Fundamentals of Soil pH and Crop Response to Liming

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Soil pH

- Soil water pH is a measure of the hydrogen ion concentration in the soil (active acidity).
- Buffer pH is a measurement of total soil acidity (active + reserve acidity).
- Reserve acidity is a measure of the buffering capacity of the soil.
- Soils with low buffering capacities (low CEC) usually have less total acidity than soils with high CEC if the pH is the same.
  - Coarse textured and low SOM = low CEC

Ideal pH range

- pH of 7.0 is neutral, but few crops require a neutral pH.
- pH of 6.5 is best for crops like alfalfa, alsike clover, apple and asparagus (Group 1).
- pH of 6.0 is adequate for crops like corn, barley, canola, grass hay, oat, pea, soybean, sugar beet, sweet corn and wheat (Group 2).
- Many crops & plants like or tolerate acid soils.
  - Potato, grass sod, blueberry and wild rice.

https://extension.umn.edu/liming/lime-needs-minnesota

Other benefits – pH effects

- pH of 6.0 to 6.5 or higher provides an ideal environment for bacteria and microbial activity, also for nodulation on roots of legumes.
- Phosphorus availability in soils is greatest at pH of 6.0 to 6.5.

https://extension.umn.edu/liming/lime-needs-minnesota

Kaiser and Rosen, reviewed 2023

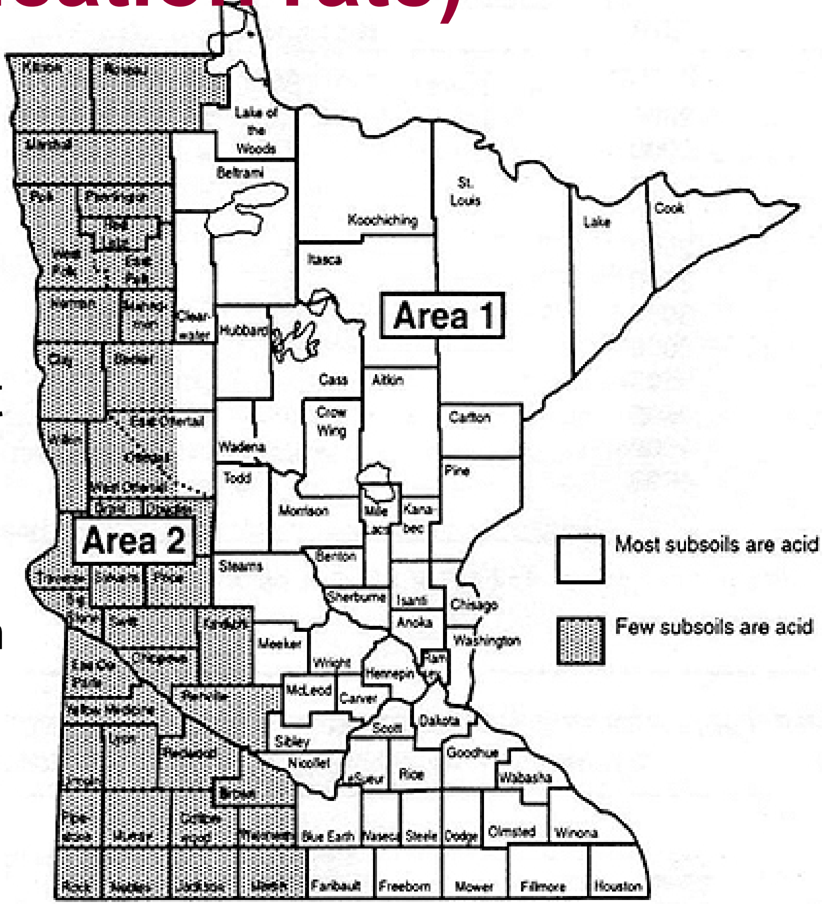
Soil pH and lime requirement

- pH is determined in the lab from a soil sample to a fixed depth (**6-inch depth**).
- pH is taken from a 1:1 mixture of soil and water (water pH)
- If water pH is less than 6.0, then a buffer solution is added to the soil/water mixture and another pH reading is taken (buffer pH).
- U of M currently uses the Sikora buffer

