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In-Season N Predictions Using Canopy Sensors

Daniel Kaiser
Associate Professor
Department of Soil,
Water and Climate

U of M Twin Cities
612-624-3482
dekaiser@umn.edu

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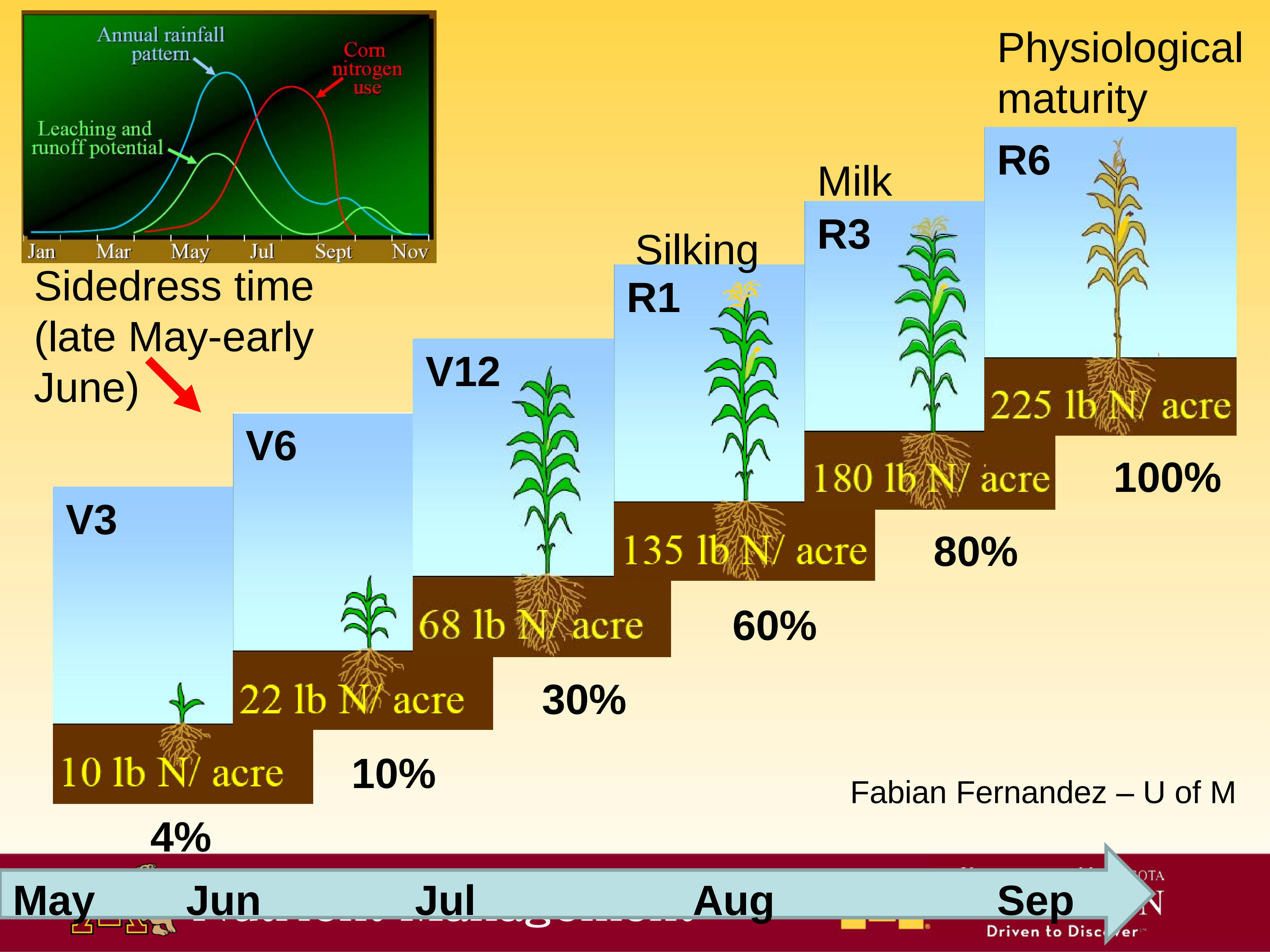
Sensor Based N Management

- In theory, offers a relatively simple method to manage N without having to physically take a sample
- Sensors have been in place for about 20 years
  - Earliest was SPAD Chlorophyll meter
- Satellite imagery has been around for longer
  - Offers some advantages but also some major limitations
    - Limitations: return rate, minimum amounts of data to purchase, limited control on when the picture will be taken


Annual rainfall pattern
Corn nitrogen use
Leaching and runoff potential
Jan
Mar
May
Jul
Sept
Nov
Sidedress time (late May-early June)
Physiological maturity
Milk
Silking
V3
V6
V12
R1
R3
R6
10 lb N/ acre
22 lb N/ acre
68 lb N/ acre
135 lb N/ acre
180 lb N/ acre
225 lb N/ acre
4%
10%
30%
60%
80%
100%
Fabian Fernandez – U of M
May
Jun
Jul
Aug
Sep
Driven to Discover

