BASICS OF SOIL FERTILITY

Soil pH, Soil CEC and Root Traffic

Nutrient, Soil, and
Water Management Conference

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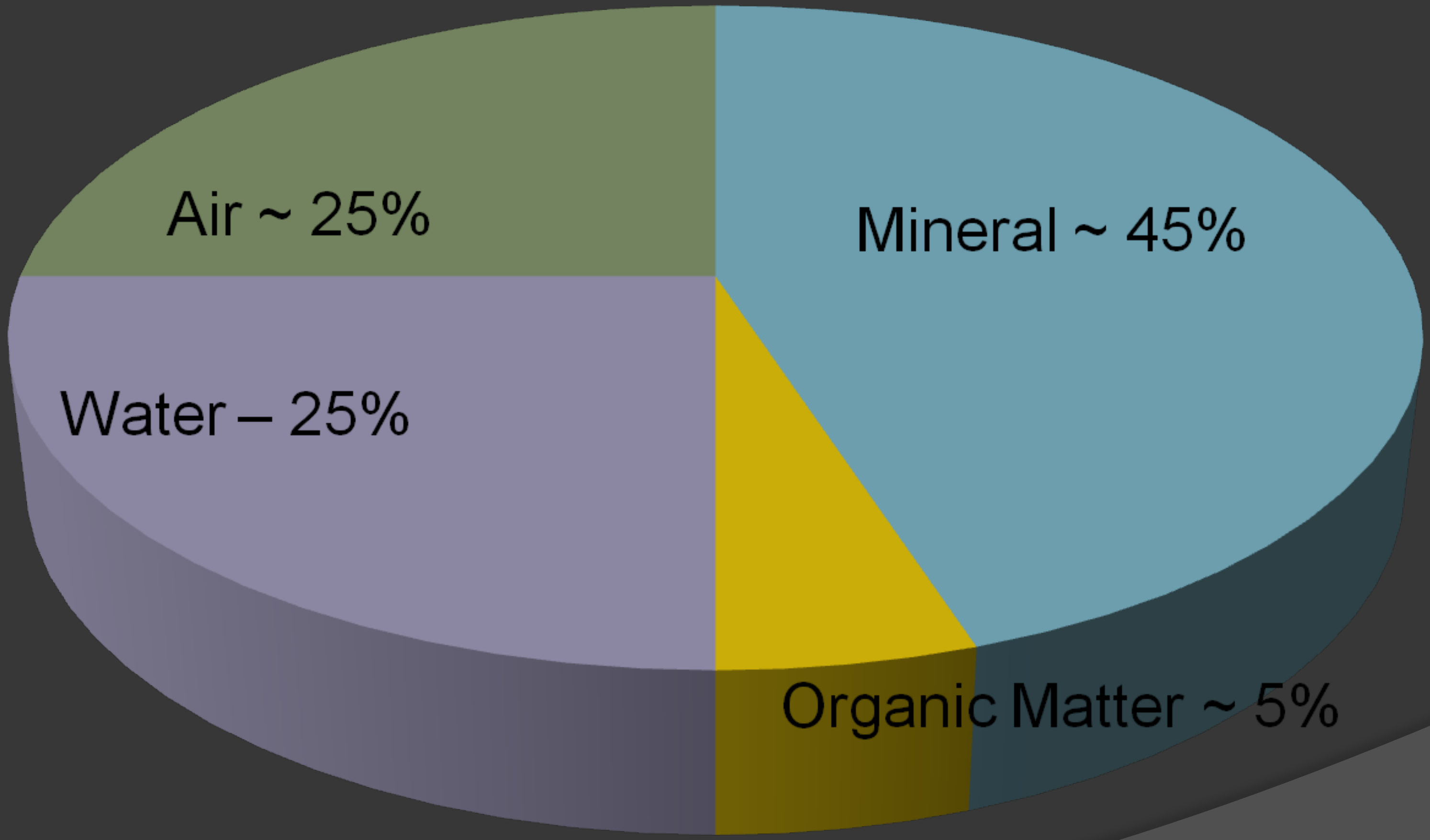
Basics of Soil Fertility

Soil pH, Soil CEC and Root Traffic

a) Define what it is
b) How affects soil fertility
c) Can we influence it

Soil Components



ORGANIC MATTER BENEFITS SOIL IN MANY WAYS:

- Improves physical condition
- Increases water infiltration
- Improves soil tilth
- Decreases erosion losses
- Supplies plant nutrients
- Increases CEC

Cation Exchange Capacity (CEC)

The total number of exchangeable cations a soil can hold
(meq/100g or cmol/kg)

