INSTITUTE FOR
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MCPR Trade Show

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Minneapolis Convention Center

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Sustainability of Continuous Corn as a Feedstock for Bio-fuels

Joe Lauer
University of Wisconsin-Madison

Crop Pest Management Short Course and Minnesota Crop Protection Retailers Trade Show

Minneapolis, MN on December 5, 2007
Overview

• The Rotation Effect - What is it?

• Sustainability of Current Midwest Corn Belt Cropping Systems
  ✓ “The Lancaster Rotation Experiment”
  ✓ Yield is the “integrator”

• Can Continuous Corn Be Used as a Feedstock for Bio-fuels?
  ✓ Maybe? Depends upon economics (corn price versus N price), but not likely in long run.
Corn yield in Wisconsin since 1866

The yield march continues ...

- **Top Hybrid = 2.6 bu/A yr**
- **Arlington = 2.7 bu/A yr**
- **Marshfield = 2.6 bu/A yr**

Source: UW Hybrid Trials

- 1866 to 1930 = 0.0 bu/A yr
- 1931 to 1995 = 1.4 bu/A yr
- 1996 to 2006 = 1.9 bu/A yr

Source: USDA Statistics

- 1866 to 1930 = 0.0 bu/A yr
- 1931 to 1995 = 1.4 bu/A yr
- 1996 to 2006 = 1.9 bu/A yr

Source: USDA Statistics
Corn Yield Progress in Wisconsin
Top Producer in Category (1983-2006)

All = 3.6 bu/A yr
- PEPS Cash Corn = 4.8 bu/A yr
- PEPS Livestock Corn = 4.4 bu/A yr
- NCGA Non Irrigated = 4.8 bu/A yr
- NCGA No Till/Strip Till Non Irrigated = 4.5 bu/A yr
- NCGA No Till/Strip Till Irrigated = 3.0 bu/A yr
- NCGA Irrigated = 3.2 bu/A yr
- NCGA Ridge Till Irrigated = 3.3 bu/A yr
- NCGA Ridge Till Non Irrigated = 3.5 bu/A yr

Data derived from grower yield contests
(PEPS = 1987 to 2006; NCGA = 1983 to 2006)
The Rotation Effect – What is it?

• **Crop Rotation**
  - Universal management practice
  - Proven management decision that increases crop yields
  - Currently, increased economic benefit for monoculture

• **Rotation Effect**
  - The effect of all conditions, other than N, supplied by legumes in a rotation (Baldock et al., 1981)
  - Other non-legume crops can provide benefits as well (Robinson, 1966; Langer and Randall, 1981; Crookston et al., 1988)
  - Additional benefits of rotating crops
    - All production inputs can be optimized
    - Typical problems associated with monoculture are not apparent.

• **Mechanism for effect is unknown**
Crop Sequence for 2-Crop Rotation Experiment in Lamberton and Waseca, MN and Arlington, WI

C= Corn, S= Soybean

<table>
<thead>
<tr>
<th>Sequence</th>
<th>&quot;Setup years&quot;</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C C C C C</td>
<td>C C C C C C</td>
</tr>
<tr>
<td>2</td>
<td>S S S S S</td>
<td>S S S S S S</td>
</tr>
</tbody>
</table>

http://corn.agronomy.wisc.edu

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The rotation effect lasts two years increasing corn grain yield 10 to 19% for 1C and 0 to 7% for 2C ...

Corn Yield Response Following Five Years of Soybean

Control treatments averaged across tillage treatments at Arlington, WI.

Source: Lauer, unpublished

C = Corn, S = Soybean, Number = consecutive year of corn
If there is only a one year break in the rotation, then the second corn phase is equivalent to continuous corn ...

**Corn Yield Response to Crop Rotation**

<table>
<thead>
<tr>
<th>Cropping Sequence</th>
<th>Grain Yield (bushels/acre)</th>
<th>Source: Lauer, unpublished</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td>CCCS-1C</td>
<td>218</td>
<td></td>
</tr>
<tr>
<td>CCCS-2C</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>CCCS-3C</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td>CCS-1C</td>
<td>214</td>
<td></td>
</tr>
<tr>
<td>CCS-2C</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td>Source: Lauer, unpublished</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C = Corn, S = Soybean, Number = consecutive year of corn

1998 to 2000 Control treatments averaged across tillage treatments at Arlington, WI.
At least two break years are needed to measure a response in the second corn phase (compared to CC) ...

