Changing Climate, Extreme Weather and Challenges to Midwest Agriculture

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Objectives

• Review historical changes in climate
• Present model projections of changes to future weather and climate
• Describe the challenges to growers
Grand Challenges for Food and Agriculture

- Double food production by 2050 to feed 10B people

- Do so without expanding current land use footprint

- Adopt management practices that protect and improve quality of soils, water, and other natural resources

- Succeed at all of these with moving targets in place: changing economies, human demands & climate change
Observed US Temperature changes:
1986-2015 average minus 1901-1960 average

Source: US Global Change Research Program, 2017
Total change in average maximum temperature during summer (Jun-Aug) from 1976-2016

Total change in average minimum temperature during summer (Jun-Aug) from 1976-2016

Data Source: CRU 4.0
Change in Coldest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average

Coldest days are warming

Change in Warmest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average

Hottest days are cooling

Source: US Global Change Research Program, 2017

Wisconsin Growing Season Changes 1950-2006

Source: Kucharik et al. 2010; WICCI 2011

Source: US Global Change Research Program and National Climate Assessment 2014
Observed US Precipitation Change:
1986-2015 average minus 1901-1960 average

Source: US Global Change Research Program, 2017
Top 10 wettest years
In Madison all-time

#2 – 2018 (50.64")
#5 – 2019 (46.38")
#6 – 2016 (45.56")
#7 – 2013 (45.38")
#8 – 2007 (44.41")
#9 – 2008 (44.06")
#10 – 1993 (43.34")

23% increase since 1970!

Data from NOAA, NWS, and Midwestern Regional Climate Center
https://mrcc.illinois.edu/CLIMATE/
In addition to warming temperatures, increases in humidity across the Midwest US are providing more fuel for nighttime convection that is forced by the low-level-jet.
Projected Changes in Annual Average Temperature

By 2050, +2 to 6°F in Midwest US

By 2100, +4 to 9°F in Midwest US

Source: US Global Change Research Program, 2017
Number of $>90^\circ$ Days, $<0^\circ$ Nights

More “very hot” days, less “very cold” days
Growing season length change in Midwest
Future Precipitation Changes
2070-2099 relative to 1976-2005

Source: US Global Change Research Program, 2017
Annual frequency of 20mm+ (~0.78in) rainfall events in Midwest
<table>
<thead>
<tr>
<th></th>
<th>Year 2050 High Emissions</th>
<th>Year 2050 Low Emissions</th>
<th>Year 2090 High Emissions</th>
<th>Year 2090 Low Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>+6°F</td>
<td>+5°F</td>
<td>+11°F</td>
<td>+7°F</td>
</tr>
<tr>
<td>Annual precipitation</td>
<td>+1.3 inches</td>
<td>+1.5 inches</td>
<td>+2.3 inches</td>
<td>+1.5 inches</td>
</tr>
<tr>
<td>Growing season duration</td>
<td>24 days longer</td>
<td>20 days longer</td>
<td>48 days longer</td>
<td>32 days longer</td>
</tr>
<tr>
<td>Frequency of 90°F days</td>
<td>20 more days</td>
<td>15 more days</td>
<td>48 more days</td>
<td>20 more days</td>
</tr>
<tr>
<td>Frequency of sub-0°F nights</td>
<td>15 fewer nights</td>
<td>13 fewer nights</td>
<td>22 fewer nights</td>
<td>17 fewer nights</td>
</tr>
<tr>
<td>Frequency of 1” precipitation events</td>
<td>Additional event every 20 months</td>
<td>Additional event every 20 months</td>
<td>Additional event every 10 months</td>
<td>Additional event every 17 months</td>
</tr>
</tbody>
</table>

Given future climate projections, what are the key challenges to agriculture?
Future warming increases probability of globally synchronized maize production shocks

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Meeting the global food demand of roughly 10 billion people by the middle of the 21st century will become increasingly challenging. Climate change and extreme weather events will likely increase both the frequency and severity of yield declines, making it more difficult to sustain global food production. Heat stress has been identified as the single most significant threat to maize yield and productivity, with current climate models projecting an increase of up to 31% in the frequency of months with daily maximum temperatures exceeding 30°C by 2080. Future warming is likely to increase the probability of synchronized maize yield declines across regions, which would significantly reduce the supply of maize globally. As maize production becomes more sensitive to extreme heat, it will become more essential for governments to develop strategies to reduce the impacts of heat stress on yield and productivity and to increase the adaptability of maize production systems.
1. **Nitrogen management** – challenged by changing rainfall variability, extremes

2. **Water management** – challenged by increased crop water demand and more chaotic rainfall patterns and heavier rainfall events

