Agricultural Machinery Conference
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On-the-Go Soil Sensing Technology

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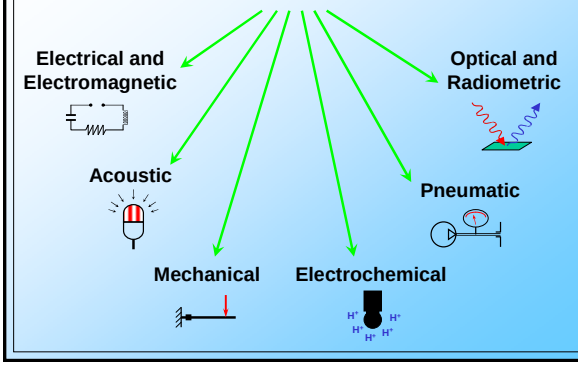
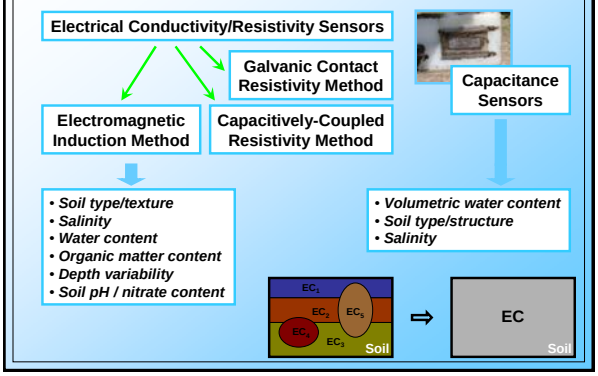
Agenda

- Family of on-the-go soil sensors
- Nebraska examples
  - Deep tillage implement
  - Integrated mapping of soil physical properties
    - Soil mechanical resistance
    - Dielectric characteristics (moisture)
    - Subsurface optical reflectance
  - Integrated agitation chamber module
    - Soil pH
    - Soluble potassium content
    - Residual nitrate content
  - Portable probe for on-the-spot measurements
- Sensor fusion

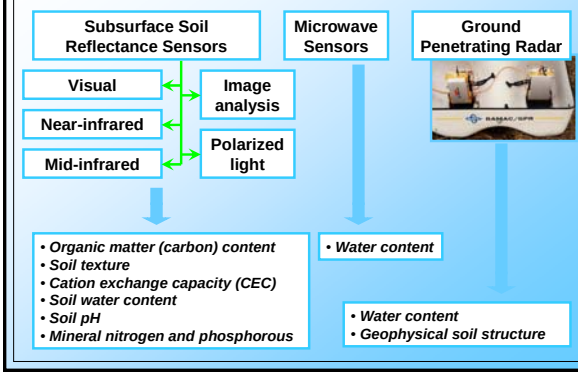
On-the-go Soil Sensors



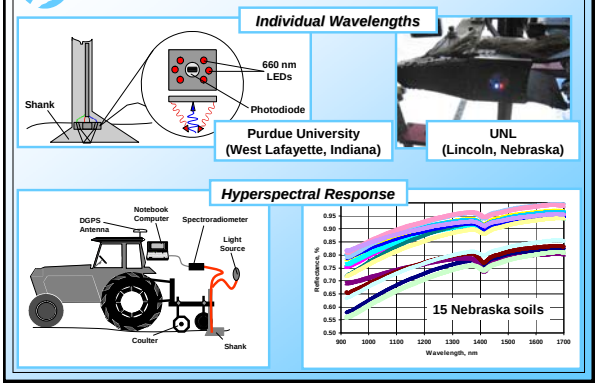
Electrical and Electromagnetic Sensors



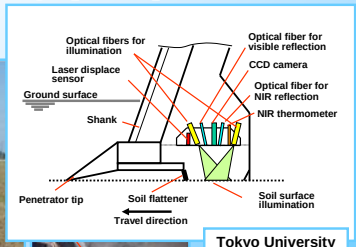
Optical and Radiometric Sensors

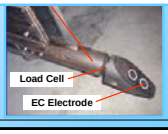


Subsurface Soil Reflectance Sensors



Real-time Soil Mapping with a Traveling Spectrophotometer

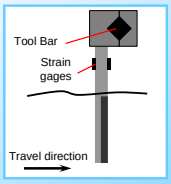




Tokyo University of Agriculture and Technology (Tokyo, Japan)

