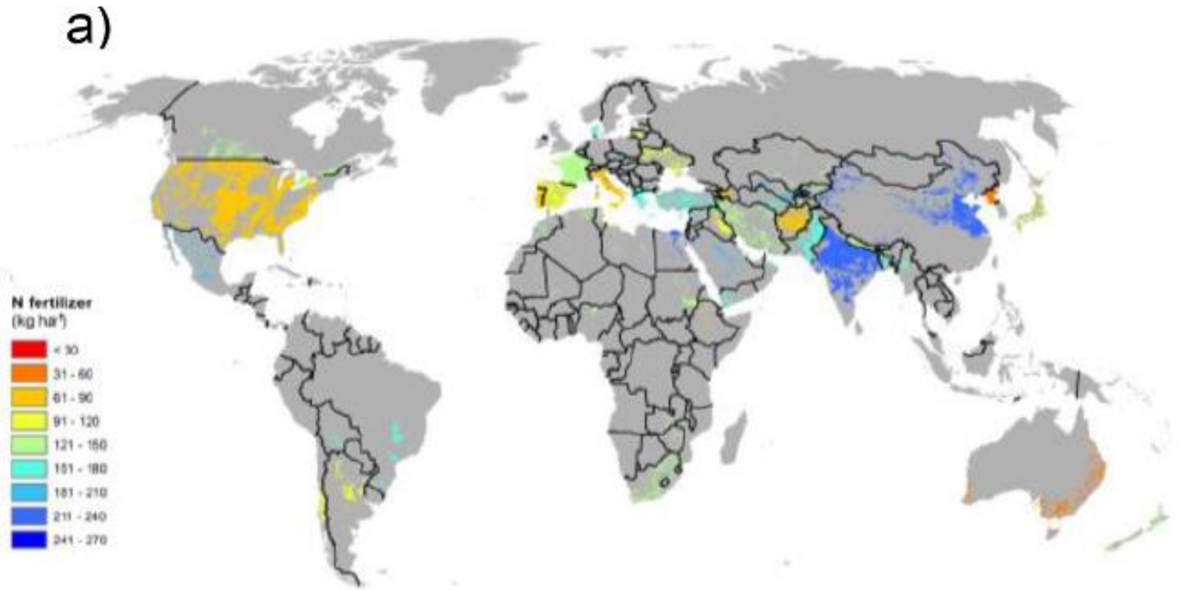
2030 Targets for sustainable food production

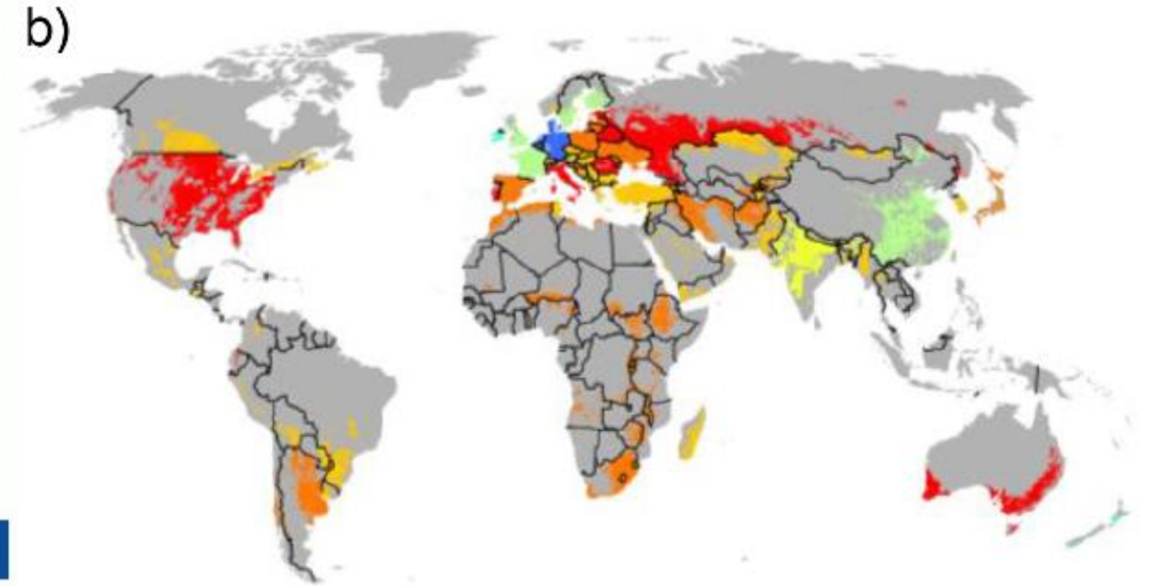
Reduce by 50% the overall use and risk of **chemical pesticides** and reduce use by 50% of more hazardous **pesticides**

