Real-time Sensor Systems for Fertility Management

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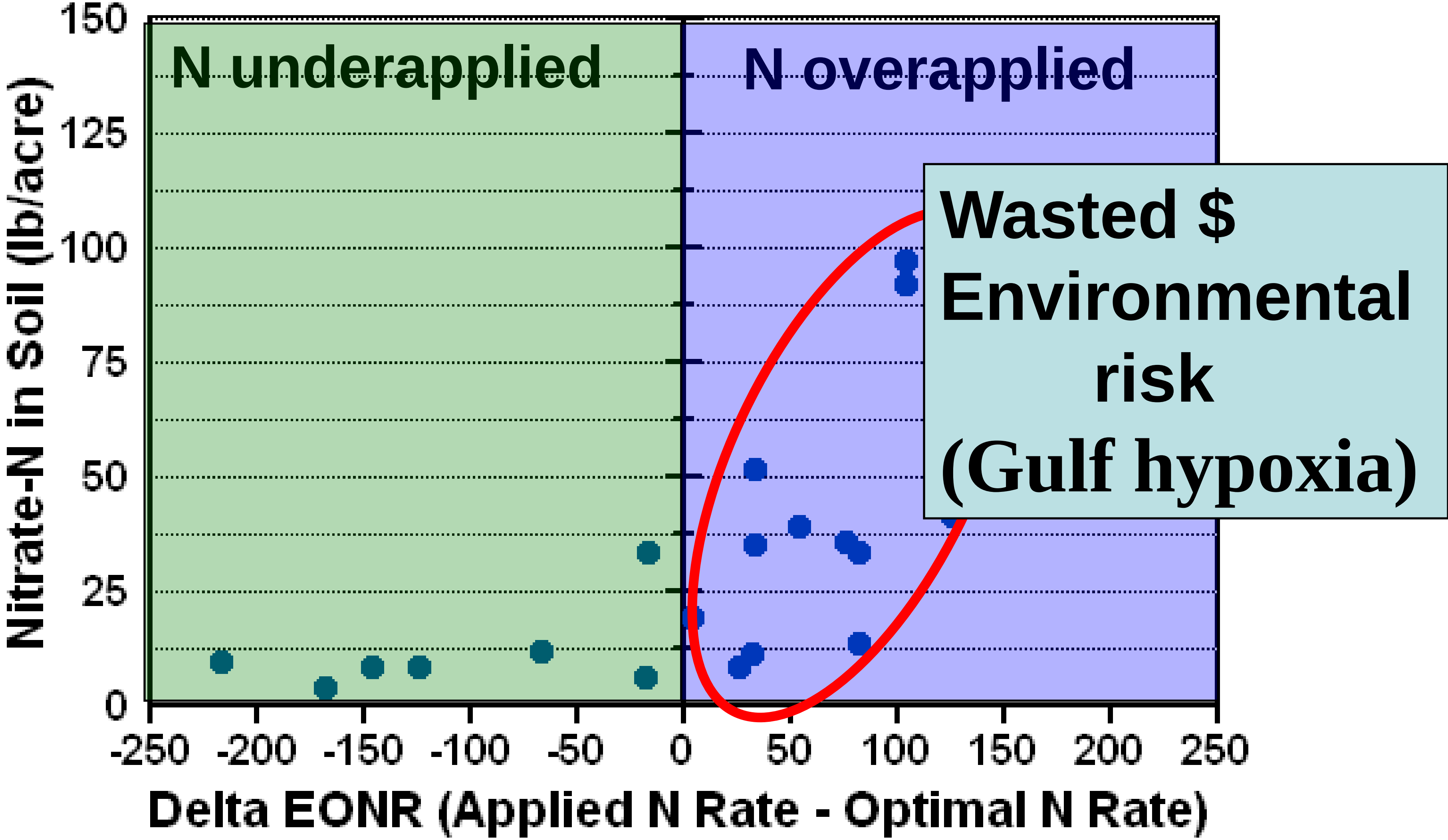
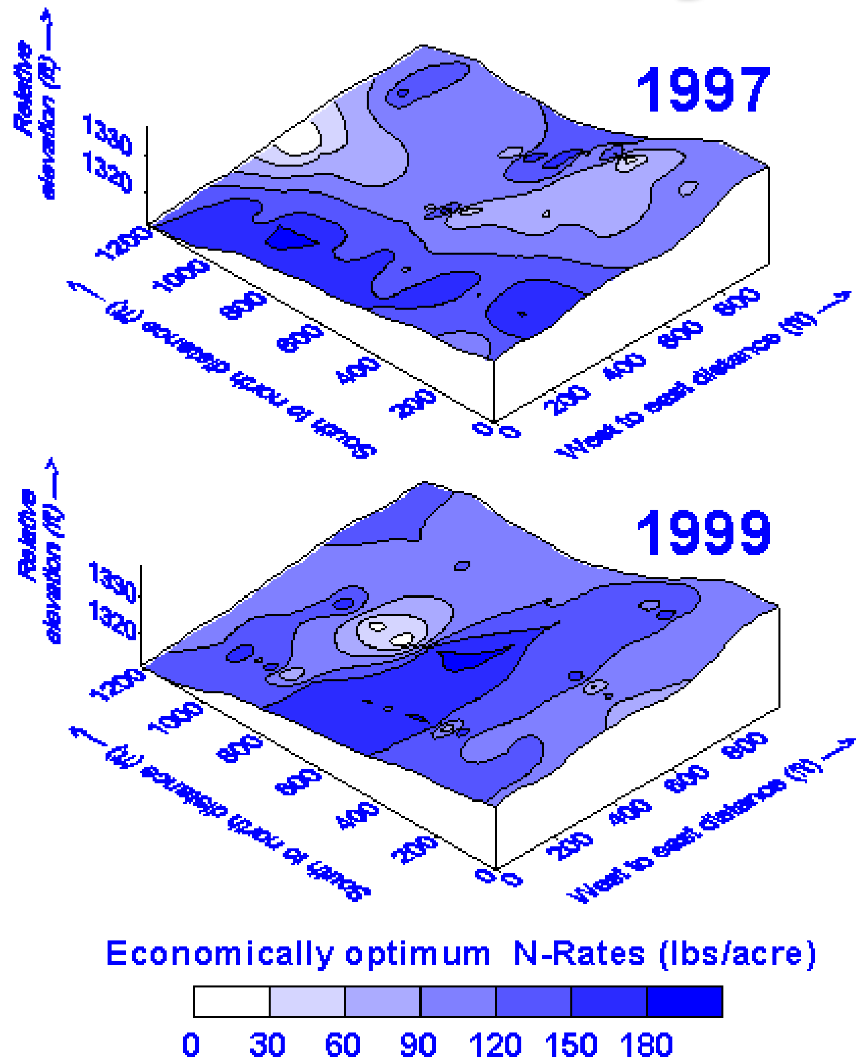
Why not use uniform application rates for nutrients?

