State of the art in crop modelling for climate-impact research

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(with contributions from Munir Hoffmann and Marian Koch)

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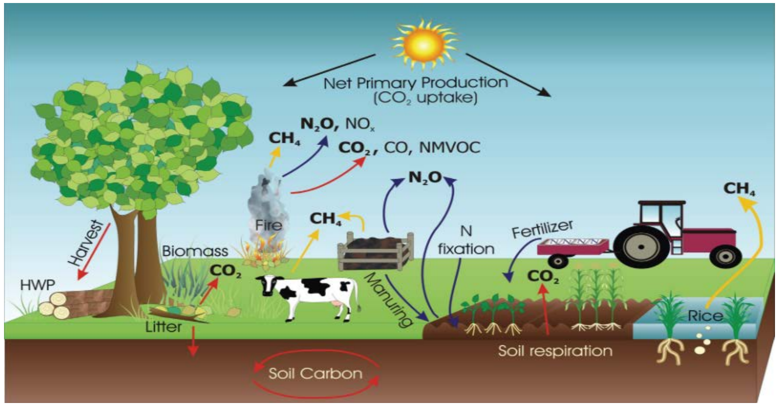
1. CHALLENGES

⇒Food and Nutrition Security

Agriculture's dual role:

(i) **Being affected by CC**

(ii) **Affecting CC**



2. Brief history of crop modelling (CropM) for climate impacts research

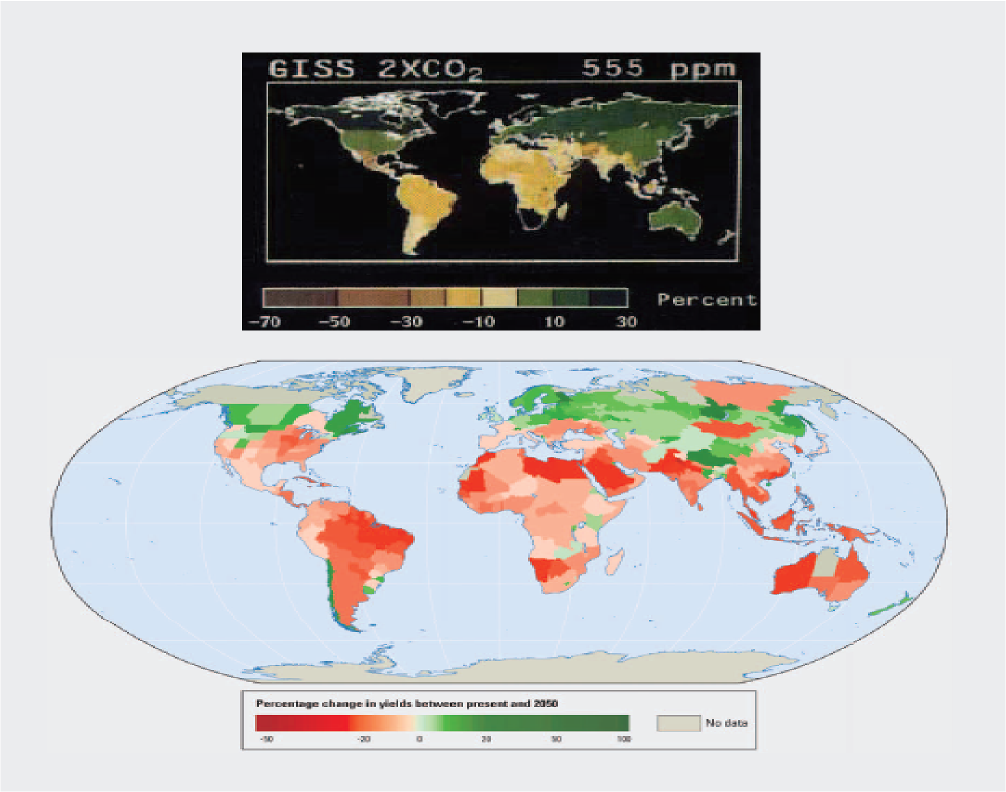


Fig. 2. Global impacts of climate change on crop productivity from simulations published in 1994 and 2010. (Top) The 1994 study (*22*) used output from the GISS GCM (in this example) with twice the baseline atmospheric CO_2 equivalent concentrations as input to crop models for wheat, maize, soybean, and rice that were run at 112 sites in 18 countries. Crop model outputs were aggregated to a national level using production statistics. **(Bottom)** The 2010 study (*27*) simulated changes in yields of 11 crops for the year 2050, averaged across three greenhouse emission scenarios and five GCMs. [Reprinted by permission from (top) Macmillan Publishers Ltd. (*22*); (bottom) World Bank Publishers (*27*)]

(source: Wheeler & von Braun, 2013, Science)

Considering agriculture in IPCC assessments , John R. Porter et al., Commentary, Nature Climate Change (2017)

2.1 Crop Simulation approach (G x E x M)

e.g. The CT de Wit Wageningen School of crop simulation models (SUCROS type - of moderate to high complexity; daily time step) (see, Bouman et al., 1996; van Ittersum et al 2003)

Different Cul
- early ↔ late
- current – futu

Different soil typ *(examples):*
- Fine sandy soil
- Clay loam
- Heavy clay
- Organic soil