NEGATIVELY CHARGED COLLOIDS ATTRACT CATIONS

Cation Exchange Capacity

Clay

Kaolinite	Illite	Smectite
meq/100g		
3-15	10-40	100-150

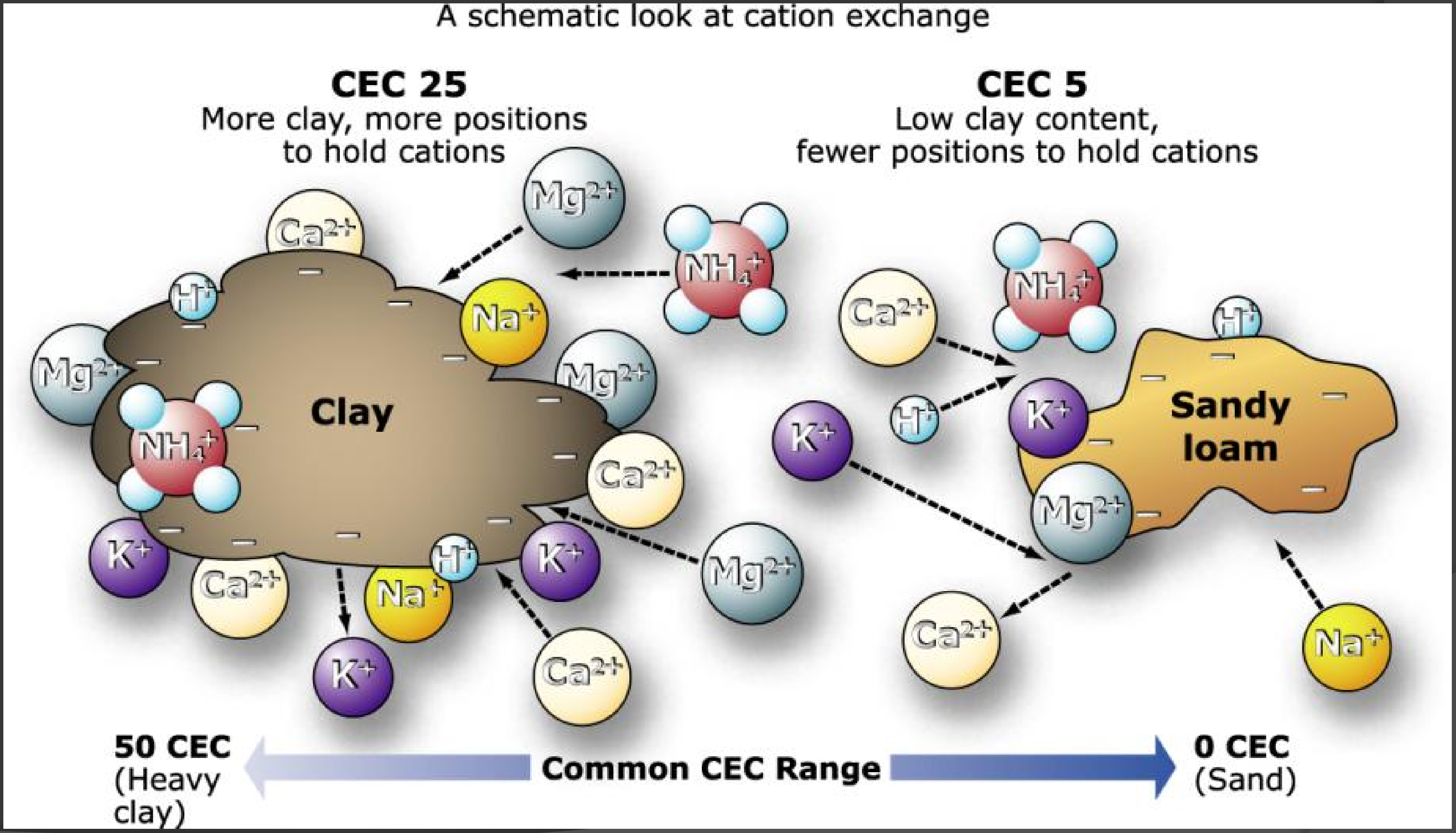
Organic Matter

OM
meq/100g
200-400

Texture

Sands	FineSandy Loam	Loams, silt loams	Clay loams	Clay
meq/100g				
1-5	5-10	5-15	15-30	>30

CATION EXCHANCE CAPACITY



Cation Exchange Capacity (CEC)

Typical Upper Midwest soils

- Coarse texture, low OM = 5 – 15
- Medium texture, moderate OM 15 – 20
- Fine texture, high OM 20 - 30

Cation Exchange Capacity (CEC)

Estimate with :

- **Sum of extractable cations (Ca, Mg, K, Na), with some adjustment for H^+ using pH), gives estimate of “true” CEC**

Cation Exchange Capacity (CEC)

How CEC related to Soil Fertility ?

Higher CEC generally more fertile – not necessarily more productive.

Sands generally leach or lost cations or plant nutrients over time

Generally ….

- The more fertile the soil tends to be …
- The more clay the soil tends to have …
- The more organic matter a soil tends to have

