In-Season Fertilization of Corn: The Potential for Sensor-Based Management

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Ground-vehicle mounted active sensors

Aerial-vehicle mounted passive or active sensors
Nitrogen Management Regulation

Nitrate Vulnerable Zones (NVZs) in Europe

Gulf of Mexico Hypoxia Zone, 2014
Nebraska Groundwater Nitrate-N: 2013

Nitrate Levels
- > 0 – < 7.5 mg/l
- 7.5 – 10 mg/l
- 10 – 20 mg/l
- > 20 mg/l
Central Platte NRD
Groundwater Management Area (GWMA)

Initiated 1988

Phase 1 (0-7.5 ppm NO$_3$-N)
- Fall application banned on sandy soils; allowed after Nov. 1 on heavier soils.

Phase 2 (7.6 – 15 ppm)
- No N application until Mar. 1; soil and water tests required annually; reporting to District of test results, N application, and water applied.

Phase 3 ( > 15 ppm)
- Split N application, or use of an approved nitrification inhibitor.

Phase 4 – areas with rising NO$_3$-N concentrations (not yet implemented).
- District will set expected yield.
Sustainability Initiatives

Field to Market®

Membership includes many industry leaders, such as Walmart, Coca Cola, Monsanto, DuPont Pioneer, Cargill, BASF, John Deere,; organizations such as the Environmental Defense Fund, National Corn Growers Association, Cotton Inc., and universities, such as the University of Nebraska, North Carolina State University, and Auburn University.

www.fieldtomarket.org

NutrientStar

Initiative to evaluate the efficacy of nutrient management products or practices.

http://nutrientstar.org/
Nitrogen Use Efficiency of Corn Production in Nebraska

Partial Factor Productivity for Nitrogen (kg Grain kg N⁻¹)

- **Statewide**
  - $y = 0.2015x - 339.89$
  - $R^2 = 0.0628$

- **CPNRD-GWMA**
  - $y = 0.729x - 1400.1$
  - $R^2 = 0.7385$
Iron Deficiency/Chlorosis
Crop Canopy Reflectance

- Canopy reflectance varies with chlorophyll content, which varies with N rate, particularly in visible bands.
- Reflectance changes with N rate are different in different wavebands.
Vegetation Index

A combination of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation.

- Normalized Difference Vegetation Index (NDVI)
  \[ \frac{(\text{NIR}_{760}-\text{VIS}_{670})}{(\text{NIR}_{760}+\text{VIS}_{670})} \]

- Normalized Difference Red Edge (NDRE)
  \[ \frac{(\text{NIR}_{760}-\text{RE}_{720})}{(\text{NIR}_{760}+\text{RE}_{720})} \]

- Chlorophyll Index (CI)
  \[ \frac{(\text{NIR}_{880}-\text{VIS}_{590})}{-1} \]

- DATT
  \[ \frac{(\text{NIR}_{760}-\text{RE}_{720})}{(\text{NIR}_{760}-\text{VIS}_{670})} \]

- Meris Terrestrial Chlorophyll Index (MTCI)
  \[ \frac{(\text{NIR}_{760}-\text{RE}_{720})}{(\text{RE}_{720}-\text{VIS}_{670})} \]

- Water Index (WI)
  \[ \frac{(\text{NIR}_{900})}{(\text{NIR}_{970})} \]
$R^2 = 0.65$

$R^2 = 0.75$

Relative Chlorophyll
Sufficiency Index Concept

Developed from reflectance from a target area of the field compared to an area of the field without N stress.

\[
\text{Sufficiency Index (SI, or relative sensor value)} = \frac{0.789}{0.934} = 0.844
\]

\[
\text{NDRE} = 0.789
\]

\[
\text{NDRE} = 0.934
\]
Algorithm Development

\[ S_{SPAD} = 0.5549 S_{SENSOR} + 0.4272 \]
\[ R^2 = 0.76^{**} \]

\[ N_{estimated} (lbs \text{ ac}^{-1}) \]
\[ N \text{ need: } \sim 120 \text{ lbs ac}^{-1} \]
$N \text{ Rate} = 317\sqrt{0.97 - SI_{sensor}}$
Active Crop Canopy Sensors

