Algorithms for Use in Directing In-season N Rates for Corn

Lakesh Sharma
PhD Candidate
Department of Soil Science
NDSU
The first 6 weeks of growth, little N is needed

Seasonal N Uptake, %

- Early Growth
- Rapid Growth
- Maturing
- Late Loss

May | June | July | Aug | Sept

Over 80% of N required after V8

Source: Dr. Jim Schepers, NUE conference presentation, Fargo-http://nue.okstate.edu/Nitrogen_Conference2012/North_Dakota.htm
Soils within a field vary in residual N and N supplying power.

Addition N should be site-specific.

By determining in-season N variability total N efficiency may be increased. In-season active-optical sensors can be used to estimate yield at the time of sensing and use difference between high N area and other areas to estimate N side-dress rates.
Active optical sensors have been identified as a tool to increase nitrogen-use efficiency

GreenSeeker™ (Trimble)

Holland Crop Circle Sensor™ (Holland Scientific)
Why Active Optical Sensors

- They can be used at any growth stage.
- Low Cost
- Easy to handle
- Readily available
- Can be used at any time
- Highly Efficient
- The sensors shine coded light of specific wavelengths.
- Sensors allow the prediction of crop response to N

Reading is 2 dimensional not 3D
Major components of visible light spectrum are violet, blue, green, yellow, orange and red

Blue and red are used in photosynthesis
- Red wavelength-Green leaves have a reflectance of 20 percent or less in the 500 to 700 nm range (green to red)

- Red Edge and Near Infra-red Wavelength- 60 percent in the 700 to 1300 nm range (near infra-red).
Difference between Red and Red Edge Wavelength

- Red spectrum measures green biomass but only sensitive to low chlorophyll (3-5 μg/cm²) (Gitelson et al., 1997)
  - Means good at early stage

- Red Edge Spectrum (700-750nm) is sensitive to a wide range of chlorophyll (0.3 – 45 μg/cm²) (Gitelson et al., 1997)
  - Works at later crop stages
Normalized Difference Vegetative Index - NDVI

- Calculated from the red (visible) and near-infrared bands
- Equivalent to a plant physical examination

\[ \text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \]

Correlated with:
- Plant biomass
- Crop yield
- Plant nitrogen
- Plant chlorophyll
- Water stress
- Plant diseases
- Insect damage
1991

Initial sensor research focused on detecting and spraying weeds.

In the summer of 1992, a first-order bindweed detection/sprayer was evaluated for fall applications.

1992

First discussion between the Departments of Plant and Soil Sciences and Biosystems and Agricultural Engineering concerning the possibility of sensing biomass in wheat and bermudagrass. Biomass was to be used as an indicator of nutrient need (based on removal).
Ongoing sensor readings in bermudagrass, N rate * N timing experiments with NFS at Oklahoma. Results were promising to continue work in wheat.

Dr. Marvin Stone adjusts the fiber optics used in early bermudagrass N rate studies, 1994.
In the fall of 1993, variable N rates using an inverse N-rate, NDVI scale were attempted at Miller-2. Using this approach, N rates were cut in half with no differences in grain yield compared to fixed rates. Grain N uptake levels using VRT across a 70 meter transect were less variable when compared to the fixed rates (left).

The initial algorithms used to spatially treat N deficiencies in wheat and bermudagrass employed an inverse N Rate-NDVI scale. Later, critical NDVI levels were established (both min and max) resulting in a plateau-linear-plateau function.

In the summer of 1994, John Ringer and Shannon Osborne collected sensor readings and later applied variable N fertilizer rates based on an initial bermudagrass algorithm developed by TEAM-VRT.
• Samples collected every 1 square foot.
• Experiments showed that each 4ft$^2$ in agricultural fields need to be treated as separate farms.

1995

Experiments looking at changes in sensor readings with changing, growth stage, variety, row spacing, and N rates were conducted.
Capstan nozzle controller hooked to a Trimble or Raven rate controller
Holland Crop Circle-470

Source: Dr. Jim Schepers, NUE conference presentation, Fargo-
http://nue.okstate.edu/Nitrogen_Conference2012/North_Dakota.htm
Greenseeker emits two bands visible and near infrared:
NDVI = (NIR – Red)/(NIR+Red)
(774nm reading – 656nm reading)/(774nm + 656nm)

Crop Circle-470 emit three bands visible, red edge, and near infrared:
NDVI = (NIR – Red)/(NIR+Red)
(760nm reading – 670nm reading)/(760 + 670)

Or
NDVI = (NIR – Red Edge/NIR+Red Edge)
(760nm reading – 730nm reading)/(760 + 730)
Algorithms will not use sensor readings by themselves.

