AGRI-SENSING 2011 (Haifa, Israel)

On-the-Go Proximal Soil Sensing for Agriculture

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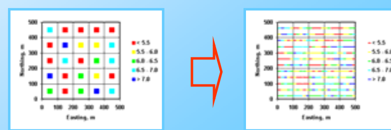
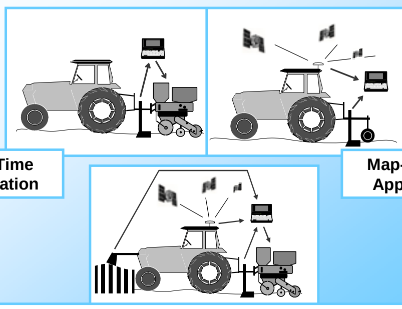
McGill

Problem Statement

- The assessment of soil variability is one of the most important steps in site-specific management
- Conventional means to attain soil variability data are incapable of accurately identifying spatial inconsistency within a production field at an economically feasible cost
- There is a need to develop equipment for mapping soil attributes on-the-go

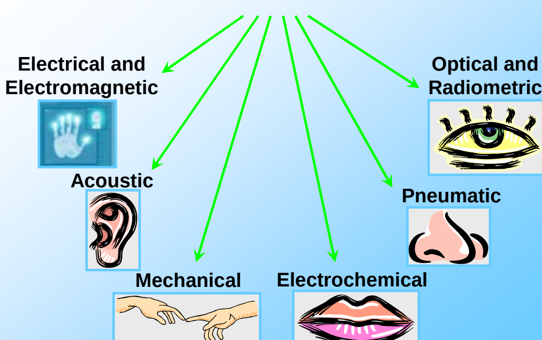


Sensor Use Approaches



Nature of Sensing

On-the-go Proximal Soil Sensors



Electrical end Electromagnetic Sensors

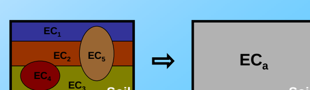
Electrical Conductivity/Resistivity Sensors

- Galvanic Contact Resistivity Method
- Electromagnetic Induction Method
- Capacitively-Coupled Resistivity Method

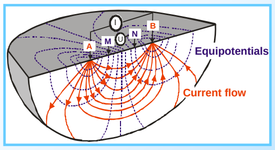
Dielectric Sensors

Magnetic Sensors

Electrical Conductivity/Resistivity Sensors	Dielectric Sensors	Magnetic Sensors
• *Soil type/texture* • *Salinity* • *Water content* • *Organic matter content* • *Depth variability* • *Soil pH / nitrate content*	• *Volumetric water content* • *Soil type/structure* • *Salinity*	• *Subsurface soil impurities* • *Iron*

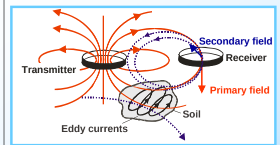


Galvanic Contact Resistivity Method



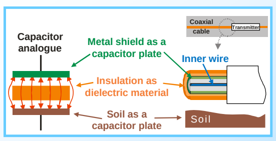
Company	System
Veris Technologies, Inc. (Salina, Kansas) *http://www.veristech.com*	Veris® 3100 and MSP (0.3 and 0.9 m)
Geocarta (Paris, France) *http://www.geocarta.net*	Geocarta ARP (0.5, 1, and 2 m)
Crop Tehchnologies, Inc. (Spring, Texas) *http://www.soildoctor.com*	Soil Doctor® System (real-time approach)

Electromagnetic Induction Method



Company	System
Geonics Limited (Mississauga, Ontario) *http://www.geonics.com*	Geonics EM-38 horizontal – 0.75 m vertical – 1.5 m
Dualem, Inc. (Milton, Ontario) *http://www.dualem.com*	DUALEM – 1S co-planar – 0.4 m perpendicular – 0.95 m

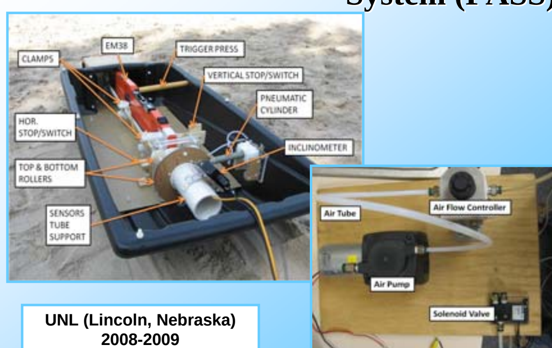
Capacitively-Coupled Resistivity Method



Geometrics, Inc.
(San Jose, California)
http://www.geometrics.com

Geometrix OhmMapper TR1

Pneumatic Angular Scanning System (PASS)