Innovations in Remote Sensing

Adapted From D.J. Mulla

Year	Innovation	Citation
1992	SPAD meter (650, 940 nm) used to detect N deficiency in corn	Schepers et al., 1992
1995	Nitrogen Sufficiency Indices	Blackmer and Schepers, 1995
1996	Optical sensor (671, 780 nm) used for on-the-go detection of variability in plant nitrogen stress	Stone et al. (1996)
2002	Yara N sensor	Link et al. (2002), TopCon Industries
2002	GreenSeeker (650, 770 nm)	Raun et al. (2002), NTech Industries
2004	Crop Circle (590, 880 nm or 670, 730, 780 nm)	Holland et al (2004), Holland Scientific
2002	CASI hyperspectral sensor based index measurements of chlorophyll	Haboudane et al. (2002; 2004)
2002	MSS remote sensing of ag fields with UAV	Herwitz et al. (2004)
2003	Fluorescence sensing for N deficiencies	Apostol et al. (2003)

Development of Satellite Imagery

Adapted from D.J. Mulla

Satellite (Year)	Spectral Bands (Spatial Resolution)	Return Frequency (d)	Suitability for PA
Landsat 1 (1972)	G, R, two IR (56x79 m)	18	L
AVHRR (1978)	R, NIR, two TIR (1090 m)	1	L
Landsat 5 TM (1984)	B, G, R, two NIR, MIR, TIR (30 m)	16	M
SPOT 1 (1986)	G, R, NIR (20 m)	2-6	M
IRS 1A (1988)	B, G, R, NIR (72 m)	22	M
ERS-1 (1991)	Ku band altimeter, IR (20 m)	35	L
JERS-1 (1992)	L band radar (18 m)	44	L
LiDAR (1995)	VIS (vertical RMSE 10 cm)	N/A	H
RadarSAT (1995)	C-band radar (30 m)	1-6	M
IKONOS (1999)	Panchromatic, B, G, R, NIR (1-4 m)	3	H
SRTM (2000)	X-band radar (30 m)	N/A	M
Terra EOS ASTER (2000)	G, R, NIR and 6 MIR, 5 TIR bands (15-90 m)	16	M
EO-1 Hyperion (2000)	400-2500 nm, 10 nm bandwidth (30 m)	16	H
QuickBird (2001)	Panchromatic, B, G, R, NIR (0.61-2.4 m)	1-4	H
EOS MODIS (2002)	36 bands in VIS-IR (250-1000 m)	1-2	L
RapidEye (2008)	B, G, R, Red edge, NIR (6.5 m)	5.5	H
GeoEye-1 (2008)	Panchromatic, B, G, R, NIR1, NIR2 (1.6 m)	2-8	H
WorldView-2 (2009)	P, B, G, Y, R, Red edge, NIR (0.5 m)	1.1	H

How do we use these tools?

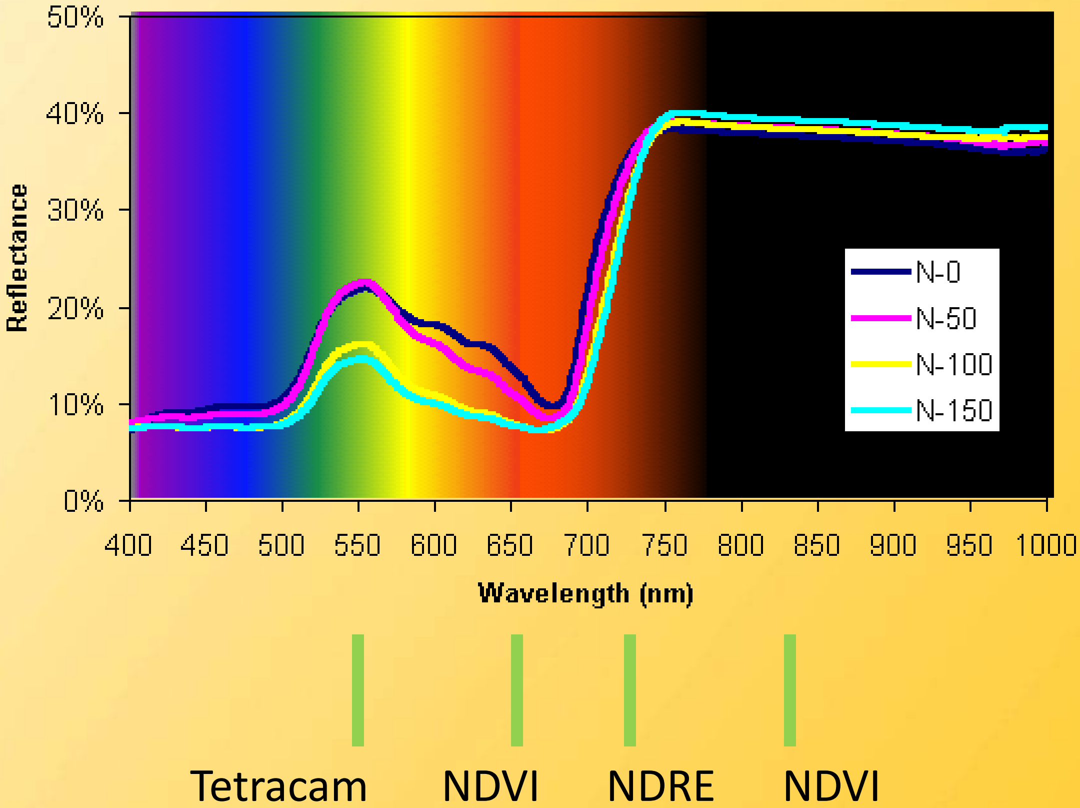
1. Use to schedule application during the season. – all N put on in-season.
2. Put a small amount on at planting and use the tool to determine the need in-season?
3. Put half or more pre-plant and use the tool to determine if it needs to be topped off?