https://extension.umn.edu/liming/lime-needs-minnesota

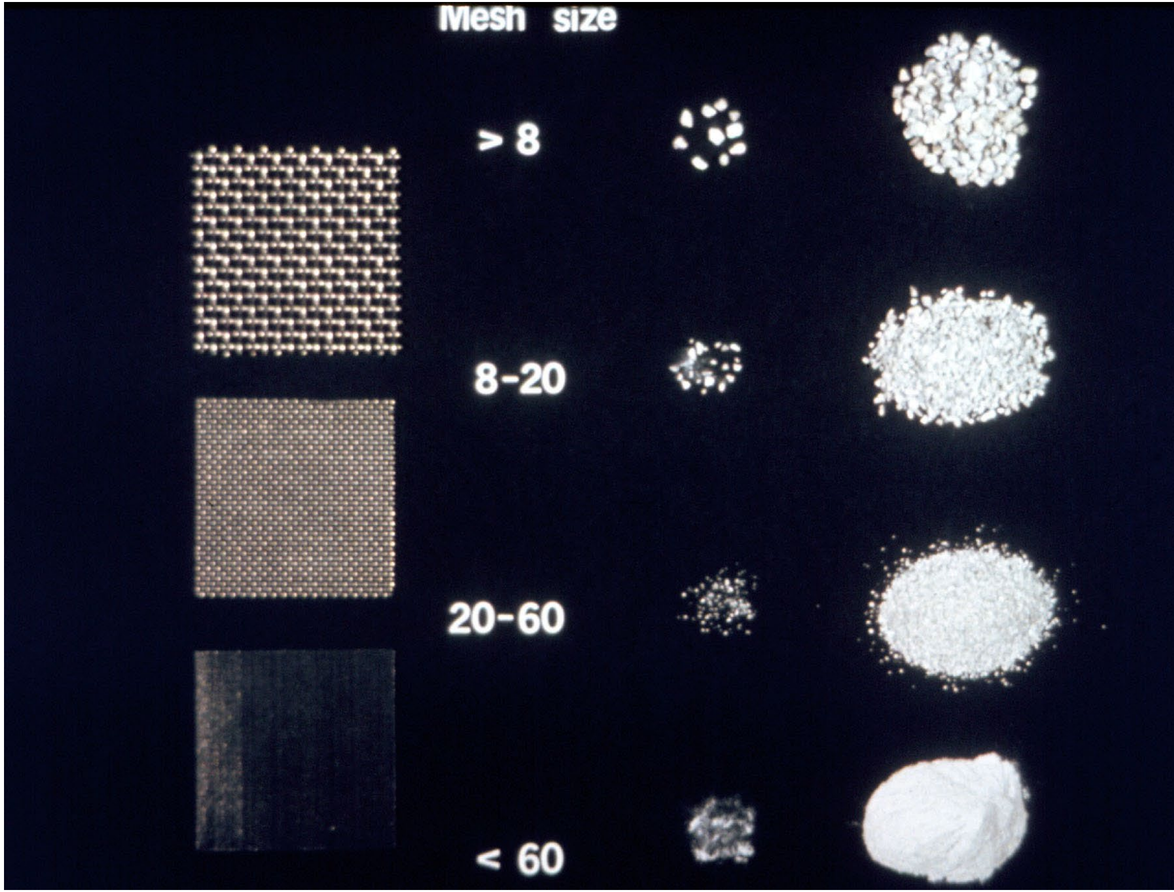
Lime requirement (application rate)

- Lime requirement in Minnesota is determined from the water or buffer pH and a lime area designation.
- A lime requirement is calibrated to raise the water pH to a desired “target pH”, usually 6.0 or 6.5
- Factors that affect subsoil pH
  - Parent material – glacial till, loess, outwash
  - Free calcium carbonates
  - Native vegetation – forest vs prairie
  - Rainfall and climate
  - Internal drainage



What determines the quality of a liming material?

- Purity
  - Calcium carbonate equivalent (CCE)
  - Determined by a lab
- Fineness
  - Particle size
  - Dry sieve analysis



Lime terminology and materials

- Effective neutralizing power, ENP
  - Lime suggestions are in lb of ENP/ac
  - ECCE in Iowa
- Calcium carbonate equivalent, CCE
  - CCE = Total neutralizing power, TNP old term
- Fineness index, FI
- Equations:
  - %ENP = %CCE × FI ÷ 100
  - ENP (lb/ac) = (2000 lbs/ton × %ENP ÷ 100) × (%dry matter ÷ 100)

- Liming materials include:
  - limestone (both calcitic and dolomitic),
  - burned lime,
  - slaked lime,
  - marl,
  - shells,
  - and by-products like sugar beet lime and sludge from water treatment plants.

https://extension.umn.edu/liming/lime-needs-minnesota

https://www.mda.state.mn.us/ag-lime-analysis-results

Minnesota Paving & Materials, Mankato, 507-625-4848

Production/Storage Site Name and/or Address	Site Location State-County	Ag Lime Type	Product Description	Analysis Date	Passing #8 Sieve	Passing #20 Sieve	Passing #60 Sieve	FI	CCE	ENP	Moisture	Min. Lbs. ENP/Ton
Owatonna Quarry	MN-Steele	Quarry	Screened Lime	6/5/2023	97%	75%	59%	73	68%	50%	4%	955
Kasota Quarry - Product #5032	MN-Blue Earth	Quarry	Screened Lime	5/22/2023	99%	80%	62%	77	89%	68%	4%	1315

City of Mankato, MN, 507-387-8661

Production/Storage Site Name and/or Address	Site Location State-County	Ag Lime Type	Product Description	Analysis Date	Passing #8 Sieve	Passing #20 Sieve	Passing #60 Sieve	FI	CCE	ENP	Moisture	Min. Lbs. ENP/Ton
740 Mound Avenue	MN-Blue Earth	Municipal By-Products	Water Treatment Lime	7/10/2023	100%	100%	100%	100	98%	98%	41%	1145

Calcium Products, Gilmore City, IA, 515-598-2762

Production/Storage Site Name and/or Address	Site Location State-County	Ag Lime Type	Product Description	Analysis Date	Passing #8 Sieve	Passing #20 Sieve	Passing #60 Sieve	FI	CCE	ENP	Moisture	Min. Lbs. ENP/Ton
Gilmore City Location @ 50602 330th Ave., Gilmore City, IA 50541	IA-Pocahontas	Pellet	98G Standard Pelletized Limestone	9/22/2023	100%	99%	98%	99	96%	95%	1%	1882

How does lime neutralize soil acidity?

$$H^{+}\text{-Clay} + CaCO_3 \rightarrow Ca^{++}\text{-Clay} + H_2CO_3$$

Limestone — Carbonic acid

Then:

$$H_2CO_3 \rightarrow H_2O + CO_2$$

Water — Carbon dioxide

https://extension.umn.edu/liming/liming-materials-minnesota-soils

Corn, Soybean and Alfalfa Response to Dolomitic and Calcitic (Pell) Lime

Gyles Randall and Jeff Vetsch
University of Minnesota Southern Research and Outreach Center