Reduce **nutrient losses** by at least 50% while ensuring no deterioration in soil fertility; this will reduce use of **fertilisers** by at least 20 %

Reduce sales of **antimicrobials** for farmed animals by 50%

Achieve at least 25% of the EU's agricultural land under **organic farming** and a significant increase in **organic aquaculture**

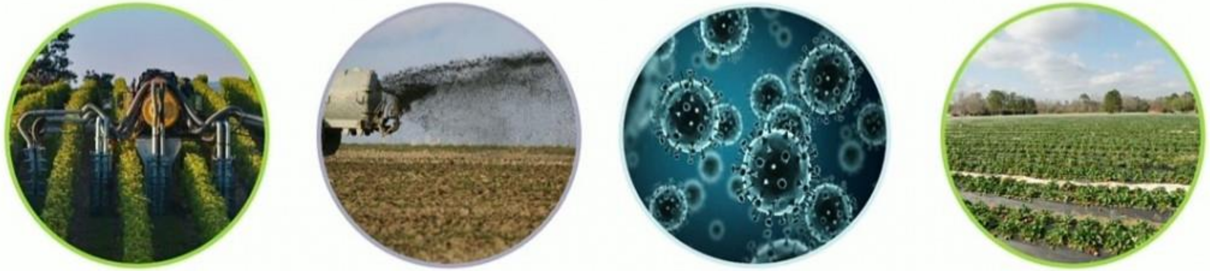




Resource limited conditions ➔ divers production systems

- Future production systems need to meet multiple targets

2030 Targets for sustainable food production



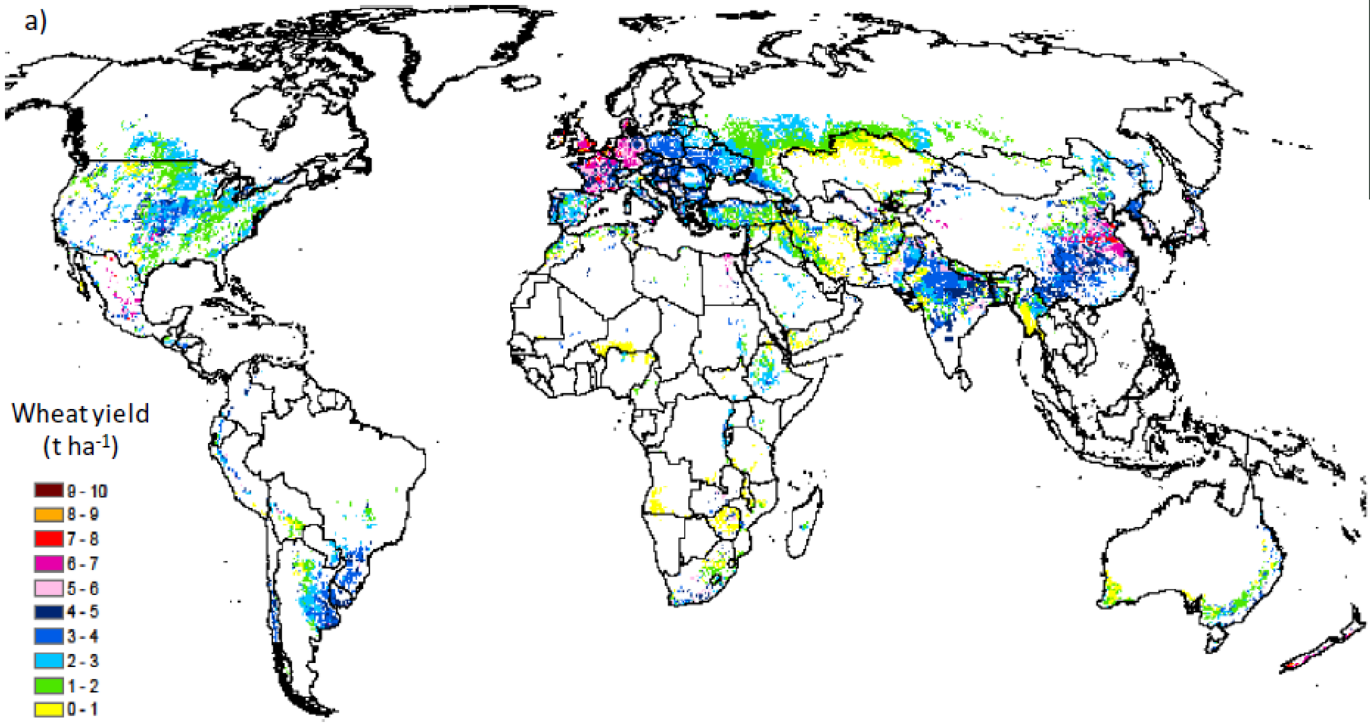
Reduce by 50% the overall use and risk of **chemical pesticides** and reduce use by 50% of more hazardous **pesticides**	Reduce **nutrient losses** by at least 50% while ensuring no deterioration in soil fertility; this will reduce use of **fertilisers** by at least 20 %	Reduce sales of **antimicrobials** for farmed animals by 50%	Achieve at least 25% of the EU's agricultural land under **organic farming** and a significant increase in **organic aquaculture**

