Agroeconomic Evaluation of Intense Soil pH Mapping

Viacheslav Adamchuk
Biological Systems Engineering
University of Nebraska-Lincoln

Mark Morgan
Agricultural and Biological Engineering

Jess Lowenberg-DeBoer
Agricultural Economics

Purdue University

July 30, 2001

"The sensing of soil variability is probably the most important step in site-specific management. Without accurate maps, varying application rates are no more appropriate than an average, uniform rate. Obtaining this descriptive information about a field is expensive using today's techniques."

(Schueller et al., 1993)

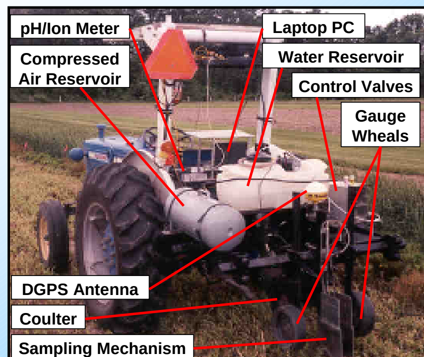
"Future research and development efforts will undoubtedly provide new and improved sensors, leading to opportunities for improved profitability and reduced environmental impact through the adoption of site-specific management."

(Sudduth et al., 1997)

Background

- **Automated soil sampling system is an alternative to common manual soil sampling and laboratory analysis of soil pH**

Automated Soil Sampling System



Background

- Automated soil sampling system is an alternative to common manual soil sampling and laboratory analysis of soil pH
- **Measurements are done on-the-go every 5-20 s (10 s on average)**
- **Standard deviation of these measurements equals to 0.38 pH**
- **Estimated cost of the system is $2,183/year**

Objectives

- **Assess economical benefits of increased sampling density via automated mapping of soil pH**
- **Create a model to quantify net return over cost of liming for different soil sampling strategies, lime management techniques and field conditions**
- **Compare economical effect of several practices for an arbitrary virtual field**

General Approach

+
- **Information value of soil pH**
  - Economics >>> optimal lime application rate for a given soil pH
  - Spatial statistics >>> soil pH estimation error associated with different types of sampling strategies

–
- **Information cost**
  - Cost of manual or automated mapping

Economic Rule Assumptions

- Corn-soybean rotation (4 years)
- All variables, but soil pH, are constants (spatially and temporally)
- Lime is applied every four years prior to corn
- It takes 3.0 t/acre of lime to increase pH by 1 unit within a year
- Corn and soybeans “consume” equivalents of 0.35 t/acre and 0.15 t/acre of lime per year
- There is no application rate error
- Minimum increase of lime application rate is 0.5 t/acre

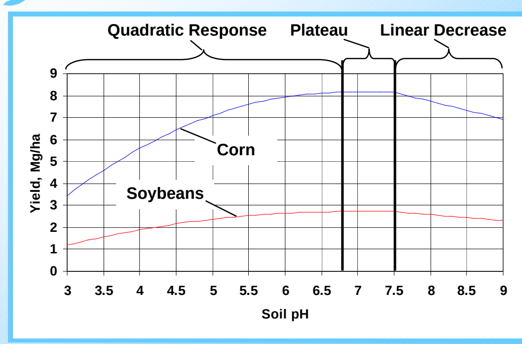
Wealth Equation

Has to be maximum

$$\underbrace{W_L}_{\text{Has to be maximum}} = \underbrace{\frac{Pc}{1+d}Yc_1}_{\text{Year 1 income}} + \underbrace{\frac{Ps}{(1+d)^2}Ys_2}_{\text{Year 2 income}} + \underbrace{\frac{Pc}{(1+d)^3}Yc_3}_{\text{Year 3 income}} + \underbrace{\frac{Ps}{(1+d)^4}Ys_4}_{\text{Year 4 income}} \underbrace{- C_L \cdot Q_L - \cancel{C_S} - \cancel{C_A}}_{\text{Cost of lime material, application and soil analysis}}$$