Corn Yield Response to Crop Rotation

Control treatments at Lancaster, WI.

Source: Stanger and Lauer, 2008

Cropping Sequence
A= Alfalfa, C= Corn, O= Oat, S= Soybean, W= Wheat

Source: Stanger and Lauer, 2008

http://corn.agronomy.wisc.edu
Adding a third crop does not increase corn grain yield, but does improve soybean grain yield ...

Source: Lauer, unpublished

Corn and Soybean Yield Response to Crop Rotation

<table>
<thead>
<tr>
<th>Cropping Sequence</th>
<th>Corn Grain Yield (bushels/acre)</th>
<th>Soybean Grain Yield (bushels/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>200</td>
<td>16%</td>
</tr>
<tr>
<td>CSW</td>
<td>192</td>
<td>11%</td>
</tr>
<tr>
<td>CWS</td>
<td>192</td>
<td>11%</td>
</tr>
<tr>
<td>CC</td>
<td>173</td>
<td>11%</td>
</tr>
<tr>
<td>CS</td>
<td>56</td>
<td>22%</td>
</tr>
<tr>
<td>CSW</td>
<td>59</td>
<td>28%</td>
</tr>
<tr>
<td>CWS</td>
<td>57</td>
<td>24%</td>
</tr>
<tr>
<td>SS</td>
<td>46</td>
<td>24%</td>
</tr>
</tbody>
</table>

C = Corn, S = Soybean, W = Wheat

2004-2006: Values averaged across seed fungicide treatments at Arlington, WI.

Source: Lauer, unpublished
Ethanol per acre increases with rotation (13 to 21%) and affects ethanol per bushel (< 1%) ...

Source: Lauer, unpublished

Corn Recoverable Ethanol Response to Crop Rotation

Cropping Sequence
C= Corn, S= Soybean

2004-2006: Values averaged across split-treatments at Arlington, WI.
Adding a third crop increases ethanol per acre (10 to 12%) and affects ethanol per bushel (< 1%) …

Source: Lauer, unpublished

Corn Recoverable Ethanol Response to Crop Rotation

<table>
<thead>
<tr>
<th>Cropping Sequence</th>
<th>Ethanol per bushel</th>
<th>Ethanol per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>2.88</td>
<td>577</td>
</tr>
<tr>
<td>CSW</td>
<td>2.85</td>
<td>550</td>
</tr>
<tr>
<td>CWS</td>
<td>2.89</td>
<td>555</td>
</tr>
<tr>
<td>CC</td>
<td>2.87</td>
<td>498</td>
</tr>
</tbody>
</table>

2004-2006: Values averaged across seed fungicide treatments at Arlington, WI.

Source: Lauer, unpublished

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Management Decision Interactions with Rotation

**Significant**
- Tillage
- N rate
- CR Insecticide
  - CR Variant = NS (need all the time)
- Environment

**Non-significant**
- Plant density
- Row spacing
- Modern hybrids versus old hybrids
  - Modern hybrids can “handle” continuous corn
Modern corn hybrids and management practices have the same rotation response as older hybrids and practices ...

Corn Yield Response Following Five Years of Soybean

Control treatments averaged across tillage treatments at Arlington, WI. Transgenic hybrids used since 1998.

Source: Lauer, unpublished

C = Corn, S = Soybean. Number = consecutive year of corn
Tillage does not affect corn yield the first year following soybean, but improves yield 5% in the second year, and 9% in the third year ...

No tillage response is observed in the second cycle ...

Corn Yield Response Following Five Years of Soybean

Source: Lauer, unpublished

C = Corn. S = Soybean. Number = consecutive year of corn
N fertilization response increases in 2C and 3C of the rotation, so err on the high side of the recommended N application range …

Corn Yield Response to N Following Five Years of Soybean

Source: Lauer, unpublished

Cropping Sequence

C= Corn, S= Soybean, Number = consecutive year of corn
Rotation is more important in stress environments...

