Project SENSE: A Summary of 3 Years of On-Farm Research and Demonstration on Crop Canopy Sensors for In-Season N Management

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Vegetation Indices:

- Vegetation indices quantify crop reflectance based on reflectance at particular wavelengths

\[
NDVI = \frac{NIR_{760} - VIS_{670}}{NIR_{760} + VIS_{670}}
\]

\[
NDRE = \frac{NIR_{760} - RE_{720}}{NIR_{760} + RE_{720}}
\]
Example of NDRE

- Below shows how corn ‘looks’ with different N supply according to NDRE:

![Image showing corn fields with different NDRE values]

NDRE = 0.385

Going from VIs to N Recommendations…

- Several steps in the process, for real-time application:
  - Selection of sensor system
    - This typically sets algorithm to be used
  - Determine Economic Optimum N Rate (EONR)
  - Preferred time of application window
  - Determine Sufficiency Index (SI) from reference reflectance data
  - Real-time N application
Active Systems and Algorithm

- Sensor selection will determine VI to be used as well as algorithm
- For corn in NE, two algorithms have been developed:
  - Solari
  
  \[ N \text{ (lb/ac)} = 317 \cdot \sqrt{0.97 - SI} \]

- Holland-Schepers (OptRx system)
  
  \[ N \text{ (lb/ac)} = (N_{OPT} - N_{PreFert} - N_{CRD}) \cdot \sqrt{\frac{(1-SI)}{\Delta SI}} \]

Estimating EONR or ONR

- Several methods exist…
  - N Models (Maize-N, Adapt-N, Encirca, Fieldview, etc.)
  - Field Research
  - N removal

2017 greater than 2015 by 42 lb/acre, greater than 2016 by 50 lb/acre
Timing for sensor-based N

- Recommended practice is to apply a base rate of 75-100 lb-N/ac at or near planting
- In-season application would follow targeting v8 to v12 growth stages
- Why?
- Consider N uptake rate:

Reference VI

- A reference value for ‘healthy’ (or non-N limited) corn is required for the SI calculation
- Two methods exist for creating a reference VI:
  - High-N reference strip: apply 250 lb-N/ac base rate
  - Virtual reference strip: record NDRE values just prior to N application, select 95th percentile (automatic function in OptRx system)
Calculating the Sufficiency Index

- For real-time application, the system will store the reference VI
- The SI values are calculated on-the-go by dividing the ‘target’ (where you’re applying) values by the one reference value

![Image showing sufficiency index calculation](image)

\[
SI = \frac{0.319}{0.385} = 0.83
\]

N Application in real-time

- Once we have the previous information, the system will apply the N algorithm in real-time
- For the Holland-Schepers algorithm, a N response curve might look something like this (note additional settings available to limit N):

![Image showing N application curve](image)
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- A three year project comparing sensor-based N management with current grower practices
  - Overall goal was to increase fertilizer nitrogen use efficiency (NUE), and reduce nitrate loss to groundwater

![Map of nitrate levels in Nebraska]

- A responsive approach, using crop canopy sensors, has been proven through research to be an effective way to approach EONR, adjusting for spatial and temporal variation.

- The SENSE project utilized the Ag Leader OptRx system
- A total of 52 field studies were conducted with cooperating growers from 2015 to 2017
- Four sites were removed due to in-season issues based on input from growers at annual meeting
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- Three treatments:
  - Grower’s normal N management (rate & timing)
  - Sensor-based N application (base rate + in season)
  - High-N reference (non-limiting N rate)
- Randomized complete block design with 6 replications
- Strip width depended on grower’s equipment 16, 12, and 8 rows
- Total study area: 20-30 acres

Data analysis process:
- N application data were summarized per field-length strip
- Base N and grower applications estimated based on target rates
- As-applied data from Ag Leader monitor used to calculate total N
- Yield monitor data were post-processed using Yield Editor software and buffered approximately 50’ within strips
- Yield data were averaged within field-length strips for grower and SENSE treatments
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• Data analysis process:
  • SENSE outperformed Grower = green
  • Grower outperformed SENSE = red
  • PFP<sub>N</sub> = Pounds Grain per Pound N
  • NUE = Pounds N per Bushel Grain
  • Profit = (Yield * Corn Price) – (N Rate * N Price)

<table>
<thead>
<tr>
<th>Year</th>
<th>Corn Price</th>
<th>N Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>$3.65/bu</td>
<td>$0.65/lb</td>
</tr>
<tr>
<td>2016</td>
<td>$3.05/bu</td>
<td>$0.45/lb</td>
</tr>
<tr>
<td>2017</td>
<td>$3.15/bu</td>
<td>$0.41/lb</td>
</tr>
</tbody>
</table>

• Differences were statistically analyzed using PROC GLIMMIX in SAS 9.4 (SAS Institute, Cary, NC)

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• 2015 Differences (Grower – SENSE) All sites averaged by year:

<table>
<thead>
<tr>
<th></th>
<th>Grower N Management</th>
<th>Project SENSE N Management</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N Rate (lb/ac)</td>
<td>198 A</td>
<td>153 B</td>
<td>45</td>
</tr>
<tr>
<td>Yield (bu/ac)†</td>
<td>235 A</td>
<td>231 B</td>
<td>4.2</td>
</tr>
<tr>
<td>PFP&lt;sub&gt;N&lt;/sub&gt; (lb grain/lb N)</td>
<td>67 B</td>
<td>91 A</td>
<td>-23</td>
</tr>
<tr>
<td>Lb N/bu Grain</td>
<td>0.87 A</td>
<td>0.66 B</td>
<td>0.20</td>
</tr>
<tr>
<td>Marginal Net Return</td>
<td>$728.06 A</td>
<td>$741.97 B</td>
<td>$13.91</td>
</tr>
</tbody>
</table>
### Project SENSE
Sensors for Efficient N Use and Stewardship of the Environment

