Effects of Irrigation and In-Season Fertilization Strategies on Water Use and Nitrogen Use Efficiency and Yield of Irrigated Corn

Amy Shober, James Adkins, Cory Whaley, Alexander Soroka, and Jennifer Volk

University of Delaware
Soil Properties Affect Water Availability for Grain Production

- Agricultural soils tend to be sandy and low in organic matter
- Low moisture holding capacity
- Crops grown in these areas are highly susceptible to drought
Several Years of Regional Drought
Drought Severity Affects Corn Yields

Non-irrigated

Irrigated

Average Yield Top 10 Hybrids (bu/ac)
Non-Irrigated Corn Yields Subject to Climate

- Wide variation in yield & losses
- Driest years: 105 bu/ac
- Normal Years: 195 bu/ac
Irrigation Stabilizes Corn Yields

- Much less variation in yield
- Steady yield increase due to genetic improvements

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A Surge in U.S. Corn Prices Made Irrigation More Attractive

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**Cropping System**

<table>
<thead>
<tr>
<th>Yield (bu/ac)</th>
<th>2007</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>164</td>
<td>157</td>
</tr>
<tr>
<td>Non-irrigated</td>
<td>70</td>
<td>59</td>
</tr>
</tbody>
</table>

**Price per acre**

<table>
<thead>
<tr>
<th>Price per acre</th>
<th>2007</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>$556</td>
<td>$966</td>
</tr>
<tr>
<td>Non-irrigated</td>
<td>$237</td>
<td>$363</td>
</tr>
</tbody>
</table>

Rental income (2010)
- Irrigated: $105/ac
- Non-irrigated: $69/ac

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Source: USDA-NASS; Delaware Dept. of Ag
Delaware Irrigation Trends

Source: USDA-NASS

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Delaware is a National Leader in Irrigation

Source: USDA-NASS, 2014
Irrigation of Corn in Delaware

Thousand Acres Harvested

- Irrigated Acreage
- Dryland acreage

Source: USDA-NASS
Continued Expansion of Irrigation

Should it be supported to:

• Stabilize yields and reduce crop failure?
• Mitigate climate change?
• Improve nutrient management and water quality?
Project Objectives

1. Quantify the effects of 1) irrigation treatments and 2) selected fertilizer strategies on WUE and NUE of corn under center pivot irrigation

2. Compare WUE and NUE of farmer managed corn under irrigated and non-irrigated conditions

3. Evaluate long-term NUE estimates for irrigated and non-irrigated corn in UD Variety Trials
Objective 1

WARRINGTON FARM EXPERIMENTAL DESIGN
UD Irrigation Study Site

Rosedale-Pepperbox loamy sand soils
Organic Matter ≈ 1.3%
Corn, wheat, double-crop soybean or Corn, soybean rotation
Poultry Litter Applied (3 ton/ac)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N, lb/ton</td>
<td>54.4</td>
<td>50.8</td>
<td>72.8</td>
</tr>
<tr>
<td>Total NH₄-N, lb/ton</td>
<td>9.48</td>
<td>9.10</td>
<td>8.50</td>
</tr>
<tr>
<td>Plant Available N, lb/ton</td>
<td>34.6</td>
<td>32.4</td>
<td>45.4</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>37.1</td>
<td>39.0</td>
<td>14.1</td>
</tr>
<tr>
<td>Dry matter, %</td>
<td>62.9</td>
<td>60.9</td>
<td>85.9</td>
</tr>
</tbody>
</table>

- PAN = 60% of total N + some % of NH₄-N based on when manure incorporated

Manure PAN applied
- 2014: 104 lb/ac
- 2015: 97 lb/ac
- 2016: 136 lb/ac
Center Pivot Irrigation

- Four span system with 85 low drift nozzles
- Precision variable rate irrigation (VRI) controller
- Soil matric potential monitored at 15, 30, and 45 cm
Monitoring Soil Moisture
# Irrigation Treatments

<table>
<thead>
<tr>
<th>Treatment #</th>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 cbar</td>
<td>Irrigation triggered when soil moisture at 15 cm reaches threshold from emergence to maturity</td>
</tr>
<tr>
<td>2</td>
<td>30 cbar</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>40 cbar</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>50 cbar</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>20-40-20 cbar</td>
<td>Irrigation triggered when soil moisture at 15 cm meets threshold from 1) emergence to V16; 2) from V16 to R3; 3) from R3 to maturity</td>
</tr>
<tr>
<td>6</td>
<td>40-20-40 cbar</td>
<td></td>
</tr>
</tbody>
</table>
## Irrigation Treatments (Continued)

