Soil pH and Liming

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What Is pH?

- Definition of pH
  - Measure of acidity or alkalinity
  - Negative log of hydrogen ion concentration
    - As H^+ ion concentration increases, pH number decreases
    - One unit change in pH = 10 fold change in concentration of H^+ ions

What Is pH?

Hydrogen Ion Concentration	pH	Interpretation
moles/liter		
.00000001	8	Strongly alkaline
.0000001	7	Neutral
.000001	6	Slightly acid
.00001	5	Strongly acid
.0001	4	Extremely acid

Importance of soil pH

- Affects chemical and biological reactions
  - Availability of essential nutrients
    - Influences soil chemical reactions and nutrient forms
  - Activity of microorganisms
  - Solubility (toxicity) of non-essential elements
  - Performance/carryover of some herbicides

Mechanisms That Control Soil pH

Soil pH Range	Major Mechanisms
2 to 4	Oxidation of reduced S minerals, pyrite
4 to 5.5	Exchangeable Al and H
5.5 to 6.8	Exchangeable H
6.8 to 7.2	Dissolved carbon dioxide
7.2 to 8.5	Dissolution of carbonates, $CaCO_3$
8.5 to 10.5	Exchangeable sodium (low salt conditions) Dissolution of Na_2CO_3

How Soils Become Acidic

- Nitrification of ammonium
- Bases removed by crops
- Bases removed by leaching
- Acidic parent material
- Carbonic acid from microbial and plant respiration
- Organic acids secreted by plant roots
- Precipitation
- Oxidation of sulfide

Limestone Needed to Offset Acidity from Nitrogen Fertilizers

Nitrogen Source	Pound of Aglime per Pound of N
Ammonium Sulfate	7
Ammonium Phosphates	7
Anhydrous Ammonia	4
Urea	4
28% Solution	4
Ammonium Nitrate	4

Approximate amount. Adapted from Modern Corn Production.

Effect of N Application on Soil pH

lb N/acre/year	Soil pH
0	6.1
40	6.1
80	6.0
120	6.0
160	5.8
200	5.7

Ammonium Nitrate applied each year for 5 years, 7 in. incorporation. Plano silt loam soil.

Walsh, 1965. Fert. & Lime Conf. UW-Madison.

Amount of $CaCO_3$ Equivalent Needed to Replace Basic Cations in Crop Removal

Crop	Yield per acre	Lb Aglime per Acre
Corn Grain	150 bu	20
Corn Silage	8 ton	200
Oats	75 bu	5
Soybean	45 bu	95
Alfalfa	4 ton	515

Pierre & Banwart, 1973. Agron. J. 65:91-96.

Nature of Soil Acidity

- **Active acidity**
  - **Free hydrogen ions in soil solution**
    - **Measured by soil water pH**
    - **Very small part of total acidity in soil**
    - **Would take less than 1/3 lb/acre limestone to neutralize**

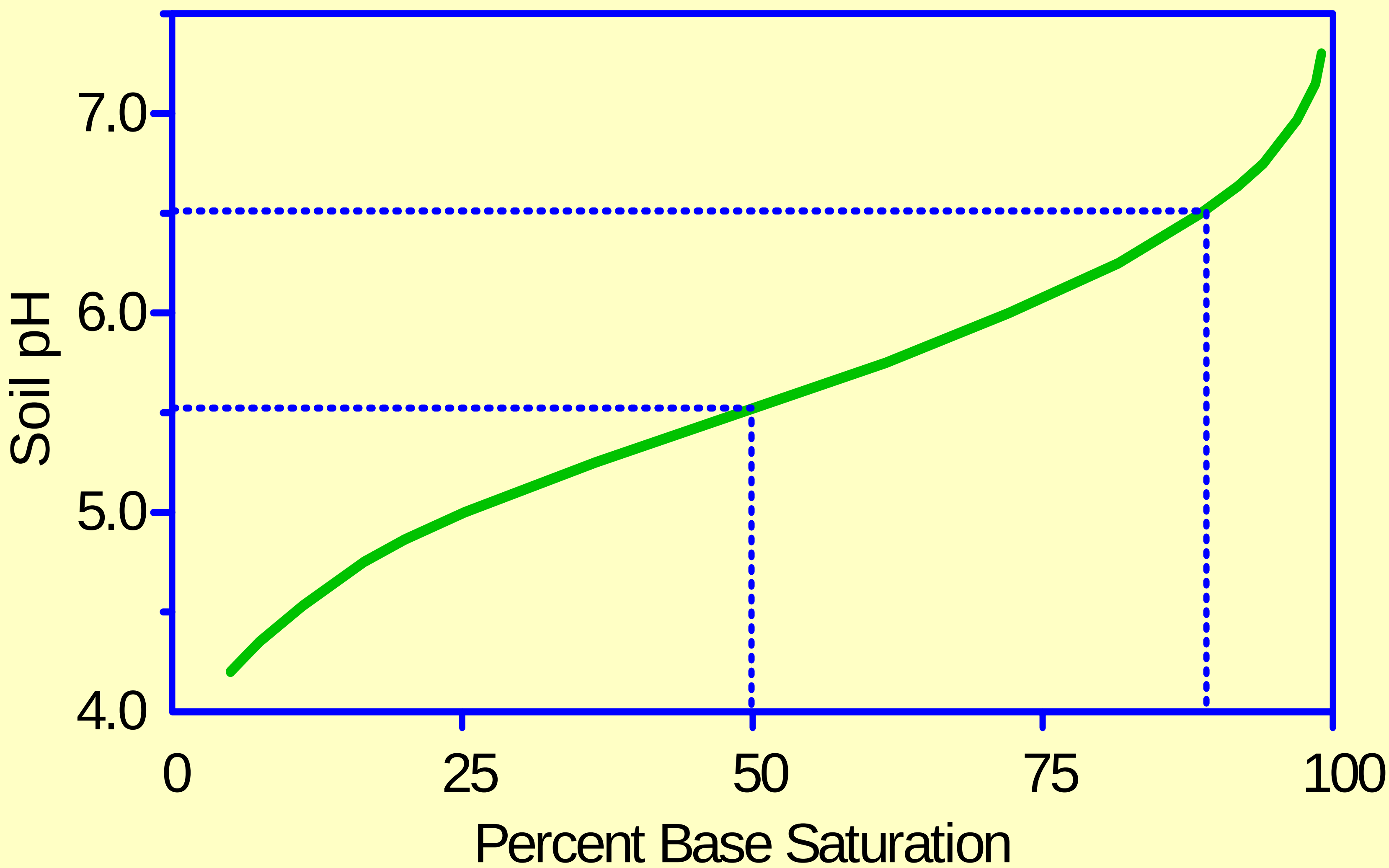
Nature of Soil Acidity

- **Reserve acidity**
  - **Neutralizable H ions and aluminum chemically bound to organic matter and clay**
  - **Accounts for virtually all of the total acidity in soil**
  - **Active acidity is in equilibrium with reserve acidity**
  - **This is what limestone must neutralize when acid soils are limed in order to increase pH**
  - **Estimated by SMP buffer pH**