How to Make Sensors Work

- Sensor/Index used must be reflect sufficiency of a particular nutrient
  - Sensors will generate values but they must be made relative to a reference area/strip
- Sensor/Index must be able to forward predict nutrient sufficiency
  - Nutrient sufficiency at the time data are collected must be relative to the overall sufficiency at the end of the season
- For a given nutrient: we must have confidence differences detected by sensors are due to a particular nutrient

Properties of N deficient Plants

- Green reflectance increases
- Red reflectance increases & NIR reflectance decreases
- Differences in reflectance greatest between 550 – 600 nm, followed by red-edge (680 – 730 nm)

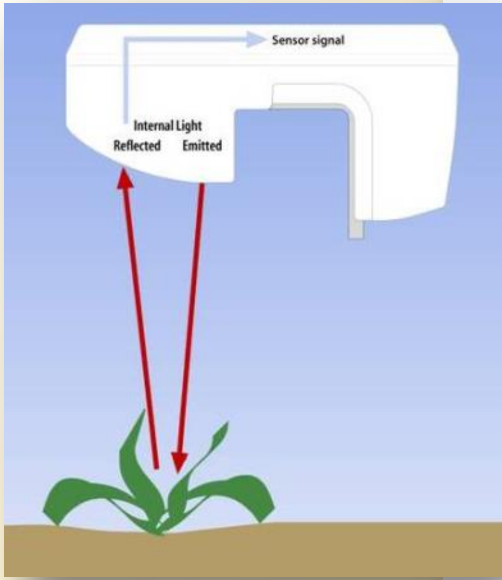


D.J. Mulla, University of Minnesota

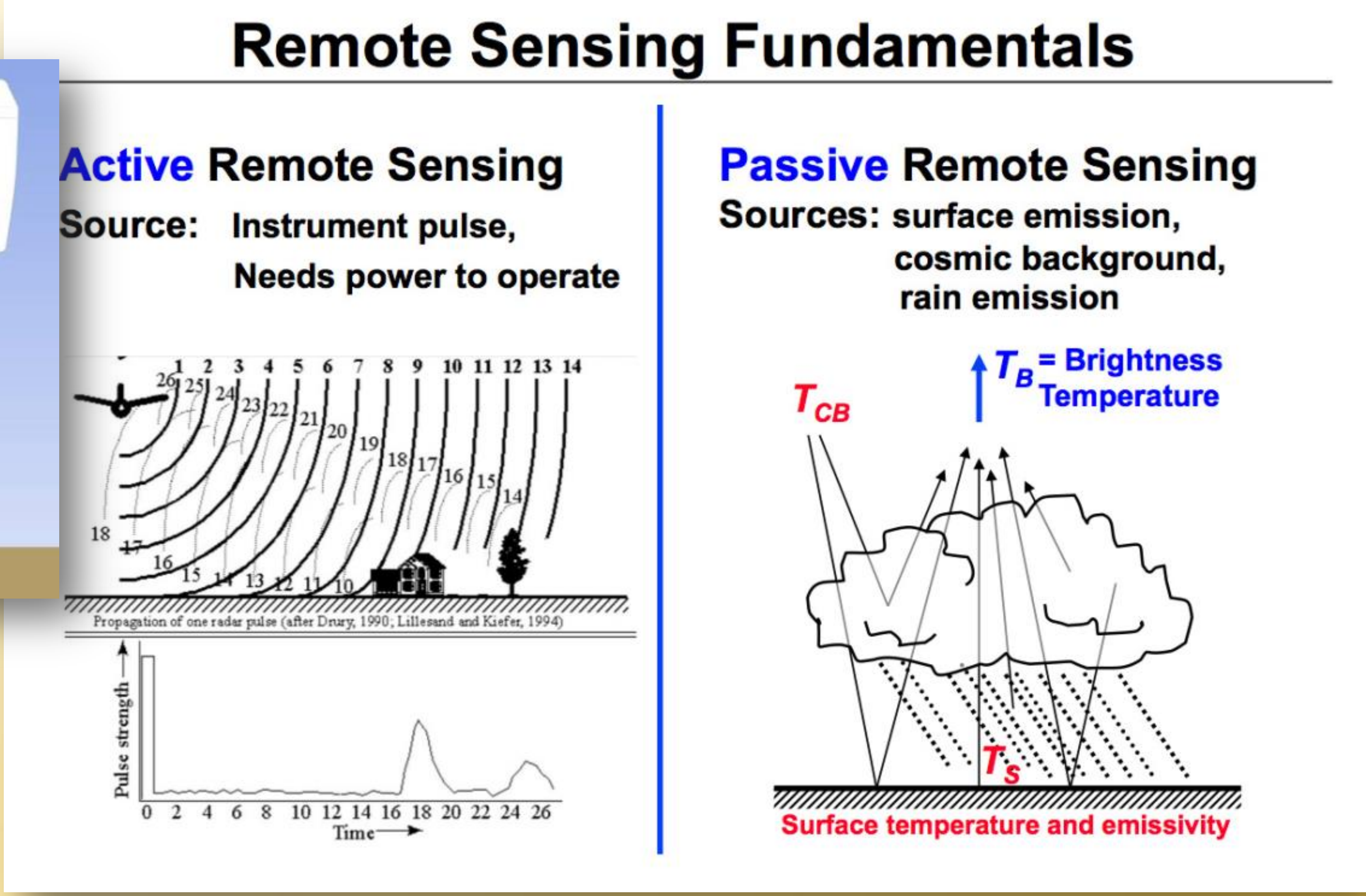
Sensor/Imaging Options

- R-G-B pictures
- Multi-spectral imagery
  - Images captured at specific wavelengths
    - Narrow and wide band
- Thermal
- Fluorescence
- Hyper spectral imaging
  - Data collected across the spectrum at set intervals (nm)

Active or Passive Sensing



Active Sensors emit their own light source



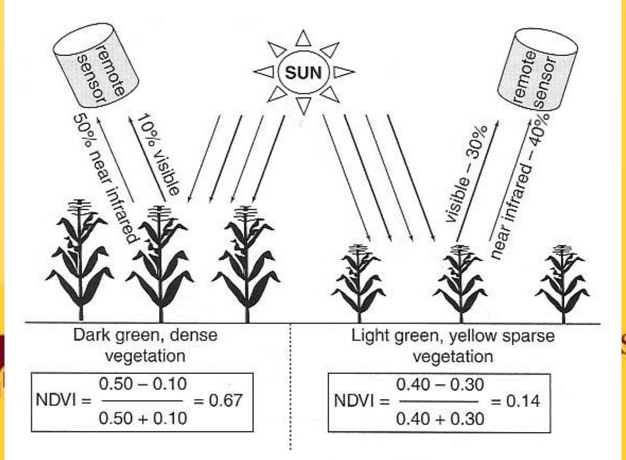
Active or Passive Sensors

- Active sensors
  - Pros – have their own light source, some are plug and play, can work with fertilizer controllers for on-the-go application