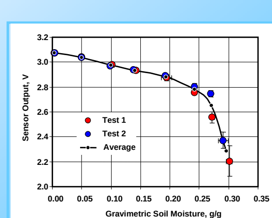


UNL (Lincoln, Nebraska)
2008-2009

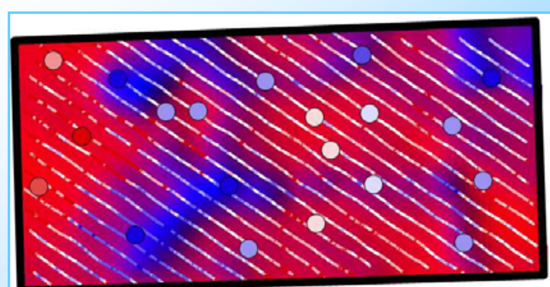
Dielectric Sensor

UNL (Lincoln, Nebraska) – Retrokool (Berkeley, California)
2001-2003

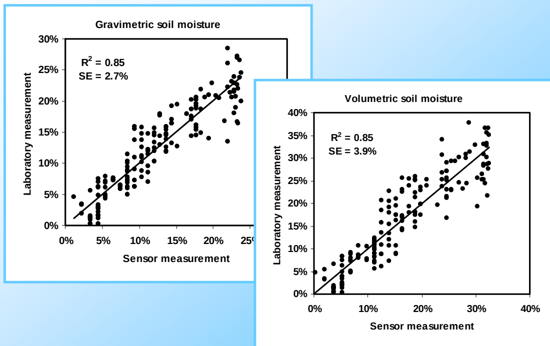
- Silty clay loam soil
- Triple replicates
- Two tests



Dielectric Sensor Map



Soil Water Content



Optical and Radiometric Sensors

Subsurface Soil Reflectance Sensors

- Visual
- Near-infrared
- Mid-infrared

Image analysis

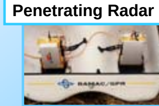
Polarized light

- *Organic matter (carbon) content*
- *Soil texture*
- *Cation exchange capacity (CEC)*
- *Soil water content*
- *Soil pH*
- *Mineral nitrogen and phosphorous*

Microwave Sensors

- *Water content*

Ground Penetrating Radar



- *Water content*
- *Geophysical soil structure*

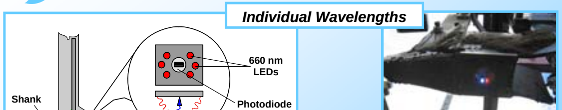
Gamma Radiometer

- *Potassium*
- *Uranium*
- *Thorium*

Small Scale Topography

Subsurface Soil Reflectance Sensors

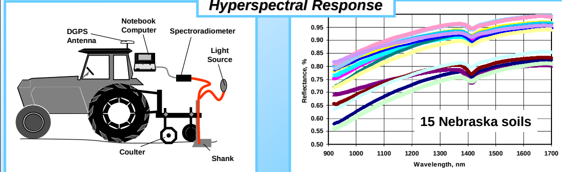
Individual Wavelengths



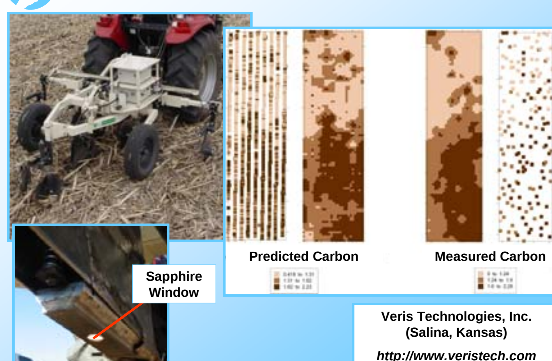
Purdue University (West Lafayette, Indiana)

UNL (Lincoln, Nebraska)

Hyperspectral Response



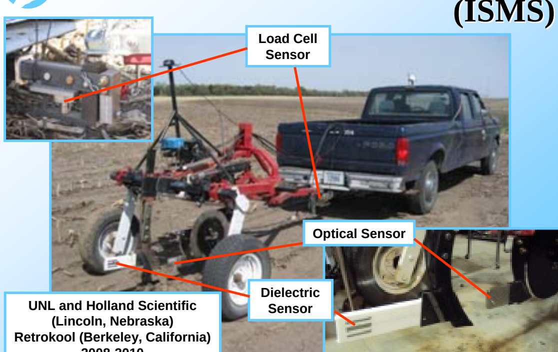
VIS/NIR Spectrophotometer



Veris Technologies, Inc. (Salina, Kansas)

http://www.veristech.com

Integrate Soil Mapping System (ISMS)