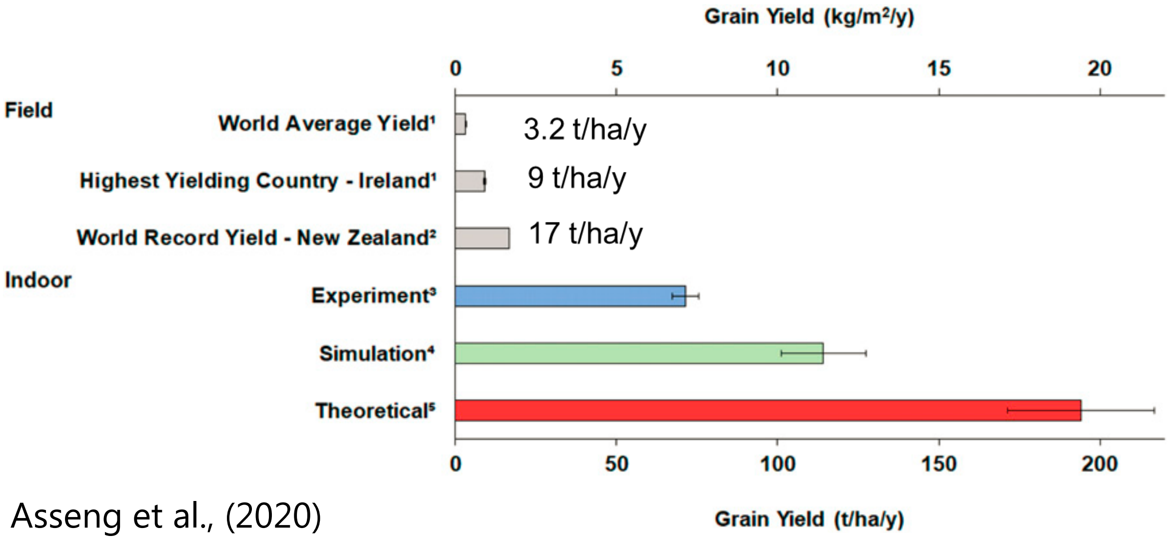
- Increasing diversification

- Inter, mixed, relay, … cropping
- Patch croping
- Agroforestry
- Agro-photovoltaic
- …