Nature of Soil Acidity

- **Reserve acidity**
  - **Soils with large CEC can hold large amount of acidity**
    - **These soils are highly buffered**
    - **Require large amounts of lime to increase soil pH**
  - **Soils with small CEC (low organic matter, sandy) can hold smaller amount of acidity**
    - **Usually are low in buffering capacity**
    - **Require less lime to increase soil pH**

Impact of Base Saturation on Soil pH



Chemical Soil Test Procedure
Soil Water pH

- **Scoop 5-g Soil Sample**
- **Add 5 ml Distilled Water**
- **Stir for 5 Seconds; Let Stand for 10 Minutes**
- **Place pH Electrodes in the Slurry, Swirl and Read pH Immediately**

NCR Pub. 221

Chemical Soil Test Procedure
SMP Buffer Lime Requirement Test

- Add 10 ml SMP Buffer Solution to the Soil-Water
  Slurry Saved From pH Determination
- Shake for 10 min.; Let Stand For 30 min.
- Swirl and Read pH

  - SMP Buffer Solution (pH 7.50)
    - Contains: paranitrophenol; potassium chromate; calcium chloride dihydrate; calcium acetate; triethanolamine; adjusted to pH 7.50 with sodium hydroxide

NCR Pub. 221

Alkaline Soils

- Soil pH > 7.0
- CEC saturated with basic cations
- pH controlled by:
  - Dissolved carbon dioxide chemistry
  - Solid Ca and Mg carbonates
    - pH 7.2 to 8.5
  - Exchangeable Na and dissolution of Na_2CO_3
    - pH 8.5 to 10.5

How Soils Become Calcareous

- Enriched calcium carbonate parent materials -- glacial till
- Deposition of carbonates in low-lying areas of the landscape
  - Transpiration and evaporation of water
    - Low leaching
    - Precipitation of calcium carbonate

Calcareous Soils

- pH 7.2 to 8.5
  - Contain various amounts of solid calcium carbonate (1 to 20% $CaCO_3$ by weight)
  - $CaCO_3$ controls soil pH

$$CaCO_3 \text{ (solid)} + 2H^+ = Ca^{+2} + CO_2 + H_2O$$

Calcareous Soils

- Not economical to lower pH
  - All $CaCO_3$ must be dissolved before pH can be lowered
  - If soil contains 1% lime in top 7 inches
    - Would require 68 tons concentrated sulfuric acid to neutralize
- Bray P_1 test will give false low readings on some soils with pH above 7.4
  - Use Olsen bicarbonate extractant
  - Use Mehlich 3 extractant

Liming Soils

Lime Corrects Problems from Excessive Acidity

- **Reduces Al and other metal toxicities**
- **Improves soil physical condition**
- **Stimulates microbial activity**
  - **Including symbiotic bacteria that fix N**
- **Improves availability of essential nutrients**
- **Supplies Ca and Mg for plants**

Frequency of Liming Influenced By

- Soil texture
- Rate of N fertilization
- Rate of crop removal of Ca and Mg
- Amount of lime applied
- Quality of lime applied
- Soil buffer capacity
- Tillage
- Desired pH range

How Lime Reduces Soil Acidity

- Ca^{++} and Mg^{++} from lime replaces two H^+ ions on the cation exchange complex (reserve acidity)
- The H^+ ions combine with OH^- (hydroxyl) ions to form water
- pH increases because the acidity source (H^+) has been reduced

$$CaCO_3 + 2H^+ = Ca^{+2} + CO_2\uparrow + H_2O$$

Liming Requirement

- Depends on soil pH and CEC
  - The amount of reserve acidity

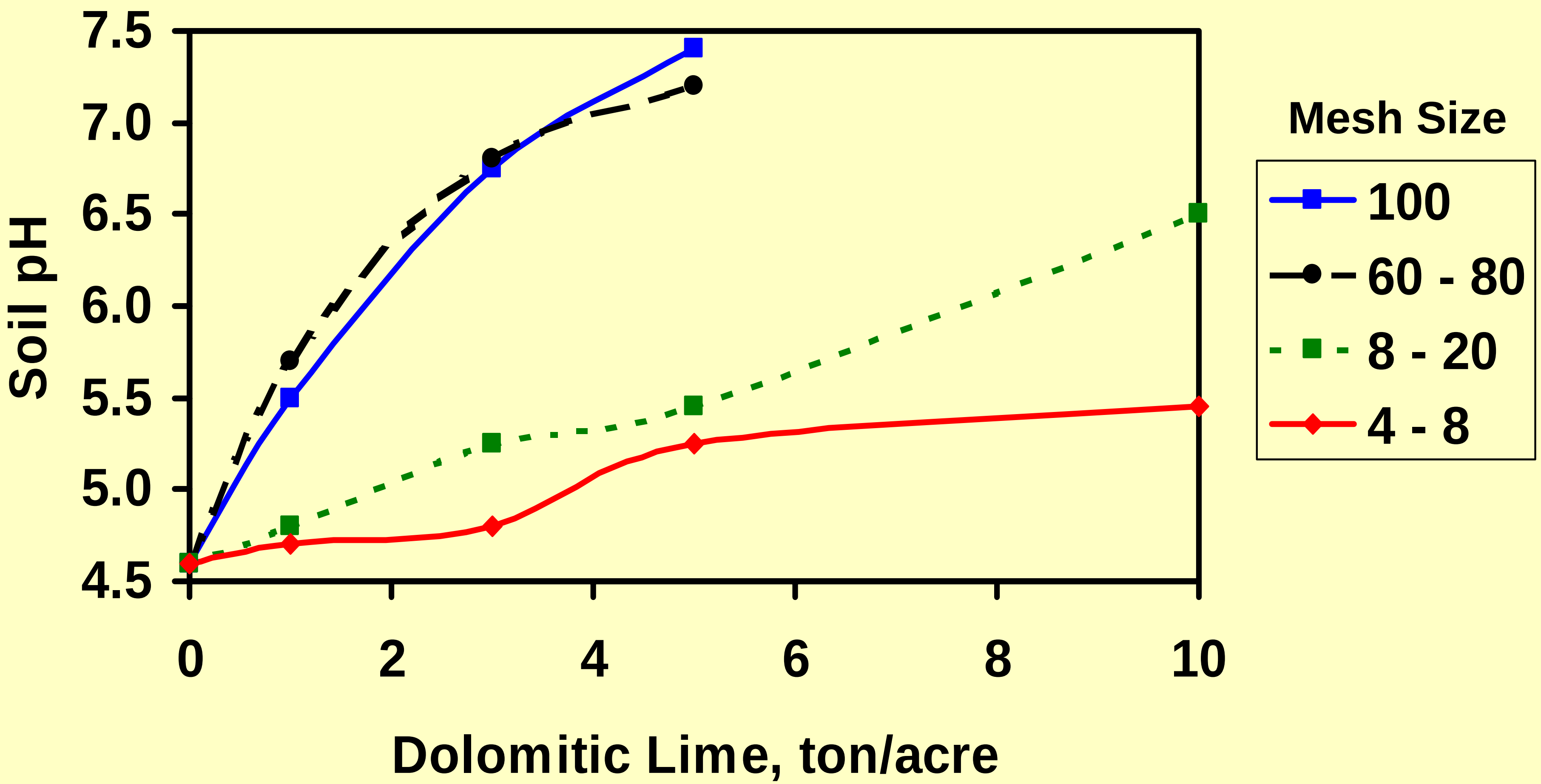
Limestone Quality Impacts Application Rate