the higher the CEC

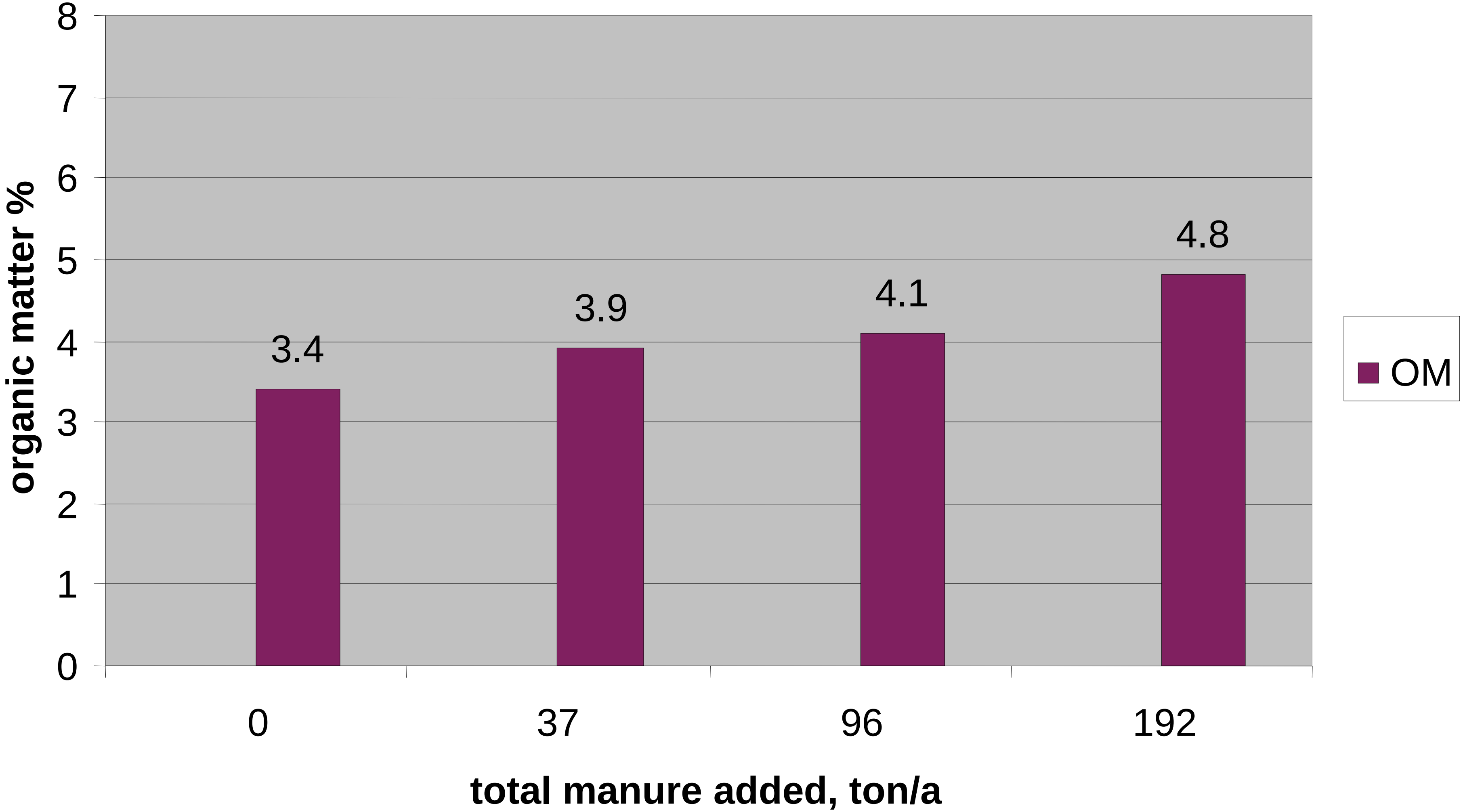
Cation Exchange Capacity (CEC)

- What can we do to improve?

 - texture or clay type are set.

Organic matter ? > with less tillage, more Carbon additions, residue ,manure additions

Fig. 3. Influence of nine years of manure additions on organic matter levels, Beresford, SD, 2011.



Cation Exchange Capacity (CEC)

What can we do ?

Increase Organic matter

Slow process and CEC changes are small because OM small part of CEC.

So not much can be done to change.

ANION RETENTION IN SOILS

- Phosphate is held strongly due to quick formation of insoluble compounds
- Sulfate will move but not as readily as nitrate. Forms gypsum lower in profile
- Nitrate and chloride are not held in soils and move freely with soil water

CEC Magic Myths

- 1. Cation Ratios
- 2. Apply N rates according to CEC

Basic Cation Saturation Ratios (BCSR)

Basic Cation Saturation Ratios (BCSR)

- Sometimes used as an indicator of nutrient availability
- Idea originated New Jersey in 1940s

'Desired Saturation'
65 to 75% for Ca^{++}
about 10% for Mg^{++}
2.5 to 5% % for K^{+}
& remainder for H^{+}

'Desired Ratios'
7:1 for Ca/Mg
15:1 for Ca/K
3:1 for Mg/K

According to published research since 1940s

- McLean & Brown, 1984, Soil Acidity and Liming, 2nd ed. Agronomy No. 12, ASA-CSSA-SSSA
  - “The only conclusion one can reach from the results of both growth chamber and field studies, and the other studies cited, is that there is no ideal basic cation saturation or range of saturation where crop yields are maximum.”

In Soil Testing and Plant Analysis, 3rd ed.,1990, SSSA Book Series No.3

- **Dahnke & Olson** -"It is surprising that the cation saturation concept has received the credibility accorded to it in consideration of other early and recent literature accounts on the issue."
- **Haby and others** - "Use of the BCSR typically increases fertilizer recommendations compared to other approaches. This method also ignores the selectivity that plants demonstrate during absorption of ions from soil solution."