Underapplication = lost yield
Overapplication = leftover N in soil



Crop N need is variable: from year to year



Minnesota corn: the places that needed the most and least N were not the same in the two years

G. Malzer data from Doerge (2002) Crop Mgmt. doi. 10.1094/cm-2002-0905-01-RS

So we need to look at Variable Rate Application (VRA)

- Production inputs are applied on an optimum basis for the local conditions.
- VRA requires
  - Knowledge of ***economic*** optimum rates at chosen management scale
  - Ability to apply desired rate at desired scale

Imagery has shown promise as basis for VRA, but many believe that in-field sensing is the future of nutrient management

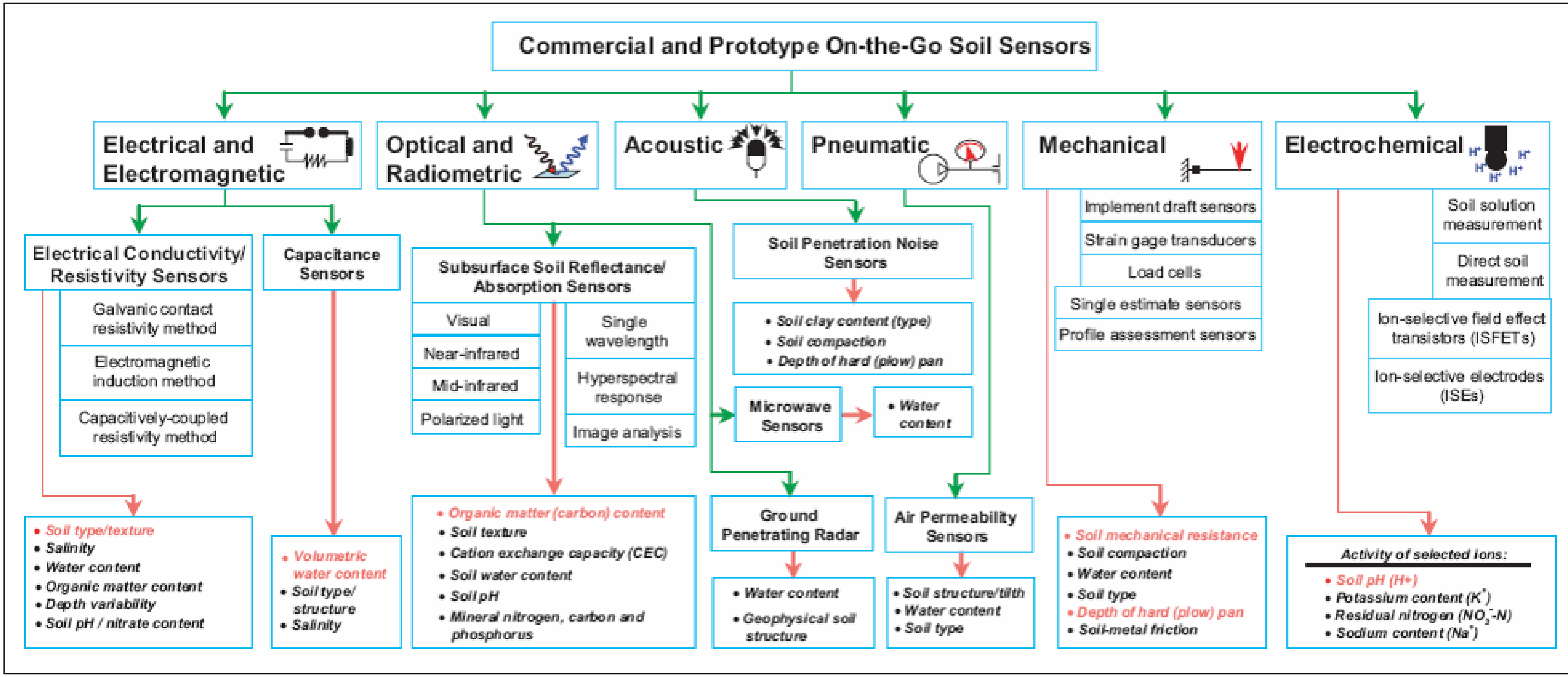
- The primary benefit of sensor-based measurements is improved accuracy.
- Sensors can increase sampling intensity by orders of magnitude compared to traditional methods. As a result, a significant decrease in overall error can be realized.

