Wheat yield sensitivity to climate change across a European transect for a large ensemble of crop models


¹Finnish Environment Institute (SYKE), ²-²⁹see programme
Introduction

- Crop modelling experiment as part of FACCE-JPI, MACSUR

- To study crop model sensitivity to changes in precipitation and temperature using a large ensemble of crop models

- To quantify differences in average yield responses to changed climate across models

- To contrast multi-model responses of yield variability and reliability for each crop under baseline and changed climate across the transect.

- By plotting results of the sensitivity analysis as impact response surfaces
## Ensemble of 26 wheat models

<table>
<thead>
<tr>
<th>Model</th>
<th>Contact person(s)</th>
<th>Modelling groups Institute</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFRCWHEAT2</td>
<td>Manuel Montesino</td>
<td>University of Copenhagen</td>
<td>Denmark</td>
</tr>
<tr>
<td>APSIM-Wheat</td>
<td>Senthold Asseng, Davide Cammarano</td>
<td>University of Florida</td>
<td>USA</td>
</tr>
<tr>
<td>APSIM</td>
<td>Enli Wang</td>
<td>CSIRO Land and Water</td>
<td>Australia</td>
</tr>
<tr>
<td>AquaCrop</td>
<td>Ignacio Lorite</td>
<td>IFAPA Junta de Andalucia</td>
<td>Spain</td>
</tr>
<tr>
<td>ARMOSA</td>
<td>Alessia Perego</td>
<td>University of Milan</td>
<td>Italy</td>
</tr>
<tr>
<td>CARAIB</td>
<td>Julien Minet</td>
<td>Université de Liège</td>
<td>Belgium</td>
</tr>
<tr>
<td>CERES-wheat DSSAT v.4.6</td>
<td>Mirek Trnka, Petr Hlavinka</td>
<td>Mendel University in Brno</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>CERES-wheat DSSAT v.4.5</td>
<td>Margarita Ruiz-Ramos</td>
<td>Universidad Politecnica de Madrid</td>
<td>Spain</td>
</tr>
<tr>
<td>CERES-wheat DSSAT v.4.5</td>
<td>Paola Deligios</td>
<td>University of Sassari</td>
<td>Italy</td>
</tr>
<tr>
<td>CropSyst</td>
<td>Marco Moriondo, Roberto Ferrise, Marco Bindi</td>
<td>CNR-IBIMET University of Florence</td>
<td>Italy</td>
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<tr>
<td>DNDC</td>
<td>Cezary Sławinski; Piotr Baranowski</td>
<td>Polish Academy of Sciences</td>
<td>Poland</td>
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<tr>
<td>EPIC</td>
<td>Luca Doro</td>
<td>University of Sassari</td>
<td>Italy</td>
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<tr>
<td>Fasset</td>
<td>Isk Öztürk</td>
<td>Aarhus University</td>
<td>Denmark</td>
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<tr>
<td>HERMES</td>
<td>Chris Kollas, Christian Kersebaum</td>
<td>Leibniz Centre for Agric. Landscape Research (ZALF)</td>
<td>Germany</td>
</tr>
<tr>
<td>Lintul2</td>
<td>Holger Hoffmann, Thomas Gaiser, Frank Ewert</td>
<td>University of Bonn</td>
<td>Germany</td>
</tr>
<tr>
<td>Lintul4</td>
<td>Iwan Supit</td>
<td>Wageningen University</td>
<td>Netherlands</td>
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<tr>
<td>LPJ-GUESS</td>
<td>Per Bodin</td>
<td>Lund University</td>
<td>Sweden</td>
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<tr>
<td>MCWLA</td>
<td>Fulu Tao</td>
<td>Luke Natural Resources Institute Finland</td>
<td>Finland</td>
</tr>
<tr>
<td>MONICA V1.2</td>
<td>Claas Nendel</td>
<td>Leibniz Centre for Agric. Landscape Research (ZALF)</td>
<td>Germany</td>
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<td>SALUS</td>
<td>Bruno Basso</td>
<td>Michigan State University</td>
<td>USA</td>
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<td>Sirius 2010</td>
<td>Mikhail Semenov, Pierre Stratonovitch</td>
<td>Rothamsted Research</td>
<td>UK</td>
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<td>Sirius Quality</td>
<td>Roberto Ferrise, Marco Bindi</td>
<td>University of Florence</td>
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<td>SPACSYS</td>
<td>Lianhai Wu</td>
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<tr>
<td>STICS</td>
<td>Benjamin Dumont, Françoise Ruget, Samuel Buis</td>
<td>Université de Liège &amp; INRA EMMAH</td>
<td>Belgium &amp; France</td>
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<tr>
<td>WOFOST 7.1</td>
<td>Cezary Sławinski; Jaromir Krzyszczak</td>
<td>Polish Academy of Sciences</td>
<td>Poland</td>
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<tr>
<td>WOFOST 7.1</td>
<td>Taru Palosuo, Reimund Rötter</td>
<td>Luke Natural Resources Institute Finland</td>
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</table>
## Simulation set-up