Haby and others, 1990. Soil Testing and Plant Analysis

- 5 to 6% Mg saturation may be adequate for most crops
- 10% Mg saturation may be required for alfalfa, cool-season forages, etc. to prevent grass tetany
- Na saturation above 5 to 10% can impair K uptake.
- Na saturation above 15% can also cause very poor soil physical conditions

Comments on Sodium (Na) Saturation

- Na saturation from 10 to 20% can also cause poor soil physical conditions
- Na saturation above 20% (sodic soil) will severely limit crop production
- Usually alleviate with added Calcium (gypsum), with improved drainage

The data do not support the claims of the BCSR, and continued promotion of the BCSR will result in the inefficient use of resources in agriculture and horticulture.

In SSSAJ 2006, Review of BCSR by Kopittke and Menzies

- "the chemical, physical, and biological fertility of a soil is generally not influenced by the ratios of Ca, Mg, and K."

"The data do not support the claims of the BCSR, and continued promotion of the BCSR will result in the inefficient use of resources in agriculture and horticulture."

CEC Magic Myths

- 1. Cation Ratios

- 2. Apply N rates according to CEC

Vary N Rate with CEC ?

- Not sure where this started

Concerning Anhydrous

$NH_3 + H_2O = NH_4 + OH^-$

NH_3 (Ammonia) can be lost as gas

NH_4 (Ammonium) is held by soils

A soil with 10 meq/100g CEC could hold about 2900 lbs of N as ammonium

Vary N Rate with CEC ?

Concerning Nitrate ?

$2\ NH_4 + 3\ O_2 \rightarrow 2\ NO_3^- + 8\ H^+$

NO_3^- can move with water. Leaching influenced by

Soil water, amount of precipitation

Soil texture – Coarse soils < H_2O holding

When Nitrification occurs

CEC is important – no rule on amount

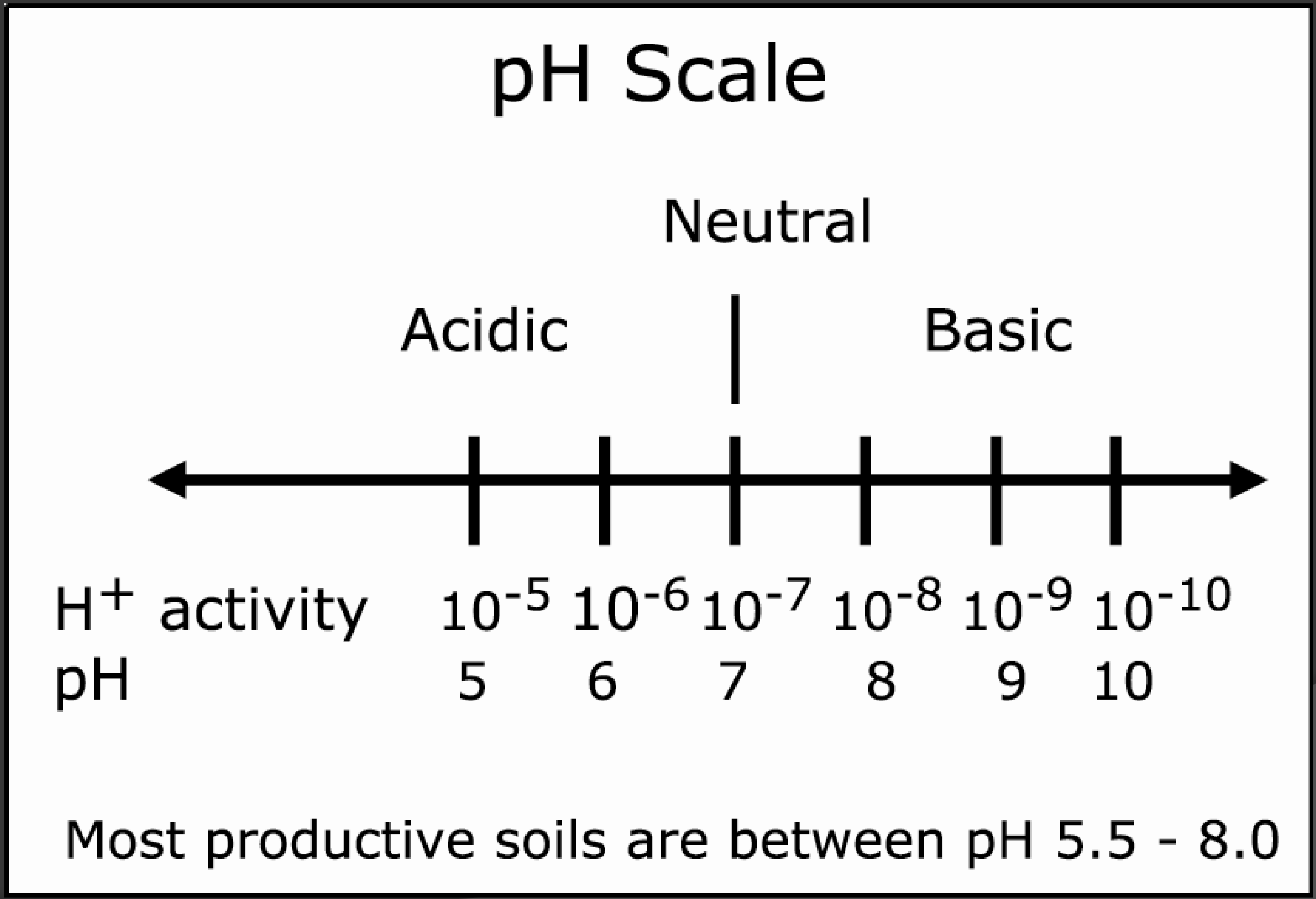
Vary N Rate with CEC ?