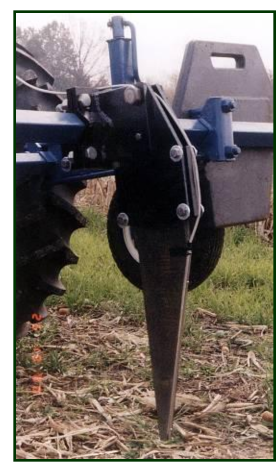
Sensor-Based Nutrient Management

- Monitor (measure) nutrient status in the field
- Apply supplemental nutrients at variable rates to meet crop needs

It Makes ***Sense***

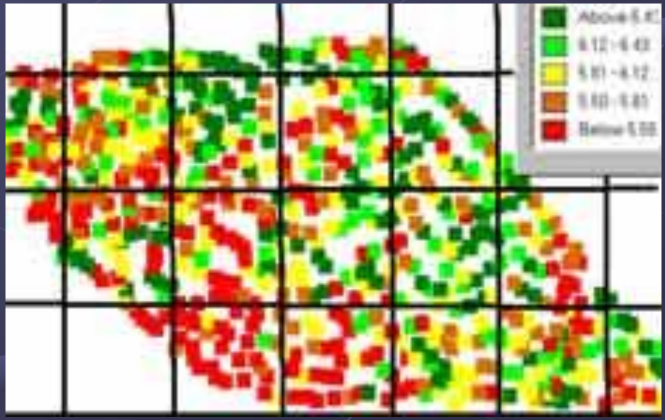
- Soil Sensing
- Plant Sensing


Commercial and Prototype On-the-Go Soil Sensors
Electrical and Electromagnetic
Optical and Radiometric
Acoustic
Pneumatic
Mechanical
Electrochemical
Electrical Conductivity/ Resistivity Sensors
Galvanic contact resistivity method
Electromagnetic induction method
Capacitively-coupled resistivity method
Capacitance Sensors
Subsurface Soil Reflectance/ Absorption Sensors
Visual
Near-infrared
Mid-infrared
Polarized light
Single wavelength
Hyperspectral response
Image analysis
Soil Penetration Noise Sensors
• Soil clay content (type)
• Soil compaction
• Depth of hard (plow) pan
Microwave Sensors
• Water content
Implement draft sensors
Strain gage transducers
Load cells
Single estimate sensors
Profile assessment sensors
Soil solution measurement
Direct soil measurement
Ion-selective field effect transistors (ISFETs)
Ion-selective electrodes (ISEs)
• Soil type/texture
• Salinity
• Water content
• Organic matter content
• Depth variability
• Soil pH / nitrate content
• Volumetric water content
• Soil type/ structure
• Salinity
• Organic matter (carbon) content
• Soil texture
• Cation exchange capacity (CEC)
• Soil water content
• Soil pH
• Mineral nitrogen, carbon and phosphorus
Ground Penetrating Radar
• Water content
• Geophysical soil structure
Air Permeability Sensors
• Soil structure/tilth
• Water content
• Soil type
• Soil mechanical resistance
• Soil compaction
• Water content
• Soil type
• Depth of hard (plow) pan
• Soil-metal friction
Activity of selected ions:
• Soil pH (H+)
• Potassium content (K+)
• Residual nitrogen (NO3-N)
• Sodium content (Na+)