UNL and Holland Scientific (Lincoln, Nebraska)
Retrokool (Berkeley, California)
2008-2010

Mechanical Sensors

Soil strength sensors

- Draft and vertical force sensors
  - Bulk soil strength sensors
  - Vertically actuated sensors
- Soil profile sensors
  - Tip-based sensors
  - Tine-based sensors

Vertically-operated cone penetrometers

Single-tip horizontal sensors

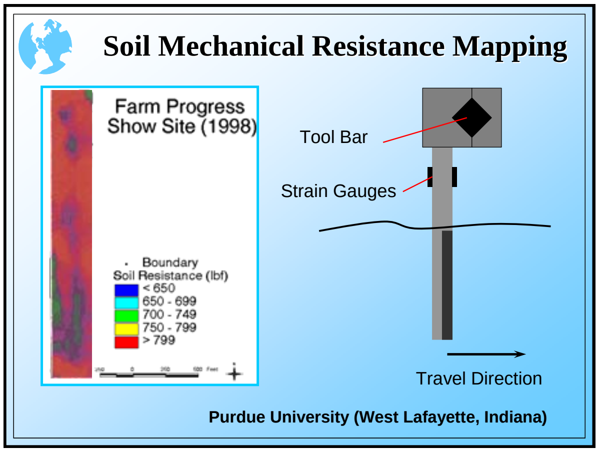
Multiple-tip horizontal sensors

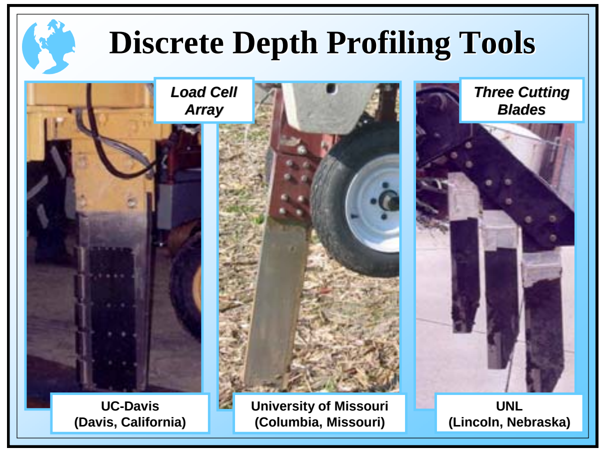
Vertically oscillating sensors

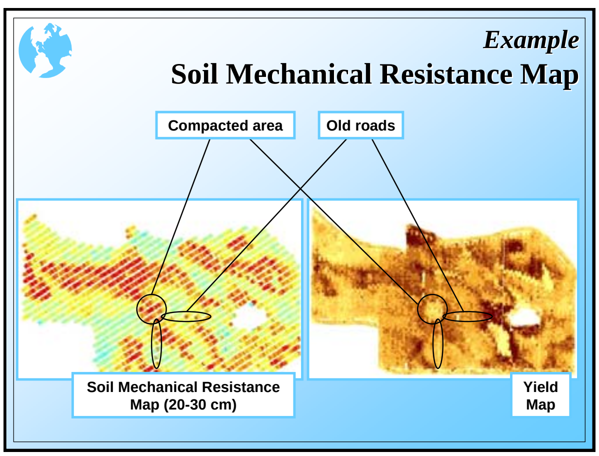
Cantilever beam sensors

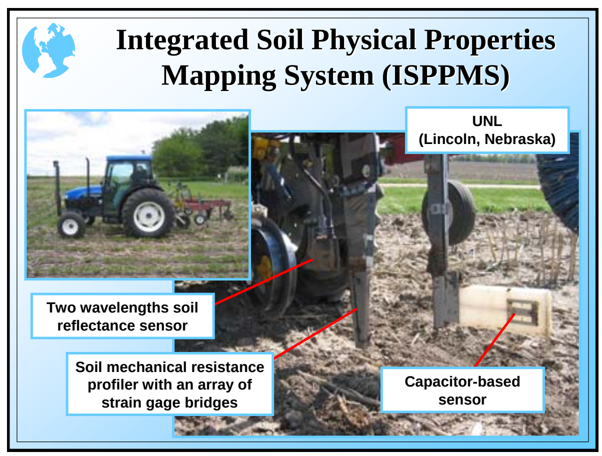
Direct load sensors

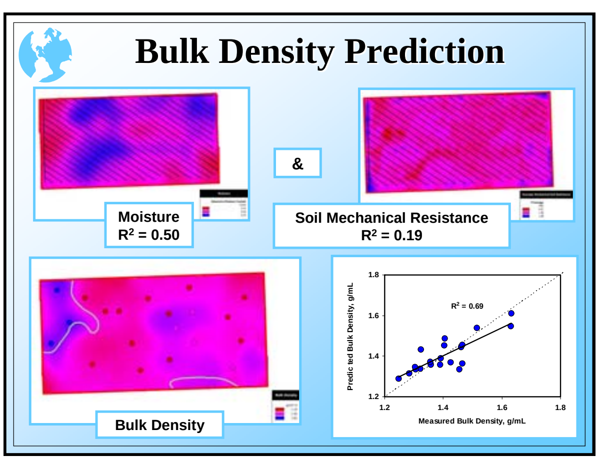
- *Soil mechanical resistance*