- **2016 Differences (Grower – SENSE) All sites averaged by year:**

<table>
<thead>
<tr>
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<th>Grower N Management</th>
<th>Project SENSE N Management</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N Rate (lb/ac)</td>
<td>186 A</td>
<td>153 B</td>
<td>33</td>
</tr>
<tr>
<td>Yield (bu/ac)†</td>
<td>192 A</td>
<td>194 B</td>
<td>-2.3</td>
</tr>
<tr>
<td>PFPₙ (lb grain/lb N)</td>
<td>60 B</td>
<td>75 A</td>
<td>-15</td>
</tr>
<tr>
<td>Lb N/bu Grain</td>
<td>1.08 A</td>
<td>0.84 B</td>
<td>0.24</td>
</tr>
<tr>
<td>Marginal Net Return</td>
<td>$502.13 A</td>
<td>$523.99 B</td>
<td>$21.86</td>
</tr>
</tbody>
</table>

### Project SENSE
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- **2017 Differences (Grower – SENSE) All sites averaged by year:**

<table>
<thead>
<tr>
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<th>Grower N Management</th>
<th>Project SENSE N Management</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N Rate (lb/ac)</td>
<td>188 A</td>
<td>173 B</td>
<td>15</td>
</tr>
<tr>
<td>Yield (bu/ac)†</td>
<td>234 A</td>
<td>231 B</td>
<td>3.5</td>
</tr>
<tr>
<td>PFPₙ (lb grain/lb N)</td>
<td>75 B</td>
<td>85 A</td>
<td>-11</td>
</tr>
<tr>
<td>Lb N/bu Grain</td>
<td>0.81 A</td>
<td>0.75 B</td>
<td>0.06</td>
</tr>
<tr>
<td>Marginal Net Return</td>
<td>$661.43 A</td>
<td>$656.38 B</td>
<td>$5.05</td>
</tr>
</tbody>
</table>
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• 2017 Differences (Grower – SENSE) All sites averaged by year:

<table>
<thead>
<tr>
<th></th>
<th>Three Year Average</th>
<th>SENSE</th>
<th>Grower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N rate* (lb-N/ac)</td>
<td>161.1</td>
<td>164.6</td>
<td>189.8</td>
</tr>
<tr>
<td>Yield* (bu/ac)</td>
<td>218.5</td>
<td>219.9</td>
<td></td>
</tr>
<tr>
<td>Partial Factor of Productivity* (lb grain/lb-N)</td>
<td>83</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Nitrogen Use Efficiency* (lb-N/bu grain)</td>
<td>0.76</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Partial Profitability* ($/ac)</td>
<td>$692.82</td>
<td>$679.59</td>
<td></td>
</tr>
<tr>
<td>Partial Profitability* ($/ac)</td>
<td>@3.65/bu and $0.65/lb-N</td>
<td>$600.39</td>
<td>$593.15</td>
</tr>
</tbody>
</table>

*values are statistically different at a 95% confidence level.

We can approach (and drop below) grain removal rates for N (0.65 lb-N/bu)

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• How did all 48 sites stack up with profitability vs. NUE?
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• Project SENSE Grower Meetings:
  • Annual meeting with cooperating growers.
  • At the final meeting, 50% of respondents indicated that they had reduced N rates or moved to split N application since interacting with Project SENSE.

• Considerations for Adoption:
  • Utilizing sensors to take advantage of growing season variability with a responsive approach has high potential for reducing N needs.
  • Terrain, soil texture, and OM variability can affect potential returns.
  • Reasonable EONR estimates are critical...still requires input.
  • Consider NUE metrics that you are currently operating at...how much more efficient can you operate economically?
  • Breakeven acres could be very low if you’re currently operating specific equipment for in-season N management.
What other options exist?

- Passive sensors for N management
- The same process may be carried out with other sensing platforms to inform a variable rate N applicator just prior to application
- Challenges still exist in terms of data processing time, sun/cloud interactions, etc.
- Image processing, raster-to-polygon transformation required…minimum of 1 day delay is expected

Further work has demonstrated the benefits of split N and sensor-based N management using passive, aerial-based systems

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (bu/ac)</th>
<th>Profit ($/ac)</th>
<th>Total N (lb-N/ac)</th>
<th>N Cost ($/ac)</th>
<th>MNR ($/ac)</th>
<th>NUE (lb-N/bu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero N</td>
<td>168.1 A</td>
<td>$542.96</td>
<td>0</td>
<td>$ -</td>
<td>543 A</td>
<td>-</td>
</tr>
<tr>
<td>Spring N</td>
<td>217.5 B</td>
<td>$702.53</td>
<td>150</td>
<td>$44.80</td>
<td>657.7 B</td>
<td>0.69</td>
</tr>
<tr>
<td>V5 Split</td>
<td>218.8 B</td>
<td>$706.72</td>
<td>150</td>
<td>$48.81</td>
<td>657.9 B</td>
<td>0.69</td>
</tr>
<tr>
<td>Reactive</td>
<td>224.4 C</td>
<td>$724.81</td>
<td>110</td>
<td>$34.71</td>
<td>690.1 C</td>
<td>0.49</td>
</tr>
<tr>
<td>V12 Split</td>
<td>232.4 D</td>
<td>$750.65</td>
<td>150</td>
<td>$48.70</td>
<td>701.9 C,D</td>
<td>0.65</td>
</tr>
</tbody>
</table>
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- Supporters of the 2015-2017 project:

Our Cooperating Producers!!!

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