Mechanical Sensors

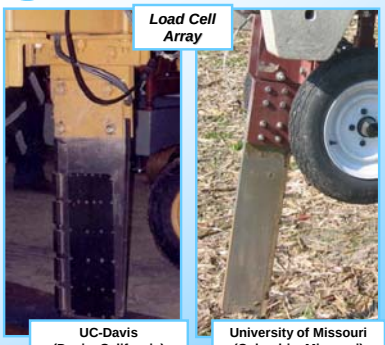
- Single Estimate Sensors
- Profile Assessment Sensors
- Implement Draft Sensors
- Strain Gage Transducers
- Load Cells



- *Soil mechanical resistance*
- *Soil compaction*
- *Water content*
- *Soil types*
- *Depth of hard (plow) pan*
- *Soil-metal friction*

Discrete Depth Profiling Tools

Load Cell Array



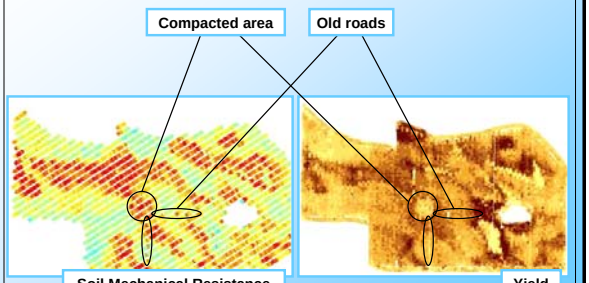
UC-Davis (Davis, California)

University of Missouri (Columbia, Missouri)

Three Cutting Blades

UNL (Lincoln, Nebraska)

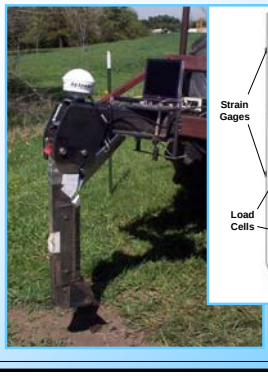
Example Soil Mechanical Resistance Map



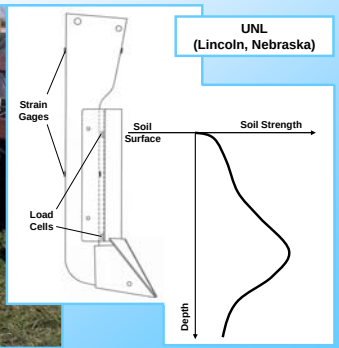
Soil Mechanical Resistance Map (20-30 cm)

Yield Map

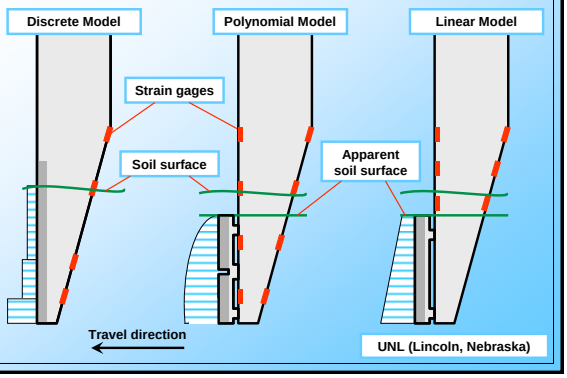
Instrumented Deep-Tillage Implement



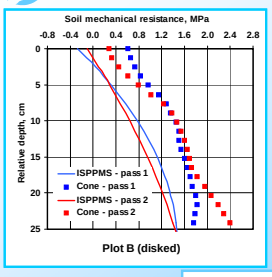
UNL (Lincoln, Nebraska)