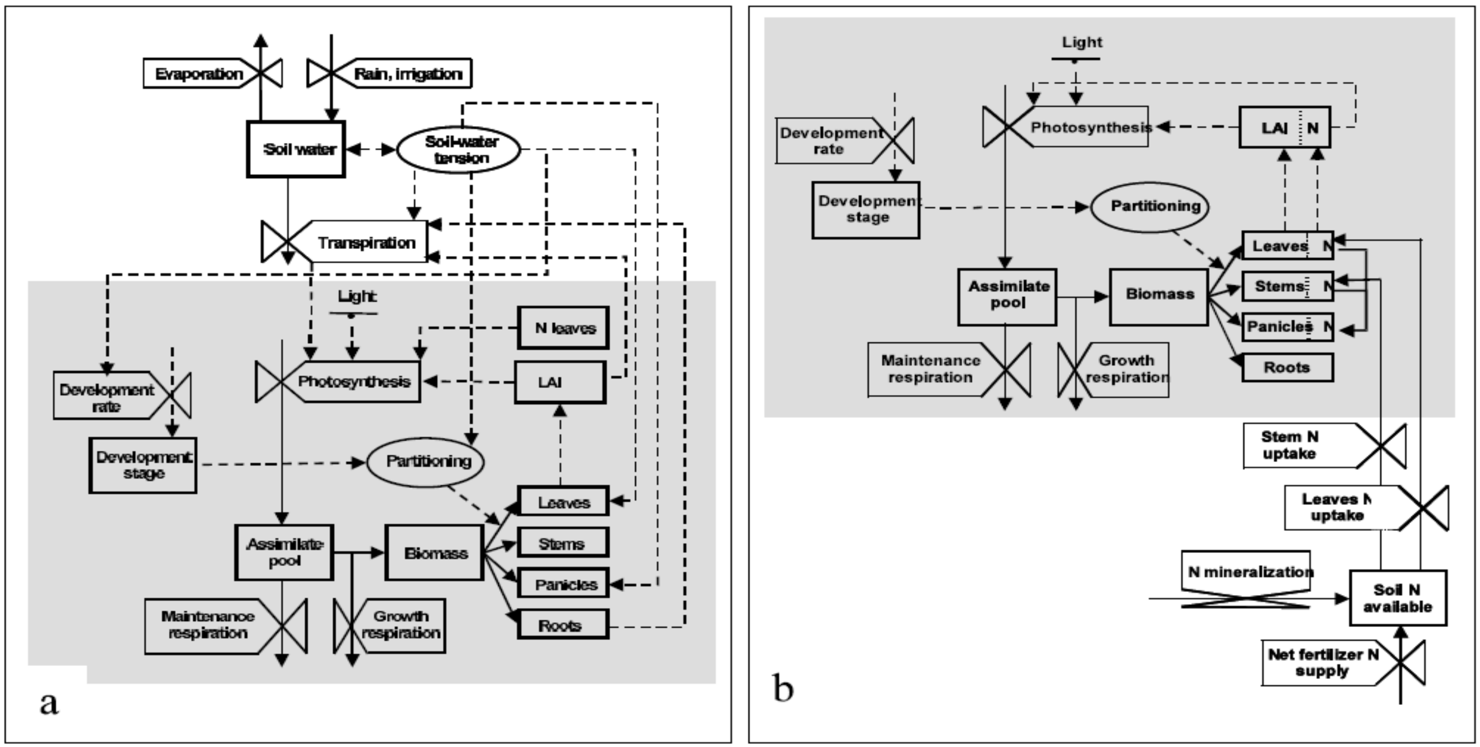


Fig. 2. A schematic representation of the photosynthesis module (in grey) for potential production, the module for water-limited production (a) and the dynamic N-approach for nutrient-limited production (b) for the ORYZA2000 model. Boxes are state variables, valves are rate variables, and circles are intermediate variables. Solid lines are flows of material and dotted lines are flows of information (Bouman et al., 2001). The same modules are used in many other models (Table 1).