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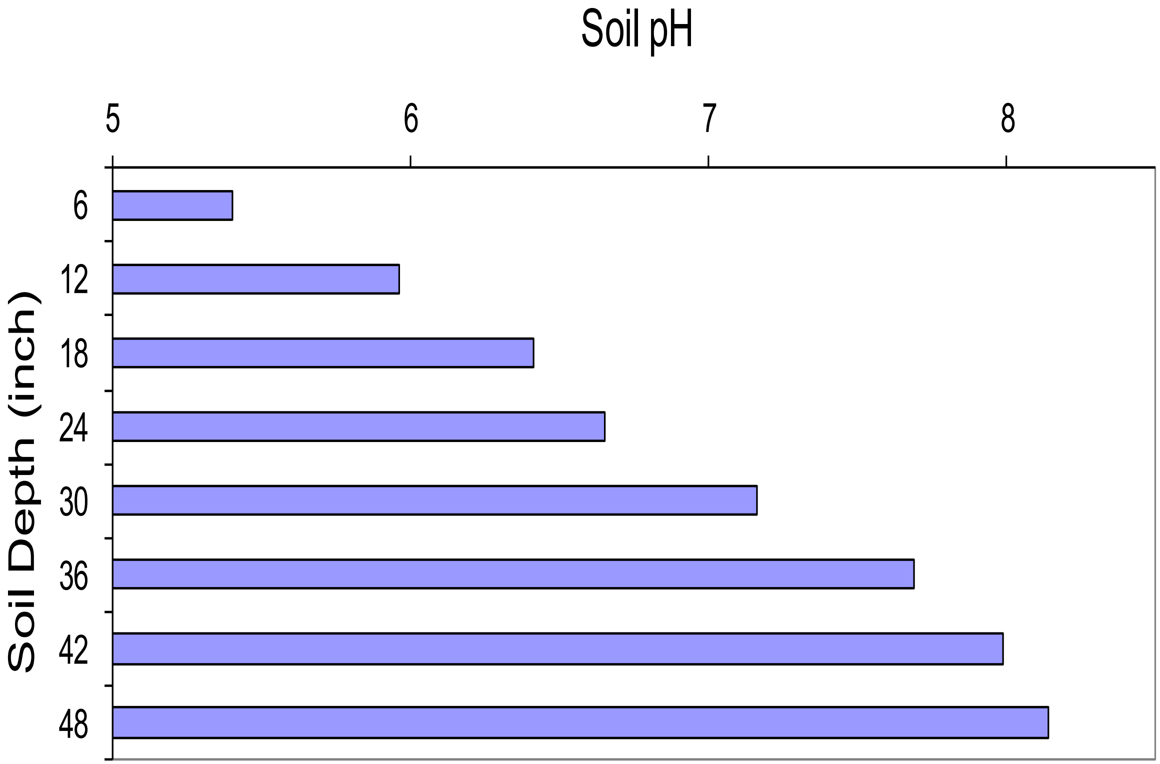
Materials and methods

- Established at SROC (Waseca) in August 1998 – 2006.
- Nicollet clay loam soil (glacial till parent material)
- Initially a corn–soybean rotation, alfalfa established in 2002
- Plots were 15 ft. wide by 28 ft. long.
- Initial soil (0-6 inch) water pH = 5.4, buffer 6.0
  - **Lime requirement for pH 6.0 = 5,000 lb ENP or 7,000 lb for pH 6.5**
- Soil sampled in early July
- Lime materials broadcast (by hand) and incorporated 4 inches deep with a roto-tiller before growing corn and soybean.
- Effective neutralizing power (ENP) was 1,030 and 1,800 lb/ton for dolomite and calcite (pell lime), respectively.

Treatments

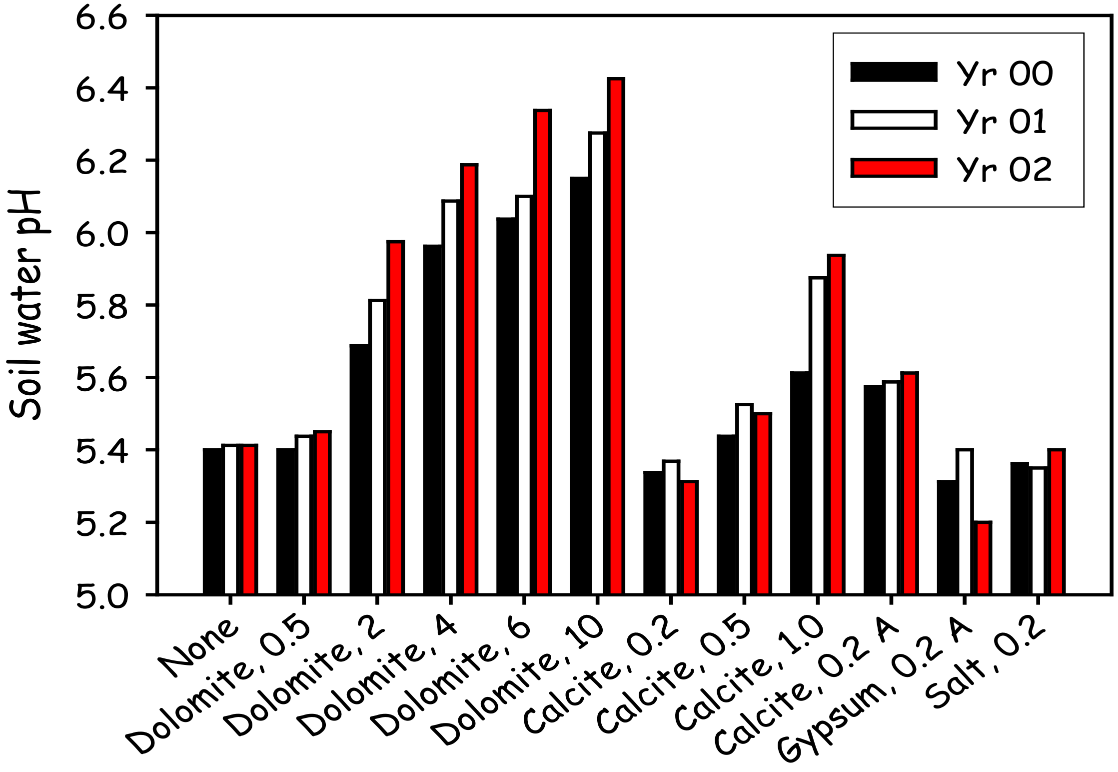
Lime Source	Rate, ton/ac	ENP, lb/ac per app.	Applications
Control	0.0	0	None
Dolomite	0.5	1,030	Aug 1998 & Oct 2000
Dolomite	2.0	2,060	Aug 1998 & Oct 2000
Dolomite	4.0	4,120	Aug 1998 & Oct 2000
Dolomite	6.0	6,180	Aug 1998 & Oct 2000
Dolomite	10.0	10,300	Aug 1998 & Oct 2000
Calcite (pell lime)	0.2	360	Aug 1998 & Oct 2000
Calcite (pell lime)	0.5	900	Aug 1998 & Oct 2000
Calcite (pell lime)	1.0	1,800	Aug 1998 & Oct 2000
Calcite (pell lime)	0.2	360	Annually (8X)
$CaSO_4$ (gypsum)	0.2	0	Annually (8X)
$CaCl_2$ (salt)	0.2	0	Aug 1998 & Oct 2000