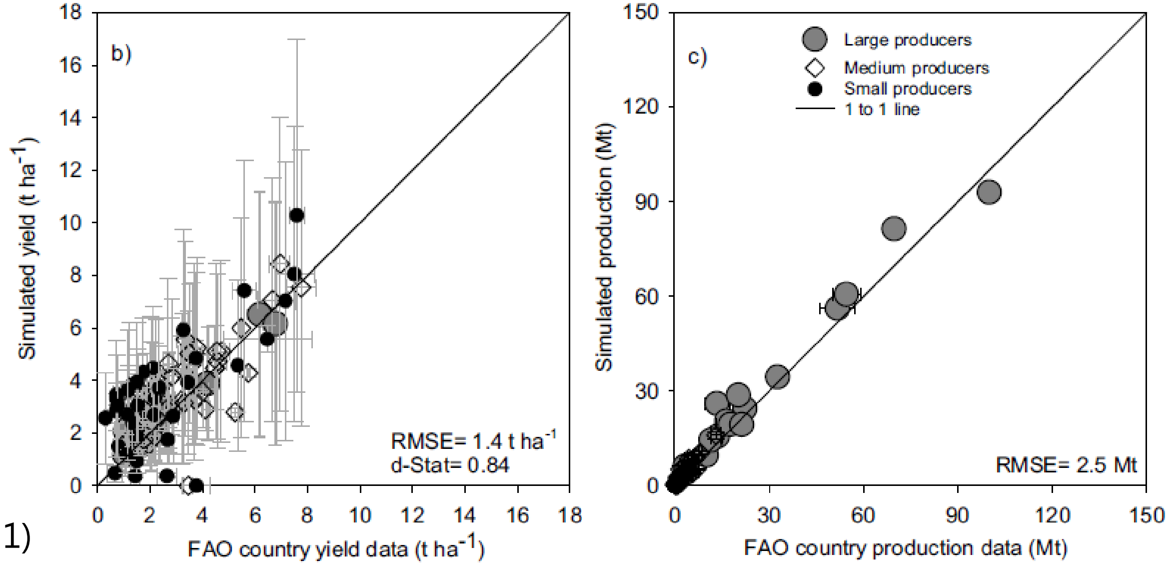
Divers production systems

Foto: Aerofarms





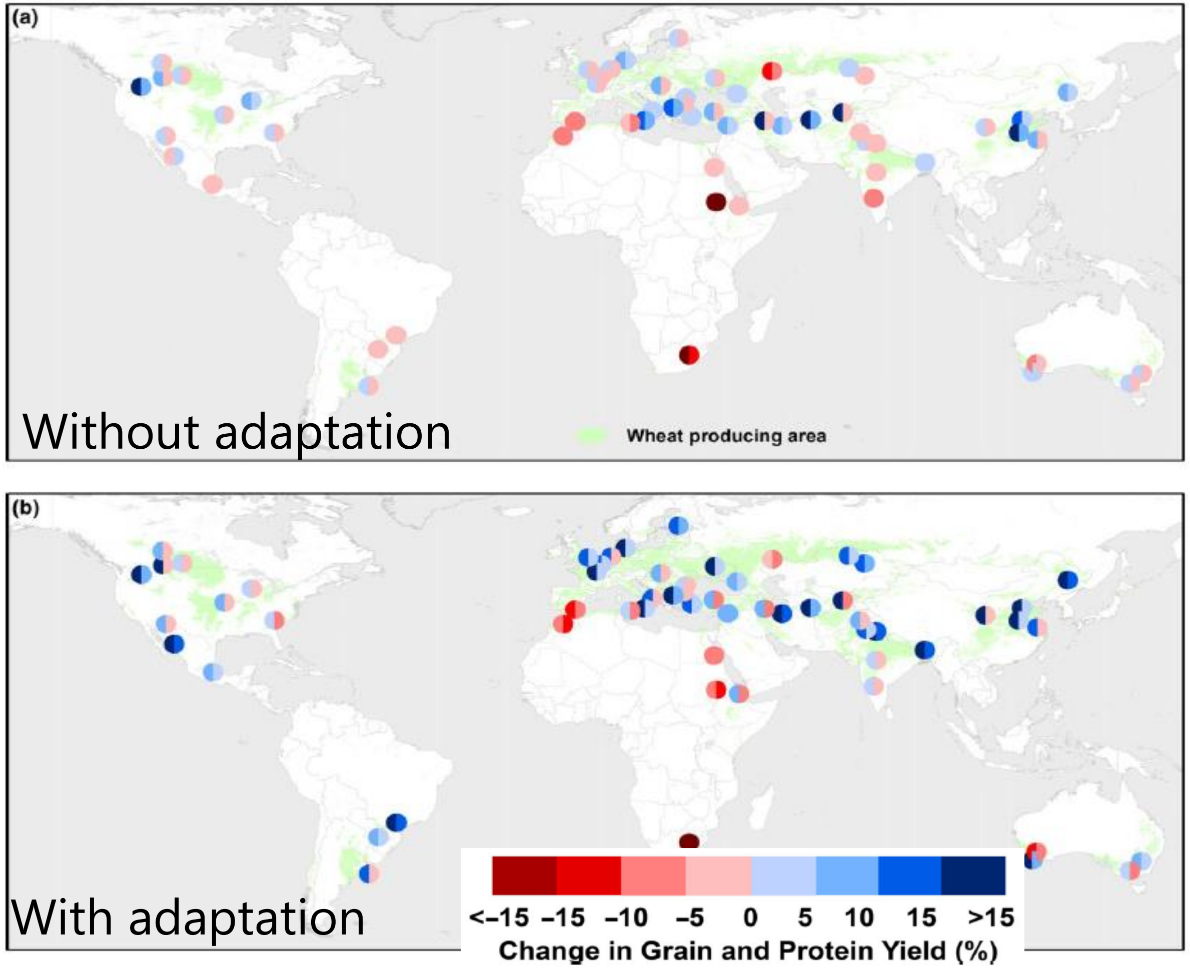
Asseng et al., (2020)