3. Highlights of recent progress in modelling crop /ag impacts of CC (MACSUR, AgMIP)

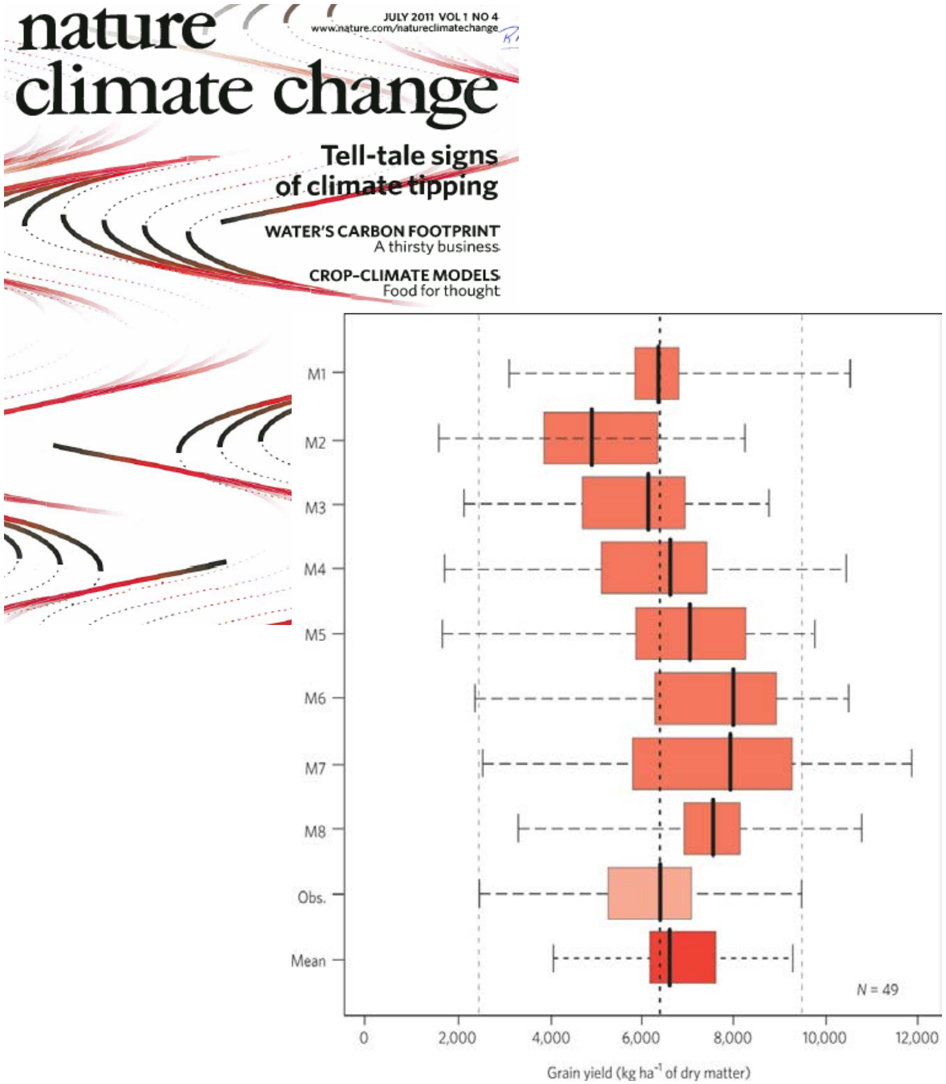
3.1 Modelling potential crop impacts

3.2 Modelling crop system adaptations

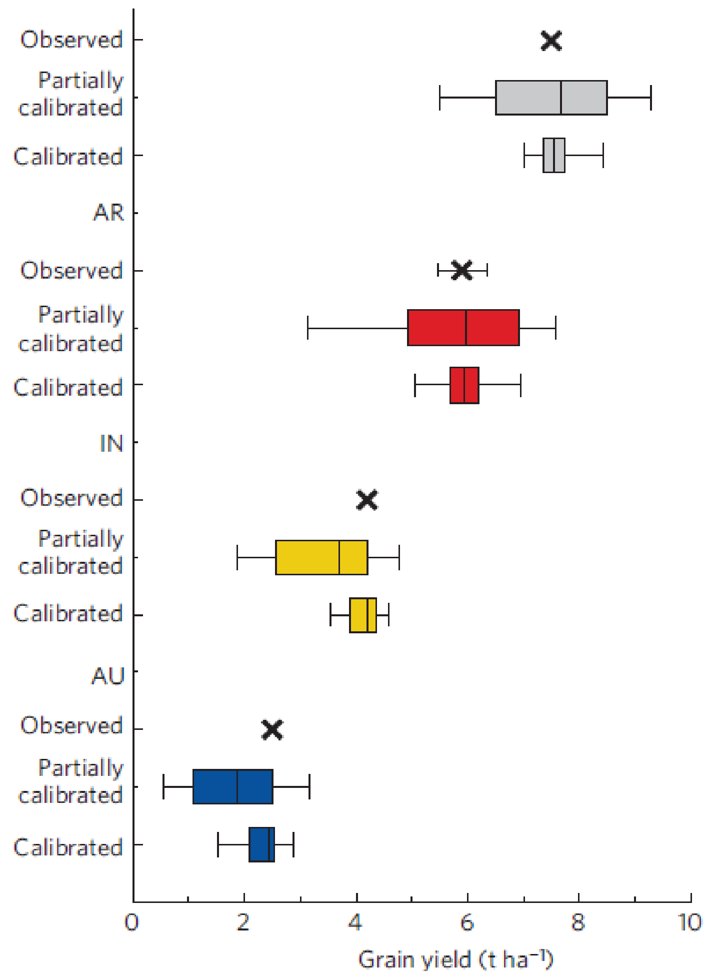
3.3 CropM contributions to IAM of CC impact and adaptations – *farm to region*

Model intercomparison and improvement

COST 734 (blind test, curr. climate); AgMIP wheat (partially & fully calibrated, curr. & future)



Source: Rötter et al., Nature Clim. Change 1, 175-177 (2011)



Source: Asseng et al., Nature Clim. Change 3, 827-832 (2013)

State-of-the-art: multi-model ensembles for wheat

nature climate change

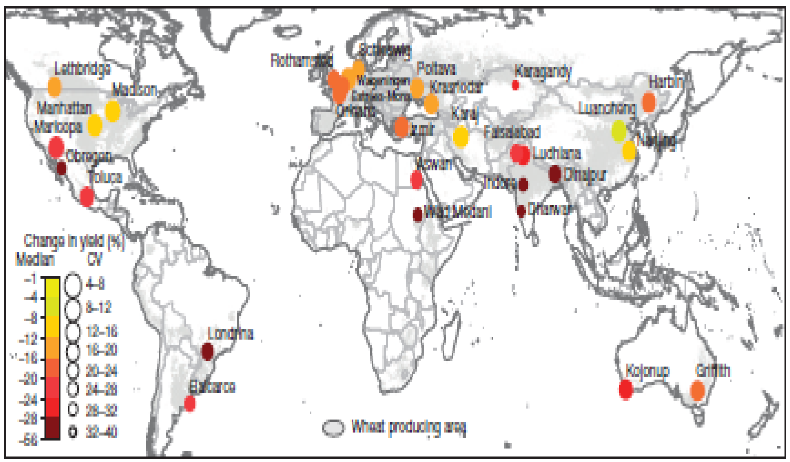
LETTERS

PUBLISHED ONLINE: 22 DECEMBER 2014 | DOI: 10.1038/NCLIMATE2470

Rising temperatures reduce global wheat production

S. Asseng et al.†

c



Application of ensemble modelling approach for bread wheat (AgMIP/Macsur) – map c shows: Relative median yield and CV for +4°C on top of 1981-2010 baseline