Soil profile pH in 1998



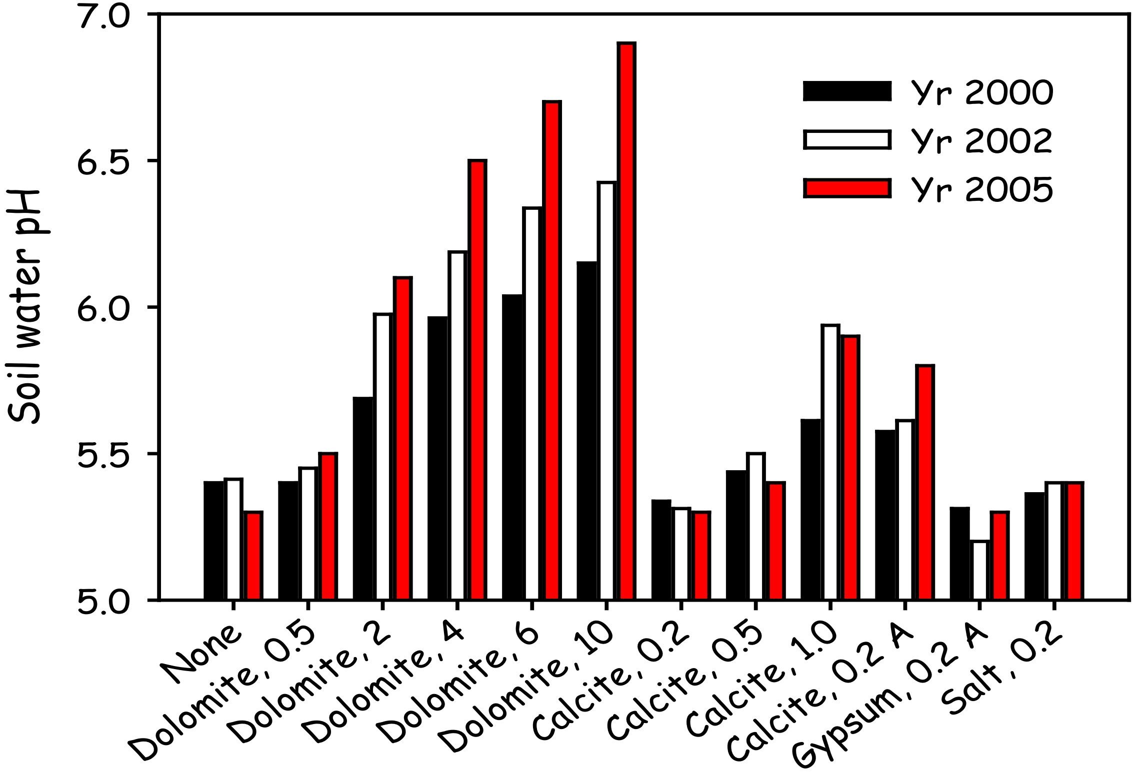
- pH ~6.0 in the 6-12” depth
- pH >6.5 in the 18-24” depth
- Calcareous subsoil at depths below 30”

