Shallow groundwater impacts on corn biophysics and yield during a drought

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Research Objectives

1. **Identify** major corn physiological responses to water stress during 2012 drought

2. **Contextualize** physiological responses in terms of groundwater availability

3. **Quantify** yield losses as a result of water stress

4. **Calculate** groundwater subsidy provided to corn from shallow water table
- Water stress impacts on corn
- Study site – GW & Soil Conditions
- Physiological response
  - Micro level – stomatal conductance
  - Macro level – leaf area index
- Yield response
  - Pollination success
  - Grain yield
  - Groundwater subsidy
WATER STRESS IMPACTS

STUDY SITE

PHYSIOLOGICAL RESPONSE

YIELD RESPONSE

CONCLUSIONS

Diagram showing cumulative precipitation with phases labeled as vegetative, pollination, and grain filling. The graph compares data from 1950-2006 and 2012 Arlington Cum P [mm].
Spring:
Warm weather, normal Y.T.D. precipitation, optimistic farmers

Corn crop expected to be biggest ever

AGRICULTURE | 2012 FORECAST

May 11, 2012 1:00 am • Associated Press
Walker declares state of emergency due to drought

July 9: <8 mm precipitation since June 1
Drought is far from over

July 18-20: 50 mm rain... but it came too late

Rain won’t help corn much

For corn crops, it’s a case of too little, too late. That’s the story in Dane County
Late July, August, September: ~Normal rains, but didn’t help
Water Stress $\rightarrow$ Reduced Biomass

- decreased root & shoot growth
- decreased nutrient uptake
- smaller cob size
Water Stress \(\rightarrow\) Reduced Grain Yield

- decreased pollination success
- lower kernel counts
- shorter cobs
Water Stress → Reduced Grain Yield & Biomass

- reduced kernel mass
- more frequent kernel abortion
- higher risk for pests
Measurements
-GW elevation
-Stomatal conductance
-Leaf area index
-Total biomass
-Grain mass
-Kernel count, kernel mass, etc.
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WATER STRESS IMPACTS

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Well
Soil moisture station
Transect site (no well)
Biophysical Transect

WATER STRESS IMPACTS STUDY SITE PHYSIOLOGICAL RESPONSE YIELD RESPONSE CONCLUSIONS

silt loam
silt loam
silt loam
silt loam
silt loam

silty clay loam

loam

Soil data from DATCP
Image from NAIP (2010)
WATER STRESS IMPACTS | STUDY SITE | PHYSIOLOGICAL RESPONSE | YIELD RESPONSE | CONCLUSIONS

- Vegetative
- Pollination
- Grain filling

Cumulative Precipitation [mm]

Date

4/15/12
5/6/12
5/27/12
6/17/12
7/8/12
7/29/12
8/19/12
9/9/12
9/30/12

1950-2006 Avg Cum P [mm]
2012 Arlington Cum P [mm]
Stomatal Conductance [mmol m\(^{-2}\) s\(^{-1}\)]

- Measure of how easily water, CO2 can enter/leave a plant
- Higher stomatal conductance $\rightarrow$ higher transpiration, photosynthesis
- Water stress $\rightarrow$ reduced stomatal conductance $\rightarrow$ reduced photosynthesis

Stomatal Conductance [mmol m$^{-2}$ s$^{-1}$]

Shallow GW

Medium GW

Deep GW

WATER STRESS IMPACTS
STUDY SITE PHYSIOLOGICAL RESPONSE
YIELD RESPONSE CONCLUSIONS
Leaf Area Index = \frac{\text{surface area leaves}}{\text{surface area ground}}
Leaf Area Index = \( \frac{\text{surface area leaves}}{\text{surface area ground}} \)

