Implementation of Precision Agriculture
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ECPA

Development of Soil pH and Lime Requirement Maps Using On-the-Go Soil Sensors

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Presentation Outline

- Background
  - Problem statement and history of sensor development
  - Principle of commercial on-the-go mapping of soil pH
- Materials and Methods
  - Evaluation of alternative mapping approaches
  - Determination of lime requirement
- Results and Discussion
  - Comparison of alternative soil pH measurements and lime requirement estimates
  - Lessons learned from mapping several thousand hectares
  - On-the-spot measurement of soil pH
  - Summary and future development

Problem Statement

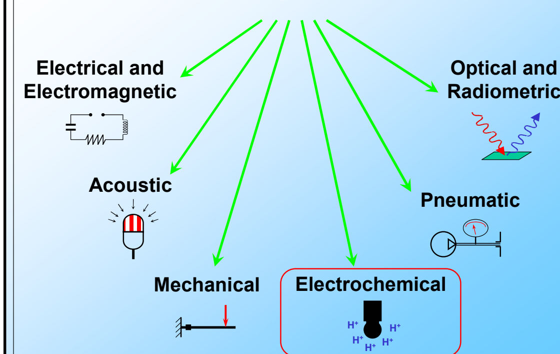
"Soil pH varied from 5.4 to 8.0 over distances of about 150 m in most transects. In some sections soil pH varied about 2 pH units over a 12 m distance…"
Bianchini and Mallarino (2002) Agronomy Journal 94(6):1355-1366

"It was concluded that a grid spacing of 30 m or less would be required to adequately assess the spatial variation of STP, STK, and soil pH. Sampling at this intensity would require approximately 11 times as many soil samples as the commonly used 100-m grid."
Lauzon et al. (2005) Agronomy Journal 97:524-532

"Data points from large grids were too far apart to provide much information about the nature of pH or lime requirement change between adjacent sampling locations."
Brouder et al. (2005) SSSA Journal 69:427-441

There is a need for on-the-go soil pH sensing technology

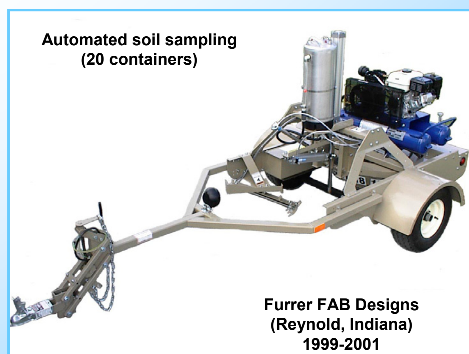
On-the-go Soil Sensors



Conventional Soil Sampling

- Random
- Grid (Systematic) Sampling
  - Grid Point (Cluster) Method
    - Regular (Center) ← 1 ha grid is the most common in US
    - Staggered and Random Start
    - Systematic Unaligned
    - Random
  - Grid Cell Method
- Adaptive
  - By Soil Types
  - By Management Zones

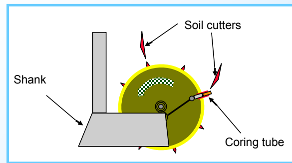
The Air Probe$_{TM}$



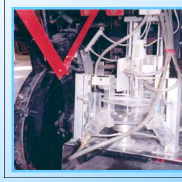
Standard Soil pH Test

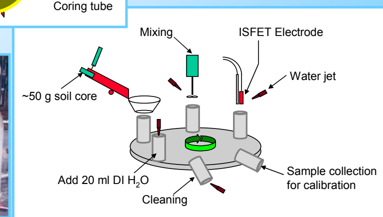
- Preparation (drying, crushing, sieving)
- Solution
  - 1:1 soil/water solution
- Extraction
  - DI water (soil pH)
  - SMP or Woodruff buffer solution (buffer pH)
- Measurement
  - Ion-selective electrode
  - Glass bulb

Automated Soil Testing



Purdue University
(West Lafayette, Indiana)
1994-1996





Direct Soil Measurement

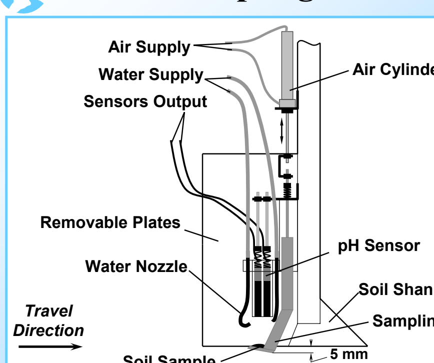
- Preparation
  - Field conditions
- Solution
  - Naturally moist soil
- Extraction
  - Available ion activity
- Measurement
  - Ion-selective electrode
  - Flat (or dome) surface