- **Particle Size**
- **<u>C</u>alcium <u>C</u>arbonate <u>E</u>quivalent**
- **Both combined determine limestone quality**
  - **ECCE**

ASTM E-11-61 U.S. Sieve Series

Sieve Designation (Tyler Mesh)	Wires No./inch	Opening Size Inch	Wire Diameter Inch
4	4	0.1870	0.0606
8	8	0.0937	0.0394
60	60	0.0098	0.0071

Effect of Particle Size and Lime Rate on Soil pH After 18 Months



Meyer et al., Soil Sci, 73:37

Limestone Survey, Indiana

			passing thru mesh			thru
Quarry	County	CCE	8	60	100	100 mesh
			------ percent -----			pounds/ton
Pipe Creek	Grant	99	94	30	26	518
New Point	Decatur	93	84	42	38	758
Stonycreek	Hamilton	95	80	26	22	442
Am. Aggr.	Marion	89	85	43	42	834
Bloom Stone	Boone	92	92	29	22	448
Mulzer	Crawford	85	88	29	20	404
Delphi Stone	Carroll	100	94	40	30	608

Calcium Carbonate Equivalent Determines Lime Neutralizing Ability

- **Amount of material in a limestone that is effective in neutralizing acid**
  - **For example, the Ca and Mg carbonates**
- **Inert or other non-liming material does not contribute to acid neutralization**

How to Calculate Limestone ECCE (Iowa)

	% of Particles Passing Each Screen		Fineness Factor		Percent Available Based on Fineness
4-mesh	100	x	0.1	=	10
8-mesh	90	x	0.3	=	27
60-mesh	55	x	0.6	=	33
Total Fineness Efficiency					**70**

Effective Calcium Carbonate Equivalent (ECCE):

(Total Fineness Efficiency ÷ 100) x (% CCE ÷ 100) x ([100 - % Moisture] ÷ 100) x 2000 = ECCE

Example:

(70 ÷ 100) x (92 ÷ 100) x ([100 - 2] ÷ 100) x 2,000 = 1,260 ECCE

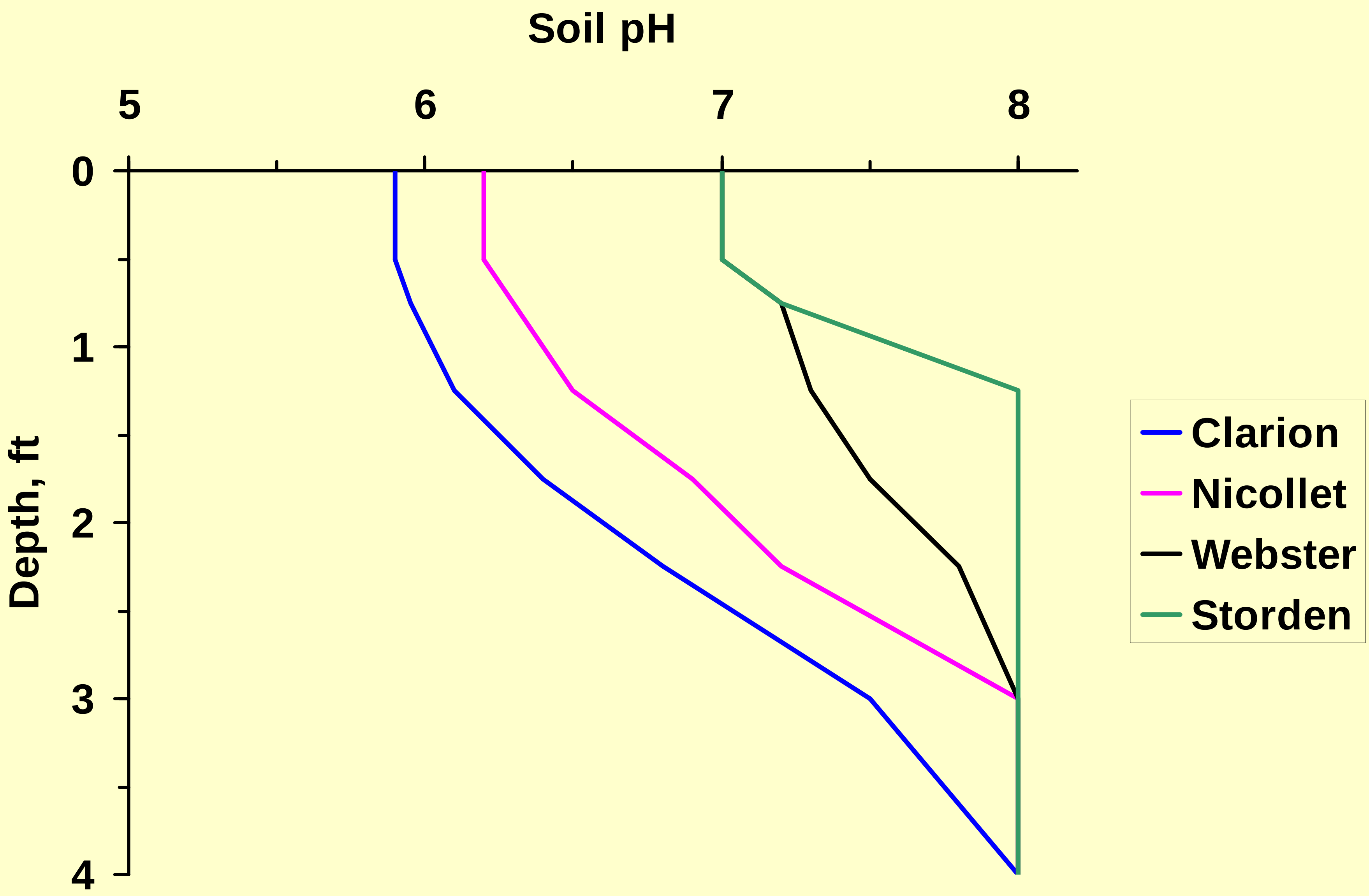
Steps in Making Limestone Recommendations