<table>
<thead>
<tr>
<th>Treatment #</th>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>30 cbar to R5</td>
<td>Irrigation triggered when soil moisture at 15 cm reaches 30 cbar from emergence to GS listed</td>
</tr>
<tr>
<td>8</td>
<td>30 cbar to milk</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>100% ET*</td>
<td>Standard ET, no soil moisture monitoring, irrigation at 50% field capacity</td>
</tr>
<tr>
<td>10</td>
<td>80% ET</td>
<td>Apply 80% of the water applied with 100% ET</td>
</tr>
<tr>
<td>11</td>
<td>No Irrigation</td>
<td>No water applied</td>
</tr>
</tbody>
</table>
Scheduling Irrigation with VRI
In-Season N Fertilization

- **Starter**
  - Poultry Manure
  - Variance: 36

- **Fertigation**
  - V5
  - V8
  - V13

- **Sidedress**
  - V5
  - V8

- **PAN Rate**
  - T1
  - T2
  - T3

- **Application Rates**
  - lb/acre

- **Rates**
  - 18
  - 32
  - 44
Plant Tissue Sampling, Analysis, and Yield

- Three whole plants cut at ground in each plot
- Harvest index = dry grain/dry whole plant
- Total N analysis of grain and tissue
- Yield from center of plot with Harvest Master graingage
Water Use Efficiency

Water Use Efficiency

\[
\frac{\text{Dry Yield}}{\text{ET}_c}
\]

Irrigation Water Use Efficiency

\[
\frac{(Y_{irr} - Y_{dry})}{\text{IRR}_i}
\]

\( \text{ET}_c \) = crop water use from KanSched 2
\( Y_{irr} \) = irrigated yield
\( Y_{dry} \) = non-irrigated yield
\( \text{IRR}_i \) = Irrigation water applied
Nitrogen Use Efficiency

Partial Factor Productivity (PFP$_N$)

\[
\text{Yield} \quad \frac{\text{Fertilizer}}{
\]

Mass Balance ($e_f$)

\[
\frac{(N_{\text{Crop}}) - (N_{\text{soil}}) - (N_{\text{other}})}{N_{\text{supplied}}}
\]

\[
N_{UA} = (1 - e_f) \times N_{\text{supplied}}
\]

$N_{\text{crop}}$ is N in aboveground biomass N

$N_{\text{soil}}$ is estimated using a 7 d anaerobic incubation

$N_{\text{atm}}$ based on regional rainfall chemistry and volume

$N_{\text{irr}}$ was estimated based on quarterly nutrient content
Collection of Soil Water Samples to Evaluate Leaching Potential
Objective 1

WARRINGTON FARM KEY RESULTS, 2014-2016
No Drought During Study Period

Area Affected (%)

Year:
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019

Categories:
- Dry
- Moderate
- Severe
- Extreme
- Exceptional
Irrigation Affected Yield in Two of Four Years

<table>
<thead>
<tr>
<th>Yield (lb/ac)</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 cbar</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>30 cbar</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>40 cbar</td>
<td>b</td>
<td>ab</td>
</tr>
<tr>
<td>50 cbar</td>
<td>b</td>
<td>ab</td>
</tr>
<tr>
<td>20-40-20</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>40-20-40</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>30 to R3</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>30 to Milk</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>100% ET</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>80% ET</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>None</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>
Irrigation Affected WUE in Two of Four Years

2014

WUE (kg/m³)

- 20 cbar
- 30 cbar
- 40 cbar
- 50 cbar
- 20-40-20
- 40-20-40
- 30 to R5
- 30 to Milk
- 100% ET
- 80% ET
- None

2016

WUE (kg/m³)

- 20 cbar
- 30 cbar
- 40 cbar
- 50 cbar
- 20-40-20
- 40-20-40
- 30 to R5
- 30 to Milk
- 100% ET
- 80% ET
- None
Fertilizer Method Did Not Affect Irrigated Corn Yields

Yield (bu/ac) vs. PAN Rate (lb/ac)