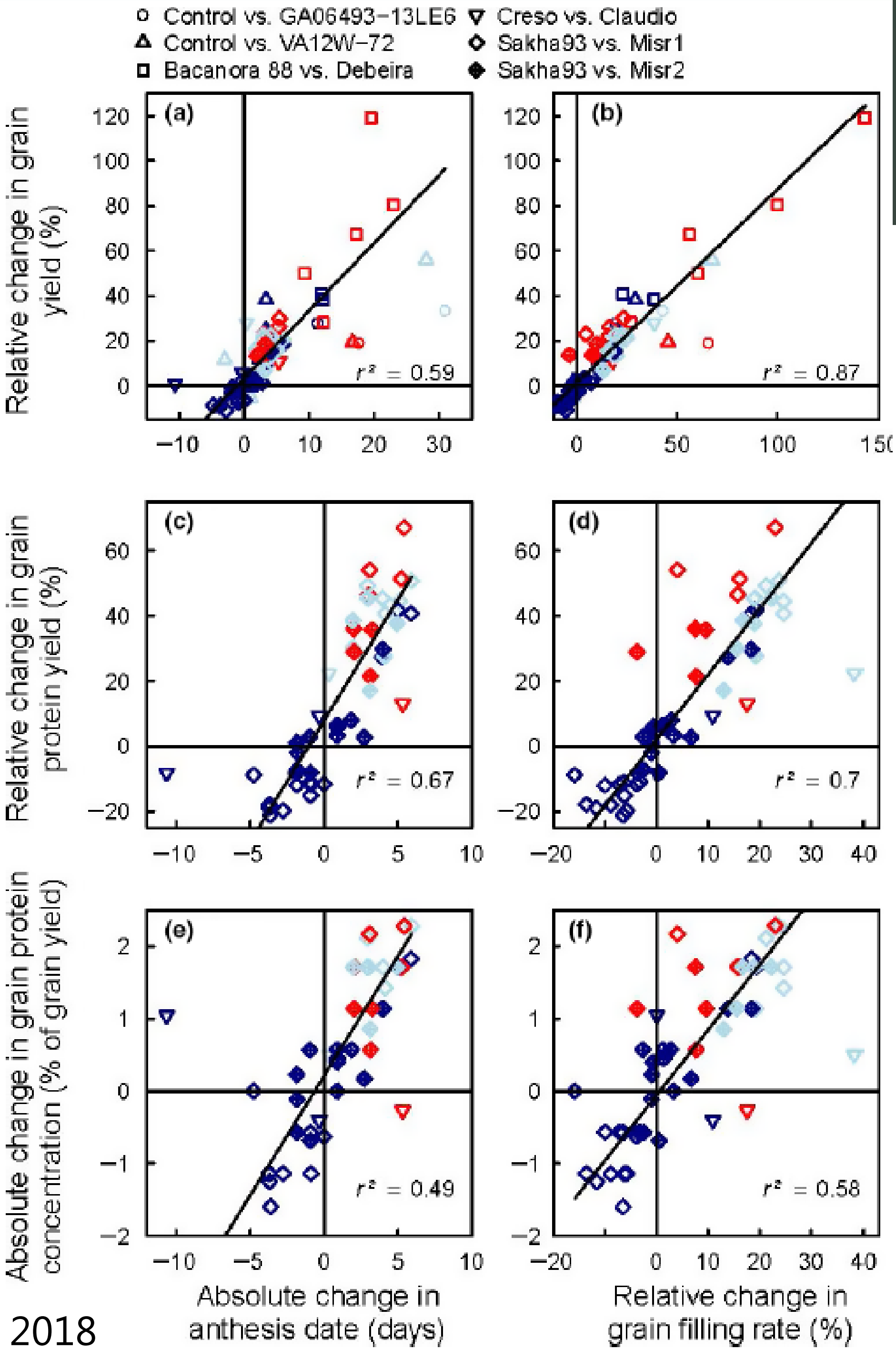
Pequeno et al. (2021)

Multiple target variables

- ➔ Relationships among traits (winter wheat)
- ➔ Multiple target variables (grain and protein yield and content)
- ➔ Ensemble predictions under CC (2036–2065, RCP8.5)



Asseng, et al., GCB 2018



Concluding remarks

- Drivers of yield variability (and limits to yield) change with space, time, crop, production system, …
- Models are helpful to analyse important drivers (and limitations) and identify improved crops (traits) and management options
- In the future: improved crops (and production systems) will need to adapt to climate change **BUT** also to comply to multiple other goals (sustainable productions systems)
- Diversification of crops and productions systems will have implications for suitable crops (genetic characteristics, suitable traits)
- Crop modelling needs to be advanced for these diversifications
- With diversification of production systems crop modelling will likely become more important for improving crops and management