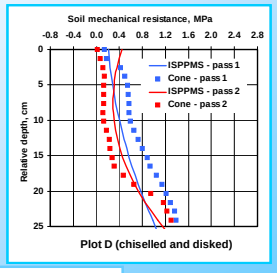


Vertical Blade with Strain Gage Array



Apparent Soil Profiles



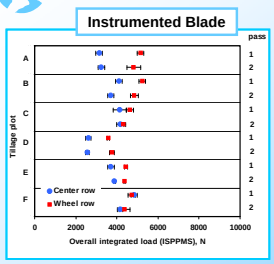


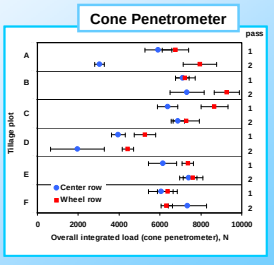
$$p(y) = a_2 y^2 + a_1 y + a_0$$

$$\begin{bmatrix} a_2 \\ a_1 \\ a_0 \end{bmatrix} = \begin{bmatrix} 1.68903*10^{-8} & -7.13568*10^{-8} & 4.24800*10^{-8} \\ -6.78951*10^{-6} & 1.79098*10^{-5} & -6.67377*10^{-6} \\ 6.65388*10^{-4} & -5.51320*10^{-4} & 1.65002*10^{-4} \end{bmatrix} \begin{bmatrix} R_A \\ R_B \\ R_C \end{bmatrix}$$

$$\begin{bmatrix} R_A \\ R_B \\ R_C \end{bmatrix} = \begin{bmatrix} 18.720 & 19.008 & -53.202 & 25.995 \\ -1.5727 & -1.5969 & 37.587 & -39.104 \\ 0.014025 & 0.014241 & 1.0893 & 15.284 \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix}$$

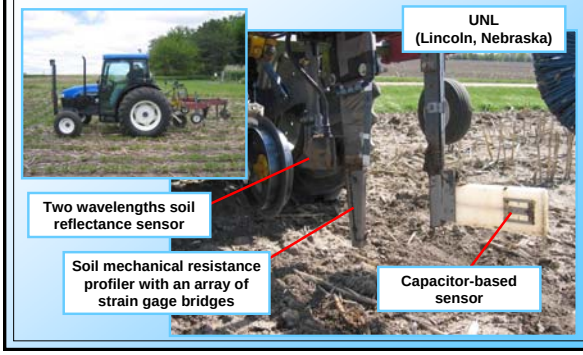
Integrated Load Comparison



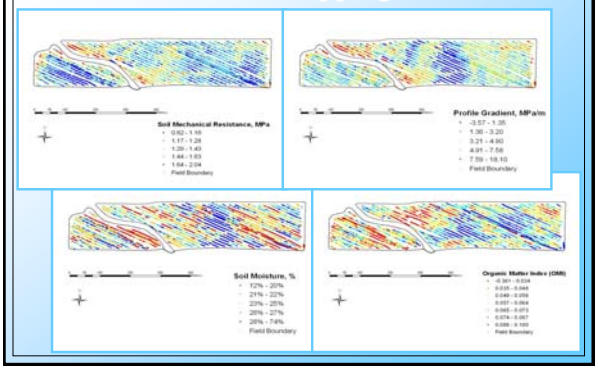


Tillage Plot	Treatment	Tillage Plot	Treatment
A	plowed and double disked	D	chiselled and disked
B	disked	E	double disked
C	no-till with cultivation	F	no-till w/o cultivation

Integrated Soil Physical Properties Mapping System



Integrated Soil Physical Properties Mapping



Acoustic and Pneumatic Sensors

Soil Penetration Noise Sensors

University of Illinois (Urbana-Champaign, Illinois)

- *Soil clay content (type)*
- *Soil compaction*
- *Depth of hard (plow) pan*

Air Permeability Sensor

University of Kentucky (Lexington, Kentucky)

- *Soil structure/tilth*
- *Water content*
- *Soil type*

Electrochemical Sensors

Ion-Selective Electrodes (ISEs)

Ion-Selective Field Effect Transistors (ISFETs)

Soil Solution Measurement

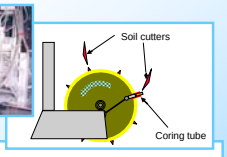
New Automated Methods

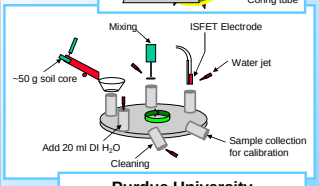
Direct Soil Measurement

Activity of selected ions

- *Soil pH (H^+)*
- *Potassium content (K^+)*
- *Residual nitrogen (NO_3^--N)*
- *Sodium content (Na^+)*