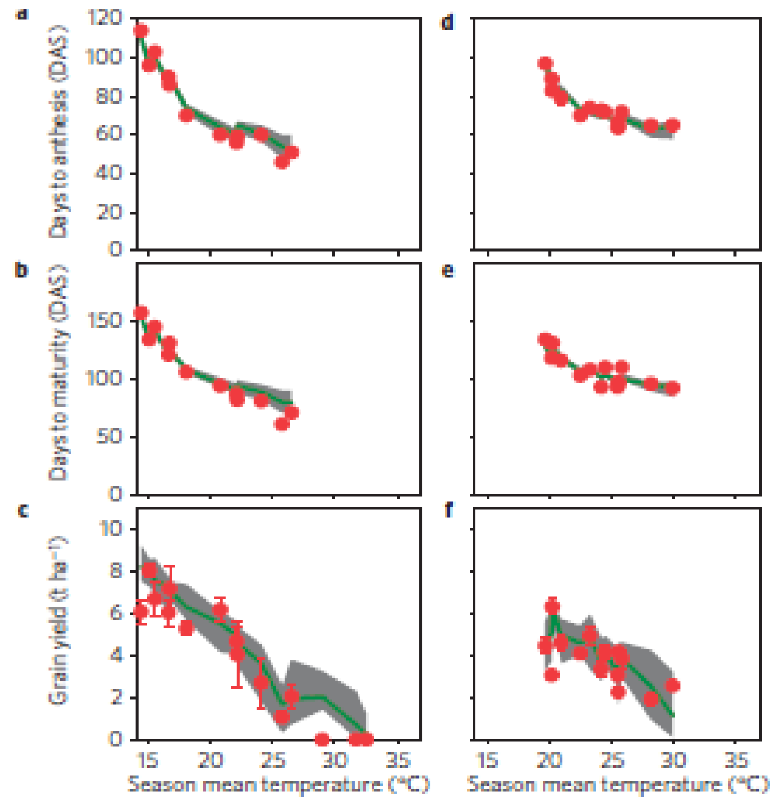


Figure 1 | Observations and multi-model simulations of wheat phenology and grain yields at different mean seasonal temperatures. a–f, Observed values ± 1 standard deviation (s.d.) are shown by red symbols. Multi-model ensemble medians (green lines) and intervals between the 25th and 75th percentiles (shaded grey) based on 30 simulation models are shown.

CropM capabilities & limitations
What kind of extremes and impacts ?

(1) Heat shocks (high Tmax) => floret mortality, heat waves => leaf senescence, shortened grain-filling period

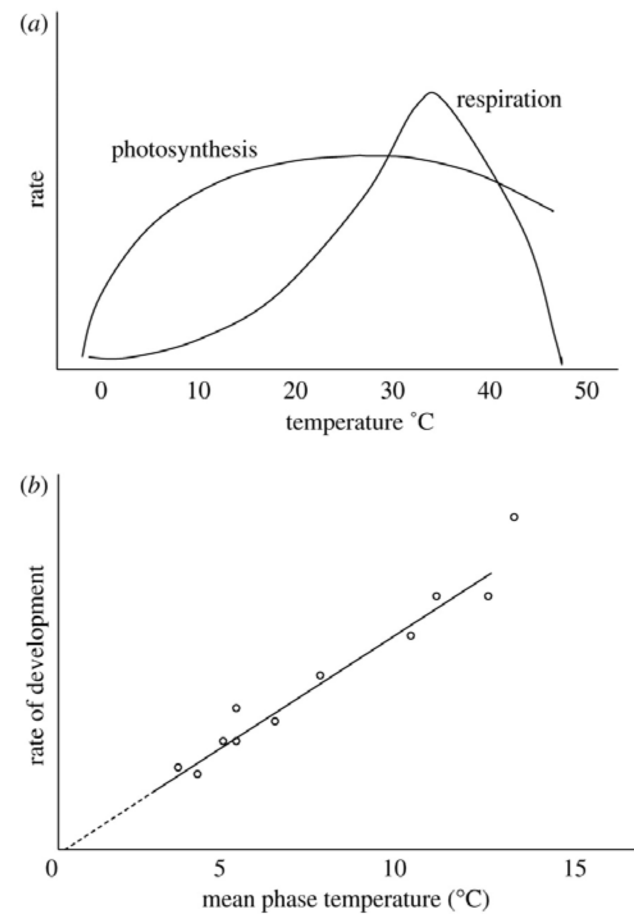
(2) **Dry spells/water deficits => VPD, stomatal closure, photosynthesis reduced, leaf senescence**

(3) Drought x Heat interactions => transpirational cooling, etc.

(4) Heavy rain => water logging, oxygen stress; delayed harvest; wetness increased occurrence of pests/ diseases

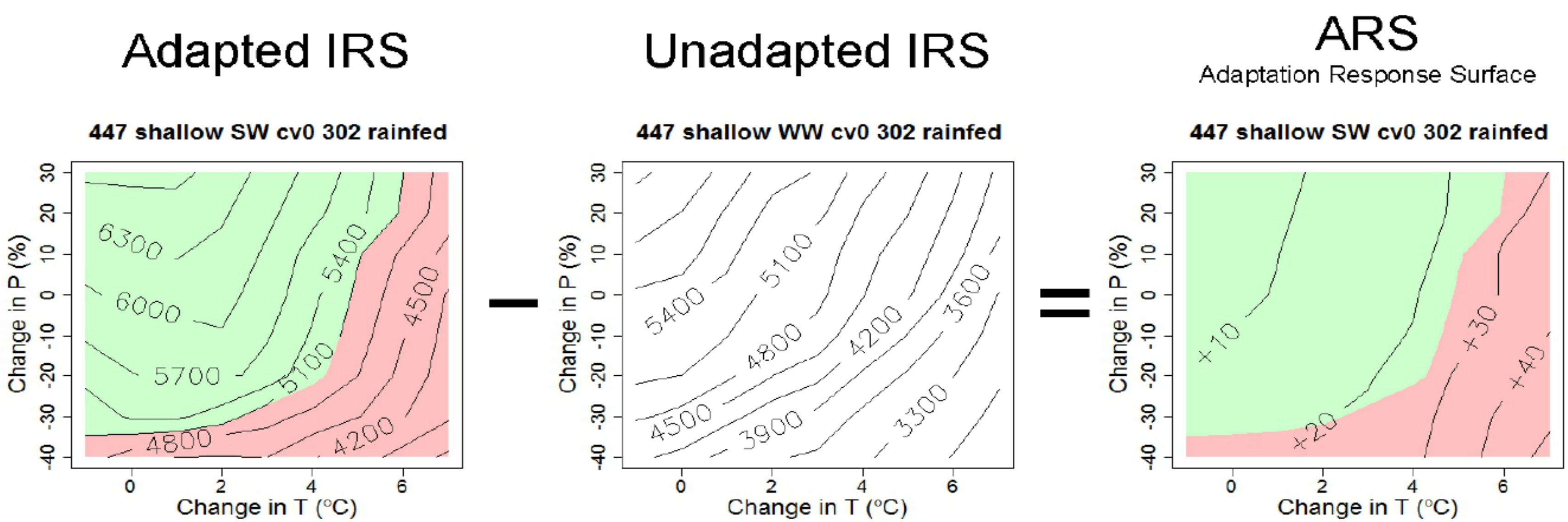
(5) Heavy rain/warm winters – indirect via soil processes (e.g. nitrogen losses by leaching)