W = wealth or **net return over cost of liming** ($/acre)
d = annual discount rate (10%)
Pc = price of corn ($102.27/Mg = $2.60/bu)
Ps = price of soybeans ($233.11/Mg = $6.35/bu)
Yc_i = yield of corn in year i (1 and 3) (bu/acre)
Ys_i = yield of soybean in year i (2 and 4) (bu/acre)
C_L = cost of lime including transportation ($24.26/Mg =$22.00/t)
Q_L = lime application rate (t/acre)
C_S = cost of soil sampling and analysis ($/acre)
C_A = cost of lime application ($/acre)

Yield Response



From Bongiovanni & Lowenberg-DeBoer, 2000

How Much Lime is Needed to Change pH

$$pH = pH_0 \pm B_S(\sqrt{2.24Q_L + 1} - 1)$$

$$B_S = \frac{34.24}{\dfrac{TEC + 0.957}{pH - 2.043} + 9.5} - 1.741$$

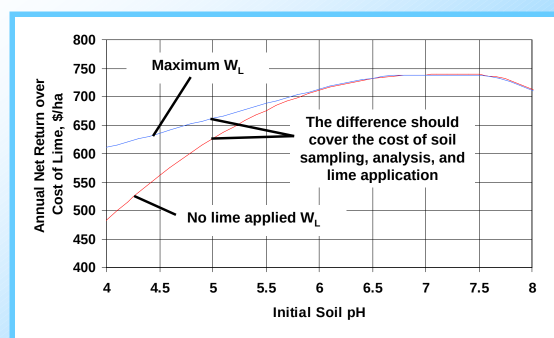
From Black, 1993

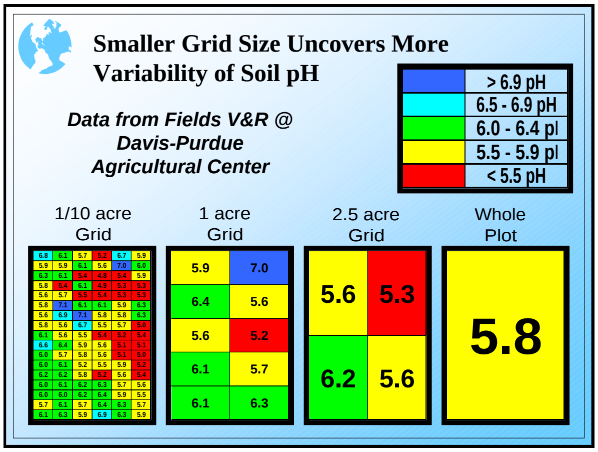
$$\underbrace{pH}_{\text{New pH}} = \underbrace{pH_0}_{\text{Old pH}} \pm \underbrace{\frac{Q_L}{B}}_{\text{Adjustment}}$$

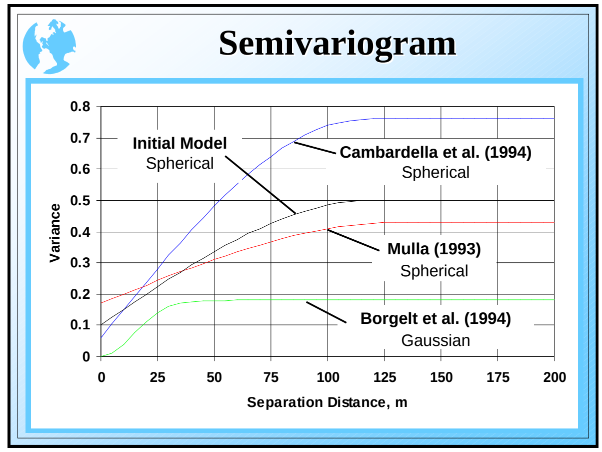
‘+’ lime application
‘-’ cropping effect