- *Soil compaction*
- *Water content*
- *Soil types*
- *Depth of hard (plow) pan*

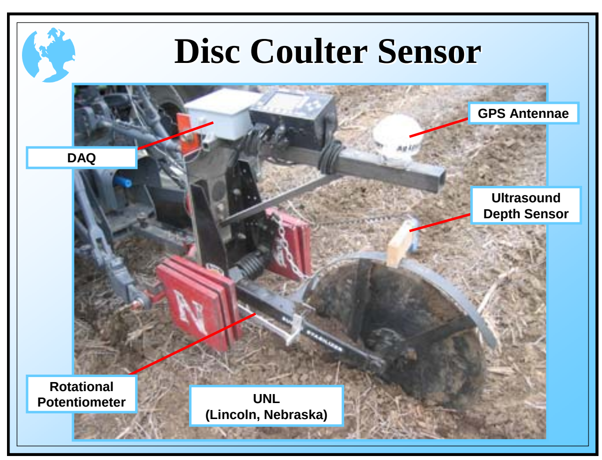

Soil Mechanical Resistance Mapping
Farm Progress Show Site (1998)
Boundary
Soil Resistance (lbf)
< 650
650 - 699
700 - 749
750 - 799
> 799
Tool Bar
Strain Gauges
Travel Direction
Purdue University (West Lafayette, Indiana)

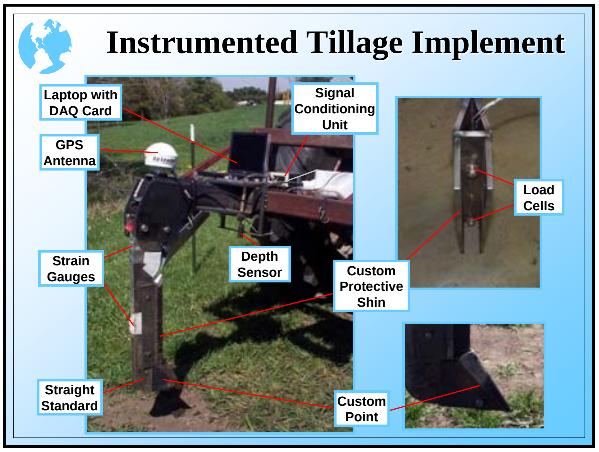

Discrete Depth Profiling Tools
Load Cell Array
Three Cutting Blades
UC-Davis
(Davis, California)
University of Missouri
(Columbia, Missouri)
UNL
(Lincoln, Nebraska)

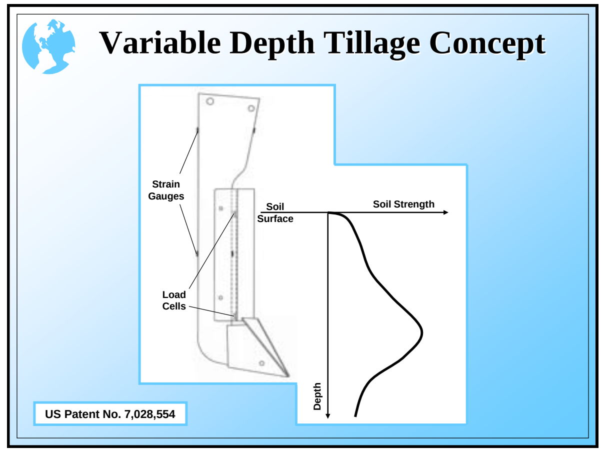

Example
Soil Mechanical Resistance Map
Compacted area
Old roads
Soil Mechanical Resistance Map (20-30 cm)
Yield Map