N management for Coarse soils

- **Apply later, side dress**
- **Multiple applications**
- **Spoon feed with irrigation**
- **Avoid fall application and nitrate forms**
- **Utilize nitrification inhibitors**

Soil pH

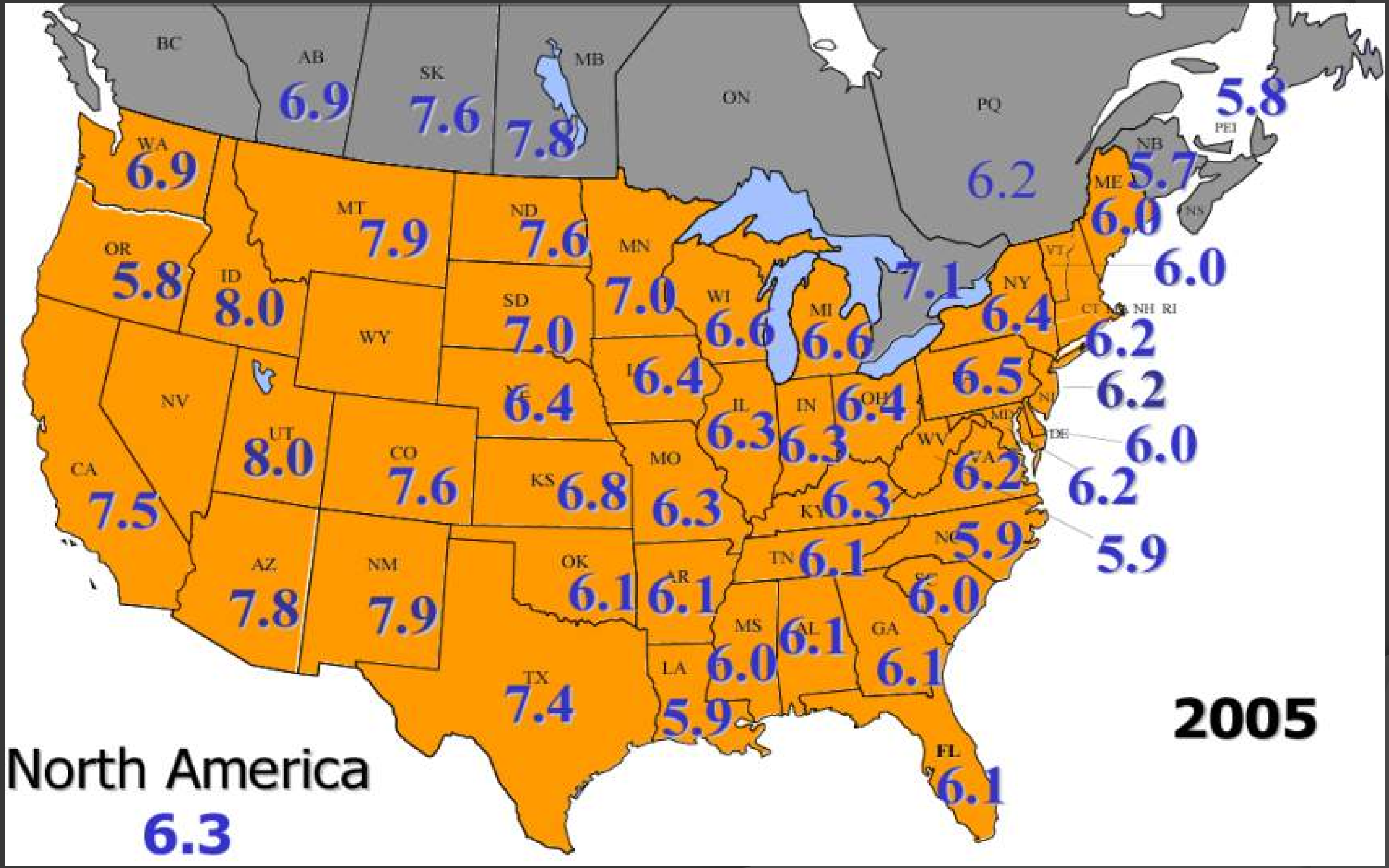
Soil pH is a term used to describe a soil's relative acidity or basicity



A Soil's pH is Affected by Several Factors:

- Decomposition of organic matter
- Parent material
- Precipitation
- Native vegetation
- Nitrogen fertilization
- Flooding

Median soil pH levels in North America



31% of samples for 2005 were below 6.0

Why Acid Soils Should Be Limed

- Reduces Al and other metal toxicities
- Improves the physical condition of the soil
- Stimulates microbial activity in the soil

- Increases CEC in variable charge soils
- Increases availability of several nutrients
- Supplies Ca and Mg to plants
- Improves symbiotic N fixation in legumes
- Improve crop yields

Nitrogen Rate Influence on Soil pH, Nitrate and Salt, 1988-2006, Beresford

N Rate[1]	pH[2]	NO_3-N	Salts
lb/a		lb/a 2 ft	mmho/cm
0	6.2	8	0.3
50	5.9	24	0.3
100	5.1	100	0.4
200	4.9	260	0.8

[1]Avg. Annual rate, all N applied to corn in corn bean rotation, corn in 2006

[2]Sampled Oct 2006

Influence of yearly lime additions on corn and soybean yields, Brandt soil, 1998-2006, Aurora SD.