Soil water pH as affected by liming



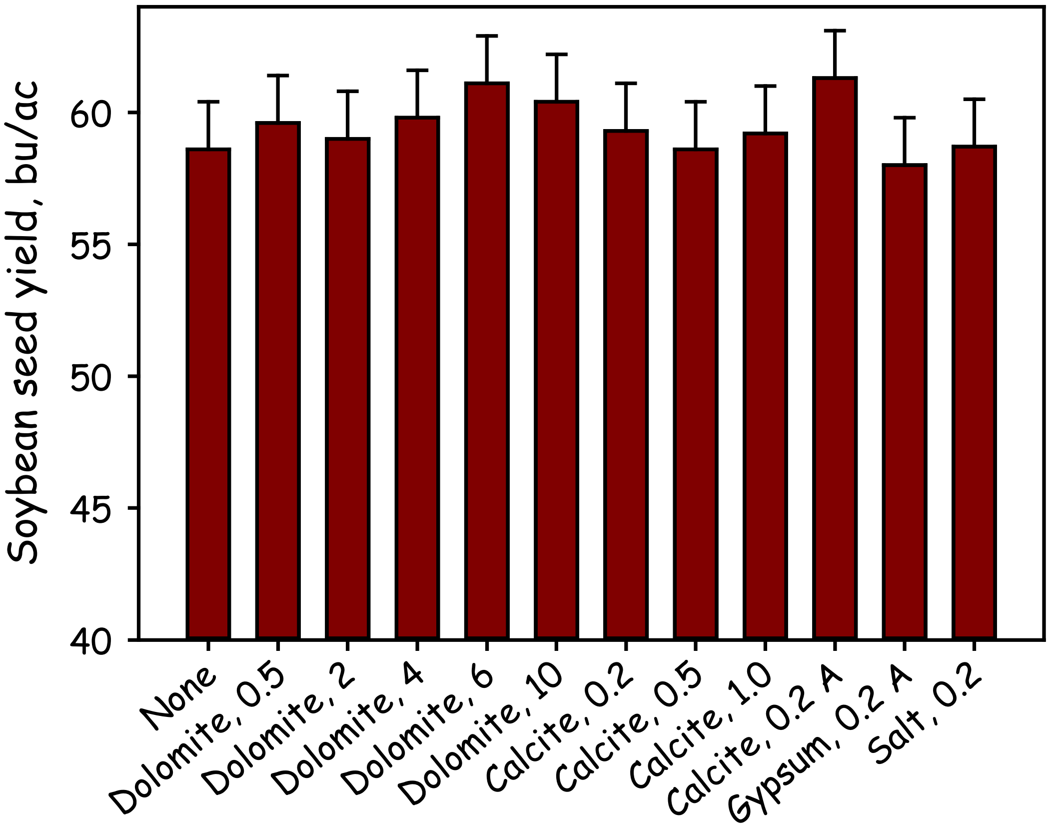
- In July of 2000, soil water pH (6" depth) was increased from 5.4 to 6.2 with dolomitic lime at 10 ton/ac (10,300 lb/ac ENP).
- By 2002, two applications of lime increased pH from 5.4 to 6.4 with 10 ton/ac of dolomite (2X) and 5.4 to 5.9 with 1 ton/ac of calcite (2X).

Soil water pH as affected by liming



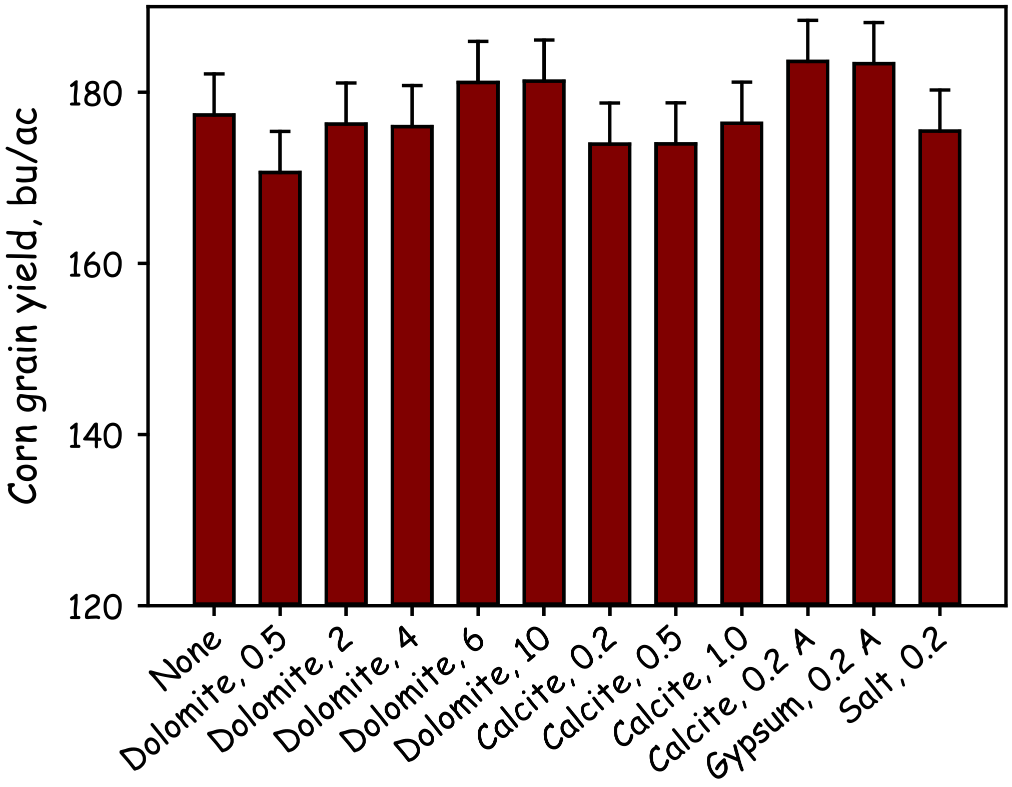
- In July of 2000, soil water pH (6” depth) was increased from 5.4 to 6.2 with dolomitic lime at 10 ton/ac (10,300 lb/ac ENP).
- By 2002, two applications of lime increased pH from 5.4 to 6.4 with 10 ton/ac of dolomite (2X) and 5.4 to 5.9 with 1 ton/ac of calcite (2X).
- By 2005, two apps of lime increased pH from 5.4 to 6.9 with 10 ton/ac of dolomite (2X) and 5.4 to 5.9 with 1 ton/ac of calcite (2X).

