Climate impacts on grain maize in Switzerland – Do the results from three different modelling approaches agree?

Annelie Holzkämper, Pierluigi Calanca, Mark Honti, Jürg Fuhrer
Background

Uncertainties in climate impact studies can be large!

How large are they?
Can we identify robust adaptation responses?

Agro-climate ensemble

A1B emission scenario

10 GCM-RCM model chains

Process-based crop model for grain maize*

10 parameter sets

10 fits with bootstrapped data samples

10 parameter sets

Statistical crop model for grain maize

Climate suitability model for grain maize

Climate uncertainty

Structural uncertainty

Parameter uncertainty

Statistical crop model

Multiple regression

\[ Y = b_0 + b_1 \cdot \text{avgRad} + b_2 \cdot \text{TMAXa35} + b_3 \cdot \text{TMINb0} + \\
 b_4 \cdot \text{avgWD} + b_5 \cdot \text{avgWD}^2 + \\
 b_6 \cdot \text{avgTemp} + b_7 \cdot \text{avgTemp}^2 \]

- \( Y \): annual grain maize yield [t/ha]
- \( \text{avgRad} \): average daily solar radiation [MJ/m²]
- \( \text{TMAXa35} \): average daily maximum temperature exceedance of 35 °C as a measure for heat stress [°C]
- \( \text{TMINb0} \): average daily minimum temperature below 0 °C in absolute values as a measure for frost impacts [°C]
- \( \text{avgWD} \): average daily water deficit (= reference evapotranspiration - precipitation) [mm]
- \( \text{avgTemp} \): average daily mean temperature as a measure for temperature determining plant growth [°C]

*all climate variables were aggregated over an estimated growing season (May, 15th - Nov, 15th)
Climate suitability evaluation

Agro-climatic indices

- Avg. daily radiation
- Avg. daily temperature
- Avg. daily TempSums < 0°C
- Avg. daily TempSums > 35°C
- Avg. daily water availability (N – ET₀)

Phase-specific factor suitability

- Radiation suitability
- Temperature suitability
- Frost stress
- Heat stress
- Water stress

Phase-suitability

- Sowing – Emergence
- Vegetative growth
- Flowering
- Maturation

Climate suitability

Weighted sum

MINIMUM

Expert- and data-based

Holzkämper et al. 2013 Agr For Met 168: 149–159
# Impact model performances

**Willmott index of agreement**

<table>
<thead>
<tr>
<th></th>
<th>Process-based model</th>
<th>Statistical model</th>
<th>Climate suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration</td>
<td>0.72 (±0.003 SD)</td>
<td>0.66 (±0.03 SD)</td>
<td>0.74 (±0.002 SD)</td>
</tr>
<tr>
<td>Validation</td>
<td>-</td>
<td>0.64 (±0.05 SD)</td>
<td>0.81 (±0.002 SD)</td>
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</tbody>
</table>
Case study locations

Avg. annual temp. 9.61 °C
Avg. annual precip. sum 892 mm

Avg. annual temp. 9.8 °C
Avg. annual precip. sum 1407 mm

Avg. annual temp. 11.66 °C
Avg. annual precip. sum 1889 mm
Climate projections (2036-2065 vs. 1981-2010)

Based on EARWIG/UKCP09 statistical weather generator (Kilsby et al. 2007, EMS 22: 1705–1719)
Climate impacts on grain maize

Projected changes in average grain yield and associated uncertainties

Yield change [t/ha]

Uncertainty sources
- Climate model chain
- Impact model approach
- Impact model parameters
- Interactions

WAE, PAY, MAG
Climate impacts on grain maize

Process-based model

Statistical model

Climate suitability

Yield change [t/ha]
Climate impacts on grain maize

Changes in climatic limitations

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<tbody>
<tr>
<td>P</td>
<td>S</td>
<td>E1</td>
<td>E2</td>
<td>E3</td>
<td>E4</td>
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</tr>
</tbody>
</table>

Change in avg. limitation

- Benefit
- Risk

SD in avg. limitation

- Low
- High

P = process-based crop model
S = statistical crop model
E = climate suitability model (E1-E4 = 4 phases)
Climate impacts and adaptation options

• Positive tendencies:
  • Improving growth temperatures
  • Decreasing radiation deficits

• Negative tendencies:
  • Accelerated development → varieties with adapted phenology
  • Increasing water deficits → irrigation, drought-tolerant varieties
  • Increasing heat stress → heat-tolerant varieties, irrigation