- Holland Scientific ACS-210
- Wavelengths
  - Amber: 590nm
  - NIR: 880nm
- Predict chlorophyll content by the Chlorophyll Index: \((\text{NIR}/\text{Amber}) - 1\)
Active Sensor Modulated Light

Light source in sensor is rapidly pulsed; light detectors in sensor are filtered and modulated such that they only detect light reflected back to the sensor from the sensor light source and in a specific waveband range. This allows the sensor to be relatively unaffected by ambient light.
Crop Canopy Sensors: Ability to Optimize N Rate for Local Conditions

2012 Research

Unusually high levels of N mineralization from soil organic matter early in the growing season resulted in the need for very little fertilizer N to optimize yield.
Quarter-Scale Cub
1998
Using Remotely Controlled Aircraft to Evaluate Stalk Breakage Following Storm Events

Image classified with ERDAS Imagine.
2.9 of 10 acres classified as broken stalks.

Natural color image, July 5, 1999
Example of stalk breakage in northwest corner of field
Yield map showing study field with yield loss resulting from wind damage

1999 Yield (bu/acre)
Current Sensing Platforms

MicaSense RedEdge: 475, 560, 668, 717 and 840 nm
UAV-Mounted RapidScan Active Sensor

Background High Resolution UAV-Mounted RGB Camera

Sampled July 9, 2014

Values are Fertilizer Nitrogen Rate (lb/acre)

V11 growth stage
Unmanned Aerial Systems – Multispectral Sensors

SlantRange 4 band multispectral sensor, incoming radiometric correction

RedEdge (5 band) and Sequoia (4 band, high res RGB), each with integrated GPS, IMU, incoming radiometric correction

Robin Eye sensor, 7 band, incoming radiometric correction
Monitoring Nitrogen Stress

UAV Image
RGB – July 20, 2016

UAV Image
NDRE – July 20, 2016
Project SENSE

Sensors for Efficient Nitrogen Use and Stewardship of the Environment

A research/educational project of the Nebraska Corn Board, the Central Platte, Little Blue, Lower Loup, Lower Platte North and Upper Big Blue Natural Resources Districts, USDA-NIFA, and the University of Nebraska-Lincoln On-Farm Research Network
Sensor-Based Nitrogen Fertilization

Canopy sensor reflectance
22 June 2015
Project SENSE 2015

Grower Rate vs. Sensor Rate - average N savings: 25%

N Application Summary

- Grower Initial N Rate
- Grower In-Season N rate
- Sensor Initial N Rate
- AVG TARGET RATE

Comparison across locations:
- Upper Big Blue
- Lower Loup
- Central Platte
- Lower Platte North
- Little Blue
2015 PROJECT SENSE BUTLER COUNTY SITE – FERTILIZER N RATE AND GRAIN YIELD
SANDY LOAM AND LOAM SOILS

With no statistical yield difference, N savings (at $0.65/lb) equals $42.90/acre.

<table>
<thead>
<tr>
<th>Project SENSE Means</th>
<th>Grower</th>
<th>SENSE</th>
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</thead>
<tbody>
<tr>
<td>Fertilizer N (lb/acre)</td>
<td>195</td>
<td>155</td>
</tr>
<tr>
<td>Yield (bu/acre)</td>
<td>227</td>
<td>222</td>
</tr>
<tr>
<td>PFP$_N$ (lb grain/lb N)</td>
<td>66</td>
<td>86</td>
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Average increase in profit: $7.75/acre
The Future?
Summary

- Sensors are available today which can accurately detect crop nitrogen status during the growing season.
- Algorithms have been developed which relate crop canopy reflectance in specific wavebands to how much nitrogen fertilizer is needed.
- Sensors can be either passive (using sunlight) or active (using an internal light source).
- Sensors can be used on a variety of platforms: handheld, ground or aerial vehicle, satellite.
- Active sensors can be used around the clock, regardless of cloud cover or sun angle.
Summary

• Unmanned aerial systems (UAS) provide tremendous opportunity to detect and manage N and water stress at high spatial and temporal density.

• Lightweight and relatively inexpensive multispectral sensors are now becoming available for UAS use.

• Active crop canopy sensors have potential for use on UAS. They have advantages of providing geo-referenced, calibrated reflectance data without image processing, and can collect data day or night.

• Research direction in Nebraska is focused on integrating spatial and temporal management of water and N, enabled by variable rate irrigation/fertigation systems.