Soybean yield (5-yr avg.) as affected by liming.



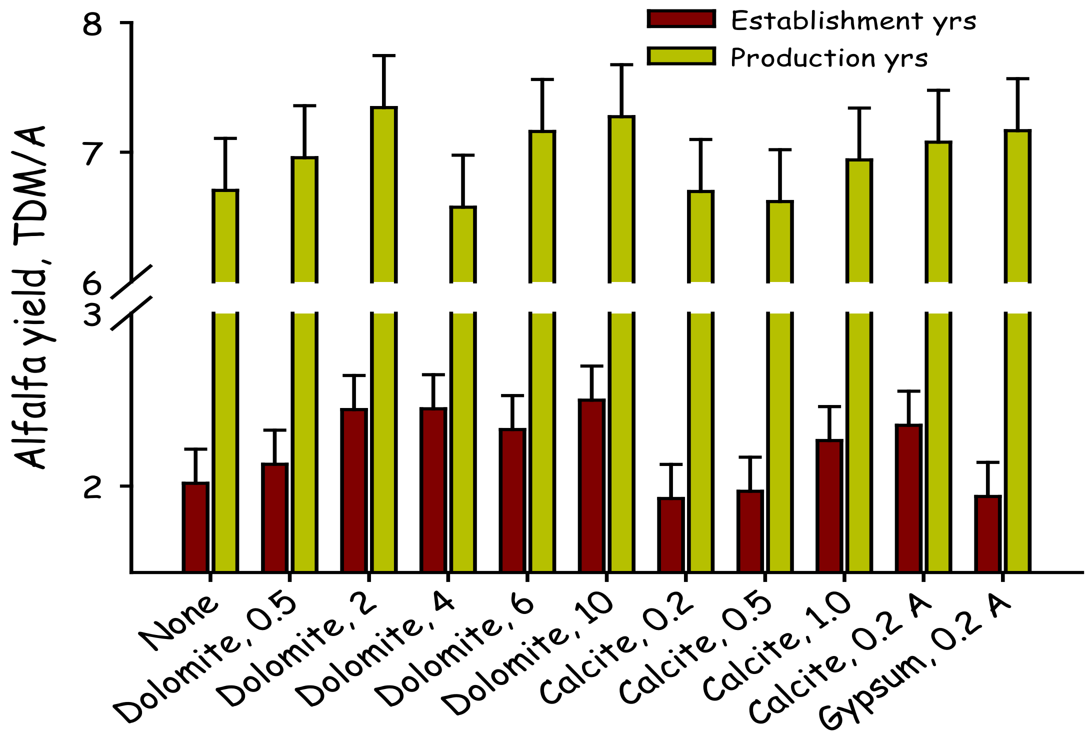
– Lime treatments increased soybean yields in 2 of 5 site years and the 5-yr average.
– The 6 ton/ac rates of dolomite applied twice and the 0.2 ton/ac rate of calcite applied annually increased soybean yields about 2.5 bu/A compared with the control.

Corn yield (6-yr avg.) as affected by liming.



- Treatments differences were found in 4 of 6 site years and the 6-yr average.
- The 6 & 10 ton/ac rates of dolomite applied twice resulted in corn yields 4 bu/ac greater than the control [NS at (0.10)].
- The 0.2 ton/ac rate of calcite and gypsum applied annually increased corn yields 8 and 7 bu/A, respectively, compared with the control.

Alfalfa yield as affected by liming.