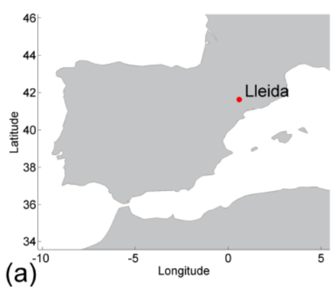
Changes in the rate of (a) C3 photosynthesis and respiration and (b) rate of crop development as a function of temperature



IRS2 Study- Results for wheat at Lleida/ES

Construction of Adaptation Response Surfaces

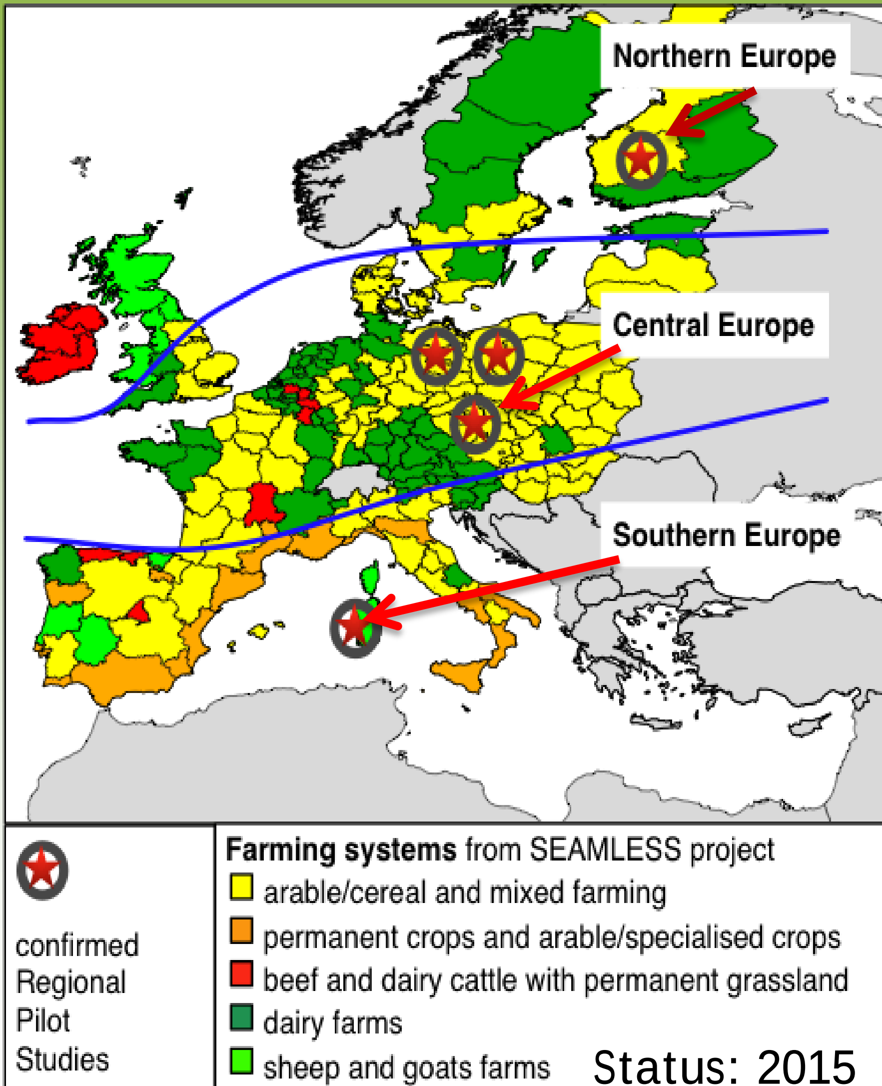




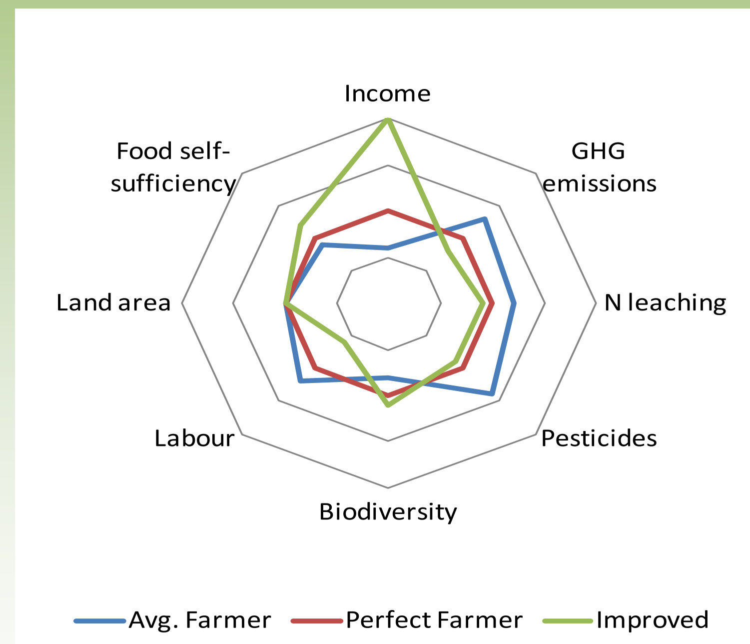
Example of adaptation response surface (ARS) construction. An ARS results from subtracting two impact response surfaces (IRSs): one considering the adaptation to be evaluated (here using spring wheat), and the other the standard, unadapted option. In this case, the isolines of yield in the IRSs are in kg ha^{-1}, while the results in the ARS are expressed as % of change from the unadapted option. Both IRSs correspond to the same [CO_2] (here 447 ppm) and the same soil

Source: Ruiz-Ramos et al., 2017. Agric Syst SI

MACSUR Regional Pilots Studies IA adaptations



Multitude of appoaches – one direction is upscaling from ***farm level*** (for typical farm types) of mitigative adaptation options via region/national to supra-national scales – also taking into account other Sustainable DevGoals



