Biomass sorghum and maize have similar water-use-efficiency under non-drought conditions in the rain-fed, Midwest, US.

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Iowa State University
Evapotranspiration

Evapotranspiration (ET) = evaporation + transpiration
Water use efficiency (WUE)

\[
WUE = \frac{\text{total aboveground dry biomass}}{\text{seasonal evapotranspiration}}
\]

Units: \(\left(\frac{\text{g dry matter}}{\text{kg water}}\right)\)
Biomass sorghum background

- Annual, C4
- Photoperiod-sensitive
- High WUE
- Drought-tolerant
- Vegetative biomass
- Familiar seeding characteristics
- Genetic variation in germplasm

Source: Mullet et al. 2014; Rooney 2014; Salas Fernandez et al. 2015
Motivation: demand for cellulosic feedstocks

Congressional Volume Target for Renewable Fuel

36 Billion Gallons of Renewable Fuel by 2022

Source: EPA

Non grain feedstocks
Motivation: a changing climate

Increase in the number of consecutive dry days

Source: Harding and Snyder, 2014
Motivation: bioethanol feedstocks

Source: USDA.gov

Source: Bagley et al., (2014)
How does biomass production compare?

Biomass production: sorghum = maize (ample water)

Biomass production: sorghum > maize (limited water)

Variation between due to environment, sub-type, and management.

Source: Hallam et al. 2001; Schittenhelm and Schroetter 2014; Yimam et al., 2015
How does WUE compare?

WUE: sorghum = maize (ample water)

WUE: sorghum > maize (limited water)

Limited data on biomass sorghum in rain-fed systems.

Source: Steduto et al., 1997
Objective and hypothesis

**Objective:** compare the total ET and WUE of biomass sorghum and maize in the rain-fed, Midwest, US.

**Hypothesis:** Similar total ET and WUE for both species (when water is not limiting).
<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planting date</strong></td>
<td>3 June</td>
<td>2 June</td>
</tr>
<tr>
<td><strong>Seeding density</strong></td>
<td>27,000 seeds acre(^{-1}) (maize)</td>
<td>34,000 seeds acre(^{-1}) (maize)</td>
</tr>
<tr>
<td></td>
<td>48,850 seeds acre(^{-1}) (b. sorg)</td>
<td>49,000 seeds acre(^{-1}) (b. sorg)</td>
</tr>
<tr>
<td><strong>N rate</strong></td>
<td>120 lbs acre(^{-1})</td>
<td>150 lbs acre(^{-1})</td>
</tr>
<tr>
<td><strong>Row spacing</strong></td>
<td>0.76 m (30 inch)</td>
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</tbody>
</table>

**n = 3**
Surface energy budget

- \( R \) net radiation (+ downward)
- \( H \) sensible heat flux (+ upward)
- \( G \) soil heat flux (+ downward)
- \( \lambda ET \) latent heat flux (+ upward)
Residual energy balance

\[ R = \lambda ET + G + H \]

Measure: \( R, G, H \)

Solve for the unknown (\( \lambda ET \)):

\[ \lambda ET = R - G - H \]
Land cover influences fluxes of energy and moisture
Quick results: similar WUE for biomass sorghum and maize

- Higher WUE in 2015 (p<0.1)
- Interannual difference due to biomass
- Conditions were better for biomass production in 2015
• Maize ET > sorghum ET for most of the growing season.

• Total ET greater for sorghum due to its longer growing season.
Biomass

Leaf area index

- **Dry biomass (kg m⁻²)**
  - Ranges from 0 to 2.5 kg m⁻²
  - Data points for 2014 and 2015
- **Leaf area index (LAI, m² m⁻²)**
  - Ranges from 0 to 6 m² m⁻²
  - Data points for 2014 and 2015

Graphs show the growth of biomass and leaf area index over the course of the year, with distinct peaks and trends for each year and crop type.
## Results: theoretical ethanol yield

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>Biomass (kg m(^{-2}))</th>
<th>ET (mm)</th>
<th>WUE (g kg(^{-1}))</th>
<th>EY (l m(^{-2}))</th>
<th>EWR (l l(^{-1}))</th>
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<tbody>
<tr>
<td>2014</td>
<td>maize</td>
<td>1.73 ± 0.09</td>
<td>566.2 ± 42.5</td>
<td>3.12 ± 0.38</td>
<td>0.45 ± 0.02</td>
<td>1272.2 ± 10.4</td>
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<td>b. sorg.</td>
<td>1.80 ± 0.05</td>
<td>582.5 ± 23.5</td>
<td>3.11 ± 0.17</td>
<td>0.47 ± 0.01</td>
<td>1244.4 ± 10.4</td>
</tr>
<tr>
<td>2015</td>
<td>maize</td>
<td>2.20 ± 0.04</td>
<td>568.2 ± 39.2</td>
<td>3.90 ± 0.20</td>
<td>0.57 ± 0.01</td>
<td>991.9 ± 52.53</td>
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<td>1014.8 ± 78.8</td>
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<td>Mean</td>
<td>maize</td>
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<td>567.17 ± 25.88</td>
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<tr>
<td>Mean (n=6)</td>
<td>maize</td>
<td>1.97 ± 0.11</td>
<td>567.17 ± 25.88</td>
<td>3.51 ± 0.26</td>
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When does ET become non-productive?
How do our results compare?

<table>
<thead>
<tr>
<th>ET</th>
<th>Biomass</th>
<th>WUE</th>
<th>Location</th>
<th>Irrigation</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>kg m⁻²</td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>423</td>
<td>1.40</td>
<td>3.39</td>
<td>Okla./Texas</td>
<td>Rain-fed</td>
<td>Hao et al. 2014; Yimam et al. 2015</td>
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<tr>
<td>544</td>
<td>2.07</td>
<td>3.75</td>
<td>Okla./Texas</td>
<td>Irrigated</td>
<td>Hao et al. 2014; Yimam et al. 2015</td>
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<tr>
<td>498</td>
<td>1.81</td>
<td>3.61</td>
<td>Okla./Texas</td>
<td>-</td>
<td>Hao et al. 2014; Yimam et al. 2015</td>
</tr>
<tr>
<td>600</td>
<td>2.09</td>
<td>3.47</td>
<td>Iowa</td>
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**Biomass sorghum**

**Maize**

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<td>540</td>
<td>1.91</td>
<td>4.04</td>
<td>IL/NE/MI</td>
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<td>578</td>
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<td>Spain</td>
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How might water stress influence results?

Irrigation deficit studies have shown:

• Grain sorghum WUE > maize

• Sweet sorghum yields were closer to potential than maize yields.

Factors contributing to drought tolerance in sorghum

- High root length density
- Assimilate partitioning to roots in drought
- Vegetative growth

Larger differences in WUE between biomass sorghum and maize

Source: Zegada-Lizarazu et al. 2012;
Implications

• Projected increases in air temperature and the number of consecutive dry days in the Midwest, US
• Mechanisms contributing to drought tolerance and high WUE in sorghum

Source:(Harding and Snyder, 2014; Pryor et al. 2014).
Conclusions

• We found similar total ET and WUE for maize and biomass sorghum in 2014 and 2015.

• Differences in ET within the growing season were due to crop development and maturity.

• Drought did not occur in either growing season

• Our results do not capture full range of climate variability in the Midwest.

Source: Dietzel et al. 2015; Steduto et al. 1997; Hao et al. 2014; Narayanan et al. 2013
Acknowledgments

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