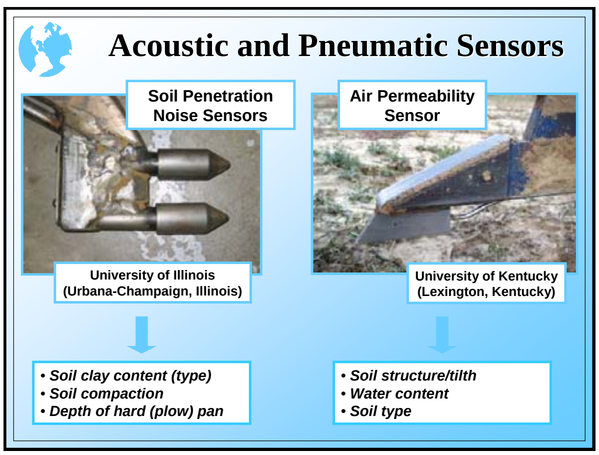

Integrated Soil Physical Properties Mapping System (ISPPMS)
UNL
(Lincoln, Nebraska)
Two wavelengths soil reflectance sensor
Soil mechanical resistance profiler with an array of strain gage bridges
Capacitor-based sensor

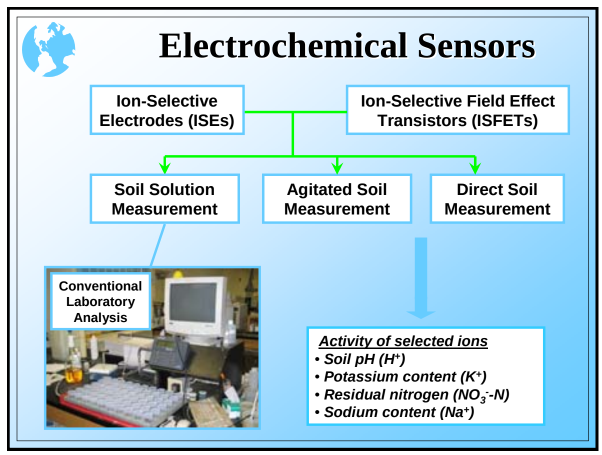

Bulk Density Prediction
Moisture
R² = 0.50
&
Soil Mechanical Resistance
R² = 0.19
Bulk Density
R² = 0.69
Predicted Bulk Density, g/mL
Measured Bulk Density, g/mL

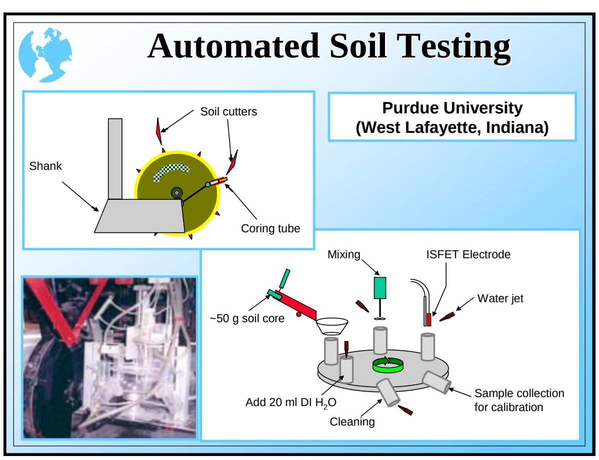

Disc Coulter Sensor
GPS Antennae
DAQ
Ultrasound Depth Sensor
Rotational Potentiometer
UNL
(Lincoln, Nebraska)

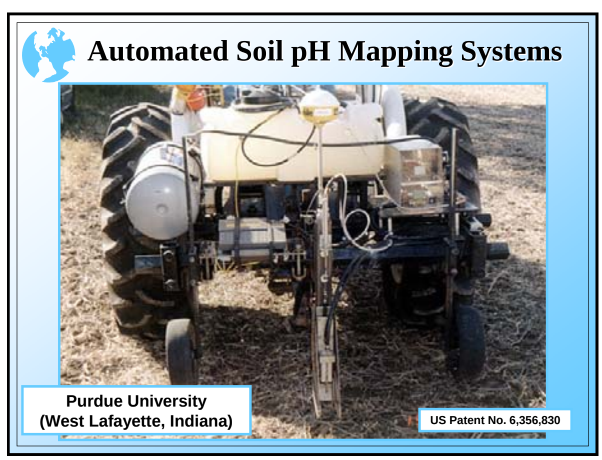

Instrumented Tillage Implement
Laptop with DAQ Card
Signal Conditioning Unit
GPS Antenna
Load Cells
Strain Gauges
Depth Sensor
Custom Protective Shin
Straight Standard
Custom Point