- 2014
- 2015
- 2016

Fertigation vs. Sidedress

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In-Season N Boosts Yield

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigated Corn Yield (bu/ac)</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>b</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>124</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>176</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In-season Plant Available N Applied (lb/A):
- 0
- 36
- 72
- 124
- 176
No Yield Bump From Irrigation

<table>
<thead>
<tr>
<th>Year</th>
<th>Dryland</th>
<th>Irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td>2015</td>
<td>0</td>
<td>116</td>
</tr>
<tr>
<td>2016</td>
<td>156</td>
<td>156</td>
</tr>
</tbody>
</table>
Nitrogen Use Efficiency

- In general, PFP$_N$ declined as in-season N rate increased.
- Yet, in-season N had no effect on $e_f$, except in 2014 when low N rate had higher $e_f$.
- UA$_N$ high in-season N > medium > low.
- Manure + Starter plots had higher NUE and lower UA$_N$ in all years than plots receiving in-season N.
High Irrigation Increased N in Leachate
Objective 2

COMPARISON OF WUE AND NUE ON-FARM
Paired Farmer-Managed Corn Fields 2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dryland Field</th>
<th>Irrigated Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Goal, lb/ac</td>
<td>160</td>
<td>245</td>
</tr>
<tr>
<td>Poultry litter, ton/ac</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Starter N, lb/ac</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>In-season N, lb/ac</td>
<td>100</td>
<td>165</td>
</tr>
<tr>
<td>Irrigation, inches</td>
<td>0</td>
<td>6.18</td>
</tr>
<tr>
<td>WUE, kg/m</td>
<td>3</td>
<td>3.04</td>
</tr>
<tr>
<td>2.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield, bu/ac</td>
<td>164</td>
<td>238</td>
</tr>
<tr>
<td>$P_{FP_N}$, lb/bu</td>
<td>1.03</td>
<td>0.97</td>
</tr>
<tr>
<td>$e_f$</td>
<td>0.79</td>
<td>0.61</td>
</tr>
<tr>
<td>$UA_N$, lb/ac</td>
<td>34</td>
<td>95</td>
</tr>
</tbody>
</table>

Differences in NUE were due to lower N application rates to the dryland field, significant applications of irrigation water N, and differences in estimated soil N mineralization potential between the two fields.
Objective 3

EVALUATE LONG-TERM NUE IN UD VARIETY TRIALS
Historical Hybrid Variety Yields
Irr $r^2 = 0.45$
Dry $r^2 = 0.05$

Yield (bu/ac)

1980 1990 2000 2010

218 bushels
62 bushels
Irrigation Raises Yield and NUE

- **Yield (bu/ac)**
  - Rainfed: 150
  - Irrigated: 200

- **PFP\(_N\) (bu/lb)**
  - Rainfed: 0.80
  - Irrigated: 0.95

**UD Variety Trials**

Rainfed: 0.12

Irrigated: 0.12
NUE By Decade – UD Variety Trials

<table>
<thead>
<tr>
<th>Decade</th>
<th>Rainfed</th>
<th>Irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981_1985</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>1986_1995</td>
<td>b</td>
<td>a</td>
</tr>
<tr>
<td>1996_2015</td>
<td>b</td>
<td>a</td>
</tr>
<tr>
<td>2006_2015</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>
Irrigation Raised NUE in UD Variety Trials

- Irrigation had higher efficiency and yield stability over a 35 year period

- Decade-scale yield summaries were affected by meteorology

- Irrigation has far higher PFPN in dry years
Key Points From Our Work

• When we measured NUE based on fertilizer inputs only (PFPN), we saw generally good efficiencies
• Mass balance approach gave much lower NUE
• It is difficult to accurately estimate ancillary sources of N (e.g. atmospheric, soil, and irrigation)
• The ability to accurately estimate these “other” N inputs is key to increasing NUE
Key Points From Our Work

- Because we received adequate to excessive rainfall, we are not able to make definitive claims about the benefits of irrigation on WUE and NUE.
- Historic UD Variety Trial data suggests that irrigation can significantly improve NUE.
- We recommend expanding WUE and NUE trials to additional farms, with differing soils and larger scale production.
Key Points From Our Work

• In the future, data should be collected:
  – From paired fields (dryland and irrigated) at each site
  – Over multiple years
  – During periods with intensive rainfall and extended dry periods
• Improvements in NUE with irrigation are expected to be best in drought years
Questions?

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