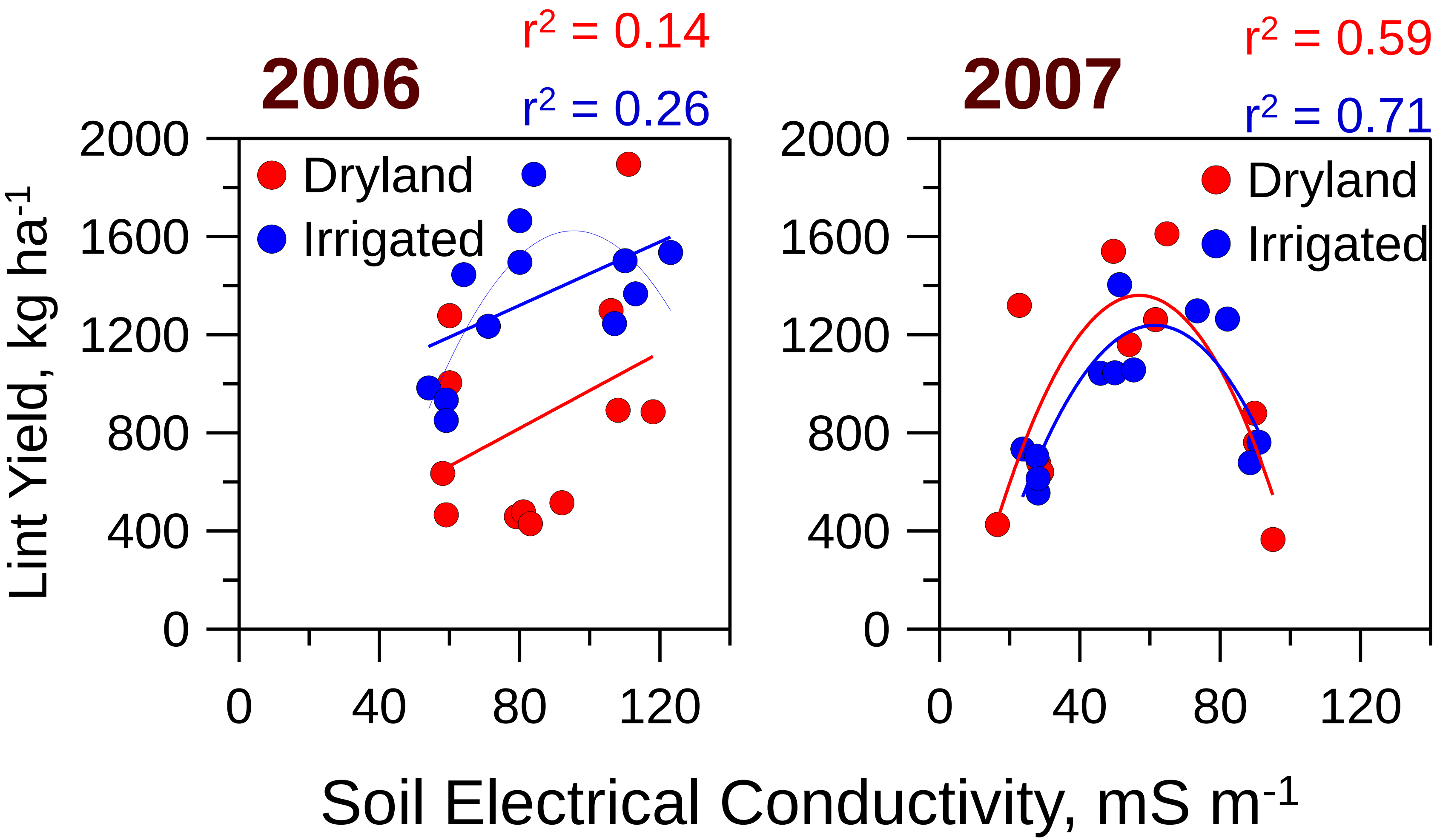


Soil Fertility/Chemistry Sensors

- **Sense levels of nutrients important for plant growth to control fertilizer additions**
  - **Macro-nutrients (Nitrogen, Potassium, Phosphorus), pH (commercially available), trace nutrients**
- **Sense compounds toxic to plants and/or bad for the environment**
- **High-throughput, on-the-go sensing is preferred to efficiently obtain data needed to map variations**



Lint Yield



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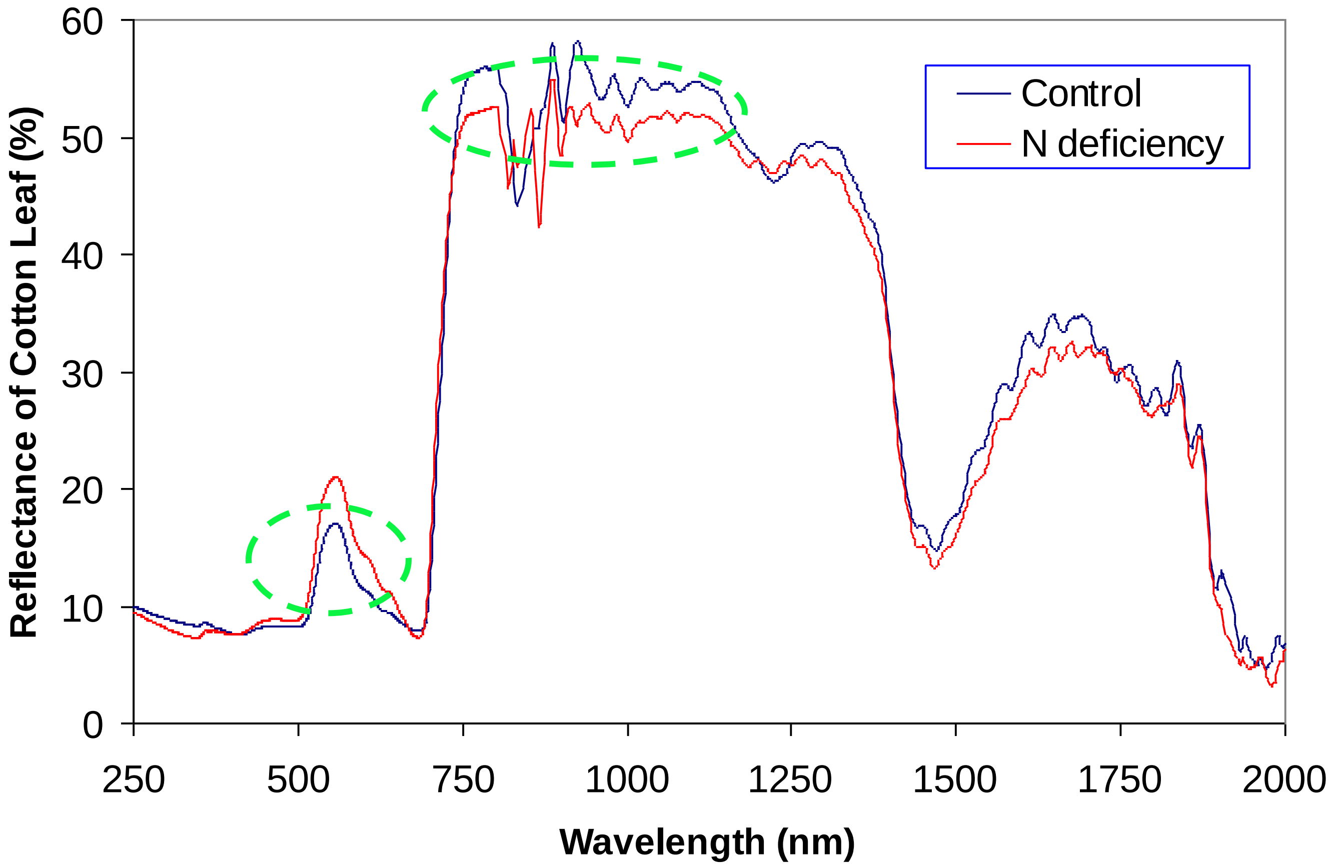
Remote Sensing System for Plant Nitrogen Determination



Spectral reflectance of cotton plant canopy relates to N status of the plants

Missouri Reflectance Study

- Six N rate experiments
  - 3 in 2006, 3 in 2007
  - Loamy sand, silt loam, clay each year
- Three commercial sensors (GreenSeeker, Crop Circle, and Cropscan)
- Three stages (early square, mid square, and first bloom)
- Revised protocol for 2008