Lime applied[1]	pH^2 (final)	Conv.	No-till
		Yield increase over check,bu/a	
		---- corn ---	
check	5.5	--	--
1ton /ac/yr	6.7	16	8
		--- soybean---	
check	5.5	--	--
1ton /ac/yr	6.7	3.5	3.7

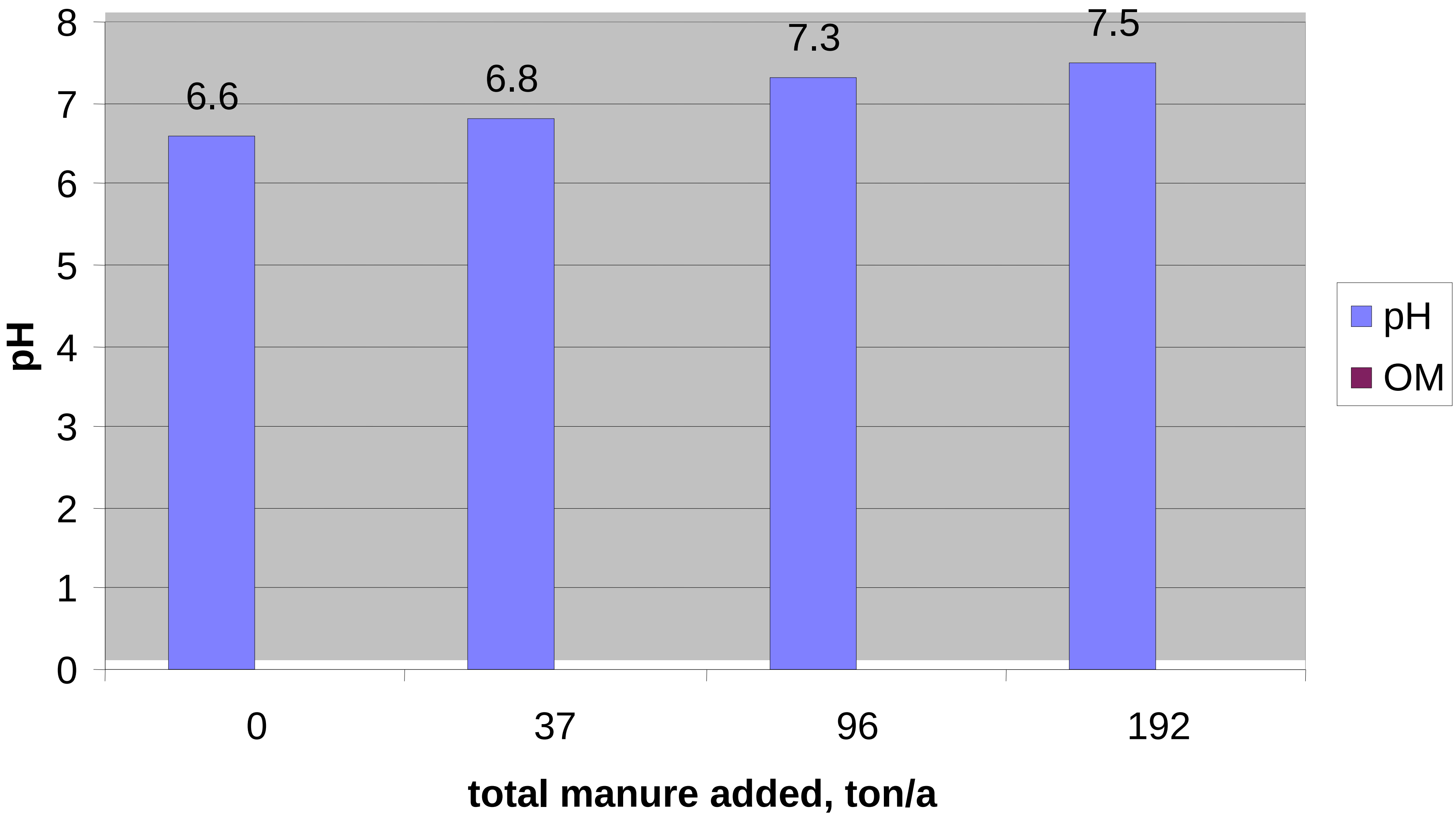
- [1] Lime (1 ton Super Cal) applied yearly except 2006.
- [2] pH values (2006) averaged over both corn and soybean years, two sites

Response to lime[1], Beresford SD, 2010			
long term N rate	no lime	lime	Corn[2] Response (lime – ck)
lb/a	------ pH -----		bu/a
0	6.2	6.9	+9 ns
100	5.9	6.6	-3 ns
200	5.6	6.4	-5 ns
400	5.2	6.2	+3 ns

[1]four ton lime applied spring 2008.