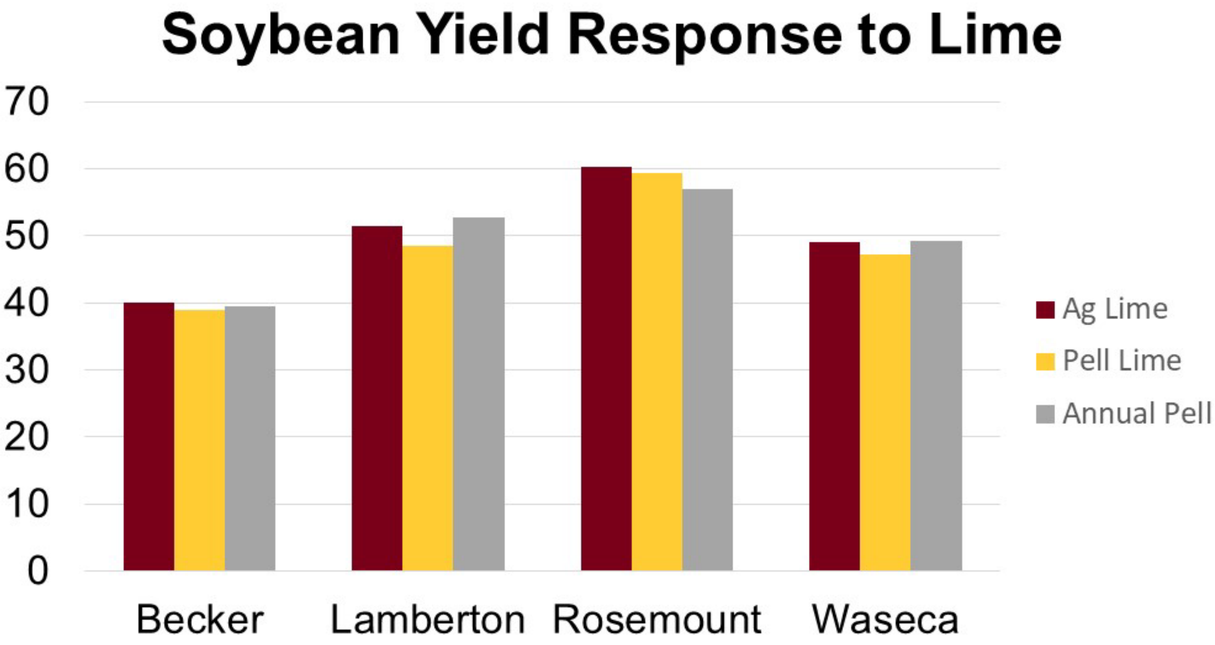


- Liming increased alfalfa yield in establishment years and in 1 of 3 production years and for the 3-year avg.
- Generally, lower rates of dolomite (2, 4, and 6 ton/ac) applied twice were adequate to increase both establishment and production year yield.
- Calcite applied twice and annually at 1 and 0.2 ton/ac, respectively increased alfalfa yield in establishment years.

Conclusion: Waseca study

- These data showed the importance of long-term studies for pH and liming:
- Corn and soybean yield responses were small and generally would not have given a ROI.
- Alfalfa consistently responded to liming.
- Data clearly showed a yield response to sulfur.

Lime application in Minnesota Crop Rotations
Daniel Kaiser



- Lime was applied at rates of 0, 1000, 2000, 3000, 4000, and 5000 lbs ENP per acre.
- Seed protein concentration was increased by lime application rate at Rosemount and Waseca
- Soil samples taken in late fall of 2023 showed minimal pH change this year.
- MSR&PC funding

Iowa Studies: Mallarino and Pagani

- On-farm studies (43 site-yrs)
- Rates 0 and 3 ton/ac of ECCE.
  - 6,000 lb of ENP/ac (MN term)
- Plot size 0.3 to 0.5 ac.
- Corn and soybean.
- Same fields for up to 4 yr.

Mallarino et al., 2011

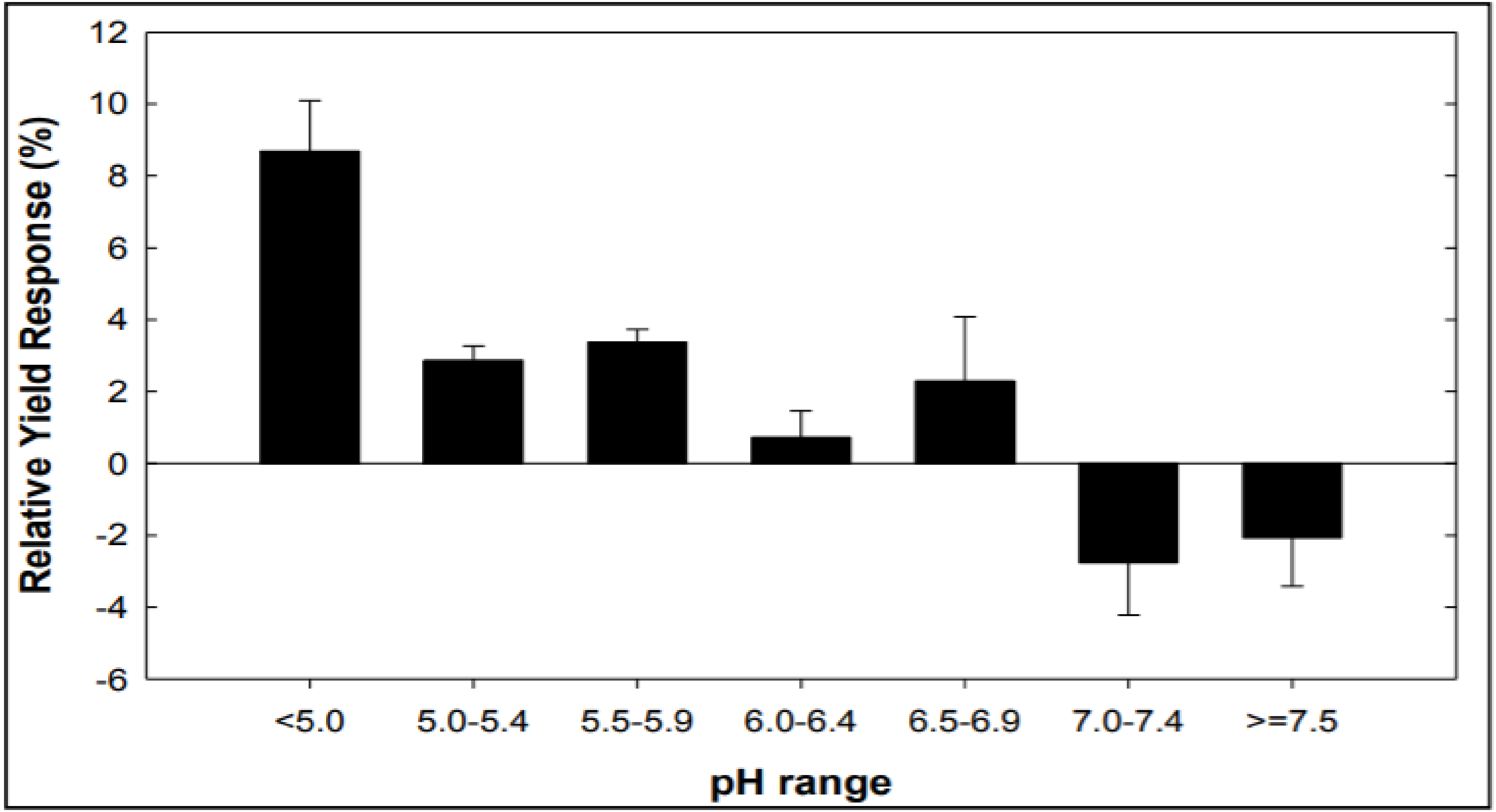


Figure 4. Relative grain yield response (combined corn and soybean) to 3 ton ECCE/acre summarized by soil pH across all strip trials and years (43 site-years). Lines represent standard errors.