Sensor vs. optimal N rate

- None of the sensors could predict optimal N rate at first square
- All of the sensors could predict optimal N rate at mid-square and first flower
  - Optimal N rate would have increased profit by $43/acre relative to typical producer rate of 100 lb N/acre
  - Required comparison to high-N area (may present problem for cotton)

Ground-Based Remote Sensing System for Plant Nitrogen Determination (Real-time management)

- Measure spectral reflectance of plant canopy and plant height
- Diagnose plant N status
- Apply what the plant needs "On-the-go"

Ground-Based Remote Sensing
Active Reflectance Sensors

- CropCircle
  2 bands (amber @590nm; NIR @880nm)

- GreenSeeker
  2 bands (red @660nm; NIR @770nm)

- Experimental Unit
  4 bands (blue, green, red, NIR)

Ground-Based Remote Sensing System for Plant Nitrogen Determination

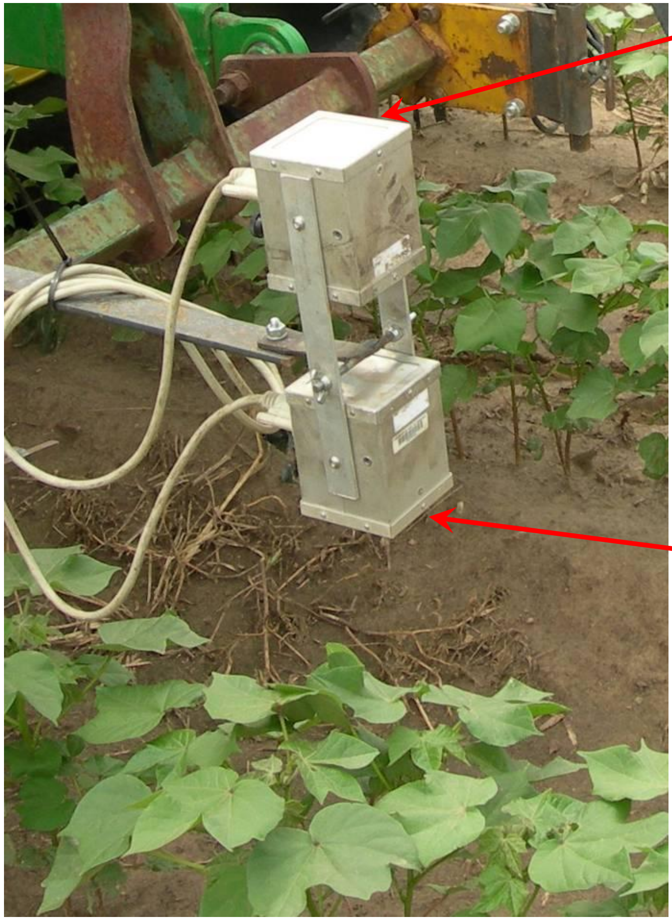
Multi-Spectral Optical Sensor

- Active optical sensor
- Modulated LED light source
- Measure reflectance at four wavebands

<u>Four Wavebands</u>

Blue band
Green band
Red band
NIR band

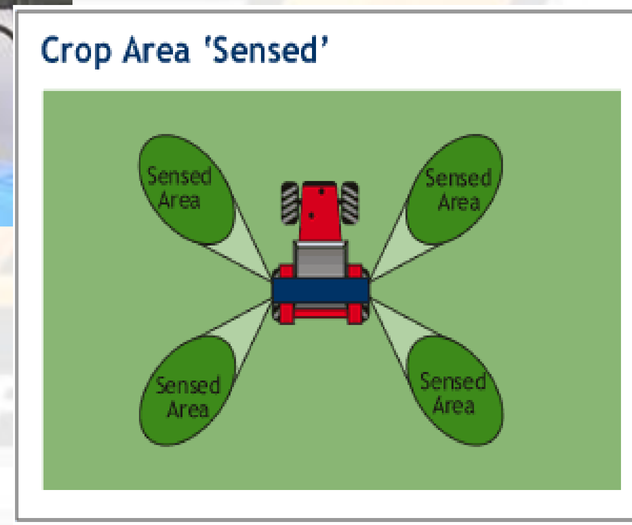
Cropscan passive sensor
uses ambient light (solar)



Multiple sensors (wavelengths) pointing up to measure incoming radiation

Same sensors pointing down to measure reflected radiation

YARA-N-Sensor (Hydro-N)



Initial system was passive, but an active light system has been developed that provides multiple spectral indices.

Images From: http://fert.yara.co.uk/en/crop_fertilization/advice_tools_and_services/n_sensor/index.html

- Reflectance above the row appeared sufficient for corn.
- Do we need another piece of information for cotton?
  - Plant height (may be useful for PGR management)?
  - Between-the-row reflectance?