[2] 180 bushel corn

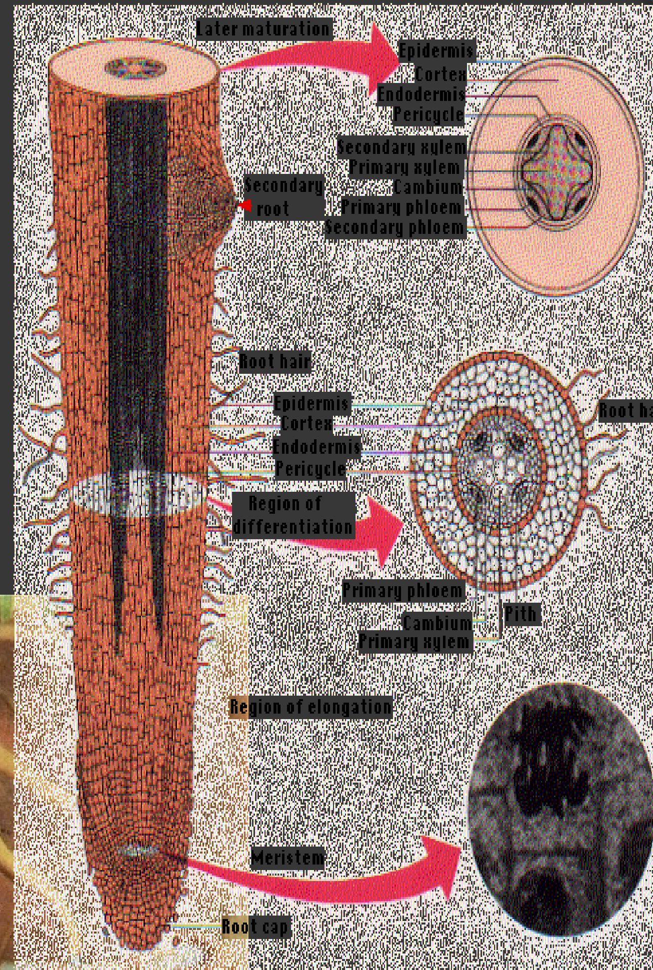
Fig. 3. Influence of nine years of manure additions on soil pH, Beresford, SD, 2011.

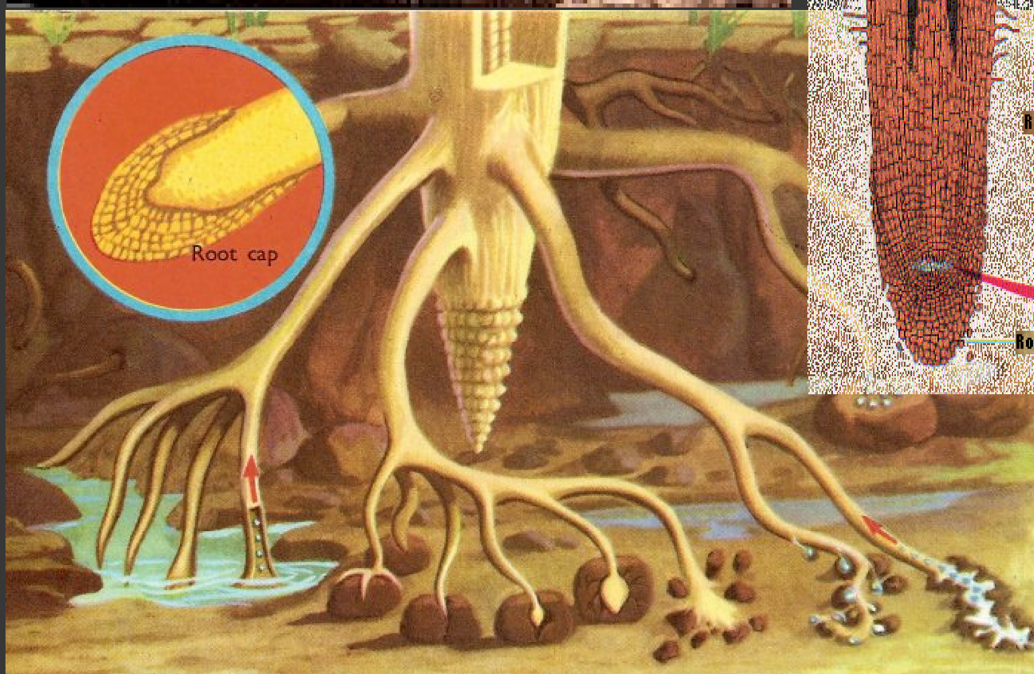


Sulfur to Lower pH ??