- Weed outbreaks and species shifts
- Brown stem rot (Races A and B)
- Soybean cyst nematode
- Corn rootworm variant

Control Treatments of CS and CC
Arlington and Lancaster, WI
1985 – 2006 (n= 65)

\[ y = -0.21x + 46.45 \]
\[ R^2 = 0.38 \]

Source: Lauer, unpublished
The Lancaster Rotation Experiment
A Long-Term Cropping System Study

• A multiple crop rotation experiment established in 1966

• Objective: To compare the benefits of growing corn continuously and in rotation using commercial nitrogen fertilizer.

• RCB in a split-plot arrangement with two replications.
  ✓ Main-plots = 21 rotations
  ✓ Split-plots = four N levels in corn production year
# History of the Lancaster Rotation Experiment

<table>
<thead>
<tr>
<th>Year of change</th>
<th>Rotations</th>
<th>Corn N rates (lbs N A⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>CC</td>
<td>CSCOaA</td>
</tr>
<tr>
<td>1977</td>
<td>CC</td>
<td>CSCOaA</td>
</tr>
<tr>
<td>1987</td>
<td>CC</td>
<td>CSCOaA</td>
</tr>
<tr>
<td>2005</td>
<td>CC</td>
<td>CSCOaA</td>
</tr>
</tbody>
</table>

- C, Corn; S, Soybean; Oa, Oat with alfalfa seeding; A, Alfalfa; W, Wheat
- C, first phase; C, second phase; C, third phase
How can you tell if a cropping system is changing?

- Improving
- Deteriorating
- No change
- Control

Yield vs. Time graph
Corn Yields in the Lancaster Rotation Experiment
(Analysis over time: 1970-2004)

Source: Stanger and Lauer, unpublished
## Analysis over Time and Space
(2-yr and 5-yr Cycles)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>CC</th>
<th>Cycle</th>
<th>CS</th>
<th>Cycle</th>
<th>CSCOaA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>1</td>
<td>C</td>
<td>S</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>1</td>
<td>S</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>2</td>
<td>C</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>2</td>
<td>S</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>3</td>
<td>C</td>
<td>S</td>
<td>1</td>
</tr>
</tbody>
</table>
Corn grain yield response to N rate in a continuous corn rotation (over time and space) at Lancaster, WI.

Source: Stanger and Lauer, 2008
Corn grain yield response to N rate in a CSCOaA rotation (over time and space) at Lancaster, WI.

Source: Stanger and Lauer, 2008

**Graph:***

- **Y-axis:** Grain yield (bu/A)
- **X-axis:** Cycle (5-yr between 1970-2004)

Legend:
- **0 lb N/A** slope = 1.2 bu/A*yr
- **50 lb N/A** slope = 1.1 bu/A*yr
- **100 lb N/A** slope = 1.4 bu/A*yr
- **200 lb N/A** slope = 1.6 bu/A*yr

Source: Stanger and Lauer, 2008
Is Corn Grain Yield Changing? (Is there a slope?)
First Corn Phase in 5-yr Cycles (1970-2004; 7 Cycles)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>N rate (lb N A(^{-1}))</th>
<th>bu A(^{-1}) yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>CC</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>CCCAA</td>
<td>1.2**</td>
<td>1.1**</td>
</tr>
<tr>
<td>CCOaAA</td>
<td>1.3**</td>
<td>1.2**</td>
</tr>
<tr>
<td>CSCOaA</td>
<td>1.2**</td>
<td>1.1**</td>
</tr>
</tbody>
</table>

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels

Source: Stanger and Lauer, 2008
Corn grain yield response to N rate in a CS\textsuperscript{CO}aA rotation (over time and space) at Lancaster, WI.

Source: Stanger and Lauer, 2008

Graph showing grain yield (bu/A) over cycles (5-yr between 1970-2004) with different N rate treatments:
- 0 lb N/A, slope = NS
- 50 lb N/A, slope = NS
- 100 lb N/A, slope = 0.9 bu/A*yr
- 200 lb N/A, slope = 1.2 bu/A*yr

Source: Stanger and Lauer, 2008

Extension

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### Is Corn Grain Yield Changing? (Is there a slope?)