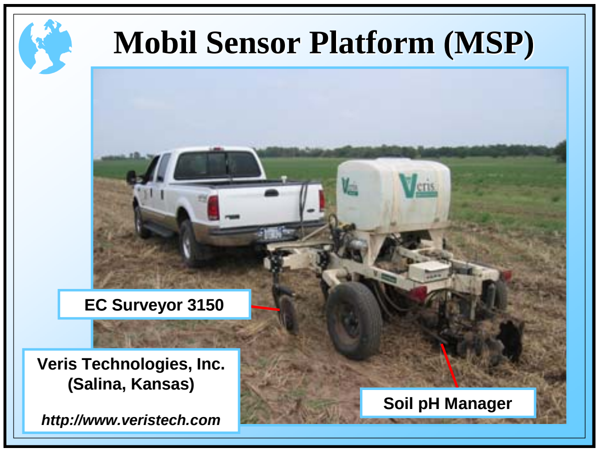

Variable Depth Tillage Concept
Strain Gauges
Load Cells
Soil Surface
Soil Strength
Depth
US Patent No. 7,028,554

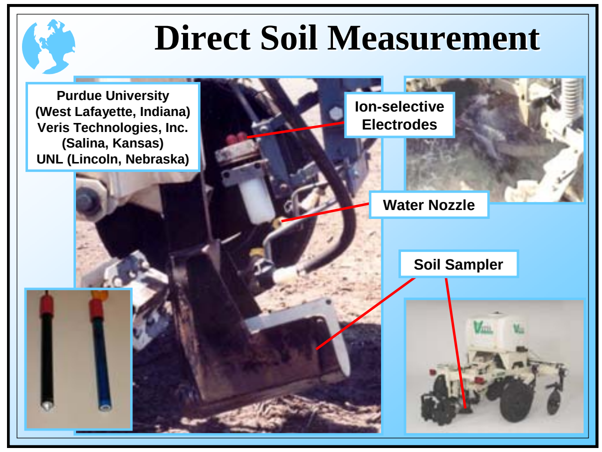

Acoustic and Pneumatic Sensors
Soil Penetration Noise Sensors
Air Permeability Sensor
University of Illinois (Urbana-Champaign, Illinois)
University of Kentucky (Lexington, Kentucky)
• Soil clay content (type)
• Soil compaction
• Depth of hard (plow) pan
• Soil structure/tilth
• Water content
• Soil type

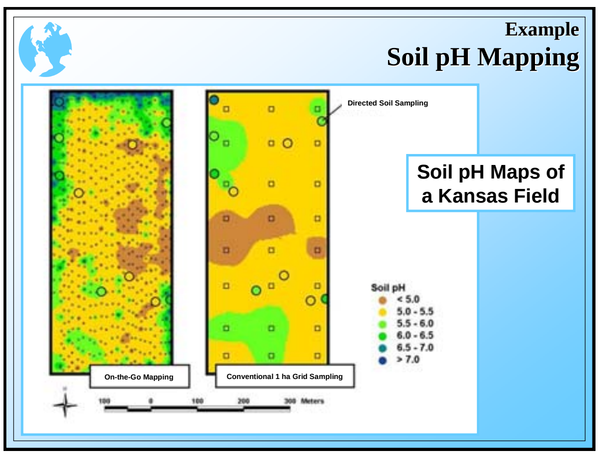

Electrochemical Sensors
Ion-Selective Electrodes (ISEs)
Ion-Selective Field Effect Transistors (ISFETs)
Soil Solution Measurement
Agitated Soil Measurement
Direct Soil Measurement
Conventional Laboratory Analysis
Activity of selected ions
• Soil pH (H^+)
• Potassium content (K^+)
• Residual nitrogen (NO_3^--N)
• Sodium content (Na^+)

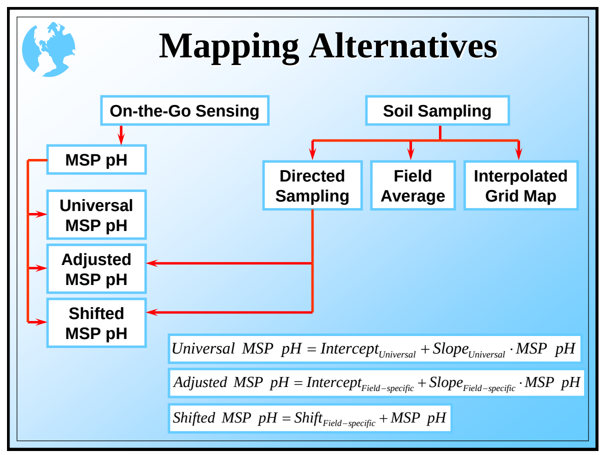

Automated Soil Testing
Purdue University (West Lafayette, Indiana)
Soil cutters
Shank
Coring tube
Mixing
ISFET Electrode
Water jet
~50 g soil core
Add 20 ml DI H_2O
Cleaning
Sample collection for calibration