For the considered time horizon adaptation through varietal changes and irrigation can diminish negative impacts of climate change
Conclusions

• Where estimates agree between the approaches, projections can be considered as robust.
• Deviations in estimated climate impacts are attributed to structural differences between approaches → comparison provides insight into the effects of model limitations for impact studies.
• Projections of changes in climatic limitations are more consistent than projections of yield changes.
• Projections of changes in climatic limitations are more informative for adaptation planning than projections of yield changes.
Thank you for your attention!
Comparison of impact model approaches

If process-based models are used as the sole approach for impact assessment,

• it has to be kept in mind that certain influences are not accounted for, which might have important modulating effects on yield (e.g. heat damage, frost, pest/diseases, excess water)

If statistical crop models are used as the sole approach for impact assessment,

• it is essential to check model responses to changes in individual climate terms and to verify their plausibility to minimize the risk of misinterpretation
• it has to be kept in mind that influences of short-term extreme events (e.g. heat, drought) can be alleviated through the temporal aggregation of explanatory variables
Climate impacts on grain maize

Process-based model

![Graphs showing changes in water stress index and temperature limitation factor for WAE, PAY, and MAG.]

- Change in water stress index [-]
- Change in temp. limitation factor [-]

WAE | PAY | MAG
---|---|---
-0.1 | 0.1 | 0.2
-0.2 | 0.2 | 0.3
Climate impacts on grain maize

Statistical model

[Graph showing changes in average temperature and grain yield across different climate scenarios]
Climate impacts on grain maize

Statistical model

- Change in TMINb0-factor [t/ha]
  - Factor: 0.1
  - Change: WAE, PAY, MAG

- Change in avgWD-factor [t/ha]
  - Factor: 1
  - Change: WAE, PAY, MAG
Climate impacts on grain maize

Statistical model

![Diagram showing the change in average temperature factor (t/ha) for WAE, PAY, and MAG categories.]

- Change in average temperature factor [t/ha]
- WAE, PAY, MAG categories
Climate impacts on grain maize

Climate suitability

- Δfreq. of drought limitation
- Δfreq. of excess water limitation
- Δfreq. of accel. phenol. limitation
- Δfreq. of prolong. phenol. limitation

WAE | PAY | MAG

- Sow.-Emergence
- Vegetative growth
- Flowering
- Maturation
Climate impacts on grain maize

Climate suitability

Δfreq. of heat. limitation

Δfreq. of growth temp. limitation

Δfreq. of frost limitation

Δfreq. of radiation limitation

WAE | PAY | MAG
---|---|---
Sow.-Emergence | Vegetative growth | Flowering | Maturation
Statistical crop model

Estimated responses to changes in the terms included in the statistical grain maize models
Statistical crop model

Estimated responses to changes in the terms included in the statistical grain maize models
Estimated responses to changes in the terms included in the statistical grain maize models
Climate suitability evaluation

• Expert-based multicriteria evaluation of crop-specific climate suitability...
  ...based on agro-climatic indices
  ...for relevant phenological phases
  ...that are dynamically estimated.

• Data-based „fine-tuning“ based on observed yield data
Climate suitability evaluation

Phase-specific factor suitability

Factor suitability

Agro-climatic index for phase X (e.g. avgTemp)
Climate suitability evaluation

<table>
<thead>
<tr>
<th>Phenology model (Base temperature = 6°C)</th>
<th>Average dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sowing</td>
<td>~ May, 5th</td>
</tr>
<tr>
<td>April, 15th – May, 31st (&gt;= 12°C soil temp.)</td>
<td></td>
</tr>
<tr>
<td>Emergence</td>
<td>~ May, 18th</td>
</tr>
<tr>
<td>100 GDD</td>
<td></td>
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<tr>
<td>Begin of flowering</td>
<td>~ July, 24th</td>
</tr>
<tr>
<td>800 GDD</td>
<td></td>
</tr>
<tr>
<td>End of flowering</td>
<td>~ Aug, 15th</td>
</tr>
<tr>
<td>1100 GDD</td>
<td></td>
</tr>
<tr>
<td>Maturity</td>
<td>~ Oct, 11th</td>
</tr>
<tr>
<td>1600 GDD</td>
<td></td>
</tr>
</tbody>
</table>
Climate suitability evaluation

Phase-specific factor suitability

- Water avail. P-ET₀ [mm]
- Average daily T_min <0°C (abs.)
- Average daily T_mean [°C]
- Avg. T_max exceed. of 35°C
- Average daily radiation [W/m²]
- Period length [days]

w = 0.25
The application