We will use a normalization concept developed by Oklahoma State Univ. during their development of the GreenSeeker

**INSEY-**
In Season Estimate of Yield

Sensor reading / growing degree days from planting date
Our research from 2011-2013 has been directed

- To develop an in-season estimate of yield.
- Develop strategies for making in-season N fertilizer recommendations.
- Compare two active optical sensors Holland- Crop-Circle and GreenSeeker.
Locations and Treatments

- 51 sites were selected in 2011-2013.
- Six nitrogen treatments: 0, 40, 80, 120, 160, and 200 lb/acre.

- Experimental design: Randomized complete block design with four replications.
- Plot size: 20 feet long by 10 feet wide
- Soil was sampled to 2-feet in depth for residual nitrate-N preplant.
- P and K applied, if found deficient and cooperator application not practical
Crop History & Soil Texture
- Previous crop
- Tillage history
- Surface-subsurface soil texture

Sensor readings
- Approximately 45 samples/row
- The NDVI values were averaged for each plot as well as for each treatment.
- Both sensors Crop Circle and Greenseeker were used
  - 8 and 12 leaf stage over the top
OBSERVATION RECORDED

- Soil testing before planting and after harvesting.
- Plant height at V8 & V12 stage.
- Greenseeker and Crop Circle readings
Crop Circle 1st Reading at Red-EDGE Wavelength with all sites

\[ y = 97.44e^{655.55x} \]
\[ R^2 = 0.0815 \]

Crop Circle RED EDGE INSEYS

Crop Circle 2nd Reading at Red-EDGE Wavelength with all sites

\[ y = 31.282e^{3397.4x} \]
\[ R^2 = 0.3427 \]

Crop Circle RED EDGE INSEYS

Crop Circle 1st Reading at Red Wavelength with all sites

\[ y = 93.002e^{392x} \]
\[ R^2 = 0.07 \]

Crop Circle RED INSEYS

Crop Circle 2nd Reading at Red Wavelength with all sites

\[ y = 29.124e^{1809.7x} \]
\[ R^2 = 0.1691 \]

Crop Circle RED INSEYS
Why GreenSeeker is most effective at V6-V8

Wide range of NDVI values

NDVI’s at early growth stages

Rate of Nitrogen

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
45
90
135
179
224

NDVI Reading

730 nm
670 nm
656 nm
Why GreenSeeker is less effective at V12

NDVI is ‘saturated’—readings fall within a narrow range of values
Soil properties influence height of corn (Hussain et al, 1999).

Plant height being used to develop algorithms (Biermacher et al, 2006).
We are currently analyzing 2013 using both manual height and acoustic sensor (Senix).

Results are pending.
Scanning sensors are also being evaluated for crop height measurements but these results have not been published to our knowledge.
Summary……

- Soil categories help to improve $R^2$ relationship between yield and INSEY.
- NDVI from red and near infrared gave poor results between yield and INSEY as compared to Red Edge under dry land.
- Crop circle was found better as compared to Greenseeker.
- V12 leaf stage was found better in predicting yield.
- The $R^2$ was weak on those locations, where Nitrogen response was less.
Location segregation

- All research sites
  - Western sites
  - No till sites East
  - High Clay sites
  - Medium Textured sites

Conventional till
Higher yields/lower yields
Example field - 160 acres

Use zone sampling to direct the initial N-rate to field

Apply about 200 lb N to a small reference area
When applicator enters the field to apply side-dress application, the reference area serves as the INSEY that is the maximum supported by an application, less an INSEY of 5%.

Example field- 160 acres

Reference area previously highly fertilized with N
INSEY in field

Field Yield estimate

Reference Yield

INSEY

Reference INSEY

Yield
Corn yield difference in pounds per acre.
X 1.25% N in corn grain divided by efficiency factor 0.6
= \( N \) rate
Example-

Reference yield predicted- 120 bushels

In-field yield estimated- 60 bushels

difference = 60 bushels × 56 lb N/bushel
= 3360 pounds
  × 0.0125 = 42 lb N
42 /0.6 efficiency factor = 70 lb N
at that location.
Conclusion

- Multiplying INSEY by the corn height improve the relationship between INEYS and Yield.
- RED EDGE NDVI is better at 2\textsuperscript{nd} stage than RED NDVI.
- Crop circle red edge was found better as compared to Greenseeker 2\textsuperscript{nd} stage.
- V12 leaf stage was found better in predicting yield as compared to V8.
The algorithms, when published in Summer 2014, will serve as a foundation.

Our plan is to develop a program so that if growers leave an untreated, but sensed strip in fields across soils, they can add the data to the algorithm development formula and develop their unique algorithm.
ACKNOWLEDGEMENTS

Special Thanks

• Dr. Dave Franzen (PhD Advisor)
• Dr. Tom DeSutter (PhD Committee member)
• Dr. R. J. Goos (PhD Committee member)
• Dr. Joel Ransom (PhD Committee member)

• Thanks to the North Dakota Corn Council, IPNI and Pioneer Hi-Bred International for their support of this project. Also to Dr. Anne Denton in the NDSU Computer Science Department and the National Science Foundation.