Automated Soil pH Mapping Systems

Purdue University
(West Lafayette, Indiana)
1997-2000

US Patent No. 6,356,830

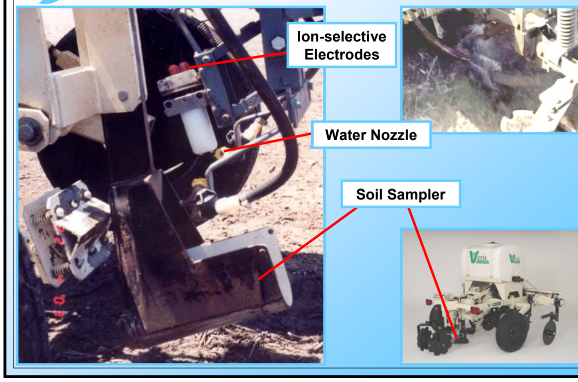
Soil Sampling Mechanism



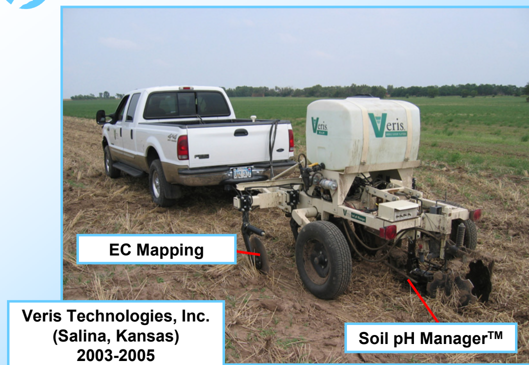
Pre-Commercial Sensor Development

Veris Technologies, Inc.
(Salina, Kansas)
2001-2003

Soil Sampling Mechanism

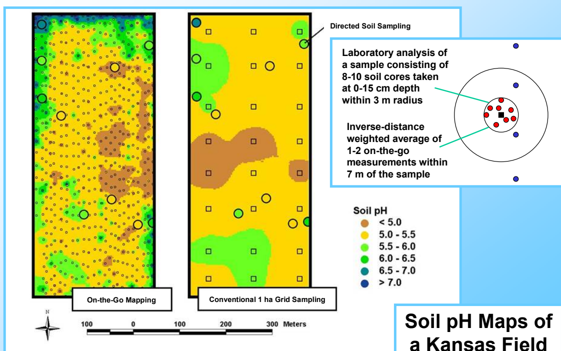


Mobil Sensor Platform (MSP)



Evaluation

On-the-Go Soil pH Mapping



Soil pH Maps of a Kansas Field

Evaluation

Lime Requirement Prescription

Conventional Methods

- Uniform lime application rate based on the average of buffer pH measurements in a commercial laboratory
- Variable rate liming based on conventional 1 ha grid soil sampling results processed using the inverse-distance second-power interpolation

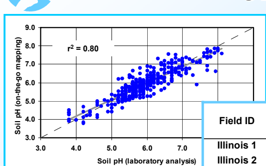
On-the-Go Methods

- Simple linear regression used to define buffer pH as a function of:
  – soil pH measurements only
  – linear combination of soil pH and shallow (0-30 cm) electrical conductivity measurements
  – locally-weighted partial least squares regression analysis of soil pH, electrical conductivity and hyper-spectral reflectance measurements

Validation - Samples obtained using a 1 ha grid pattern were used to validate lime requirement maps based on sensor data. Ten directed soil samples from each field were used to determine buffer pH prediction equations and to validate conventional liming strategies. The RMSE (root MSE) was calculated for each field and served as the major indicator of map quality.

Results

On-the-Go Soil pH Mapping



Field ID	Area, ha	Number of measurements		r^2	RMSE, pH
		On-the-go	Manual		
Illinois 1	30	260	10	0.76	0.30
Illinois 2	22	184	10	0.65	0.51
Illinois 3	30	272	10	0.85	0.36
Iowa	12	107	37	0.76	0.39
Kansas 1	20	598	34	0.76	0.34
Kansas 2	15	706	67	0.63	0.39
Kansas 3	32	456	10	0.86	0.33
Kansas 4	47	791	10	0.74	0.30
Kansas 5	32	333	15	0.78	0.28
Kansas 6	25	250	15	0.77	0.33
Kansas 7	10	199	26	0.77	0.39
Nebraska 1	30	286	42	0.40	0.41
Nebraska 2	11	250	22	0.42	0.55
Wisconsin	13	260	24	0.71	0.55
Overall	329	4952	332	0.80	0.38

