Simulating crop canopy temperature

Heidi Webber, Jeff White, Bruce Kimball, Frank Ewert, Senthold Asseng, Ehsan Rezaei, Jim Pinter, Jerry Hatfield, Matthew Reynolds, Behnam Ababaei, Marco Bindi, Jordi Doltra, Roberto Ferrise, Henning Kage, Belai Kassie, KC Kersebaum, Adam Luig, Jorgen Olesen, Micha Semenov, Pierre Stratonovitch, Arne Ratjen, Robert LaMorte, Stephen Leavitt, Doug Hunsaker, Gerard Wall, Pierre Martre

Date: 19.10.2020
Temperature impacts on global crop yields

Grain yield changes (%) with 1 °C increase

Which temperature should be used to assess temperature effects?

(Zhao et al, 2017)
How different are air and crop temperatures?

- plots have same air temperature recorded at weather station
- air temperature can not distinguish irrigated and rainfed plots

(Prasher and Jones, 2014)
Wheat grain yield response to crop temperature

Indicator of heat & drought resistance

- Cooler canopies under heat & drought stress correlate with higher yields
- Indirect indicator of water use
- Modelling could allow to test GxE: WSC vs deeper roots?

(Lopes and Reynolds, 2010)
Crop temperature better explains current yield variability

Spanish irrigated maize (1982 – 2014)

Siebert et al., 2017

(c) ES43 Maize irr

(d) ES61 Maize irr

(e) ES62 Maize irr

(Yield (tha))

R²

0.005 - 0.05
0.05 - 0.10
0.10 - 0.15
0.15 - 0.20
0.20 - 0.25
0.25 - 0.30
0.30 - 0.35
0.35 - 0.40

T_air

T_c


(R² T_air = 0.04)

(R² T_air = 0.11)

(R² T_air = 0.09)

(R² T_air = 0.38)

(R² T_air = 0.22)

(R² T_air = 0.28)
Error in simulated heat stress under climate change

Irrigated maize (2080, RCP8.5, HadGEM2-ES)

Change in heat stress

$T_{air}$

$T_{c}$

$\Delta Y$ difference

$\Delta Y_{Tair} - \Delta Y_{Tcan}$

Siebert et al., 2017
How to account for in crop models?

\[ T_c = T_a + \frac{(R_n - G)}{\rho c_p \frac{\gamma^*}{\Delta + \gamma^*}} r_a - \frac{V PD}{\Delta + \gamma^*} \]

Canopy resistance (CO\textsubscript{2}, water, nitrogen, ...)

\[ \gamma^* = \gamma(1 + \frac{r_c}{r_a}) \]

Aerodynamic resistance

\[ r_a = f(\text{wind, height, LAI, stability} = f(T_c)) \]

Evaporative cooling

Highly non-linear, analytical solution not possible

....complexity makes a case for RS data for calibration
1. Energy balance with stability corrections (EBSC)
2. Energy balance with neutral stability (EBN)
3. Empirical (EMP)

Approaches to simulate canopy temperature

- Empirical approaches did very well
- Little improvement in yield simulation with T_c
- Good yield simulation with poor T_c sims

Reflect on models & test for more conditions

Canopy temperature for simulation of heat stress in irrigated wheat in a semi-arid environment: A multi-model comparison

Physical robustness of canopy temperature models for crop heat stress simulation across environments and production conditions
Correlation across production conditions and CO$_2$

<table>
<thead>
<tr>
<th>$T_c$ model</th>
<th>CW Water</th>
<th>FACE Water</th>
<th>FACE Nitrogen</th>
<th>FACE CO$_2$</th>
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1- EBSC best; 2- variation within types
Where do the models succeed and fail?

Type 1 Sequential Sums of Squares (% of total variation)

FACE

China Wheat

Very large residuals... What is going on the with data?
Where do the models succeed and fail?

For FACE, VPD explains large part of variation in obs, but models should pick this up...
Where do the models succeed and fail?

Variation explained by simulations after VPD_{Tmax} controlled for FACE Type 1 Sequential Sums of Squares (% of total variation)

<table>
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<th>$T_c$ type</th>
<th>Model</th>
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<th>China Wheat</th>
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Process models explain little additional variability beyond VPD effects.
Where do the models succeed and fail?

Response to CO₂ over all observations
**Summary**

- Models explain up to 50% of variation in observations
- Stability correction improves model skill
- Each type could explain CO₂

**Next steps**

- **Understand cause of high residual error (Jeff White)**
  - Need for high volume, high quality datasets
- Improve ET simulations
- Extend to all growth processes
  - 2 source energy balance
- Distinguish varietal differences
- Develop hybrid RS & crop models combinations to allow less intrusive quantification of crop water use