  - Cons – data is expressed in terms of indices, narrow area where data are collected
- Passive Sensors
  - Pros – Scan larger areas of fields quickly, ability to choose what indices to use
  - Cons – Data processing, affected by ambient light, must process data to make it useful

Can We Use Crop Sensors To Improve N Management?

NDVI

- Normalized Difference Vegetative Index
  - No units associated with the value
  - Arbitrary number based on conditions within the field
- Index utilized by many types of sensors
  - Satellite imagery can produce NDVI as well
- Ratio of reflectance values in the Red and NIR bands
  - (NIR-Red)/(NIR+Red)



NDVI - Limitations

- NDVI is predicated on differences among treatments are expressed as differences in plant growth
  - Greenness does not factor in to this measure
  - Measure of stand density
- Poorly growing plants can be due to a number of factors
- NDVI reaches saturation early in the growing season

Other Options

- NDRE – Normalized difference Red-Edge
  - Ratio of red-edge to NIR
  - Red-edge is measured in the region between red and NIR
- GNDVI – Green normalized difference vegetation index
  - Ratio of Green to NIR
- Many other indices developed for use

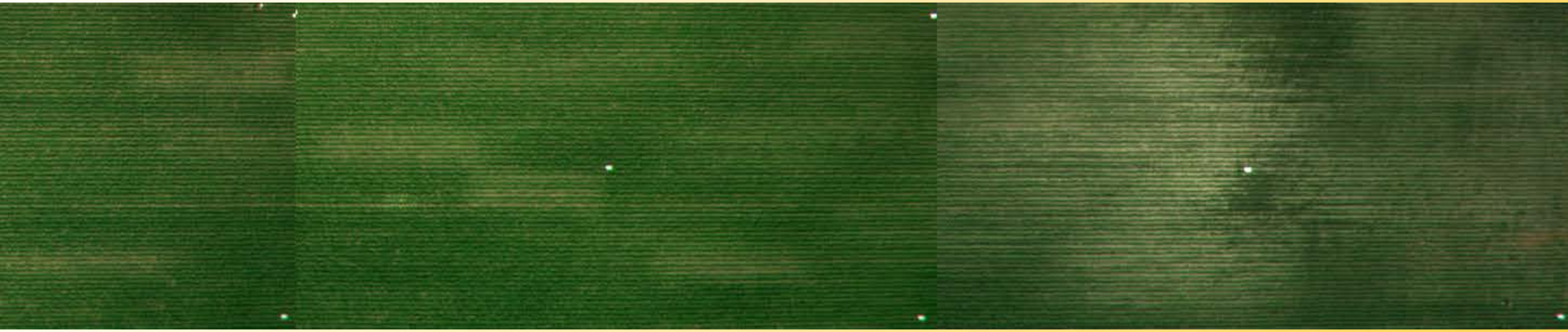
What is the best Index of N Availability