<table>
<thead>
<tr>
<th>Sites</th>
<th>Country</th>
<th>Location</th>
<th>N</th>
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<tbody>
<tr>
<td>Finland</td>
<td></td>
<td>Jokioinen</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td>Dikopshof, Nossen</td>
<td>3</td>
</tr>
<tr>
<td>Spain</td>
<td></td>
<td>Lleida</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Crops</th>
<th>Crop / Cultivar type</th>
<th>Cultivar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring wheat</td>
<td>Different cultivars for each location</td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td>Different cultivars for each location</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Harvest years</th>
<th>1981-2010</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Perturbations</th>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
<th>Interval</th>
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<tbody>
<tr>
<td></td>
<td>Precipitation (%)</td>
<td>- 50</td>
<td>+ 50</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Temperature (°C)</td>
<td>- 2</td>
<td>+ 9</td>
<td>1</td>
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</table>

<table>
<thead>
<tr>
<th>CO₂ level</th>
<th>360 ppm (Year 1995)</th>
<th>1</th>
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<table>
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<tr>
<th>Soils</th>
<th>Clay loam</th>
<th>1</th>
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<table>
<thead>
<tr>
<th>Management</th>
<th>Fixed sowing date</th>
<th>Location specific (observed)</th>
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<tr>
<td></td>
<td></td>
<td>1</td>
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<table>
<thead>
<tr>
<th>Total number of simulations</th>
<th>Sites x crops x years x P-changes x T-changes</th>
<th>23760</th>
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</thead>
</table>
Study sites across a European transect

Locations of weather stations used in this study and environmental zones of Metzger et al. (2005)

**Environmental zones**
- ALN - Alpine North
- BOR - Boreal
- NEM - Nemoral
- ATN - Atlantic North
- ALS - Alpine South
- CON - Continental
- ATC - Atlantic Central
- PAN - Pannonian
- LUS - Lusitanian
- ANA - Anatolian
- MDM - Mediterranean Mountains
- MDN - Mediterranean North
- MDS - Mediterranean South

Mainly precipitation limited
High current suitability
Mainly temperature limited
Simulation set-up

- Each group calibrated their model independently
- Limited data for calibration was provided on:
  - crop phenology and yield
  - soil conditions
  - fertilization, tillage and irrigation (Spain) where available
- Model simulations were performed
  - on a daily time-step
  - for water-limited yields
  - assuming optimal nutrients
  - as a succession of independent years (no carry-over effects)
  - for modelled harvest dates up to a local "harvest cutoff"
- Error checking and model iteration
Impact response surface (IRS) of a single crop model for spring wheat yield, Germany, 2008