Qualitative illustration goal achievement under alternative management ***(not all S-Indicators implemented yet in Macsur pilots)***

> 15 regional pilots by end 2016

=> CCAFS approach with CSA indicators

4. THE WAY AHEAD /PERSPECTIVES

- **4.1 On going work on crop impacts of extremes**
- **4.2 Future priorities in improving crop system modelling**
  - 4.2.1 Exchange insights statistical and process-based CropM
  - **4.2.2 Linking model development and experimentation**
- **4.3 Towards more meaning in global gridded CropM**
- 4.4. Towards cropping system and whole farm modelling of adaptation and mitigation options

PHD STUDENT I. ABDULAI

Issaka Abdulai

Research Topic:
Productivity, water use and resilience to climate change of cocoa cultivation systems in Ghana

Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung

Received: 22 April 2017 | Accepted: 14 August 2017
DOI: 10.1111/gcb.13885
WILEY Global Change Biology

PRIMARY RESEARCH ARTICLE

Cocoa agroforestry is less resilient to sub-optimal and extreme climate than cocoa in full sun

Available empirical and modelling studies

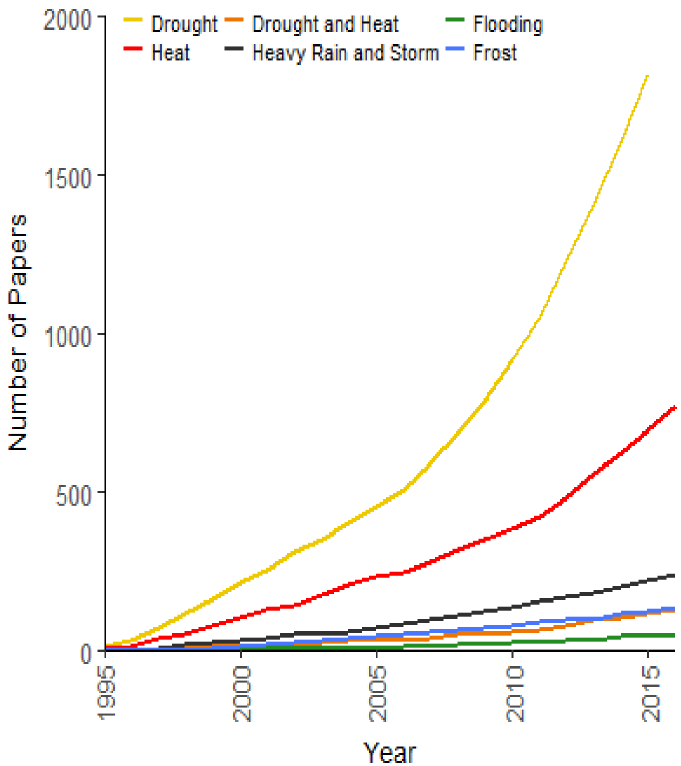


Fig S2a: Development of number of publications (n= 3226) over time per agroclimatic extreme