- Check soil pH
  - Is lime needed?
- Determine $CaCO_3$ requirement
  - Use Buffer pH
- Adjust rate for limestone quality
  - lb ECCE per ton or %
- Adjust rate for incorporation depth

Suggested Soil pH Ranges for Several Crops

- Corn and Soybean
  - pH 6.5 Sufficient
    - (pH 6.0 sufficient for high pH subsoils)
- Alfalfa
  - pH 6.9 Sufficient
- Grass Pastures and Grass Hayland
  - pH 6.0 Sufficient

Soil pH Change With Depth



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ISU Lime Recommendations -- Liming Soils to pH 6.5

SMP Buffer pH	Depth of Soil to Neutralize, inches			
	2	3	6	8
	$CaCO_3$ to apply, lb/acre			
7.0	0	0	0	0
6.9	0	0	0	0
6.8	200	300	600	800
6.7	400	700	1,300	1,700
6.6	700	1,100	2,100	2,800
6.5	900	1,400	2,800	3,700
6.4	1,200	1,800	3,500	4,700
6.3	1,400	2,100	4,200	5,600
6.2	1,700	2,500	5,000	6,700
6.1	1,900	2,900	5,700	7,600
6.0	2,200	3,200	6,400	8,600
5.9	2,400	3,600	7,100	9,500
5.8	2,600	4,000	7,900	10,600
5.7	2,900	4,300	8,600	11,500

Pm-1688 General Guide for Crop Nutrient Recommendations in Iowa

High pH Subsoils - pH 6.0 is sufficient; if liming is required, lime to 6.5

How to Calculate Limestone Requirement (Iowa)

Example	**Corn - Soybean**
Soil Test pH	**5.7**
Buffer pH	**6.6**
Target pH	**6.5**
Limestone ECCE	**1,260 (63%)**

$CaCO_3$ Rate From Chart (assume 6 inch): 2,100 lb/acre

Correction for Limestone Quality: 2,100 lb/acre / 0.63

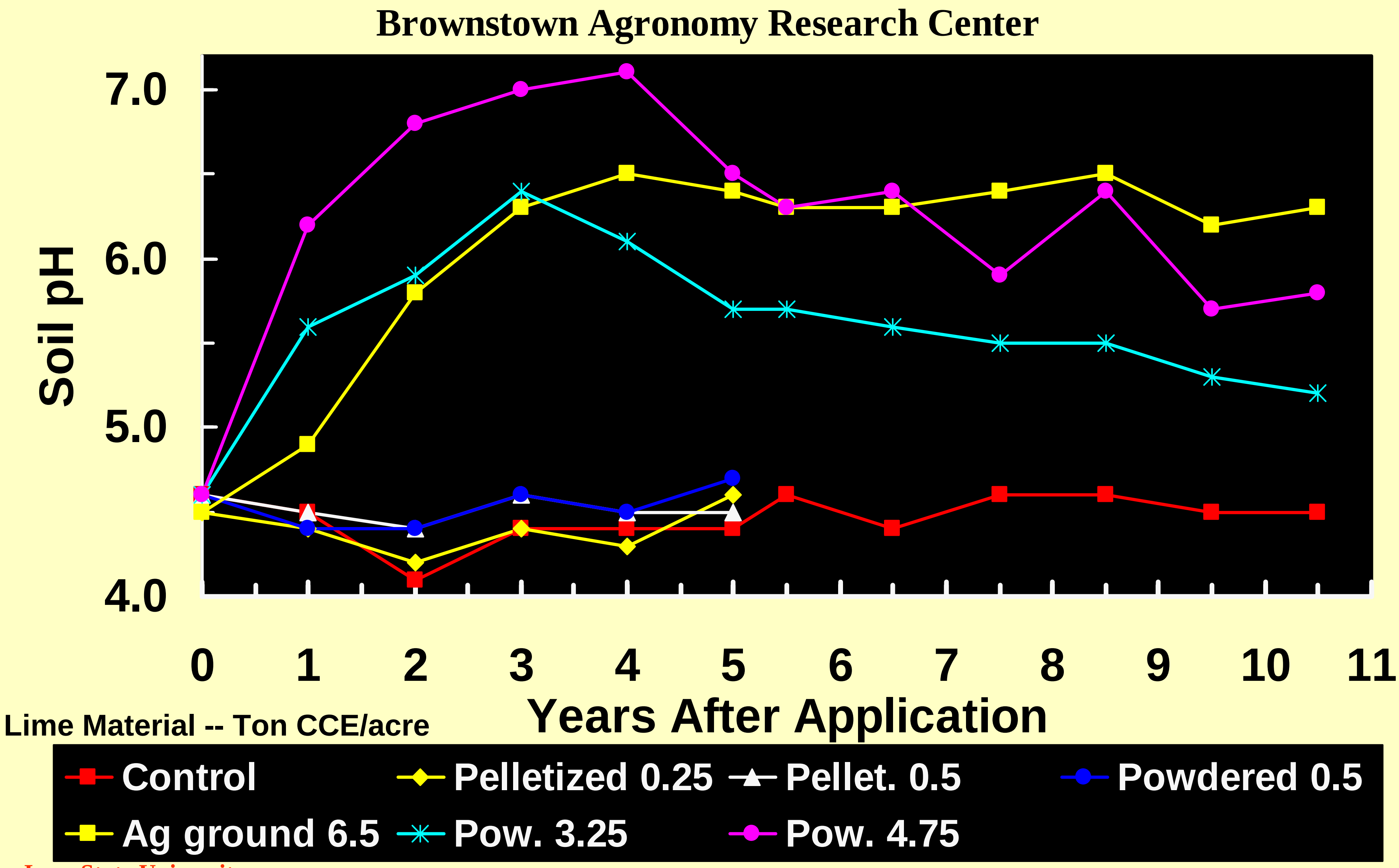
Recommended Lime Rate: 3,300 lb/acre

Effect of Aglime on Soil pH Over Time, Floyd Soil

	Year After Application				
ECCE	1	2	3	6	8
lb/acre	- - - - - - - - - - - - - - Soil pH - - - - - - - - - - - - -				
0	5.7	5.7	5.7	5.7	5.7
1,000	5.7	5.9	5.9	5.9	5.8
2,000	6.1	6.2	6.1	6.1	6.2
4,000	6.1	6.5	6.7	6.4	6.5
8,000	6.2	6.8	6.9	7.1	7.0
16,000	6.4	7.2	7.3	7.4	7.5
24,000	6.7	7.7	7.5	7.7	7.8
32,000	6.8	7.6	7.6	7.7	7.8

Long-Term Liming Practices

Cisne sil soil, 0-6 Inch Sample Depth



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Effect of Ag Lime Rate on Corn Yield

Effect of Aglime Rate on Soybean Yield, ISU Northwest Research Farm

Aglime	Year						
ECCE	1994	1995	1996	1997	1998	1999	Mean
lb/acre	- -	- - - -	- - - -	bu/acre	- - - -	- - - -	- -
0	171	144	122	153	152	164	151
500	168	146	126	150	149	163	150
1000	170	145	130	149	152	166	152
2000	170	144	130	148	154	161	151
4000	171	144	127	147	156	162	151
6000	166	146	127	149	154	162	150
Stat. Sign.	NS	NS	NS	NS	NS	NS	NS

Average across tillage systems.