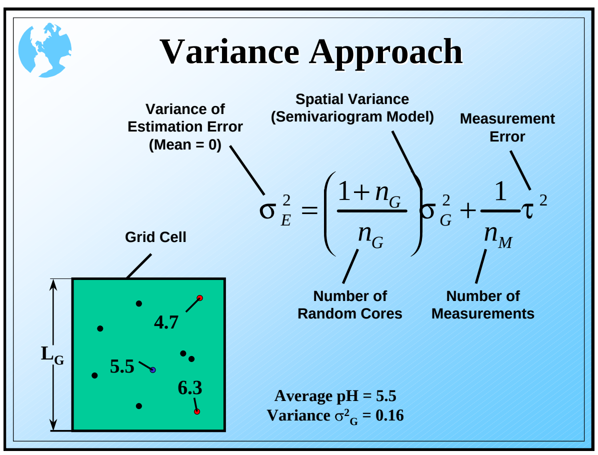
pH = adjusted soil pH
pH_0 = initial soil pH
B = buffering capacity (assume B_S = 2.3 t/acre-pH)
Q_L = application/consumption of lime (t/acre)

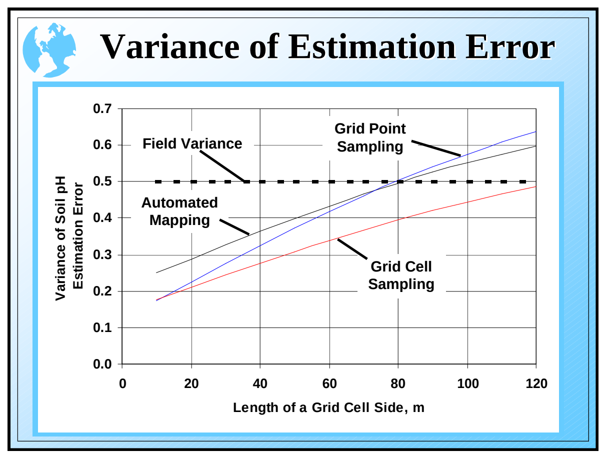
Net Return over Cost of Lime (W_L)

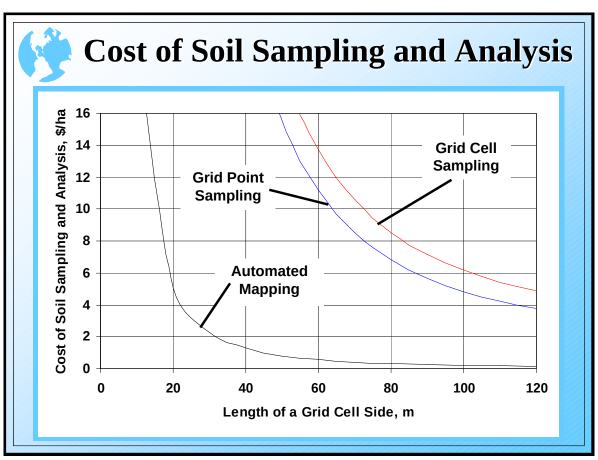


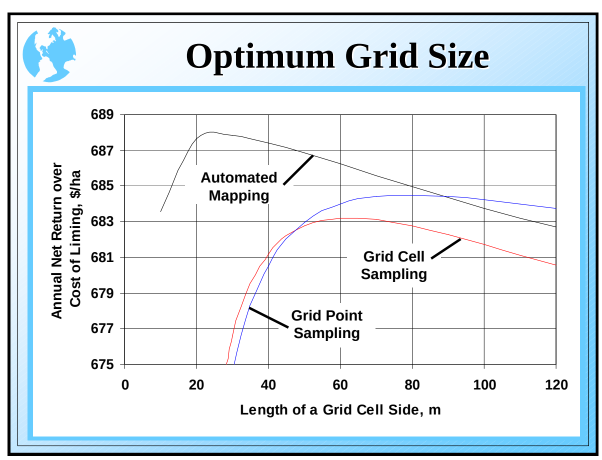

Smaller Grid Size Uncovers More Variability of Soil pH
Data from Fields V&R @ Davis-Purdue Agricultural Center
> 6.9 pH
6.5 - 6.9 pH
6.0 - 6.4 pH
5.5 - 5.9 pH
< 5.5 pH
1/10 acre Grid
1 acre Grid
2.5 acre Grid
Whole Plot
5.9
7.0
6.4
5.6
5.6
5.2
6.1
5.7
6.1
6.3
5.6
5.3
6.2
5.6
5.8