Mapping Density

- 15 measurement/ha for on-the-go mapping
- 1 sample/ha for manual grid sampling

Results

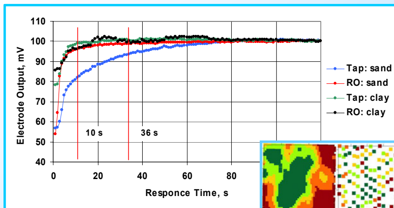
Lime Requirement Prescription

Field ID	Number of validation samples	Root mean squared error (RMSE), kg/ha			
		Uniform liming	Grid sampling	On-the-go mapping	
				pH only	pH and EC
Kansas 1	10 / 32	3550	3085	1117 UG	797 UGP
Kansas 2	10 / 57	1930	1745	1470	1450
Nebraska 2	10 / 12	2527	2088	2701	1120 UGP
Wisconsin	10 / 14	2900	2781	1400 UG	1444 UG
Overall	40 / 89	2857	2506	1354 UG	1259 UG

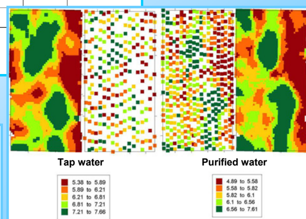
RMSE values are shown for reference only, all comparisons were done using F-statistic performed on the estimates of error variance (MSE)
U – significant ($\alpha = 0.05$) decrease of MSE compared to the uniform liming
G – significant ($\alpha = 0.05$) decrease of MSE compared to the grid sampling
P – significant ($\alpha = 0.05$) decrease of MSE compared to the on-the-go mapping of pH only

Kansas 1 field was mapped using a near-infrared spectrometer sensor in addition to the pH and EC maps. Lime requirement map generated based on the three sensors had further reduced RMSE (643 kg/ha)

Additional Observations
Rinsing Water Quality

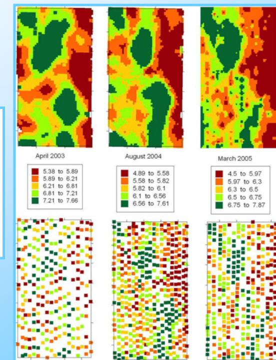


1. In coarse sands, pH electrode response is typically slower than in heavier soils or with purified water.



2. On-the-go pH measurements using tap water may be noticeably affected by the pH of the water, spatial pattern frequently remains unchanged

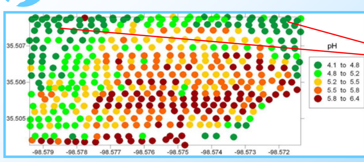
Additional Observations
Repeatability of Soil pH Map Patterns



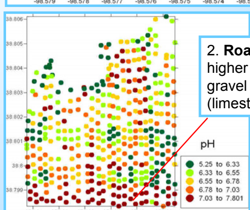
1. Soil pH values change due to:
   - pH temporal variability
   - alternative rinsing water sources
   - sampling depth
   - unknown factors

2. The pattern of pH variability remains consistent

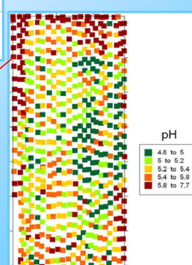
Additional Observations
Some Causes of Soil pH Variability



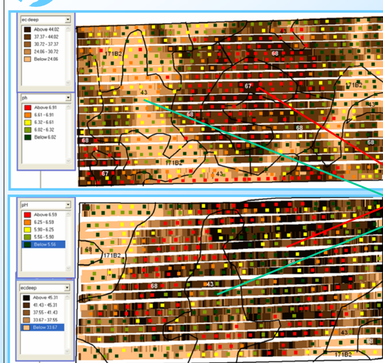
1. **Irrigation effects**: lower pH within rain-fed field corners



2. **Road effects**: higher pH along gravel roads (limestone deposits)



Additional Observations
Indirect Prediction of Soil pH Variability

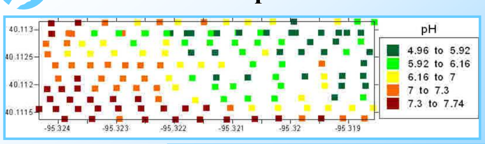


Relationships between pH and soil type (electrical conductivity) can be **strong**