Automated Soil Solution Measurement





Purdue University (West Lafayette, Indiana)

JTI (Uppsala, Sweden)

Mobil Sensor Platform (MSP)

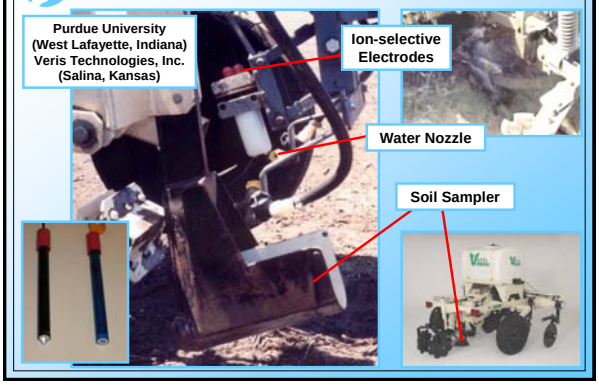
EC Surveyor 3150

Veris Technologies, Inc. (Salina, Kansas)

http://www.veristech.com

Soil pH Manager

Automated Direct Soil Measurement



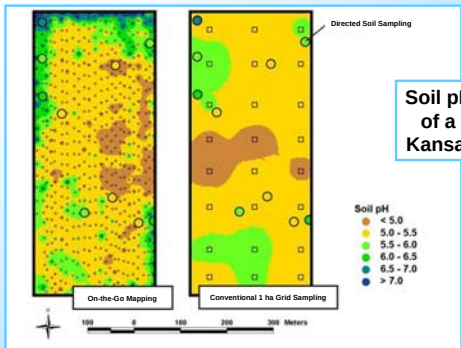
Purdue University (West Lafayette, Indiana) Veris Technologies, Inc. (Salina, Kansas)

Ion-selective Electrodes

Water Nozzle

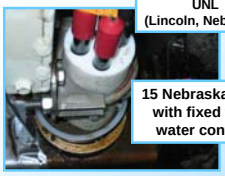
Soil Sampler

Example Soil pH Maps



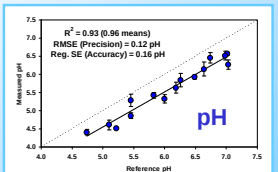
Soil pH Maps of a 24-ha Kansas Field

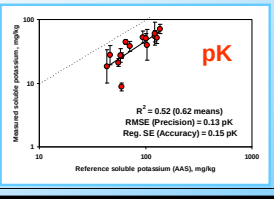
Integrated Direct Soil Measurement

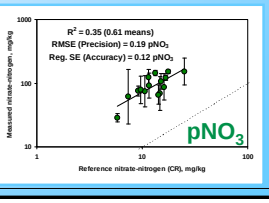


UNL (Lincoln, Nebraska)

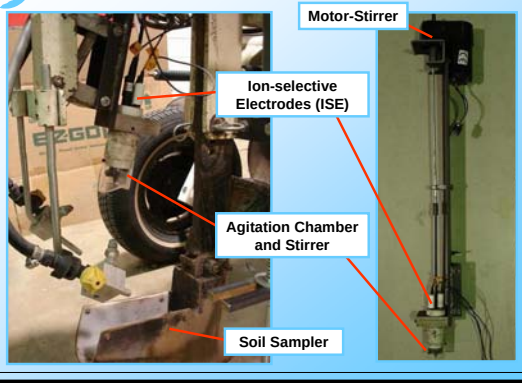
15 Nebraska soils with fixed field water content







Integrated Agitated Soil Measurement



Motor-Stirrer

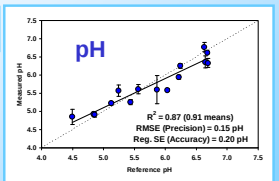
Ion-selective Electrodes (ISE)