Second Corn Phase in 5-yr Cycles (1970-2004; 7 Cycles)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>N rate (lb N A⁻¹)</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>†</td>
</tr>
<tr>
<td>CCCAA</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>1.0*</td>
</tr>
<tr>
<td>CCOaAA</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>†</td>
<td>1.1*</td>
</tr>
<tr>
<td>CSCOoAaA</td>
<td>NS</td>
<td>NS</td>
<td>0.9*</td>
<td>1.2**</td>
<td></td>
</tr>
</tbody>
</table>

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels

Source: Stanger and Lauer, 2008
<table>
<thead>
<tr>
<th>Rotation</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.9*</td>
</tr>
<tr>
<td>CCCAA</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.9**</td>
</tr>
</tbody>
</table>

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels

Source: Stanger and Lauer, 2008
Are CC, CSCOaA and CS rotations improving (+) or deteriorating (-) for grain yield? … YES!

Source: Stanger and Lauer, 2008

Improving (+) or Deteriorating (-) 1990-2004

<table>
<thead>
<tr>
<th>N rate (lb/ A)</th>
<th>0</th>
<th>200</th>
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</thead>
<tbody>
<tr>
<td>bu A⁻¹ yr⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC v. CS</td>
<td>-4.1</td>
<td>NS</td>
</tr>
<tr>
<td>CC v. CSCOaA</td>
<td>NS</td>
<td>2.5</td>
</tr>
<tr>
<td>CS v. CSCOaA</td>
<td>2.9</td>
<td>NS</td>
</tr>
</tbody>
</table>
**Are Rotations Improving (+) or Deteriorating(-)?**

**Do slopes diverge (+) or converge(-)?**

5-yr vs. 2-yr Rotations in 5-yr Cycles (1990-2004; 3 Cycles)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>N rate (lb N A⁻¹)</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
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<tbody>
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<td>100</td>
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<tr>
<td></td>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC vs. CA</td>
<td>-3.8***</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>CC vs. CS</td>
<td>-4.1***</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>CS vs. CCCAA</td>
<td></td>
<td>NS</td>
<td>NS</td>
<td>2.5*</td>
<td>2.6*</td>
</tr>
<tr>
<td>CA vs. CSCOaA</td>
<td>2.7*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>CS vs. CCCAA</td>
<td>3.3***</td>
<td>2.5*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>CS vs. CCOaAA</td>
<td>3.0***</td>
<td>2.7*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>CS vs. CSCOaA</td>
<td>2.9***</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels

**Ultimate decision for farmer is based upon economics.**

CS at 50, 100, and 200 lb N/ A and CC at 200 lb N/ A were the most profitable AND least risky of rotation treatments.
Summary of the Lancaster Experiment

• Corn grain yield of extended (5-yr) rotations increase at a greater rate over time than 2-yr rotations and CC.

• Nitrogen plays a major role in maintaining and improving corn grain yields in the absence of crop rotation.

• Extended rotations involving forage crops may be more sustainable than current short-term agricultural practices, because time (>2 yr) along with rotation and nitrogen were required to improve corn grain yields.
Conclusions

- Mechanism for rotation effect is unknown
  - Hypothesis #1: One factor causes effect.
  - Hypothesis #2: Multiple factors cause effect and risk of expression depends upon the environment.

- Continuous- versus rotated-corn results in yield advantages of 5 to 30% for rotated-corn.

- The rotation effect lasts at most two years increasing grain yield 10 to 19% for 1C and 0 to 7% for 2C.

- Modern corn hybrids and management practices have the same rotation response as older hybrids and practices.

- Adding a third crop does not improve corn yield, but does improve soybean yield.

- Rotation minimally affects ethanol per bushel (<1%) and dramatically affects ethanol per acre (10-21%).

- At least two break years are needed to measure a response in the second continuous cropping year.
  - A one year break using soybean reduces the rotation effect in the second continuous year.

- Tillage does not affect yield the first year following soybean, but improves yield 5% in the second year, and 9% in the third year.

- N fertilization response increases in 2C and 3C of the rotation, so err on the high side of the N application range.

- Crop rotation is even more important in stress environments.
The End For Now - Questions?
Thanks for your attention!

Jorge Cusicanqui
Heather Darby
Thierno Diallo
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Larry Bundy

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Photo by Justin Hopf

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