All plots cultivated at least once. Spring 1993 0-6 inch soil pH = 5.6.

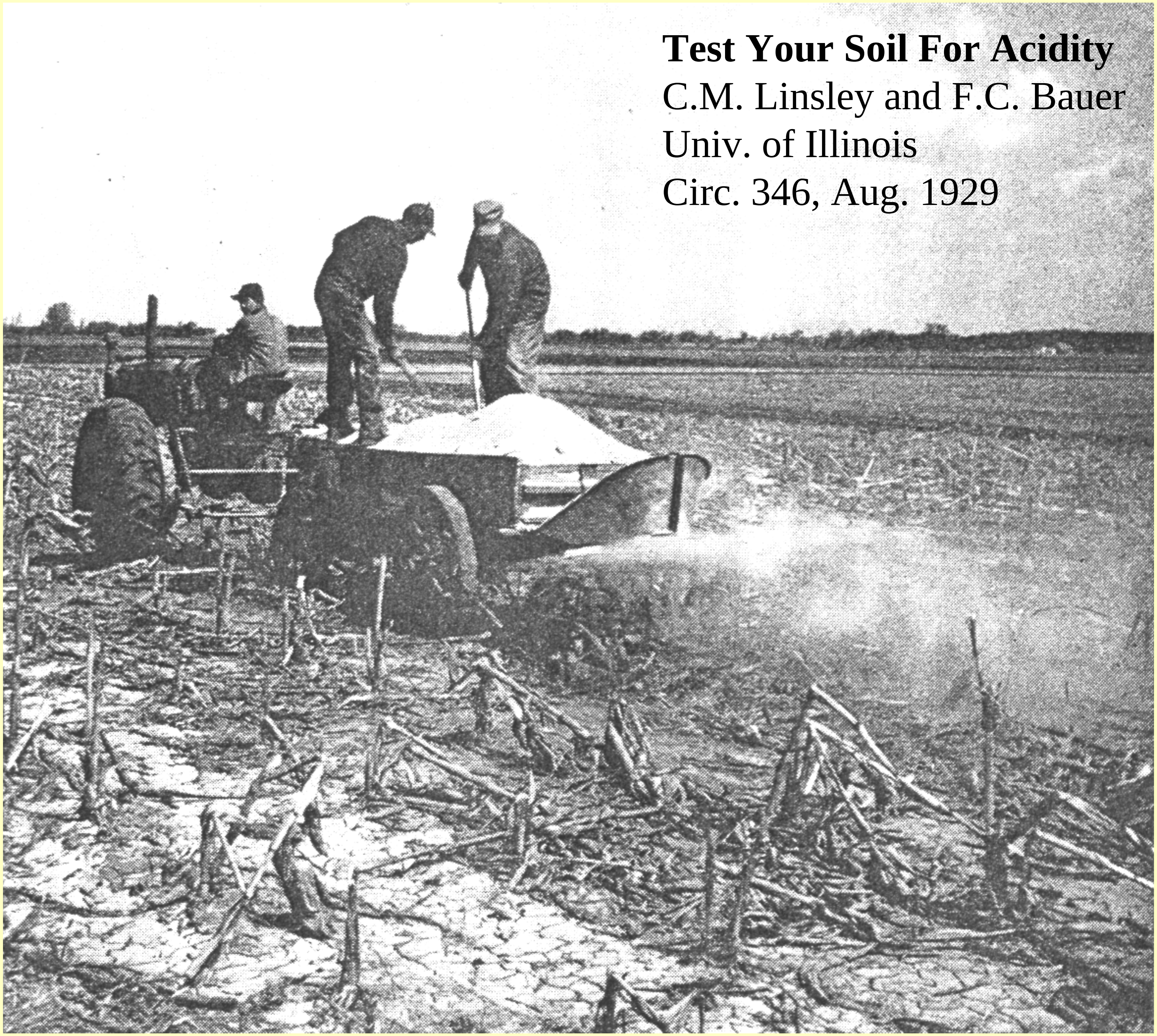
Effect of Ag Lime Rate on Soybean Yield

Effect of Aglime Rate on Soybean Yield, ISU Northwest Research Farm

Aglime	Year						
ECCE	1994	1995	1996	1997	1998	1999	Mean
lb/acre	- bu/acre -						
0	35.2	42.1	45.7	49.6	44.7	47.8	44.1
500	35.5	44.6	44.7	50.2	44.9	48.4	44.7
1000	38.1	45.8	47.1	54.5	46.5	50.7	47.1
2000	38.2	46.3	47.2	54.1	47.0	49.2	47.0
4000	37.7	46.8	47.6	57.9	46.7	51.5	48.0
6000	38.7	46.6	49.8	57.2	48.4	52.1	48.8
Stat. Sign.	**	**	**	**	**	**	**

Average across tillage systems.

All plots cultivated at least once. Spring 1993 0-6 inch soil pH = 5.6.


Test Your Soil For Acidity
C.M. Linsley and F.C. Bauer
Univ. of Illinois
Circ. 346, Aug. 1929

Test Your Soil For Acidity

C.M. Linsley and F.C. Bauer

- **University of Illinois Circular 346 August, 1929**
- **In a 40-Acre Field Measure pH & Carbonates**
  - **23 Surface Samples (2 inch depth)**
  - **5 subsurface (12 inch depth)**
  - **5 subsoil (20 inch depth)**
- **Completed Acidity Map Shows Where and How Much Limestone Is Needed**
- **Good Plan to Test After Six Years**