**Graph:**
- **Leaf Area Index** vs. **Date**
- **5/17/12 to 8/23/12**
- **3 Lines**:
  - Red: Deep
  - Purple: Medium
  - Green: Shallow
- **Key Points**:
  - 5/17/12: 0
  - 5/31/12: -6%
  - 6/14/12: -15%
  - 6/28/12: -18%
  - 7/12/12: Increase
  - 7/26/12: Peak
  - 8/9/12: Drop
  - 8/23/12: End
<table>
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<tr>
<th>WATER STRESS IMPACTS</th>
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<tr>
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<td><strong>Stomatal Conductance – Micro Scale</strong></td>
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<td></td>
<td></td>
<td>✓ <strong>Decrease</strong> in stomatal conductance during drought at all sites</td>
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<td></td>
<td></td>
<td>✓ <strong>Larger and longer decrease</strong> at deep GW site than shallow GW site</td>
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<td><strong>Leaf Area Index – Macro Scale</strong></td>
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<td>✓ <strong>Decrease</strong> in LAI at all sites due to leaf wilting/rolling</td>
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<tr>
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<td>✓ Magnitude of decrease correlated with GW depth</td>
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WATER STRESS IMPACTS

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Deep

Medium

Shallow

-66% -76%

Mean Kernel Count (kernels/cob)

- 500
- 400
- 300
- 200
- 100
- 0

Shallow  Medium  Deep
Lowry & Loheide (2010), *WRR*: Additional plant water use in the presence of shallow groundwater, as compared to free drainage conditions

\[ GW\text{ Subsidy} = WU_{GW} - WU_{FD} \]
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\[
GW \text{ Subsidy} = WU_{GW} - WU_{FD}
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\[
GW \text{ Subsidy} = (Yield_{GW} - Yield_{FD})/WUE
\]

Corn Grain WUE = 0.55 bu/mm (FAO TR07)
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Corn Grain WUE = 0.55 bu/mm (FAO TR07)

GW Subsidy = 184-258 mm

Corn Biomass WUE = 3.3 kg/m\(^3\) (UW-Ex)

GW Subsidy = up to 148 mm

GW Subsidy = \(~150-250\) mm

18-30\% mean annual precipitation

28-47\% mean annual ET
1. **Identify** major corn physiological responses to water stress during 2012 drought

2. **Contextualize** physiological responses in terms of groundwater availability

3. **Quantify** yield losses as a result of water stress

4. **Calculate** groundwater subsidy provided to corn from shallow water table
1. **Identify** major corn physiological responses to water stress during 2012 drought
   - Reduced stomatal conductance rates
   - Reduced LAI
   - Mistimed pollen release
   - Reduced transpiration, photosynthesis

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   - More extreme physiological response at deeper GW sites

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3. **Quantify** yield losses as a result of water stress
   - Relative to 2010: **23-166 bu/ac grain loss**, 17.4 tons/ac silage loss
   - Relative to shallow GW site: **up to 92% grain loss**, 79% silage loss

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- Up to **150-250 mm** additional water provided by shallow GW
- 28-48% mean annual ET
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GW is an important resource for crop production!!
### Questions?

**Funding:**
- NSF Grant DEB-1038759
- Anna Grant Birge Award

**Tons of Help:**
- Taylor Pomije
- Erin Gross
- Eric Booth

**Advice:**
- Steve Loheide
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- Gregg Sanford
- Other WSC/ WRE faculty, post-docs, students

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- Evren Soylu
- Carolyn Voter
- Nathan Wells
- Jiangxiao Xiu
- Joey & Tyler

http://wsc.limnology.wisc.edu
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18-30% mean annual precipitation

28-47% mean annual ET
Results – Silage & Grain Yields

Silage Yields [tons/acre]

- Shallow: +17% (2010 County Average), -40% (2012 Data)
- Medium: -76% (2010 County Average), -69% (2012 Data)
- Deep: -93% (2010 County Average)

Grain Yields [bushels/acre]

- Shallow: -13% (2010 County Average), -69% (2012 Data)
- Medium: -93% (2010 County Average)

Images:
- Image source: lifeonadairy.blogspot.com
- Image source: rawlingsbrokeragecompany.com
**Study Site**

**Measurements**
- GW elevation
- Stomatal conductance
- Leaf area index
- Total biomass
- Grain mass
- Kernel count, kernel mass, etc.