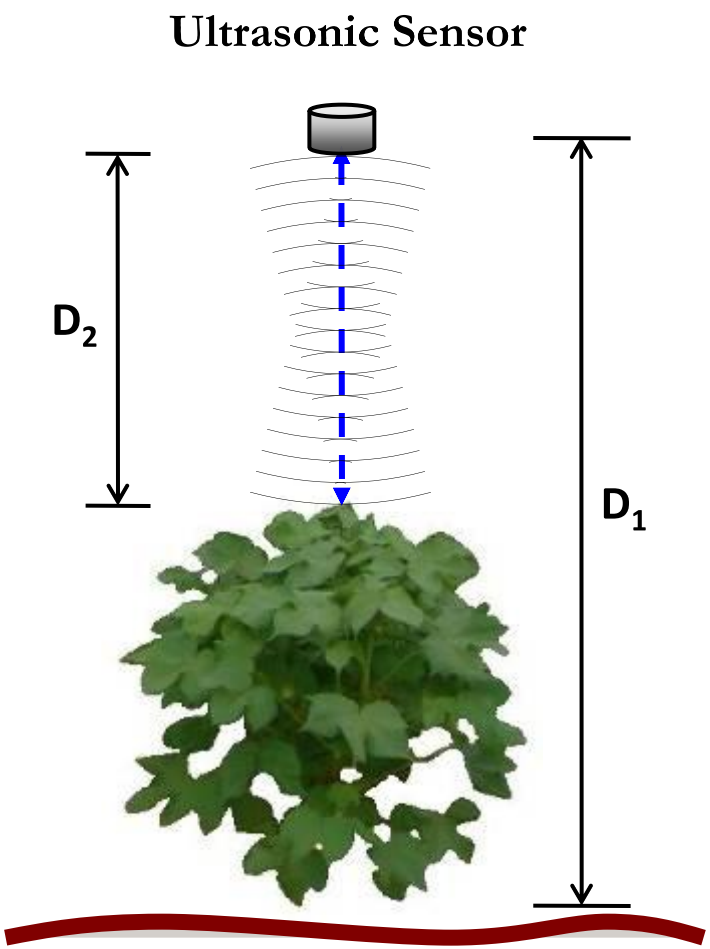
Ground-Based Remote Sensing System for Plant Nitrogen Determination

Ultrasonic sensor for measuring plant height

Polaroid Ultrasonic Sensor
Frequency: 50 KHz;
Beam angle: 12^0;
Temp: -30 – 70 ^{0}C

Univ. of Tenn. has also built ultrasonic sensor

Ground-Based Remote Sensing System for Plant Nitrogen Determination



Sensor transmits ultrasonic pulses toward plant canopy, then waits for the echo to return from the canopy. Distance from the sensor to the canopy (D_2) can be determined based on the speed of sound and the time taken for the ultrasonic pulse to travel the distance from the sensor to the canopy and back to the sensor.