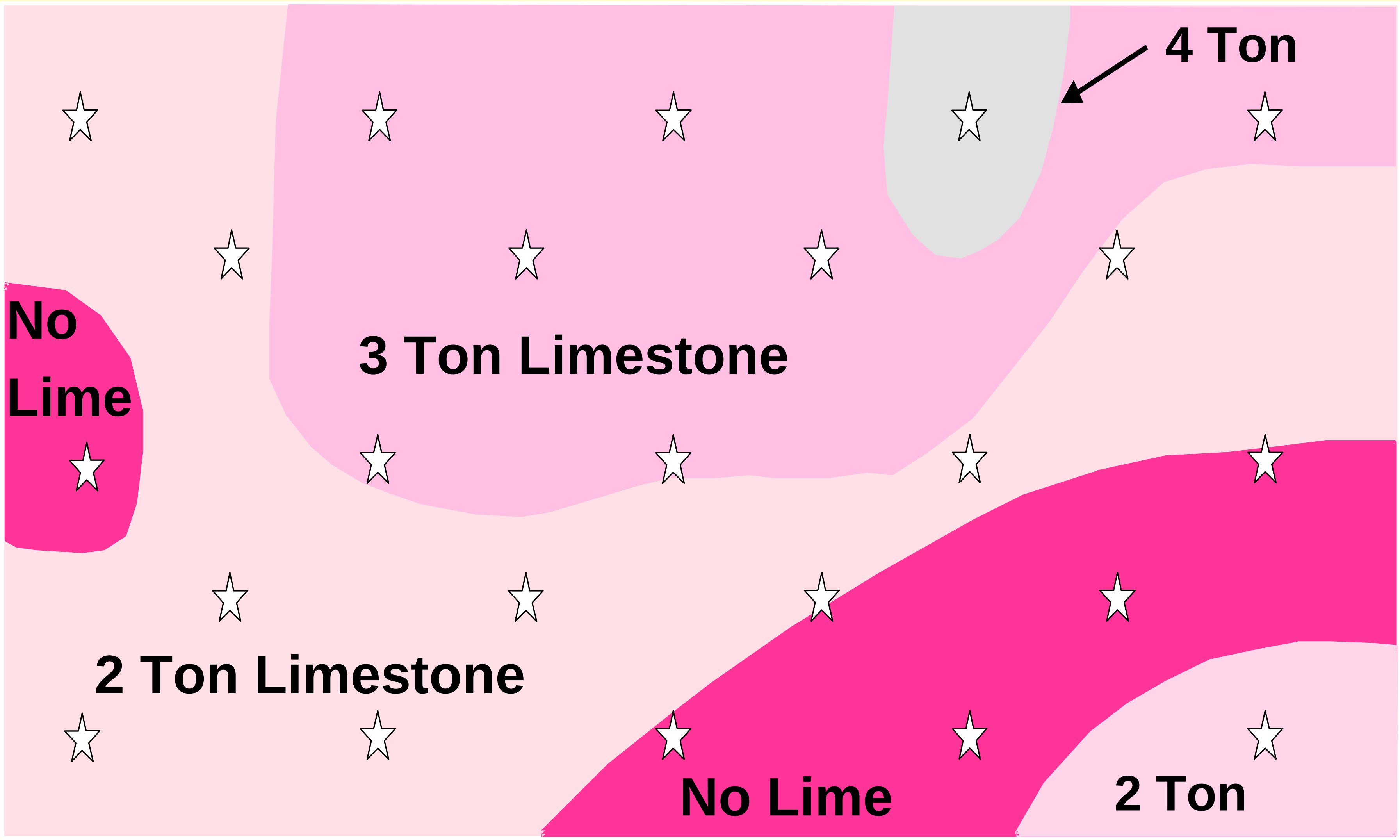
Test Your Soil For Acidity

C.M. Linsley and F.C. Bauer

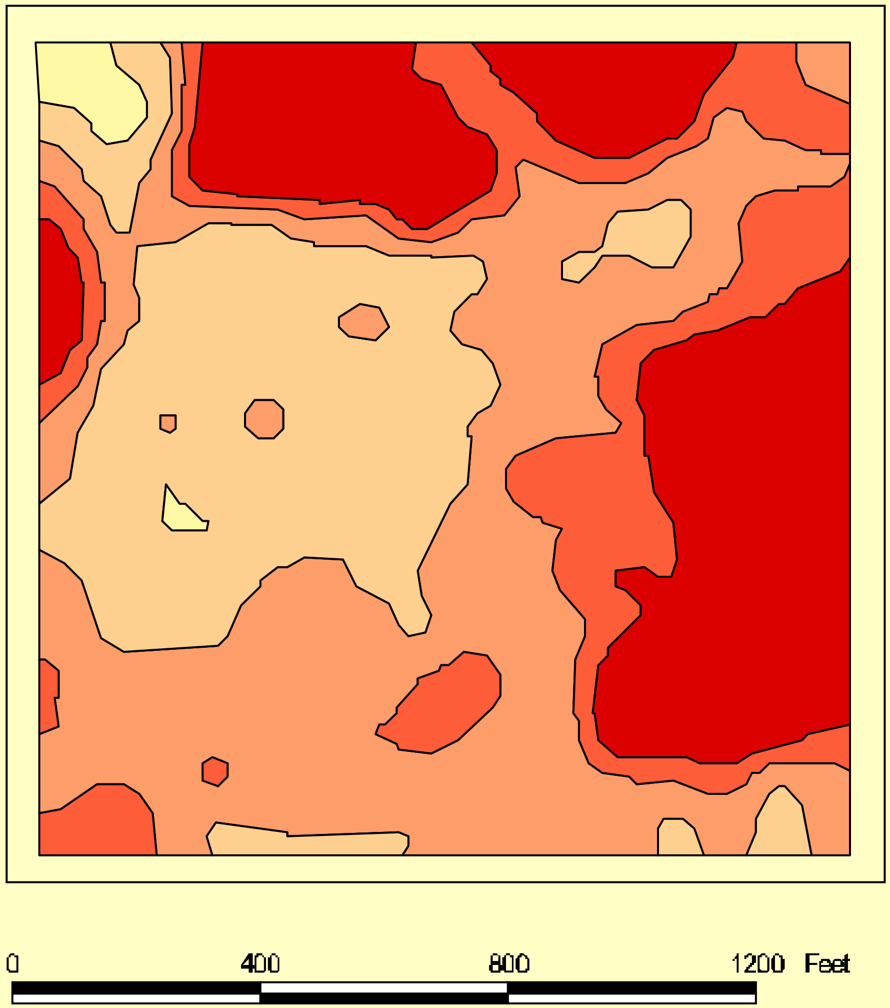
- **1929**
  - **Mapping Native Fertility Patterns**
- **Today**
  - **Also Mapping Man's Activities**
    - **More Variable**
    - **Less Tillage**
    - **Need More Samples?**
    - **Do as well as in 1929?**