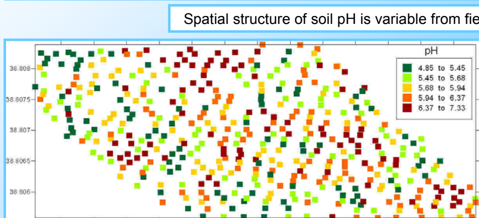
Soil Types:
Silty Clay Loam (67 and 68)
Silt Loam (43 and 171B2)

Relationships between pH and soil type (electrical conductivity) can be **weak**

Additional Observations
Spatial Structure of Soil pH



Spatial structure of soil pH is variable from field to field



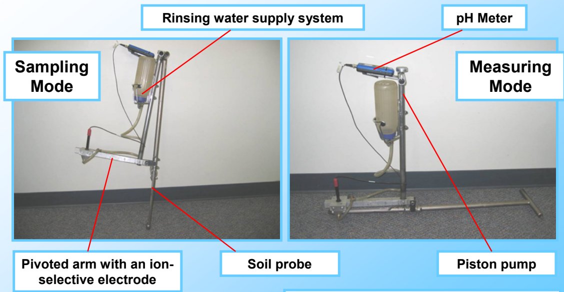
Additional Observations
Effect of Field Variability of Soil pH

Field ID	SD	RMSE	RDP = SD/RMSE	F-stat	p-value
Illinois 1	0.59	0.30	2.0	3.0	0.05
Illinois 2	0.74	0.51	1.5	1.1	0.44
Illinois 3	0.97	0.36	2.7	6.1	0.00
Iowa	0.81	0.39	2.1	3.3	0.00
Kansas 1	0.42	0.34	1.2	0.6	0.96
Kansas 2	0.61	0.39	1.6	1.5	0.04
Kansas 3	0.91	0.33	2.8	6.7	0.00
Kansas 4	0.46	0.30	1.5	1.3	0.33
Kansas 5	0.40	0.28	1.4	1.0	0.47
Kansas 6	0.39	0.33	1.2	0.4	0.97
Kansas 7	0.73	0.39	1.9	2.6	0.01
Nebraska 1	0.52	0.41	1.3	0.7	0.91
Nebraska 2	0.73	0.55	1.3	0.7	0.76
Wisconsin	0.54	0.31	1.8	2.2	0.03

Fields with potential benefits from variable rate liming

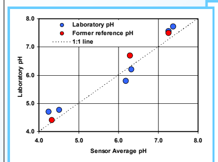
Assuming 0.3 pH measurement error, the standard deviation of a field that could benefit from variable rate liming is at least 0.6 pH (10% CV) if estimated based on 10 unbiased measurements

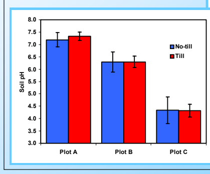
On-the-Spot Measurement of Soil pH

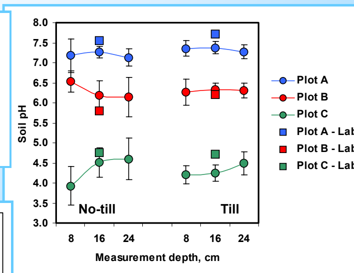


University of Nebraska-Lincoln
(Lincoln, Nebraska)
2005

Soil pH Demonstration Plots







Measurement variance (Nugget) = 0.085

Standard measurement error = 0.29 pH

Additional Observations

Field Capacity

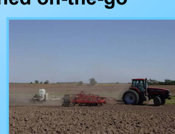
1. Growers, suppliers, and consultants are main users of the on-the-go pH mapping
2. Between 100 and 150 ha/day field capacity is typical
3. Approximately 5,000 ha/year has been accomplished by current users

Summary

- Automated mapping of soil pH on-the-go has become available commercially
- Soil pH Manager™ could produce 15-20 times more measurements than 1 ha grid sampling with a comparable effort
- Validation sampling of sensor measurements resulted in acceptable (r^2 = 0.80) correlation with conventional laboratory analyses
- Sensor-based lime prescription maps showed a reduced error in lime application rates
- In selected fields, this improvement can be enhanced through incorporation of additional on-the-go soil sensors: conventional electrical conductivity sensor (commercial) and near-infrared spectroscopy (NIRS) sensors (under development)
- Potential benefits of variable rate liming are site-specific and can be assessed using a low-cost measurement option

Future Work

- Integrating soluble potassium and residual nitrate mapping capability
- Fusion of optical reflectance and/or other spatial data for improved quality of recommendations
- Comprehensive evaluation of various lime prescription methods
- Numeric agro-economic evaluation of information value possessed by soil maps obtained on-the-go



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