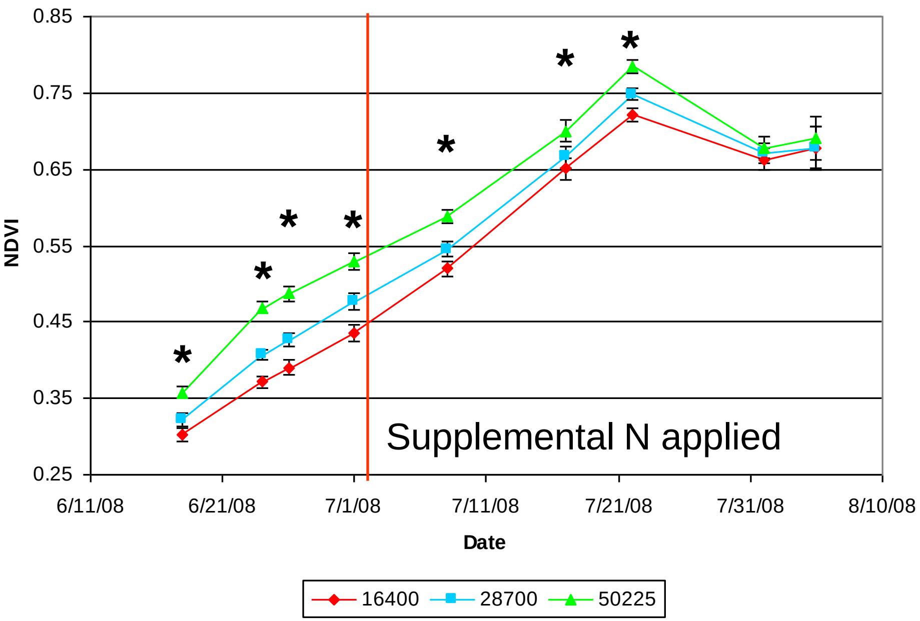
Plant Height = D_1-D_2

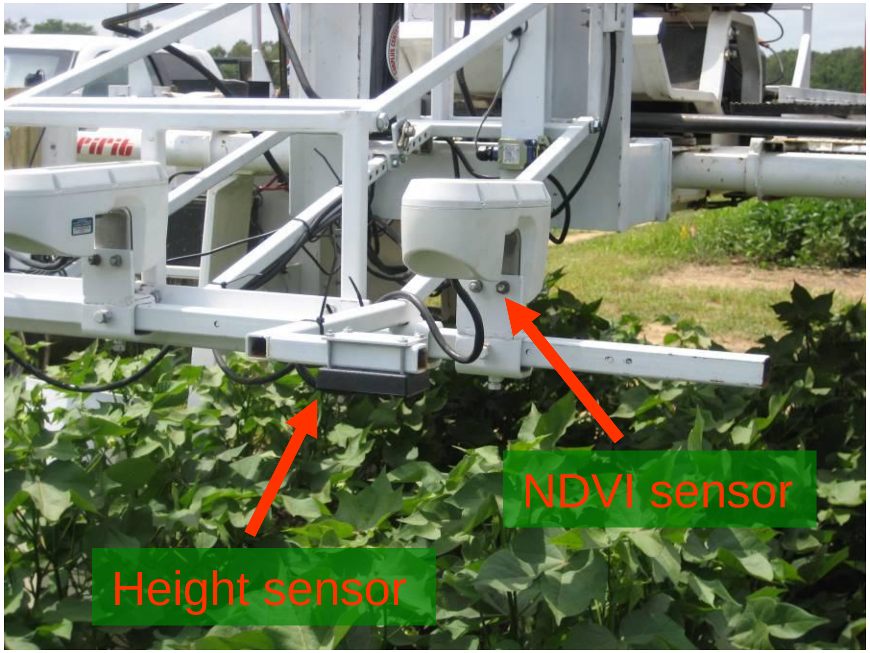
D_1: Known

D_2: Measured

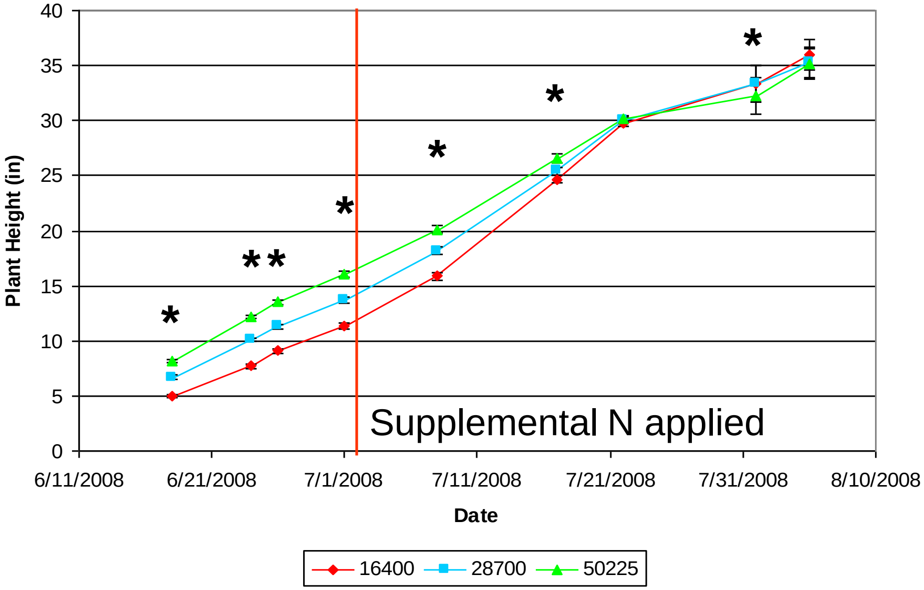
D_2= ½ Time*Sound speed

NDVI differed by plant population

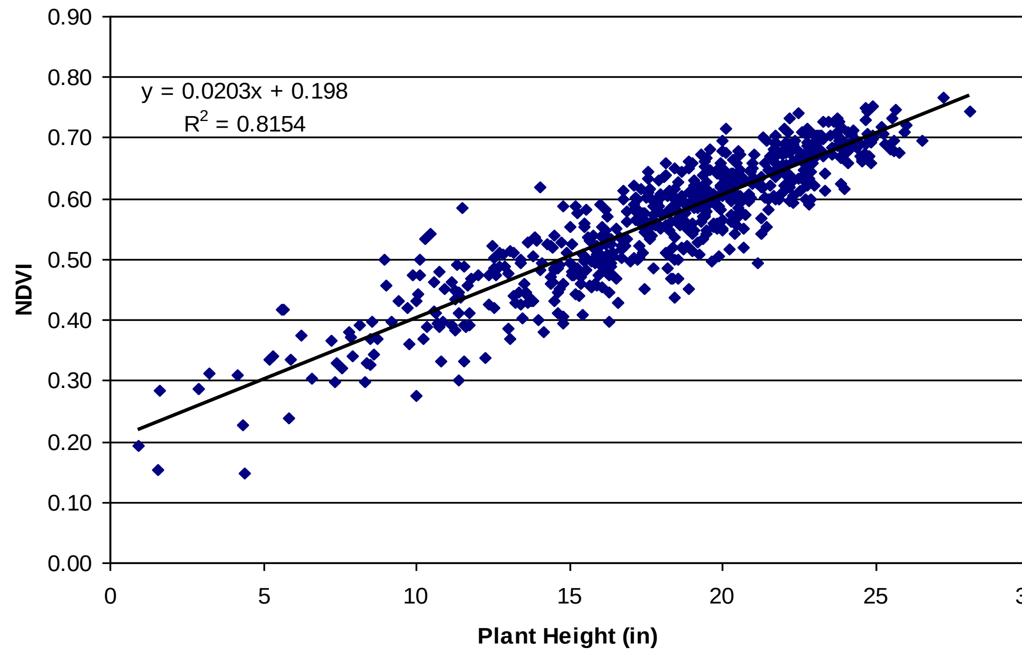




Plant height differed by plant population



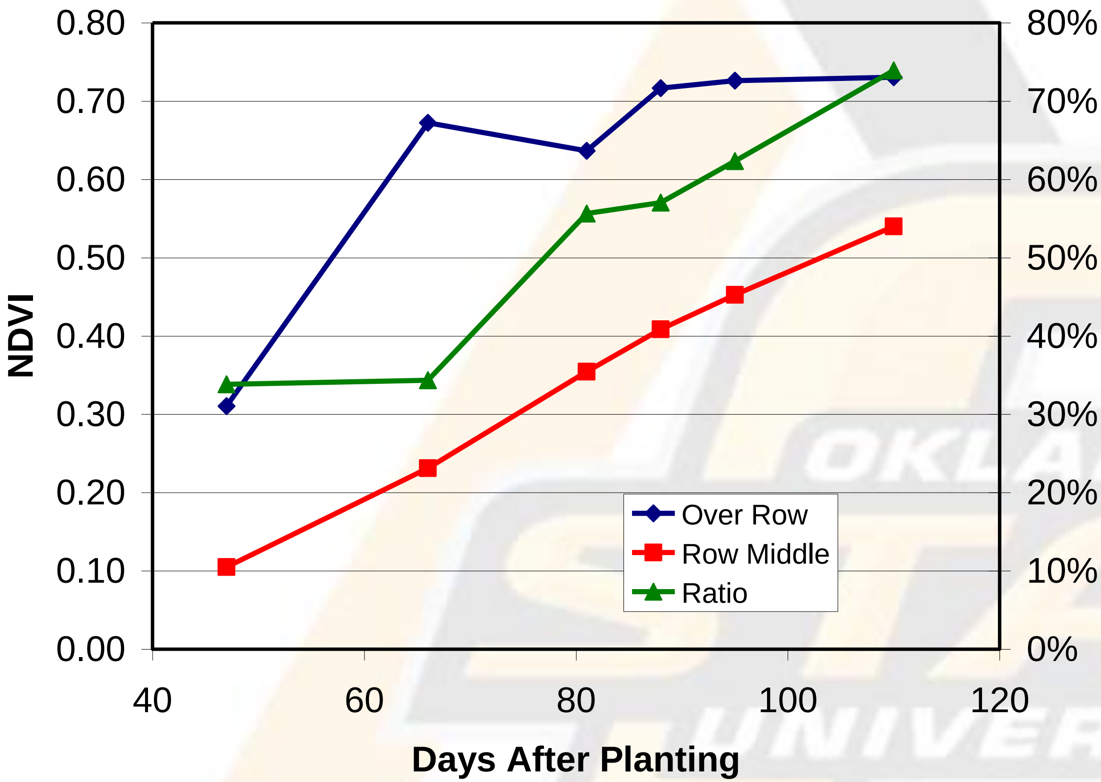
Strong relationship between NDVI and plant height (46 days after planting)