Test Your Soil For Acidity

Adapted from C.M. Linsley and F.C. Bauer



September 1991 Soil pH



Soil pH

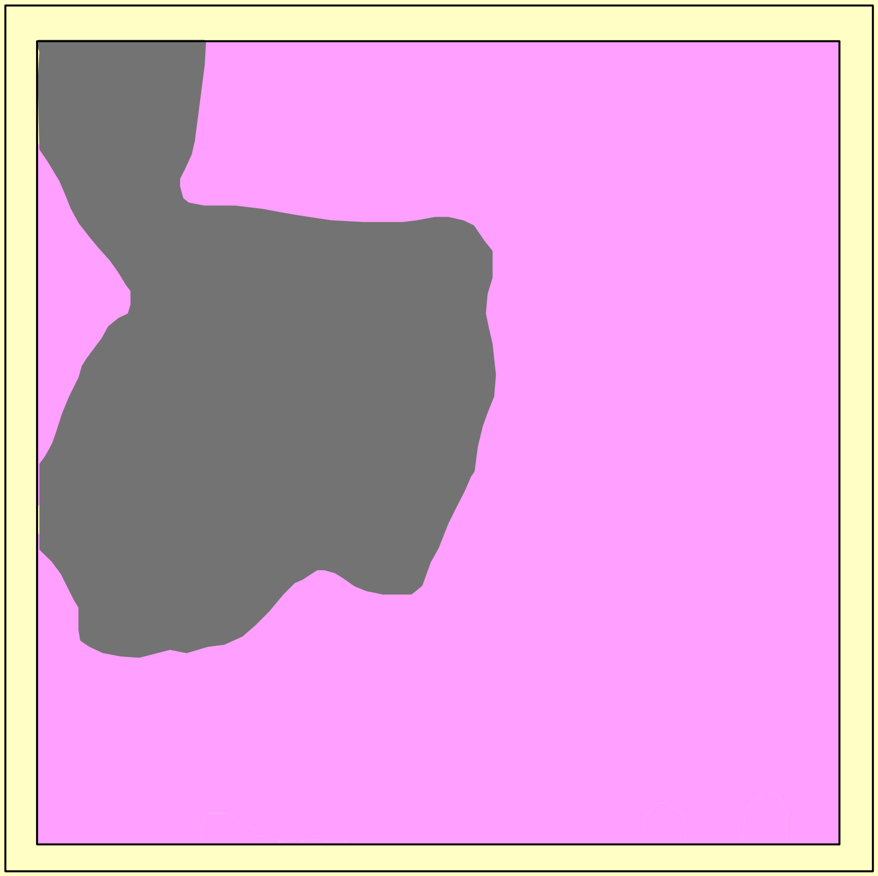
- < 5.5
- 5.5 - 6.0
- 6.0 - 6.5
- 6.5 - 7.0
- > 7.0

40 acres
16 x 16 grid
0.156 acres/sample

Mansfield Test Field

Data From:
T. Peck, Univ. of Illinois

Agricultural Limestone Application
4 Ton/acre -- October 1991



Lime Rate

4 ton/acre

0 ton/acre

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16 x 16 grid
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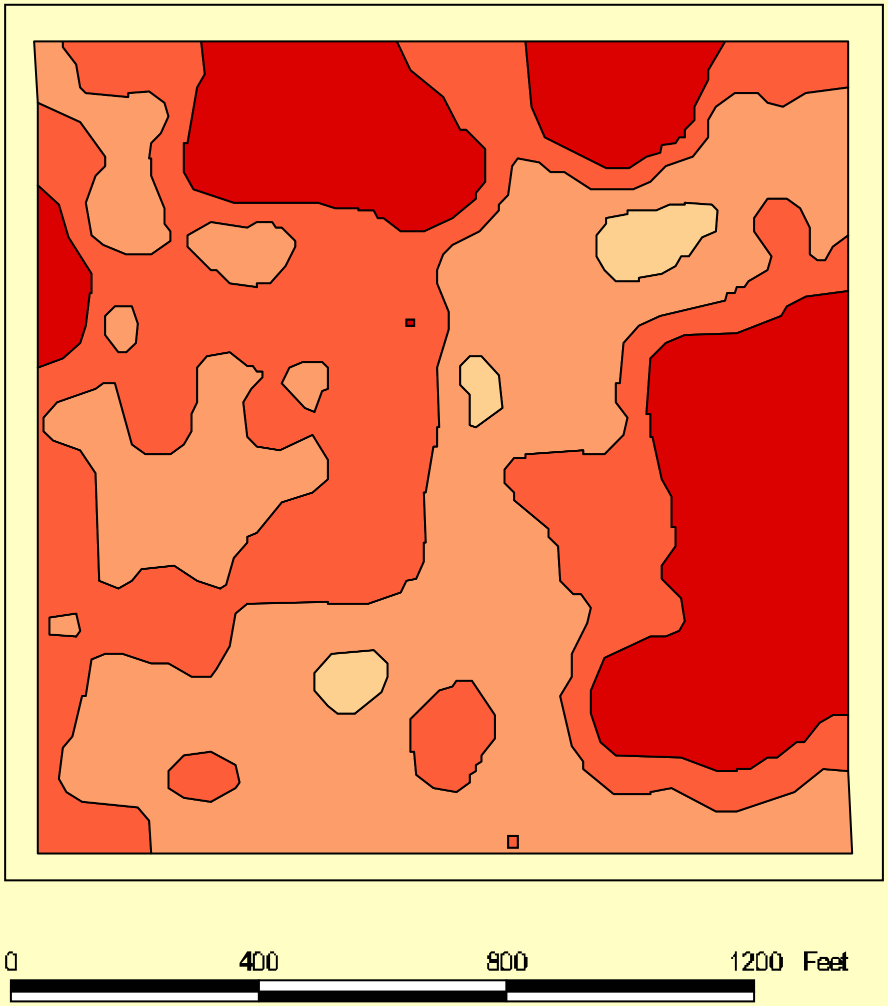
September 1992 Soil pH