Semivariogram
Variance
Initial Model
Spherical
Cambardella et al. (1994)
Spherical
Mulla (1993)
Spherical
Borgelt et al. (1994)
Gaussian
Separation Distance, m


Variance Approach
Variance of Estimation Error (Mean = 0)
Spatial Variance (Semivariogram Model)
Measurement Error
$\sigma_E^2 = \left(\frac{1+n_G}{n_G}\right)\sigma_G^2 + \frac{1}{n_M}\tau^2$
Number of Random Cores
Number of Measurements
Grid Cell
L_G
4.7
5.5
6.3
Average pH = 5.5
Variance σ^2_G = 0.16


Variance of Estimation Error
Variance of Soil pH Estimation Error
Field Variance
Grid Point Sampling
Automated Mapping
Grid Cell Sampling
Length of a Grid Cell Side, m


Cost of Soil Sampling and Analysis
Cost of Soil Sampling and Analysis, $/ha
Grid Point Sampling
Grid Cell Sampling
Automated Mapping
Length of a Grid Cell Side, m


Optimum Grid Size
Annual Net Return over Cost of Liming, $/ha
Automated Mapping
Grid Cell Sampling
Grid Point Sampling
Length of a Grid Cell Side, m

Comparison of Soil Sampling Strategies

Field:

- **Spherical model**
- **The nugget = 0.1**
- **The sill = 0.5**
- **Range = 120 m**
- **Average pH = 5.8**

Soil Sampling:

- **3 samples per field**
- **Automated (2 samples per 30 X 30 m grid)**
- **Grid Point (1 sample per 2.5 acre grid)**
- **Grid Cell (3 samples per 2.5 acre grid)**

Practice	L_G, m	n_G	n_M	τ	C_S, \$/ha	C_A, \$/ha	W_{yr}, \$/ha	w_{yr}[1], \$/ha
No liming	-	-	-	-	-	-	684.40	3.44
FRA+3 samples	Field	-	1	0.1	0.01	7.41	683.73	4.11
FRA+automated	30	2	4	0.5	2.26	7.41	685.69	2.15
FRA+grid point	100	1	1	0.1	4.83	7.41	684.88	2.96
VRA+automated	30	2	4	0.5	2.26	14.81	687.84	-
VRA+grid point	100	1	1	0.1	4.83	14.81	681.71	6.13
VRA+grid cell	100	3	1	0.1	6.15	14.81	684.23	3.61

[1] $w_{yr} = W_{yr}(\text{VRA+automated}) - W_{yr}$

MAX

Effect of Soil pH Variability

Soil pH variability is too low to pay for VRA of lime

VRA + automated sampling has the highest W_{yr}

The Sill

$\gamma(h_R)$	0.1	0.2	0.3	0.4	0.5	0.6	0.7
CV	5%	8%	9%	11%	12%	13%	14%
No liming	695.84	692.94	690.07	687.22	684.40	681.58	678.78
FRA + 3 samples	696.91	693.53	690.27	687.02	683.73	680.30	676.67
FRA + automated	**697.07**	**694.16**	**691.30**	688.49	685.69	682.88	680.05
FRA + grid point	696.25	693.34	690.49	687.68	684.88	682.07	679.23
VRA + automated	693.62	692.42	691.09	**689.59**	**687.84**	**685.76**	**683.32**
VRA + grid point	694.12	691.60	688.94	685.76	681.71	676.66	670.66
VRA + grid cell	693.48	691.54	689.47	687.11	684.23	680.68	676.43

W_{yr} (Net Return over Cost of Liming)

Conclusions

- **Automated measurement of soil pH allows higher sampling density and map accuracy at lower cost than 2.5 acre grid soil sampling**
- **Current prototype is most effective when sampling using 20-40 m grids**
- **VRA of lime is economical only when field variation of pH is higher than variability within grid (CV > 9%)**

Current Work

- **Add flexibility to constrains (probability functions)**
- **Data does not have to be normally distributed (numerical analysis)**
- **Improve agronomical module**
- **Take into account local conditions**

"Economics of site-specific management is site-specific"

Jess Lowenberg-DeBoer

http://bse.unl.edu/adamchuk
E:mail: adamchuk@engunx.unl.edu