- Red/NIR indices from active sensors are not adequate to determine yield differences due to N unless soil N availability is low
- SPAD data provides better prediction but is more labor intensive
  - May not get a good representative sample
- NDRE may be a better index overall
  - $(NIR-R_{edge})/ (NIR+R_{edge})$
- GNDVI may relate better to N stress as well

Moving Forward

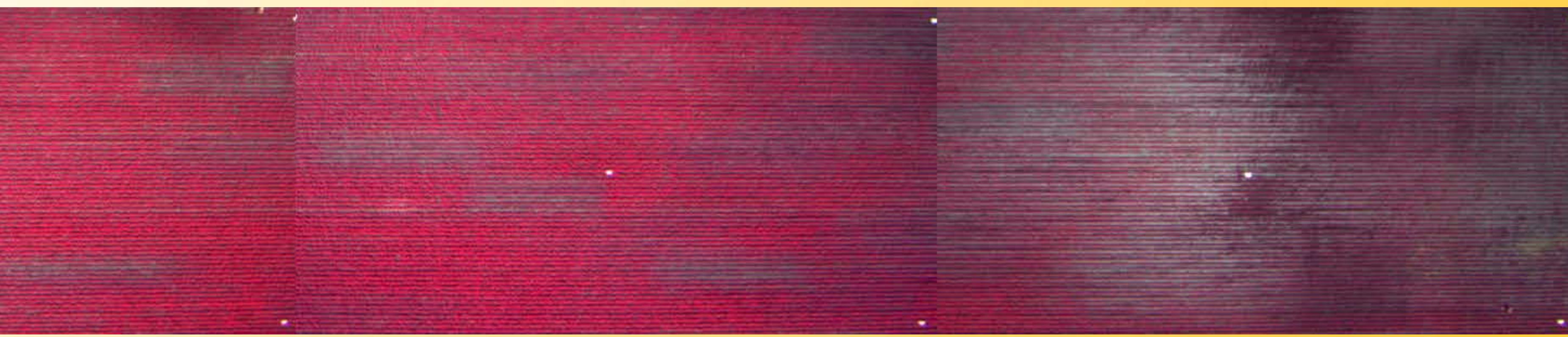
- We need to have some confidence that we can accurately predict response to N
  - In a production field how do we know yellow corn is due to N
- We still need to have reference strips
  - All values are derived in relation to a normal area
- There are many sensing options out there, how do we choose the right one?
- CASE STUDIES