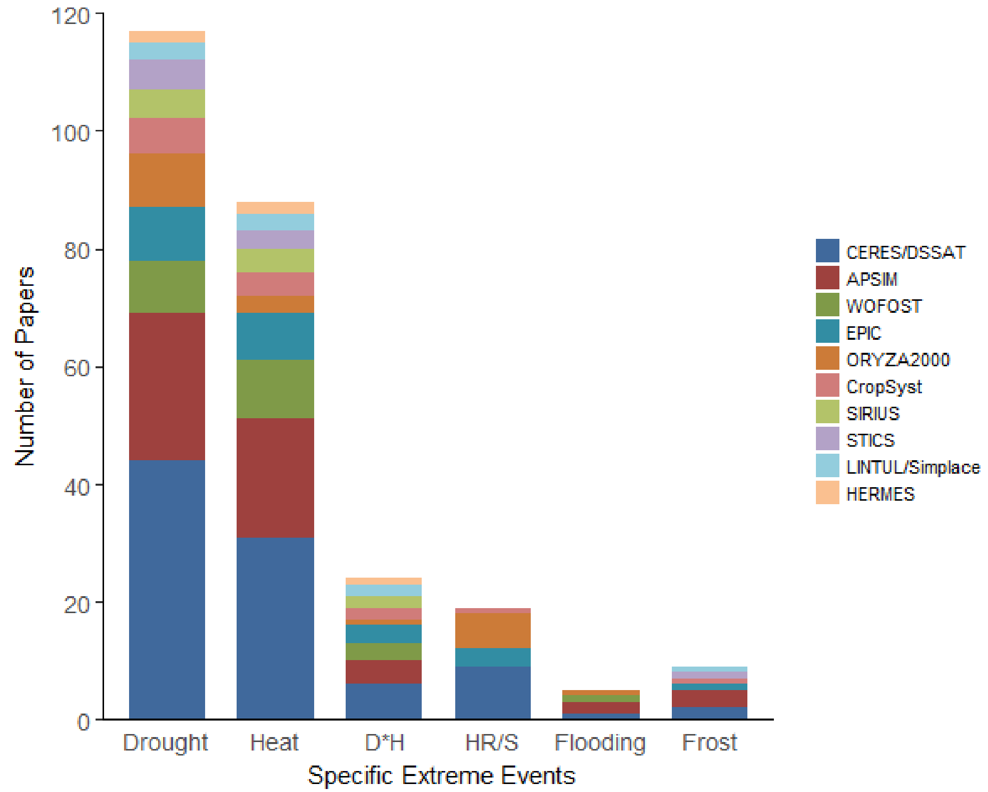


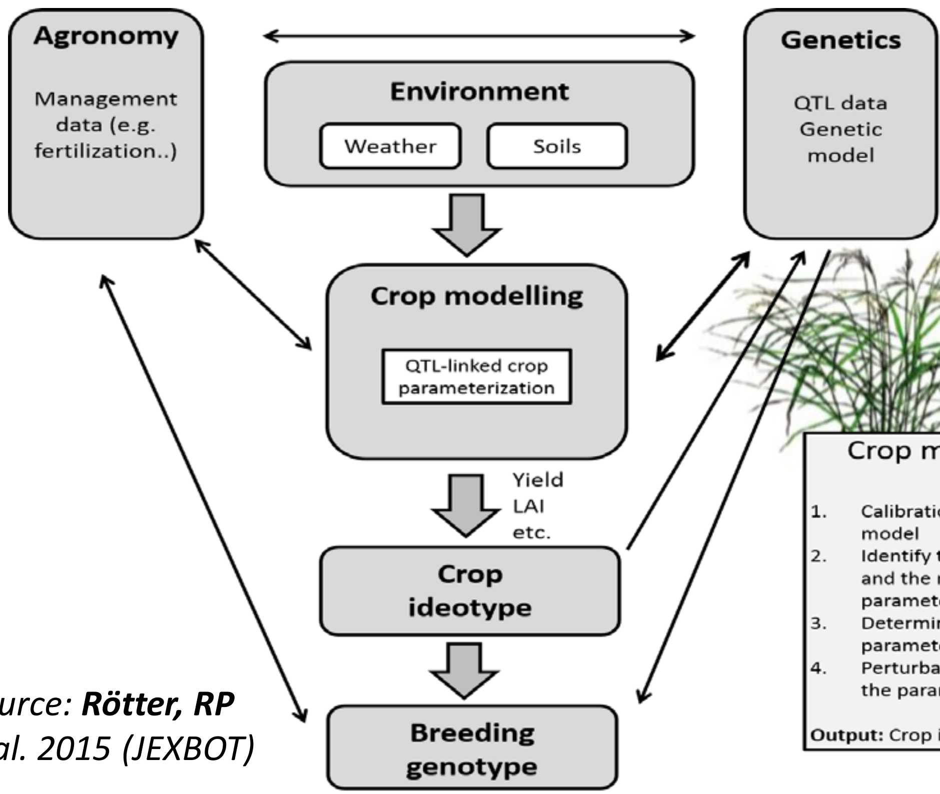
Fig. 5: Number of model-specific papers (n= 262) per agroclimatic extreme

Source: Rötter et al., submitted to FCR SI – Figures S2a and 5

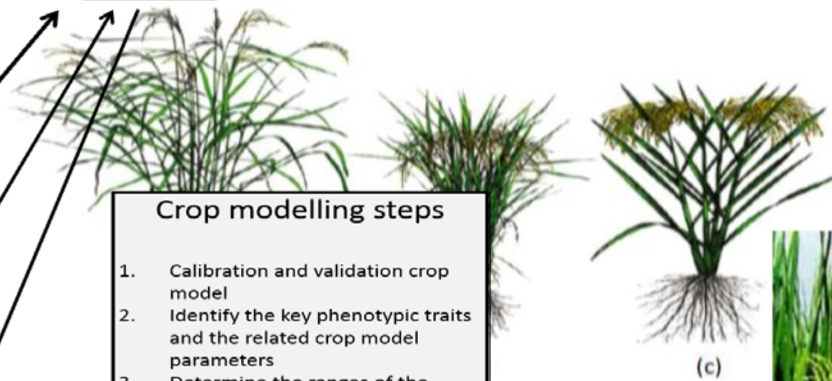
MACSUR/AgMIP

Experiments to improve models for better capturing crop impacts of extremes

MODEL-AIDED IDEOTYPING TO ACCELERATE BREEDING



Source: ***Rötter, RP*** *et al. 2015 (JEXBOT)*



Crop modelling steps

1. Calibration and validation crop model
2. Identify the key phenotypic traits and the related crop model parameters
3. Determine the ranges of the parameters
4. Perturbation and optimization of the parameters

Output: Crop ideotypic traits

⇒ **Method development model-aided ideotyping**

⇒ **More efforts to implement it with comprehensive exp. data in practice (CLIMBAR, IMPAC^3)**

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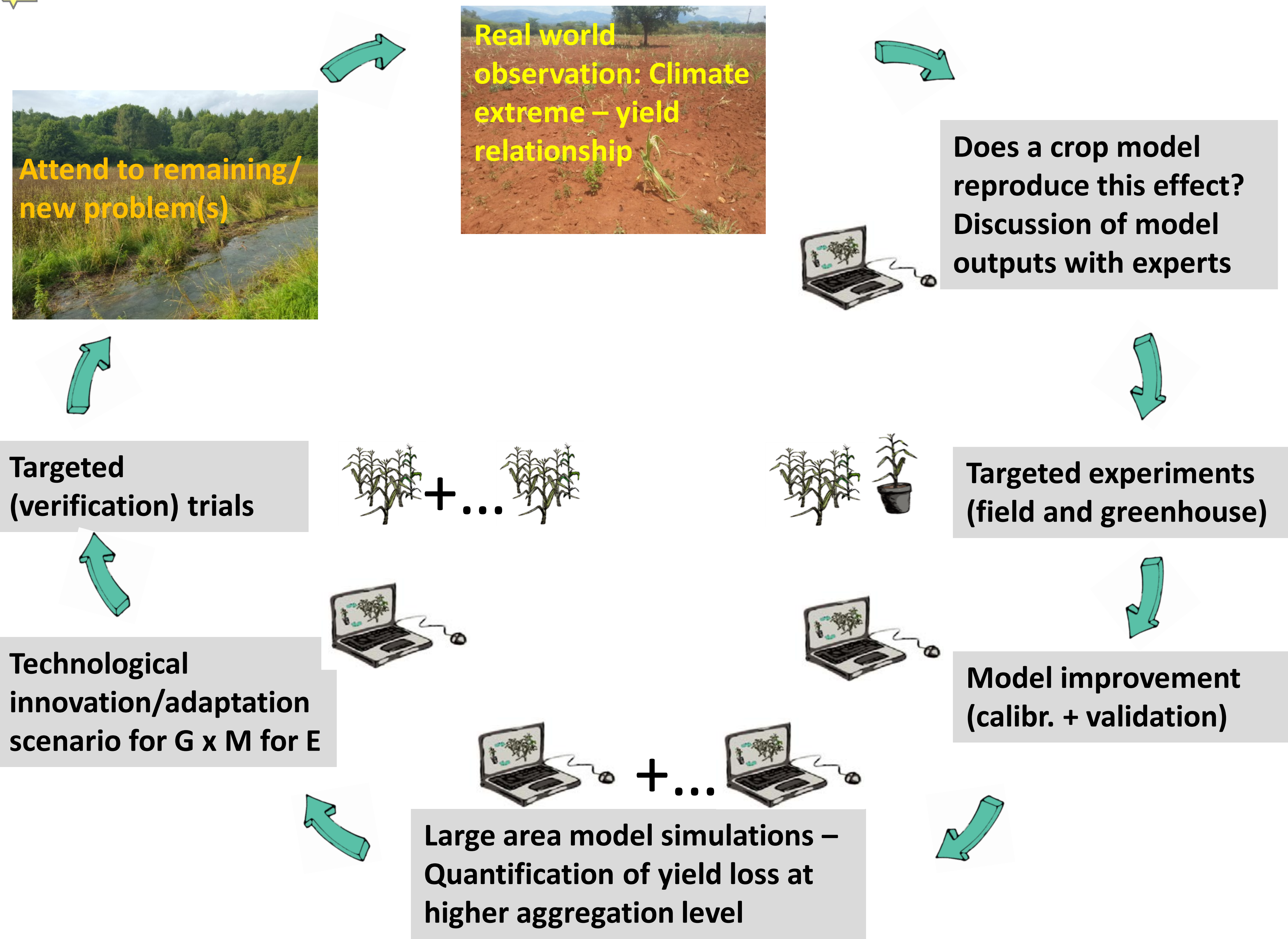
ELSEVIER