3. **Soil management** – more erosion; tillage operations more challenging

4. **Pest/disease management** – more overwintering, expanded ranges

5. Temperatures move outside optimal physiological ranges and increased stress at pollination stages
6. Increased rate of plant development (phenology)

7. Earlier onset of spring and higher frequency of “false springs”

8. Increased soil moisture stress

9. Increased atmospheric CO₂ could offset some negative impacts, but also favor more weeds to flourish

10. More challenging planting and harvest seasons with more variable weather

11. More rain falling during winter and on frozen ground: more runoff

12. Lengthening growing season: plant longer season summer crop varieties? Or cover crops?
Key Challenges in Farming

• We are being confronted with unprecedented changes in mean climate and weather variability

• There is an absence of “analogs” in the past historical record that represent growing conditions we are now experiencing or what is projected in the future

• “Stationarity is dead” in future planning: the amount of historical daily, seasonal to interannual variability that was typically helpful in future planning is now useless.

- Milly et al. 2008, Science
- Smith et al. 2009, Ecology
New "lakes in the landscape"
Farming Adaptations to Increasing Rainfall

• More N fertilizer is being added to make up for the increased risk of leaching losses

“If it keeps raining and it’s warm, we’re going to lose nitrogen, big time lose nitrogen, and that’s when you’ve got to come back in and put some more [nitrogen] on or you’re going to lose the crop, and there’s ‘why did you lose the crop?’ when with another 10 to 15 gallon of [liquid nitrogen fertilizer] you can fix it” – Indiana Farmer.

“We usually put [a little extra nitrogen on] just to make sure if we have a really wet year, like we had last year and how this year is turning out, that we still have some nitrogen left over [to ensure sufficient yields]” – Iowa Farmer.

How are farmers adapting to changing weather? More tile-drainage.


Takeaway Message

Degradation of Midwest Soil and Water Resources

The degradation of critical soil and water resources will expand as extreme precipitation events increase across our agricultural landscape. Sustainable crop production is threatened by excessive runoff, leaching, and flooding, which results in soil erosion, degraded water quality in lakes and streams, and damage to rural community infrastructure. Management practices to restore soil structure and the hydrologic function of landscapes are essential for improving resilience to these challenges.
Extra Slides
State level corn 10% planting completed trends 1979-2005

~4-5 days earlier per decade
Contributed to 20-30% of the yield trend

Kucharik, 2006 Agron. Journal
Record highs are being set much more frequently than record low temperatures in past 20 years

Cumulative totals
High temperature records: 86
Low temperature records: 22

C. Kucharik, UW-Madison unpublished data
The figure shows the percent of land area in the contiguous 48 states experiencing extreme one-day precipitation events between 1910 and 2017. These extreme events pose erosion and water quality risks that have increased in recent decades. The bars represent individual years, and the orange line is a nine-year weighted average. Source: adapted from EPA 2016. 171
Midwest Precipitation Changes by mid-Century
2041-2070 relative to 1971-2000

Source: US Global Change Research Program
Projected Mid-Century Temperature Changes in the Midwest
2041-2070 compared to 1971-2000

Source: US Global Change Research Program

Trends towards cooler & wetter summer favor larger yield gains
Every 1°C increase in summer temperature causes ~15% decline in yields

Kucharik and Serbin, 2008 *Env Res Letters*
Future summertime warming impacts on productivity?
• Heavily Influenced by glaciation
• Urbanizing agricultural region
• Seat of government, flagship university
• Lakes are environmental centerpiece
Temp & RH, every 15 min at 150 locations since March 2012
Spatial patterns

Impervious Surface is Extremely Important Driver

% Impervious

Temperature

July
We estimated that downtown Madison had 49 days > 90°F in 2012, which was 10 more than recorded at airport.
Winter 2013-14

Hours below 0°F

January $T_{\text{max}}$

January $T_{\text{min}}$

Schatz and Kucharik, 2015 Environmental Research Letters
Madison, WI
Urban Heat Island
Daytime Data
averaged from April 2012-March 2013

Schatz and Kucharik, 2014 J. Applied Meteorology and Climatology
Impacts on growing season length: average 2012 to 2014

Figure 3. Urban climate effects on the onset of spring and fall in Madison, Wisconsin, interpolated to 400 m resolution using regression kriging. Plots are average (from 2012 to 2014) dates of (a) last spring freeze (0 °C threshold); (b) first fall freeze (0 °C threshold); (c) last spring freeze (−2.2 °C threshold) and (d) first fall freeze (−2.2 °C threshold). Black lines delineate approximate urban extent; filled black polygons represent lakes (compare to study area map in Figure 1).
Impacts on growing degree days (GDDs, base 10ºC) and urban agriculture

Approximately 225 GDDs higher in core of urban areas than rural locations

Schatz and Kucharik, 2016 *International J. of Climatology*