New Richland, MN V5 Corn: 2014

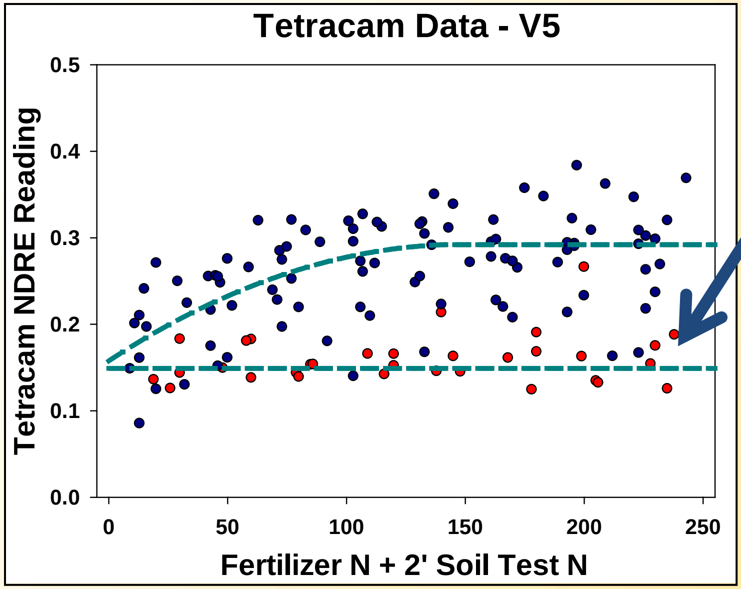


Water Free Area

Previously flooded area

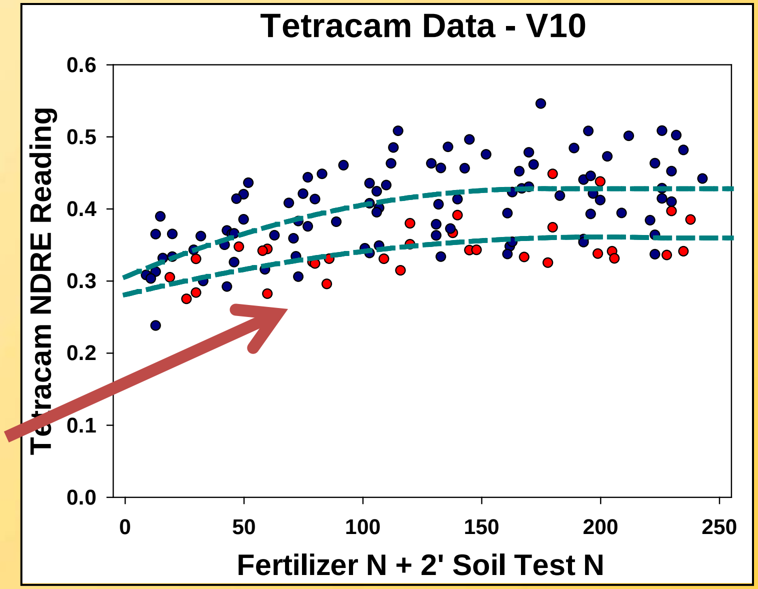


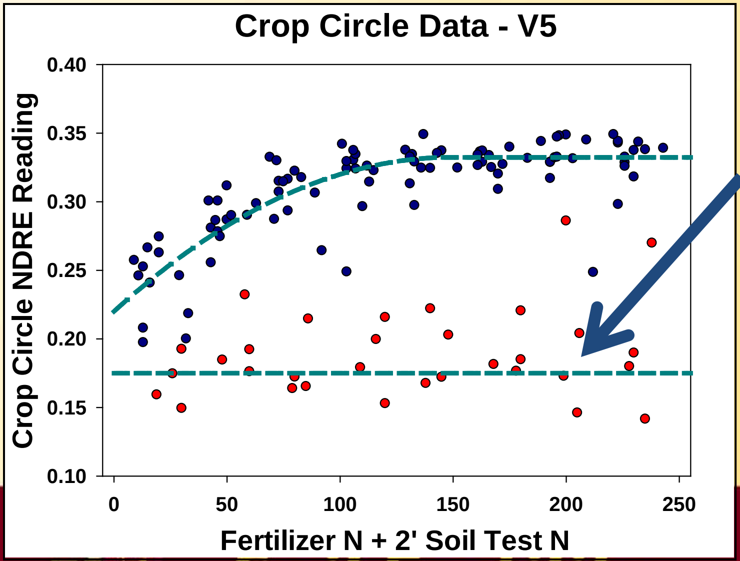
New Richland 2014



No differences in N rates @ V5 for the saturated zone

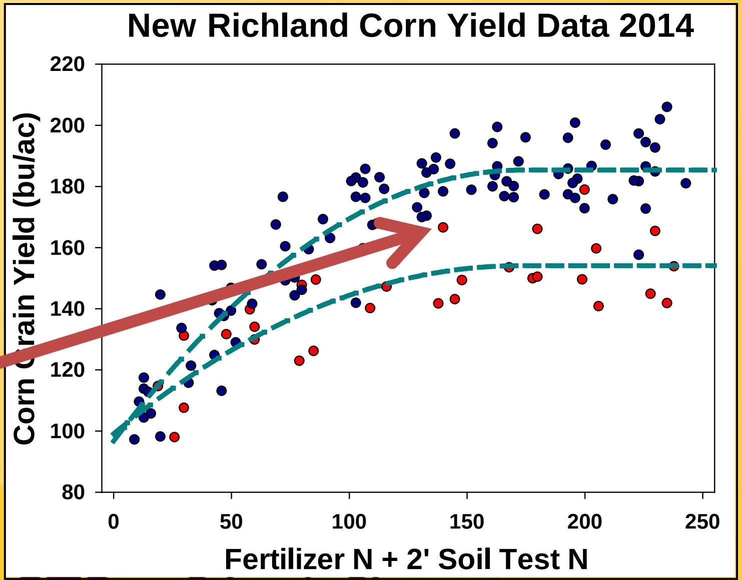
N response for the saturated zone at V10





No differences in N rates @ V5 for the saturated zone

Yield differential for the saturated zone but EONR was the same



2015 – N Prediction Methods Study

Stewart, MN Sb-C

- Nicollet Cl
- 96 day RM planted 4/25
- 5.5 GPA 10-34-0
- 22” rows
- 32 lb N @ 2’
- Applied 40 lb of N as a base rate before side-dress

Waseca, MN C-C

- Webster Cl
- 101 day RM planted 5/1
- 2.5 GPA 10-34-0
- 30” rows
- 38 lb N @ 2’
- Applied 45 lb of N as a base rate before side-dress

Methods Used

1. Soil tests – 2’ pre-plant and 1’ PSNT
2. Active sensors – SPAD @ V5, V10, and R2; Crop Circle @ V5 and V10
3. Multispectral images @ V5, V10, and R2
4. Crop models

Active Sensor Prediction: % of Max by pre-plant Nitrogen Rate

Stewart, MN Sb-C

	40	80	120
V5	------------% of Max-------------		
NDVI-CC	102	100	99
NDRE-CC	98	99	99
SPAD	93	95	100
V10			
NDVI-CC	100	100	99
NDRE-CC	95	97	99
SPAD	95	99	99

Waseca, MN C-C

	45	90	135
V5	------------% of Max-------------		
NDVI-CC	96	100	101
NDRE-CC	85	96	100
SPAD	84	99	98
V10			
NDVI-CC	94	98	99
NDRE-CC	76	89	94
SPAD	76	92	96

Assuming an economic response will occur when $\leq$ 95%

Aerial Image Prediction: % of Max by pre-plant Nitrogen Rate

Stewart, MN Sb-C

	40	80	120
V5	------------% of Max-------------		
NDVI	98	98	100
NDRE	96	98	98
GNDVI	99	98	102
V10			
NDVI	99	100	99
NDRE	92	99	96
GNDVI	96	98	98