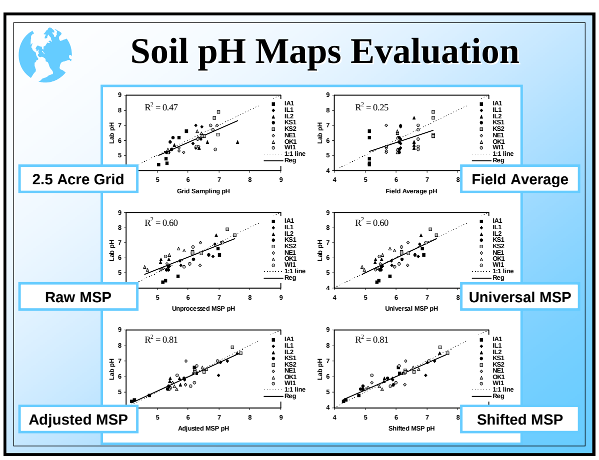

Automated Soil pH Mapping Systems
Purdue University (West Lafayette, Indiana)
US Patent No. 6,356,830

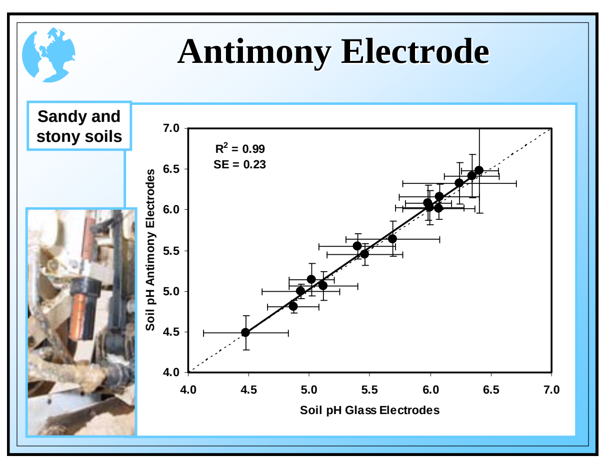

Mobil Sensor Platform (MSP)
EC Surveyor 3150
Veris Technologies, Inc.
(Salina, Kansas)
http://www.veristech.com
Soil pH Manager


Direct Soil Measurement
Purdue University
(West Lafayette, Indiana)
Veris Technologies, Inc.
(Salina, Kansas)
UNL (Lincoln, Nebraska)
Ion-selective
Electrodes
Water Nozzle
Soil Sampler

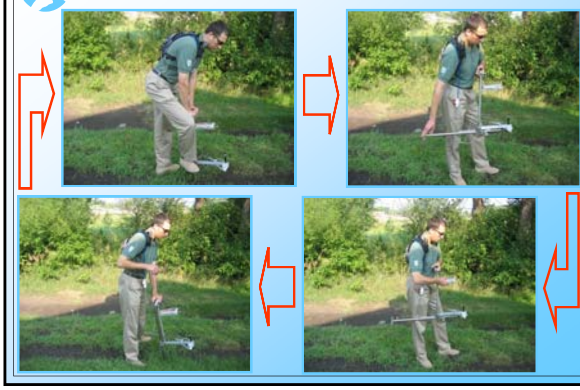

Example
Soil pH Mapping
Directed Soil Sampling
Soil pH Maps of
a Kansas Field
Soil pH
< 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
> 7.0
On-the-Go Mapping
Conventional 1 ha Grid Sampling
100
0
100
200
300
Meters


Mapping Alternatives
On-the-Go Sensing
Soil Sampling
MSP pH
Directed
Sampling
Field
Average
Interpolated
Grid Map
Universal
MSP pH
Adjusted
MSP pH
Shifted
MSP pH
$Universal\ \ MSP\ \ pH = Intercept_{Universal} + Slope_{Universal} \cdot MSP\ \ pH$
$Adjusted\ \ MSP\ \ pH = Intercept_{Field-specific} + Slope_{Field-specific} \cdot MSP\ \ pH$
$Shifted\ \ MSP\ \ pH = Shift_{Field-specific} + MSP\ \ pH$