- IRSs represent the sensitivity of modelled crop yield to incremental changes in precipitation (vertical) and temperature (horizontal)
RESULTS
Modelled yields for the baseline 1981-2010

Finland

- Individual model results
- Ensemble median

Germany: Eurostat regional statistics

Spain: provincial statistics for northern Spain, Spanish Ministry of Agriculture

- Calibration data
Baseline 1981-2010 yield levels

| Site | Crop | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | E50 | O  |
|------|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| FI   | S    | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 30  |
| FI   | W    | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 30  |
| DE   | S    | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 20  |
| DE   | W    | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 29  |
| ES   | S    | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 30  |
| ES   | W    | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 30  |

<table>
<thead>
<tr>
<th>kg ha⁻¹</th>
<th>&lt; 2000</th>
<th>2000-4000</th>
<th>4000-6000</th>
<th>6000-8000</th>
<th>8000-10000</th>
<th>≥10000</th>
</tr>
</thead>
</table>

Sites – Finland (FI), Germany (DE) and Spain (ES)
Crops – spring (S) and winter (W) wheat
Values for Observations (O) indicate the number of years for which observed crop yield data were available
Models for which no results for a specific site or crop were provided are marked with N/A.
Winter wheat DM grain yields, Germany

One crop model, individual years 1981-2010 (small sub-plots) and 30-year mean (larger sub-plot)

Crosses in the 30-year mean plot: changes in annual temperature and precipitation projected by the CMIP5 ensemble of 36 global climate models for RCP8.5 over central Europe by 2070-2099 relative to 1981-2010.
Yield changes relative to unperturbed baseline

30-year average change in winter wheat DM yields relative to baseline climate (1981-2010) in Germany

26 models (small sub-plots) and ensemble median (larger sub-plot)

By definition, the yield change is 0% for the baseline climate at the intersection of the grey lines.
Ensemble medians and IQR of yield changes

Winter wheat

Left: Median of yield changes by 26 crop models

Right: Inter-quartile range (IQR) of relative responses scaled to 100% at baseline

The ensemble median ($M_{baseline}$) and ensemble inter-quartile range ($IQR_{baseline}$) of absolute yields for the baseline are listed above each plot.
Ensemble medians and IQR of yield changes

Spring wheat

Left: Median of yield changes by 24 (Finland) or 25 (Germany, Spain) crop models

Right: Inter-quartile range (IQR) of relative responses scaled to 100% at baseline

The ensemble median ($M_{\text{baseline}}$) and ensemble inter-quartile range ($\text{IQR}_{\text{baseline}}$) of absolute yields for the baseline are listed above each plot.
Interannual variability of ensemble medians

Spring wheat

Left:
Yield reliability = % of years when yield is above the 10th %-tile of the baseline yield

Right:
Coefficient of variation (CV) of annual yields

Ensemble medians of 24 (Finland) or 25 (Germany, Spain) crop models
CONCLUSIONS
Conclusions 1/2

• Demonstration of a new method that uses Impact Response Surfaces (IRSs) for a systematic intercomparison of crop model behaviour under conditions of changing climate

• Ensemble average yields decline with higher temperatures (3–7% per 1°C) and decreased precipitation (3–9% per 10% decrease), but benefit from increased precipitation (0-8% per 10% increase)

• Yields are more sensitive to temperature than precipitation changes at the Finnish site compared to the German and Spanish sites
Conclusions 2/2

- Inter-model variability is highest for baseline climate at the Spanish site, but relatively insensitive to changed climate; modelled responses diverge most at the Finnish and German sites for winter wheat under temperature change.
- Optimal temperatures for present-day cultivars are close to the baseline under Finnish conditions but below the baseline at the German and Spanish sites.
- Future work will use IRSs
  1. to classify response patterns of different models
  2. to investigate uncertainties in modelled yield response to CO$_2$ concentration
  3. to evaluate future changes in crop yield reliability, by superimposing probabilistic climate projections.