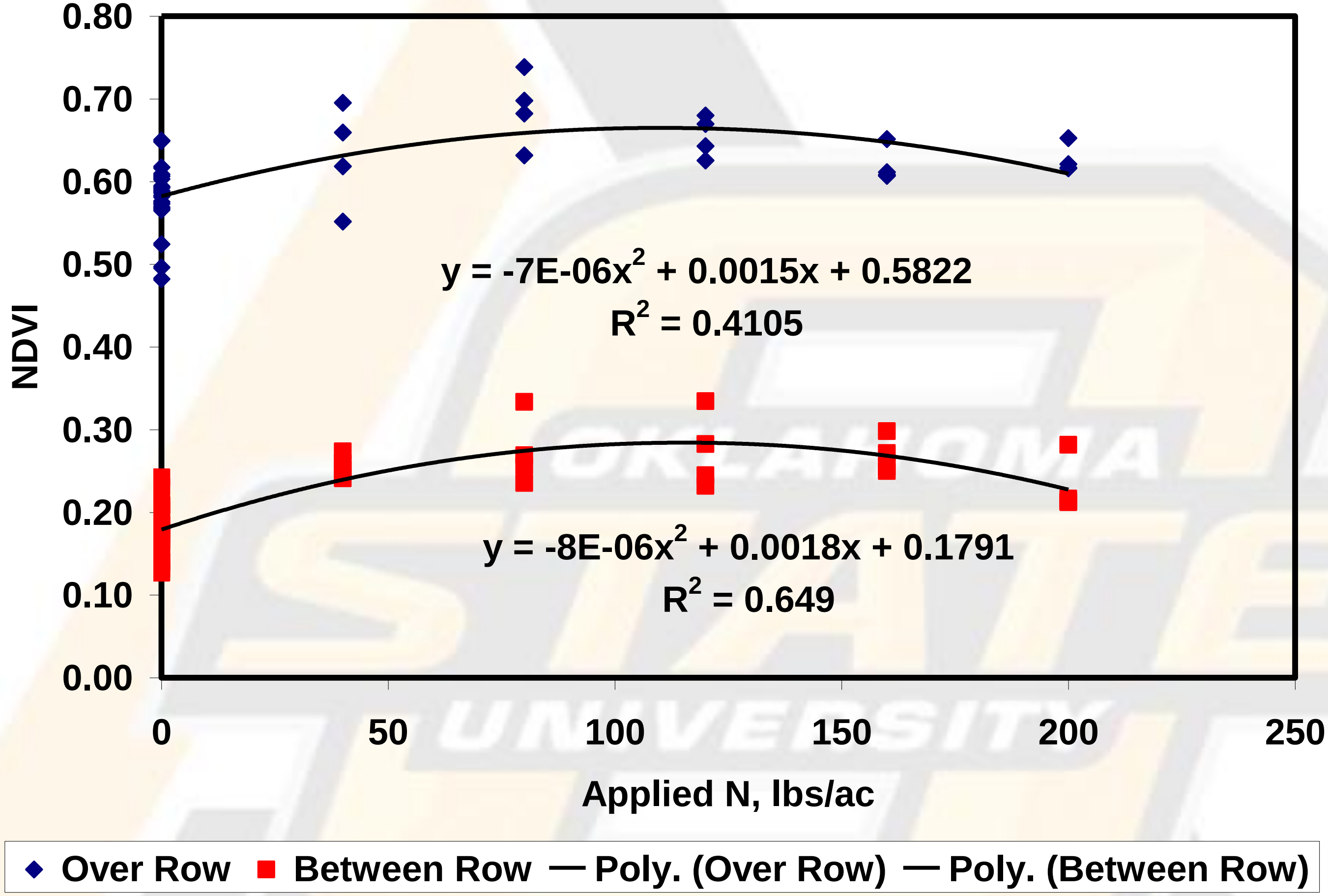
Another Approach for Cotton

- Measuring NDVI ***directly over the row*** with four sensors and ***between the rows*** with three sensors
- Collected data from research plots and farmers’ fields on multiple dates

Estimating Canopy Closure



Sensor Data – July 25



Great deal of on-going work aimed at developing real-time nutrient-management system (especially for nitrogen).

Cotton Incorporated encouraging communication among research teams.

On-farm field-scale nitrogen/sensor demo conducted in Missouri in 2008.

USDA-NRCS Conservation Innovation Grant will allow additional on-farm demonstrations.

An effective, reliable, real-time sensor systems for cotton nitrogen management should be available soon.

Systems for other nutrients will follow.