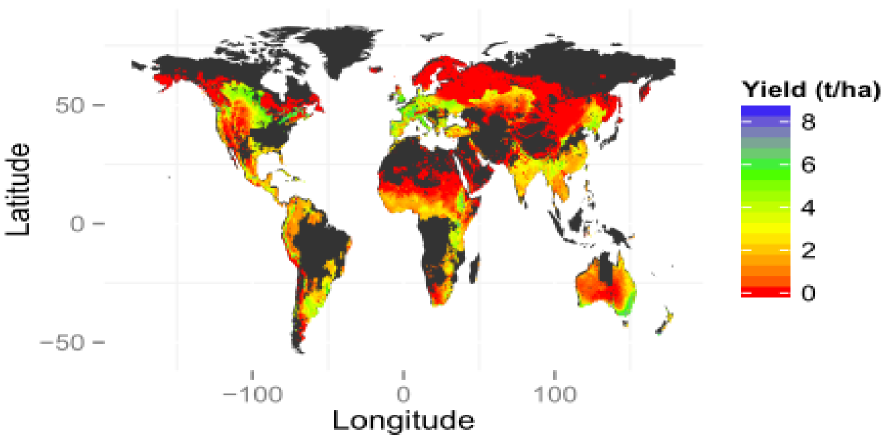
Designing future barley ideotypes using a crop model ensemble

Fulu Tao[a,*], Reimund P. Rötter[a,b], Taru Palosuo[a], C.G.H. Díaz-Ambrona[c], M. Inés Mínguez[c], Mikhail A. Semenov[d], Kurt Christian Kersebaum[e], Claas Nendel[e], Davide Cammarano[f], Holger Hoffmann[g], Frank Ewert[g], Anaelle Dambreville[h], Pierre Martre[h], Lucía Rodríguez[c], Margarita Ruiz-Ramos[c], Thomas Gaiser[g], Jukka G. Höhn[a], Tapio Salo[a], Roberto Ferrise[i], Marco Bindi[i], Alan H. Schulman[a,j]

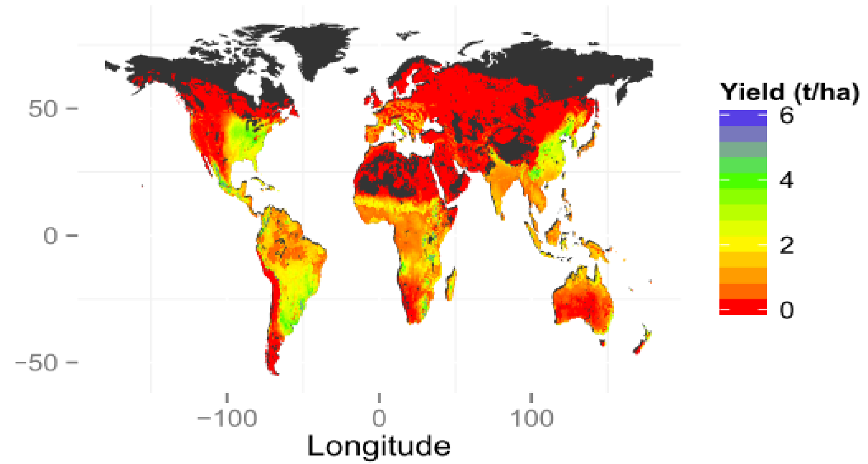

Real world observation: Climate extreme – yield relationship
Does a crop model reproduce this effect? Discussion of model outputs with experts
Targeted experiments (field and greenhouse)
Model improvement (calibr. + validation)
+...
Large area model simulations – Quantification of yield loss at higher aggregation level
Technological innovation/adaptation scenario for G x M for E
Targeted (verification) trials
+...
Attend to remaining/ new problem(s)

GGCMI phase 2 exercise (here: APSIM)

- grid resolution: 0.5°
- soil data: WISE30sec harmonized world soil property estimates (Batjes 2015, Geoderma)
- Historical weather data: AgMERRA climate forcing dataset (Ruane et al. Agric. Forest Meteorol.)
- unified crop mask
- Predefined temp/CO_2/H_2O/N scenarios
- **Example (model APSIM): median simulated yield for the 1980–2010 period, fertilization 200 kg/ha**



spring wheat



soybean

AgMIP The Agricultural Model Intercomparison and Improvement Project www.agmip.org MACSUR a FACCE JPI Knowledge Hub www.macsur.eu

THANK YOU!

https://www.uni-goettingen.de/en/539218.html

(TROPAGS)

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