Waseca, MN C-C

	45	90	135
V5	------------% of Max-------------		
NDVI	96	98	99
NDRE	88	102	102
GNDVI	88	101	103
V10			
NDVI	89	101	99
NDRE	76	95	91
GNDVI	81	97	95

Assuming an economic response will occur when ≤ 95%

Prediction Using Active Sensors

ΔEONR vs Max. Sensor Value (actual)

Stewart, MN Sb-C

Sensor	Stage	ΔEONR
NDVI-CC	V5	-60
NDRE-CC		-59
SPAD		-39
NDVI-CC	V10	-30*
NDRE-CC		-28*
SPAD		-22
SPAD	R2	34**

Waseca, MN C-C

Sensor	Stage	ΔEONR
NDVI-CC	V5	-181
NDRE-CC		-165
SPAD		-115
NDVI-CC	V10	-122*
NDRE-CC		-34*
SPAD		-39
SPAD	R2	47***

R^2: $\geq$0.75 (***), $\geq$0.50 (**), $\geq$0.25 (*)

Prediction Using Aerial Images

ΔEONR vs Max. Sensor Value (actual)

Stewart, MN Sb-C

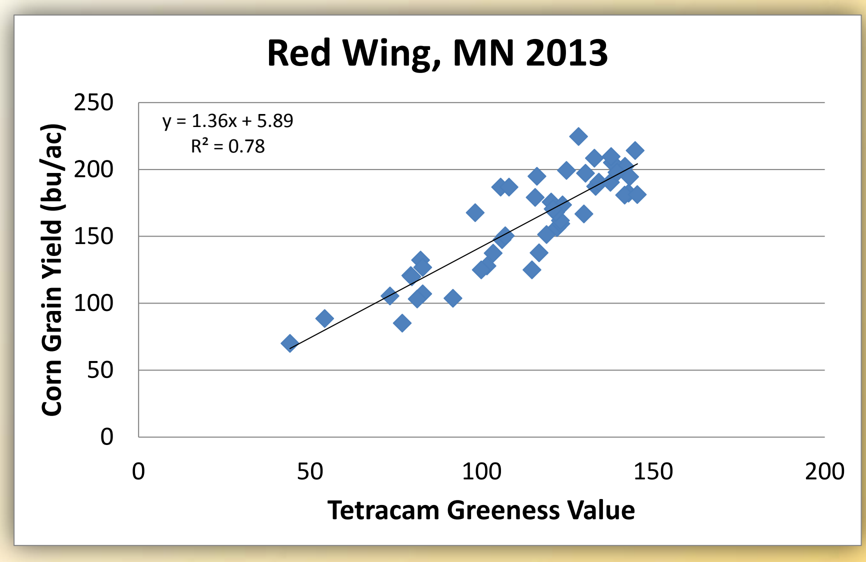
Sensor	Stage	ΔEONR
NDVI	V5	-44
NDRE		-42
GNDVI		-46
NDVI	V10	-23
NDRE		255
GNDVI		-17
NDVI	R2	-19
NDRE		19*
GNDVI		6*

Waseca, MN C-C

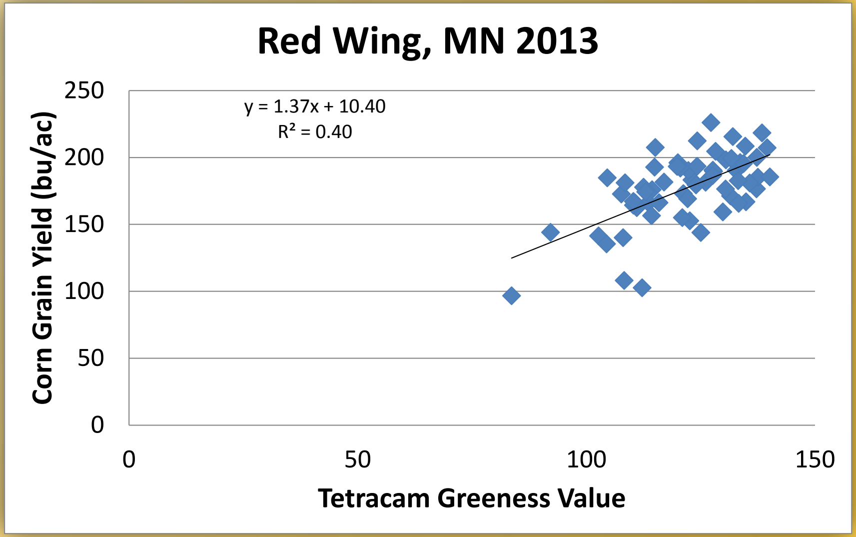
Sensor	Stage	ΔEONR
NDVI	V5	-155
NDRE		-86
GNDVI		-164
NDVI	V10	-106
NDRE		1
GNDVI		-23
NDVI	R2	27*
NDRE		60**
GNDVI		50**