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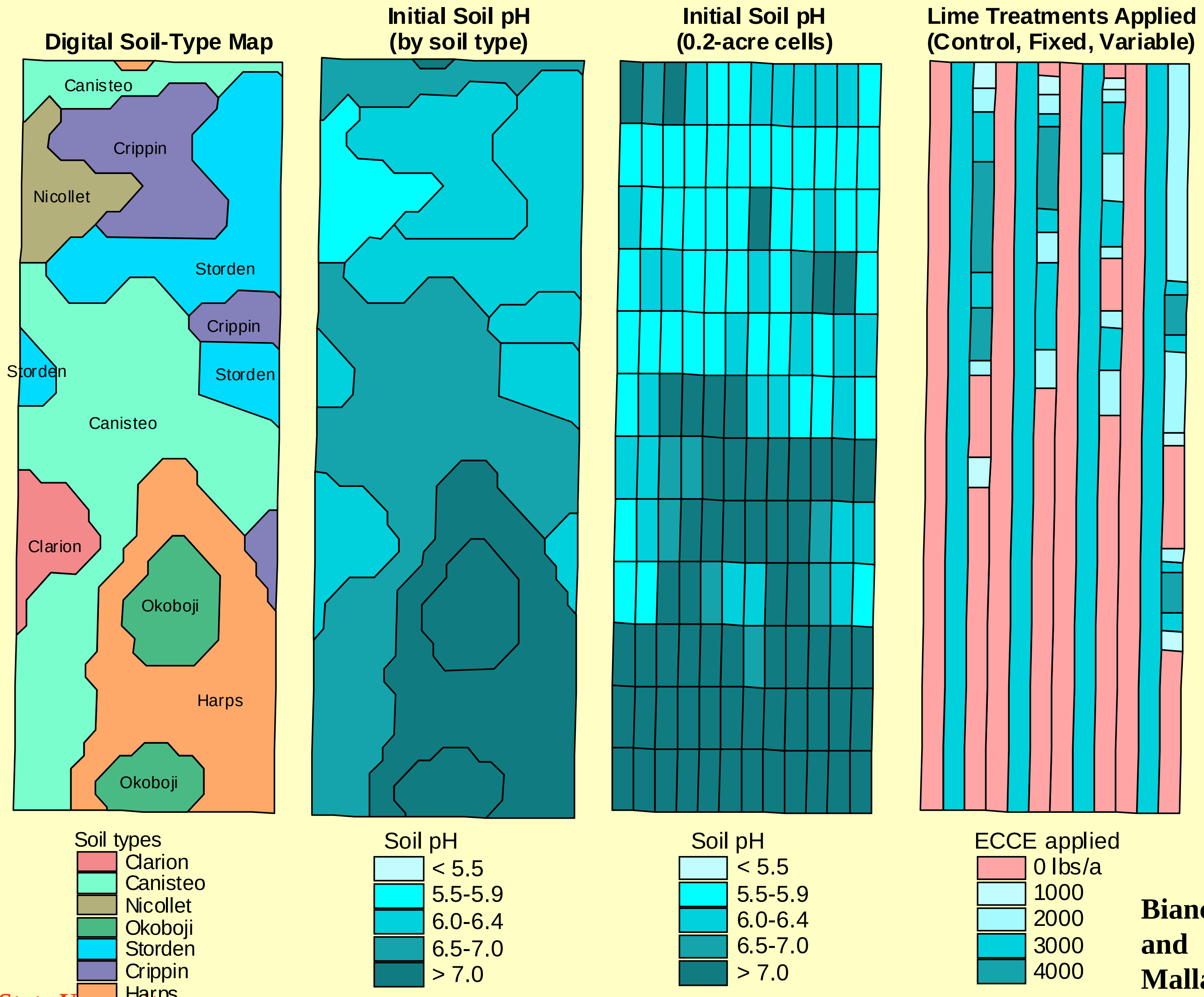
Lime Variable-Rate vs. Fixed-Rate Experiment - Heck Farm



Bianchini and Mallarino , 2002

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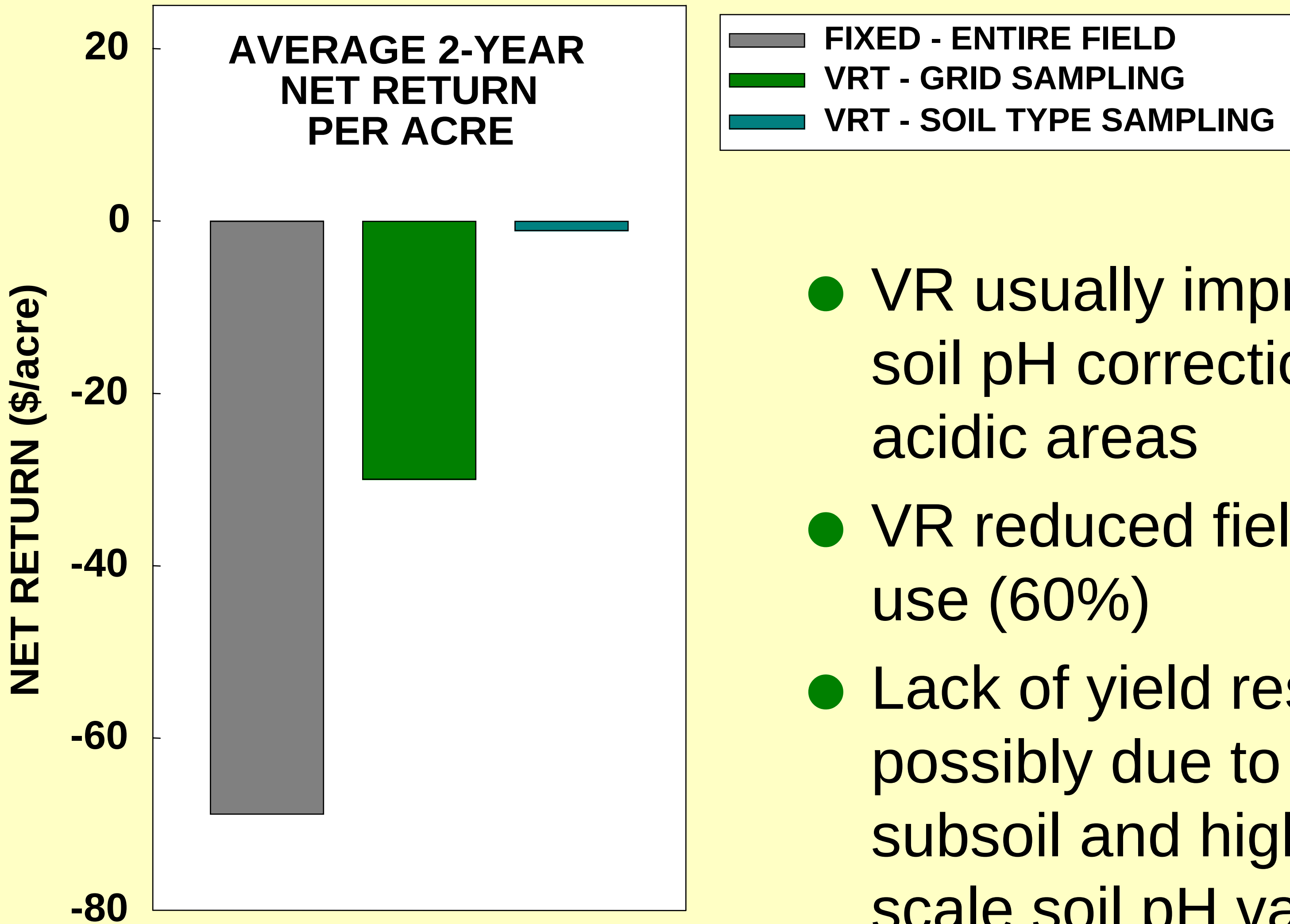
VARIABLE-RATE LIME FOR SOYBEANS AND CORN

	Soil pH			Var.	Response to VRT	
Field	Min	Avg	Max	Class	Variable - Fixed	
				acre	------ bu/acre ------	
					Beans	Corn
1	5.5	6.8	8.2		0.1	0.9
< 5.7				3.2		
5.7-6.2				14.1		
> 6.2				18.8		
2	5.3	6.6	8.2		0.0	- 0.2
< 5.7				8.9		
5.7-6.2				13.9		
> 6.2				21.7		

Bianchini and Mallarino , 2002

VRT LIME - HECK HOME 1998 & 1999



- VR usually improved soil pH correction of acidic areas
- VR reduced field lime use (60%)
- Lack of yield response possibly due to high pH subsoil and high small-scale soil pH variability

Bianchini and Mallarino , 2002

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