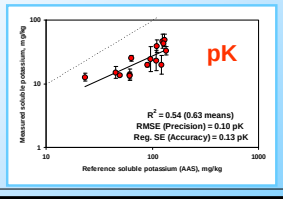
Agitation Chamber and Stirrer

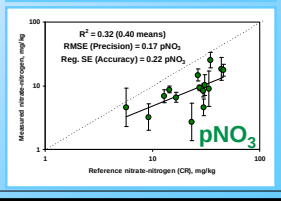
Soil Sampler

Integrated Agitated Soil Measurement

1:1 solutions with 15 Nebraska soils



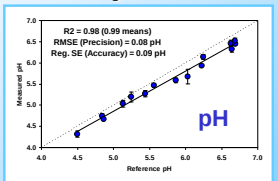


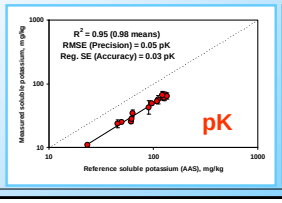


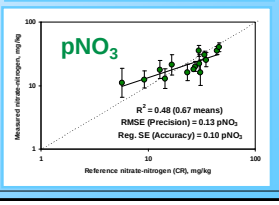
ASM - Laboratory Test

Reference tests:

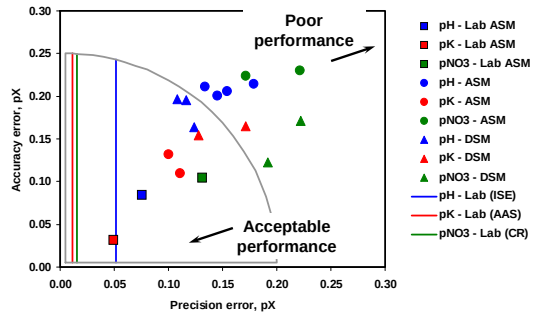
- **Soil pH**
  - glass ion-selective electrode
  - RMSE = 0.05 pH
- **Soluble potassium**
  - atomic adsorption spectroscopy (AAS)
  - RMSE = 0.01 pK
- **Residual nitrate**
  - cadmium reduction (CR)
  - RMSE = 0.02 pNO_3







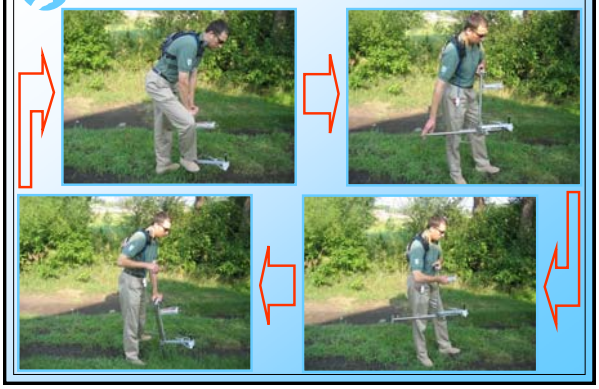
Precision vs. Accuracy Analysis



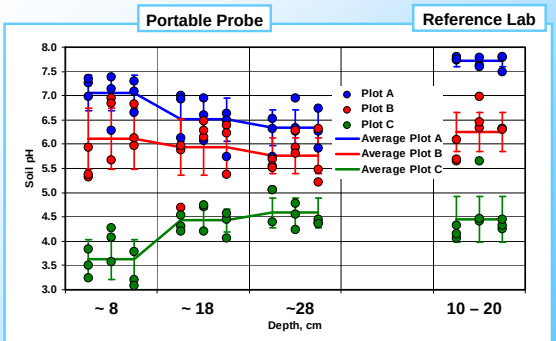
Applicability of On-the-Go Soil Sensors

Soil property					
Soil texture (clay, silt and sand)	Good	OK		Some	
Soil organic matter or total carbon	Some	Good			
Soil water (moisture)	Good	Good			
Soil salinity (sodium)	OK				Some
Soil compaction (bulk density)			Good	Some	
Depth variability (hard pan)	Some		OK	Some	
Soil pH		Some			Good
Residual nitrate (total nitrogen)	Some	Some			OK
Other nutrients (potassium)		Some			OK
CEC (other buffer indicators)	OK	OK			

Portable Probe



On-the-Spot Measurement of Soil pH



Summary

- On-the-go soil sensors can provide high density information about soil properties
- Our ability to map specific agronomic soil attributes remains questionable
- Combining (fusion) different sensors may be beneficial
- New and improved sensors are under development
- Agro-economic evaluation of the value of information is needed

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