Mallarino et al., 2011

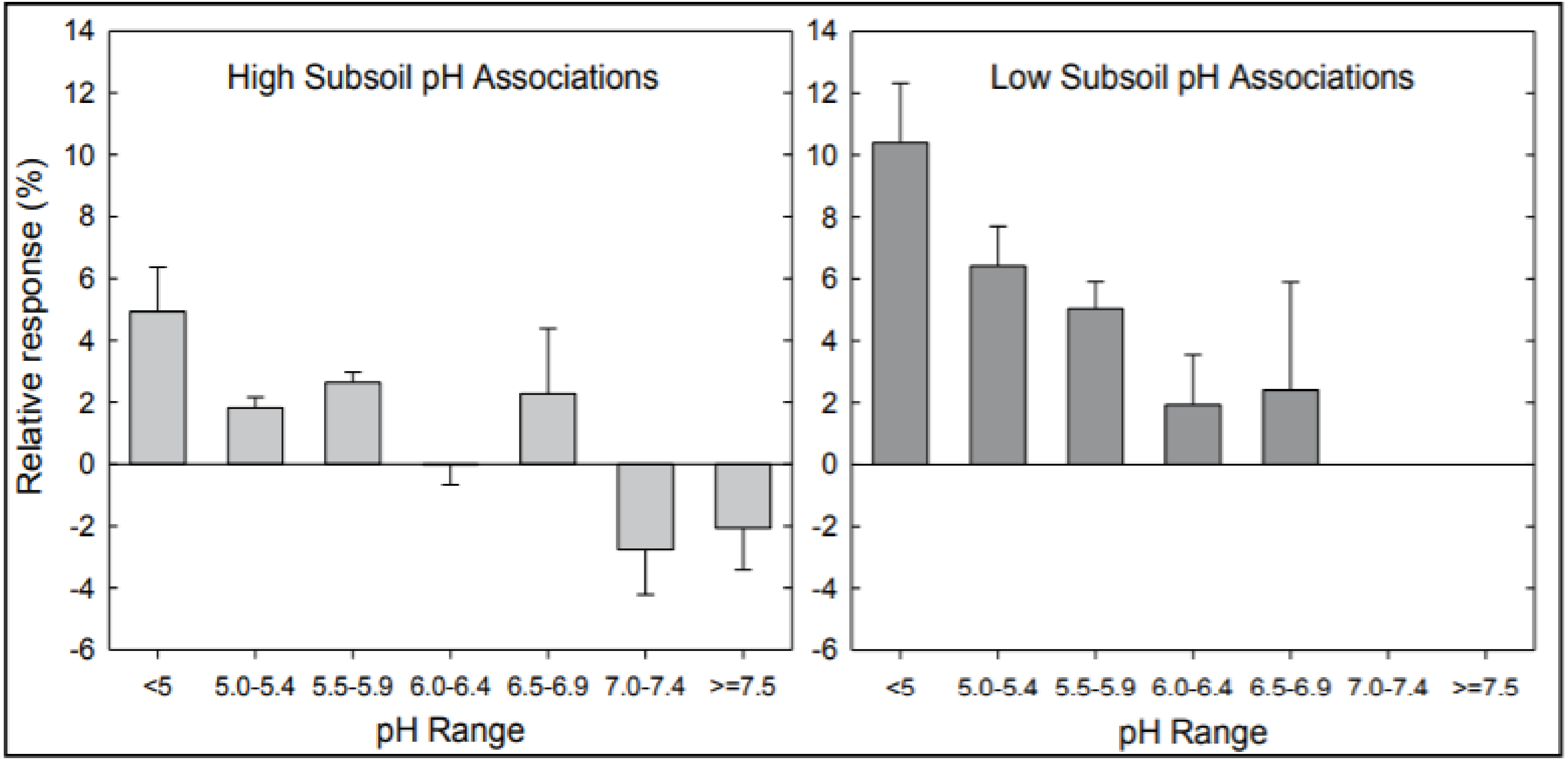


Figure 6. Relative yield response (combined for corn and soybean) to 3 ton ECCE/acre according to pH for soil associations areas with or without high-pH subsoil (lines represent standard errors).

Iowa Studies: Mallarino and Pagani

- Averaged across 43 site-yrs there were large corn and soybean yield responses for pH ranges up to 5.9, smaller and barely significant responses for ranges 6.0 to 6.9 and small yield decrease at higher pH values (Fig. 4).
- **Fields with high subsoil pH**
  – Had large yield responses to liming when surface soils were very acid (pH < 5.0), smaller but significant responses up to pH 5.9 and no significant or consistent response from pH 6.0 to 6.9 (Fig. 6).
- **For low subsoil pH fields**
  – Had large yield responses to liming up to pH 5.9, smaller but significant up to pH 6.4 and no increase for higher pH values.

Conclusions

- Corn yield responses to liming occur, especially at water pH values < 5.4; however, they may not give a ROI.
- Soybean yield responses are more common but may be small 2 to 3 bu/ac, especially on soils with high subsoil pH.
- Alfalfa generally responds to lime applications when soil tests recommend liming.
- Glacial till soils are highly buffered and in MN they had a slower pH response when limed.
- High CEC soils will need more lime ($$$).

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