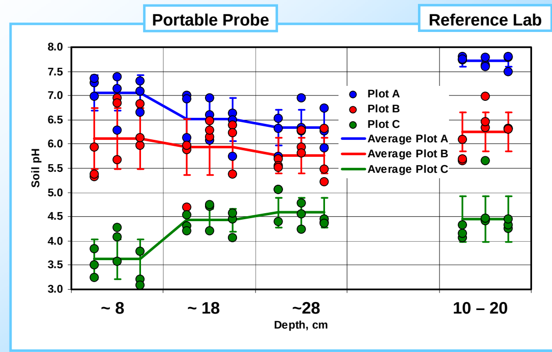

Soil pH Maps Evaluation
2.5 Acre Grid
Field Average
Raw MSP
Universal MSP
Adjusted MSP
Shifted MSP
R² = 0.47
R² = 0.25
R² = 0.60
R² = 0.60
R² = 0.81
R² = 0.81
Grid Sampling pH
Field Average pH
Unprocessed MSP pH
Universal MSP pH
Adjusted MSP pH
Shifted MSP pH
Lab pH


Antimony Electrode
Sandy and
stony soils
R² = 0.99
SE = 0.23
Soil pH Antimony Electrodes
Soil pH Glass Electrodes
4.0
4.5
5.0
5.5
6.0
6.5
7.0

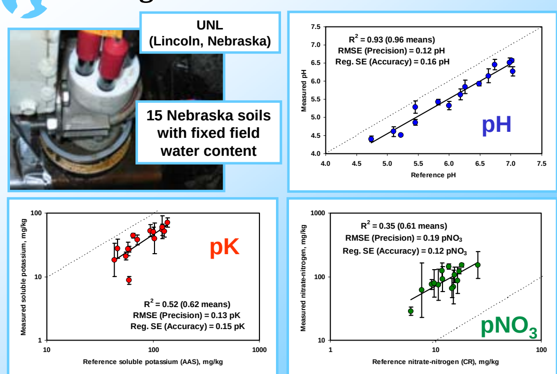
Portable Probe



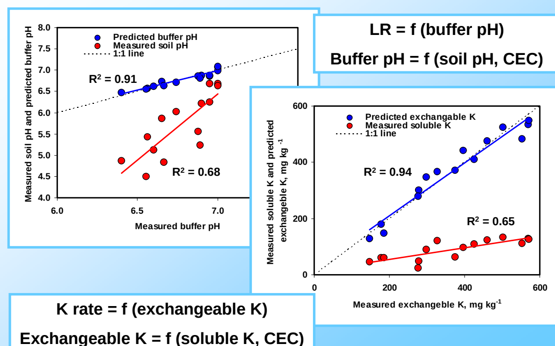
On-the-Spot Measurement of Soil pH



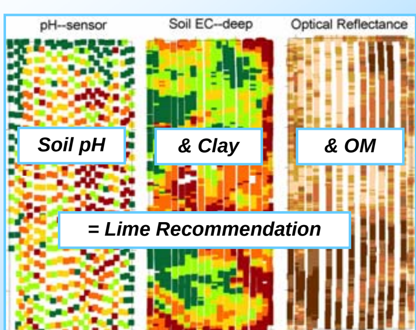
Integrated Direct Soil Measurement



VRT Prescription



Integrated Multiple Data Layers



Maps produced by Veris Technologies, Inc. (Salina, Kansas)

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			

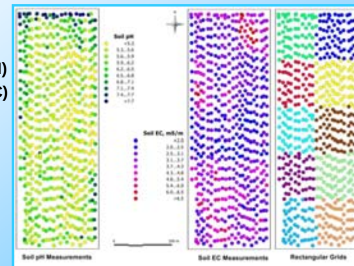
Targeted Soil Sampling

- Directed sampling should be used to calibrate and/or validate sensor data
- Directed samples should be collected from relatively homogeneous field areas away from the boundary and other transitional areas
- Directed samples should cover the entire range of sensor-based measurements, especially toward low and high ends
- Directed samples should be physically spread across the entire field
- It should be possible to process multiple sensor-based data layers

Objective Function

$$OF = \sqrt[5]{S_{opt} \cdot D_{opt-pH} \cdot D_{opt-EC} \cdot H_{cr-pH} \cdot H_{cr-EC}}$$

- S-optimality
- D-optimality (soil pH)
- D-optimality (soil EC)
- H-criteria (soil pH)
- H-criteria (soil EC)



Summary

- On-the-go soil sensors can provide high density information about soil properties
- Many sensor approaches are past initial commercialization stage
- Sensor fusion provides the ability to separate various agronomic effects
- Site-specific sensor calibration and validation are essential steps of the mapping process
- Laboratory soil analysis remains a required supplementary practice

http://bse.unl.edu/adamchuk
E:mail: viacheslav.adamchuk@mcgill.ca