Greenness Versus Grain Yield Red Wing, MN 2013

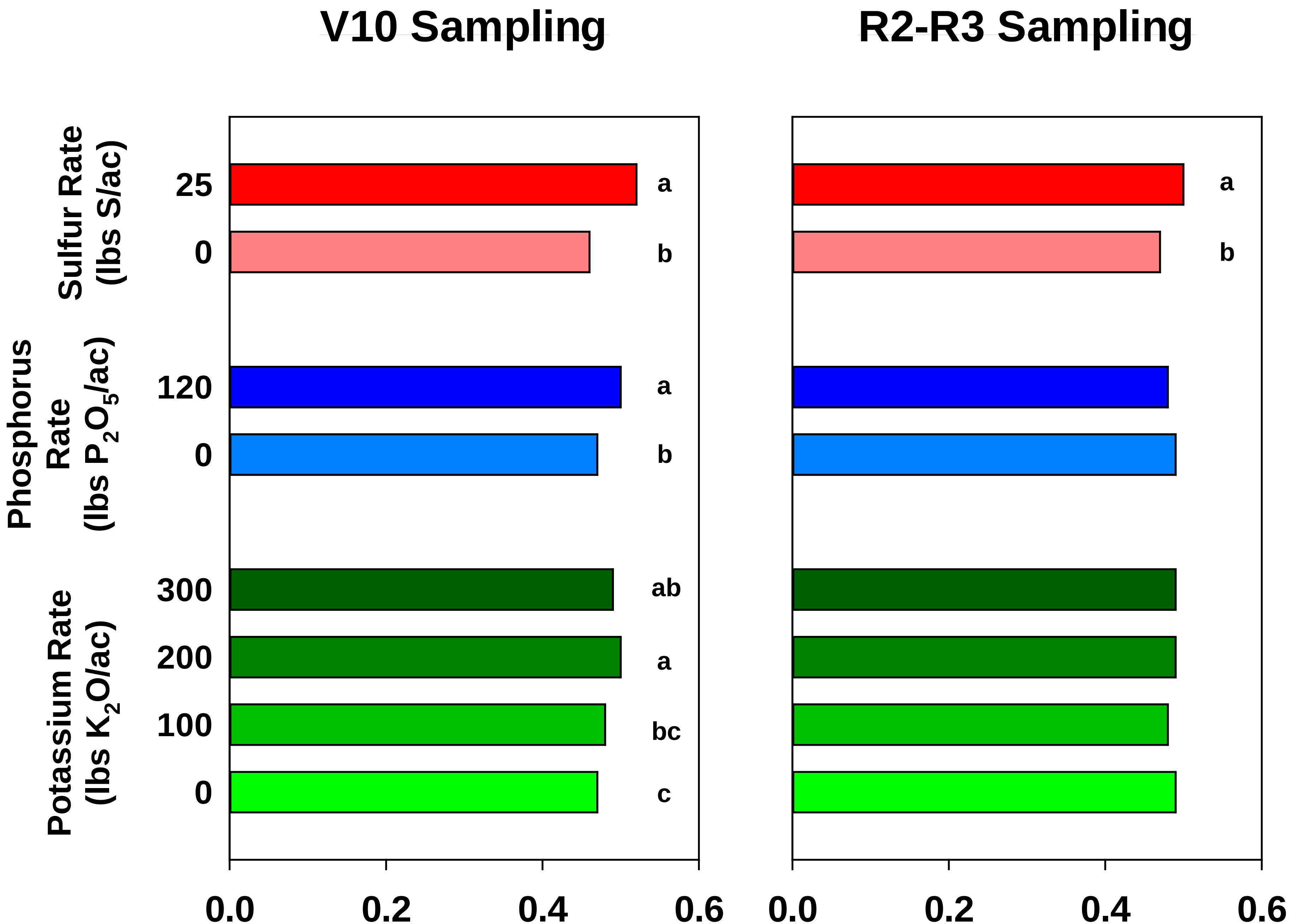
N x S Study



P x K x S Study



- Greeness value: Raw pixel values from the 550 nm band
- Strong correlation between the greenness index value and yield for the N x S study
- Weaker correlation in the P x K x S study – but it is still significant



Minnesota's Agricultural Fertilizer
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Sensing and Crop Nutrients

- Sulfur will likely prove to be the most challenging nutrient when sensing for N deficiency
  - Deficiencies are not mutually exclusive
  - S deficiency not as apparent as N late in the season, but yield differences can be large
- P and K may have an impact in the case of severe deficiencies
  - Especially for biomass indices
- What about zinc?




Final Comments

- Things can be built faster than we can figure out how to use them
- I think there still may be some benefits to using UAV's
  - General scouting tool
- Nutrient detection may get better
  - Many deficiencies result in chlorosis
  - Important question: is the deficiency due to N?
- Ground based sensors may have some utility under certain circumstances
- Still will require a reference strip if we want to manage a specific nutrient

Thank You
Questions?

SW&C Field Crew
Jeff Vetsch
Fabian Fernandez
Cooperators and Consultants

Minnesota's Agricultural Fertilizer Research & Education Council

MinnesotaCorn GROWERS ASSOCIATION

MN Soybean Research & Promotion Council

Daniel Kaiser
University of Minnesota
612-624-3482
dekaiser@umn.edu

http://.z.umn.edu/nutmgmt
http://z.umn.edu/fbnutmgmt