Impact of Heat Stress Events on Wheat Yields

Senthold Asseng

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Outline

1. Yield variability
2. Global wheat & temperature
3. Climate data to systems impact (Model)
4. Simulation experiment: temperature impact
5. Conclusions
Yield variability

Source: C Weeks, PlanFarm
What about temperature impact?
What about temperature impact?

South Australia crop yields slashed by extreme weather
Posted Wed Dec 9, 2009 8:11am AEDT

Crops ruined by extreme weather in November
Extreme weather back in November has cut the expected crop yields of some South Australian farms by half.
A record heatwave for the month wiped off between 40 and 60 per cent of yields in areas including the state’s south-east and mid-north.
Study locations: Top 8 wheat producer

Map showing the study locations for top 8 wheat producer countries: Canada, USA, France, Germany, Russia, China, India, Australia.
Grain filling into hottest months of year

Grain filling period

Mean $T_{\text{max}}$

h) Australia

Month
Grain filling into hottest months of year

Mean $T_{\text{max}}$

- **a) China (Yinchuan)**
- **b) India (New Delhi)**
- **c) America (Wichita, Kansas)**
- **d) Russia (Volgograd)**
- **e) France (Paris)**
- **f) Canada (Regina, Saskatchewan)**
- **g) Germany (Frankfurt/M)**
- **h) Australia**

**Month**

Grain filling period
Translating climate data into systems impact
Crop model APSIM-NWheat

CO₂, Light, Temperature, H₂O, Yield, Protein %, Water, N dynamics

Management

...daily time steps
APSIM-Nwheat model testing

Observed = symbols  simulated = lines

After Asseng et al. 1998; 2000, 2002; 2004
APSIM-Nwheat model testing

Grain yield (t/ha)

- Mediterranean-type WA I
- Mediterranean-type WA II
- NSW$_{N\text{O}}$
- Temperate
- Subtropical (Keating)
- High altitude, China
- FACE (Kimball et al.)
- Rainout shelter NZ (Jamieson)
- Mexico (Sayre)

Asseng 2004
Modelling temperature & heat impact
Model: T & heat impact

Day after anthesis

SPAD Value/leaf area

24-26 °C

>32°C

Zhao et al. 2007

Factor to accelerate canopy senescence (-)

Daily maximum temperature (°C)

Model
Model: leaf & yield sensitivity to $>34^\circ$C

![Graph showing relative LAI and relative grain yield as a function of days after anthesis with sum of days exceeding $34^\circ$C.]

- **Relative LAI (%)**
  - Y-axis: 0 to 100
  - X-axis: Sum of days after anthesis with $>34^\circ$C
  - Contours indicate no days, every day $>34^\circ$C

- **Relative Grain Yield (%)**
  - Y-axis: 0 to 100
  - X-axis: 0 to 40
  - Line graph showing decreasing grain yield with increasing sum of days above $34^\circ$C
Observed & simulated high temperature & heat impact after anthesis
Observed & simulated impact of heat shock

Published observations:
- Pot
- Field
- Regional

Simulated Days at 34.1 °C
Simulated Days at 38 °C

% grain yield (or kernel weight)

Sum of Days >34 °C after anthesis
Simulation experiment on impact of high temperature & heat during grain filling
## Isolation of temperature effect

<table>
<thead>
<tr>
<th>Year 1</th>
<th>$R_n$</th>
<th>$T_{mx}$</th>
<th>$T_{mn}$</th>
<th>Rain</th>
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measured

Still measured $T$!
Separated temperature impact on yield

Maximum and minimum temperature (°C)

Wheat yield (t/ha) (Wet season)

Grain yield

Western Australia

$T_{\text{max}}$

$T_{\text{min}}$
Separated temperature impact on yield

Maximum and minimum temperature (°C)

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<tbody>
<tr>
<td>Tmax</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>8</td>
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<tr>
<td>Tmin</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
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Wheat yield (t/ha) (Wet season)

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<td>Yield</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
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Wheat yield (t/ha) (Dry season)

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<td>Yield</td>
<td>1.0</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
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Grain yield

Western Australia

T_max

T_min
Separated temperature impact on yield

Maximum and minimum temperature (°C)

<table>
<thead>
<tr>
<th>Year</th>
<th>T&lt;sub&gt;max&lt;/sub&gt;</th>
<th>T&lt;sub&gt;min&lt;/sub&gt;</th>
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<td>1970</td>
<td>20</td>
<td>12</td>
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<td>1980</td>
<td>19</td>
<td>11</td>
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<td>1990</td>
<td>18</td>
<td>10</td>
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<td>2000</td>
<td>17</td>
<td>9</td>
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Wheat yield (t/ha) (Wet season)

1971: 4.5
2002: 2.0

Grain yield

Western Australia


0.4 0.6 0.8 1.0

Grain yield
Separated temperature impact on yield

Maximum and minimum temperature (°C)

Wheat yield (t/ha) (Wet season)


Grain yield

Western Australia

heat stress + indirect T effect via water stress

-50%
Heat events

Heat stress events (>34 °C) during grain filling months

Central wheat-belt

~5% yield loss per heat event!
Australia & the rest of the world

Average number of days > 34°C during grain filling period

\[ y = 0.64x - 13.0 \]
\[ r^2 = 0.34 \]

Average maximum temperature for grain-filling period (°C)

0 1 2 3 4 5 6
Da Wa Mi Cu Ke Fr Ge Ch In Ru Ca USA

Australia
International

International daily T data from Potsdam Institute of Climate Change
Conclusions

- Inter-seasonal temperature variability & heat events can cause wheat yield reductions of 50%
- Future global warming will further increase temperature-effected yield reductions
- Temperature is a poorly-recognised threat to Global Food Security.