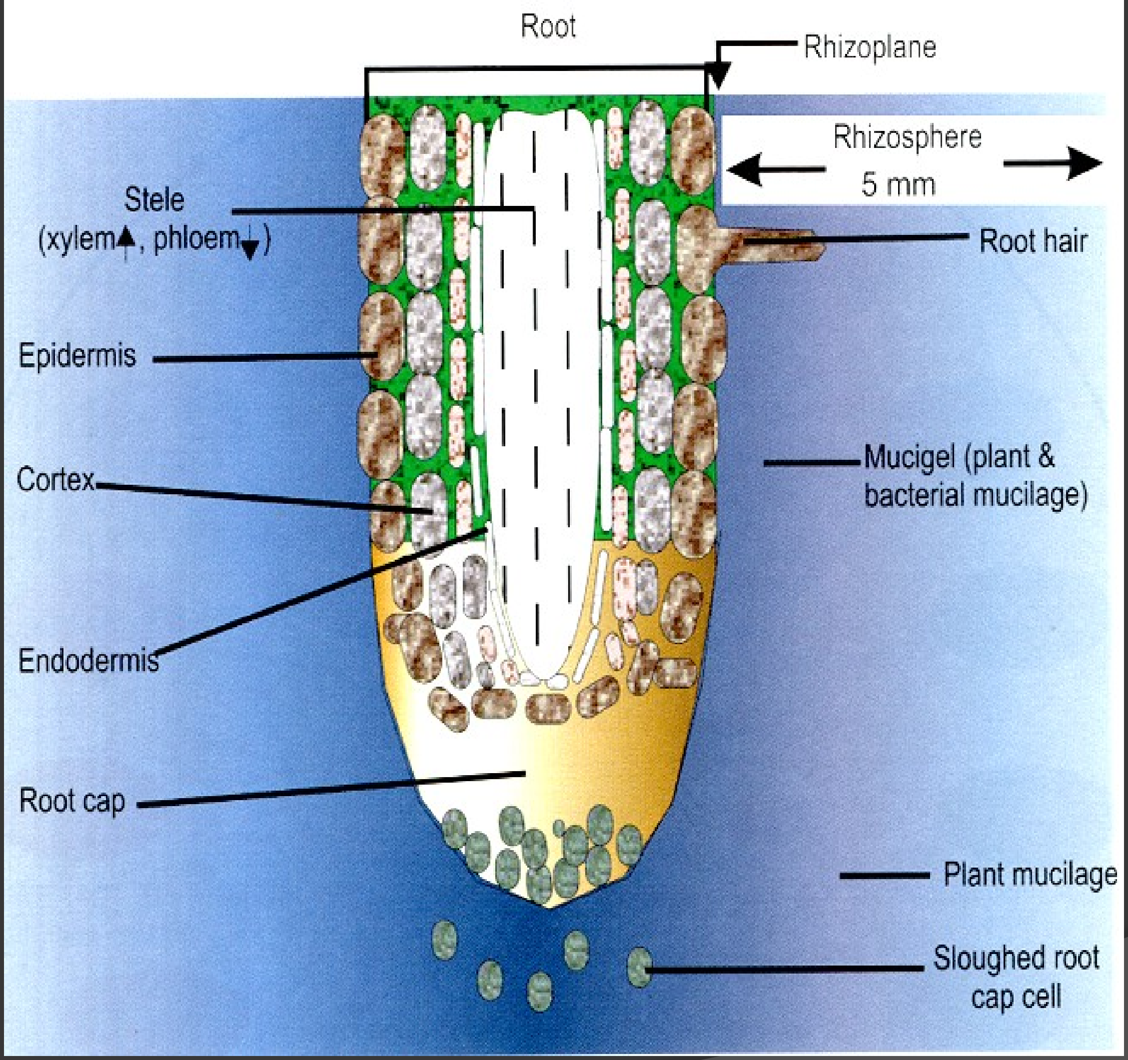
Elemental sulfur effect on soil EC and pH, Aurora, SD. 2009

Soil depth	Elemental S treatment, ton/a	
	0	2.5
inches	EC, mmho/cm	
0-2	0.6	1.5
2-4	0.6	1.3
4-6	0.6	1.0
6-12	0.6	1.0
pH	7.1	4.7


Later maturation
Epidermis
Cortex
Endodermis
Pericycle
Secondary xylem
Primary xylem
Cambium
Primary phloem
Secondary phloem
Secondary root
Root hair
Epidermis
Cortex
Endodermis
Pericycle
Region of differentiation
Root hair
Primary phloem
Pith
Cambium
Primary xylem
Region of elongation
Meristem
Root cap


Root cap

Root Rhizosphere



Root Rhizosphere

Roots exude or secrete

- ions, O_2, H_2O enzymes, mucilage, organic metabolites
- A) waste materials (no known function)
- B) known compounds for defense, lubrication etc.
- Most do not have a known function

Root Rhizosphere

Negative Plant – Plant Interactions

1) Alleolopathy – release of phytotoxins to reduce growth of other plants.

   Black Walnut, Rye

2) Parasitic Plants i.e. Witchweed.

   - seeds only germinate near host roots (chemical signal)

Root Rhizosphere

Positive Plant – Plant Interactions

1) One species of plant releasing compound that will repel aphids in an adjacent species.

Root Rhizosphere

Plant Root secretions that influence soil nutrients

1) Exudates contain chelates which can > availability of Fe, Zn, Mn and Cu

particularly effective for Fe with some grasses.

2) Soybean release phenols which similarly > Fe availability

Root Rhizosphere

Plant Root secretions that influence soil nutrients.

1) Release of organic acids (citric, malic, Oxalic) which can chelate P. Esp. for Lupines in low P soils.

Root Rhizosphere

Plant – Microbe interactions Positive

1) N fixation by many legumes. Rhizobia.

- signal chemical = flavonoids

2) Mycorrhizal symbiotic associations – fungi. 80% of plants have.

provide water, nutrients to plant

carbohydrates to fungi. Signal = GUS

Root Rhizosphere

Plant Growth Promoting Bacteria

- they stimulate plant growth. Ex. Azospirillium brasilense. Some release growth regulators.

Discovery has produced many microbial seed-inoculants products.

Thank You !

Thank you to International Plant Nutrition Institute

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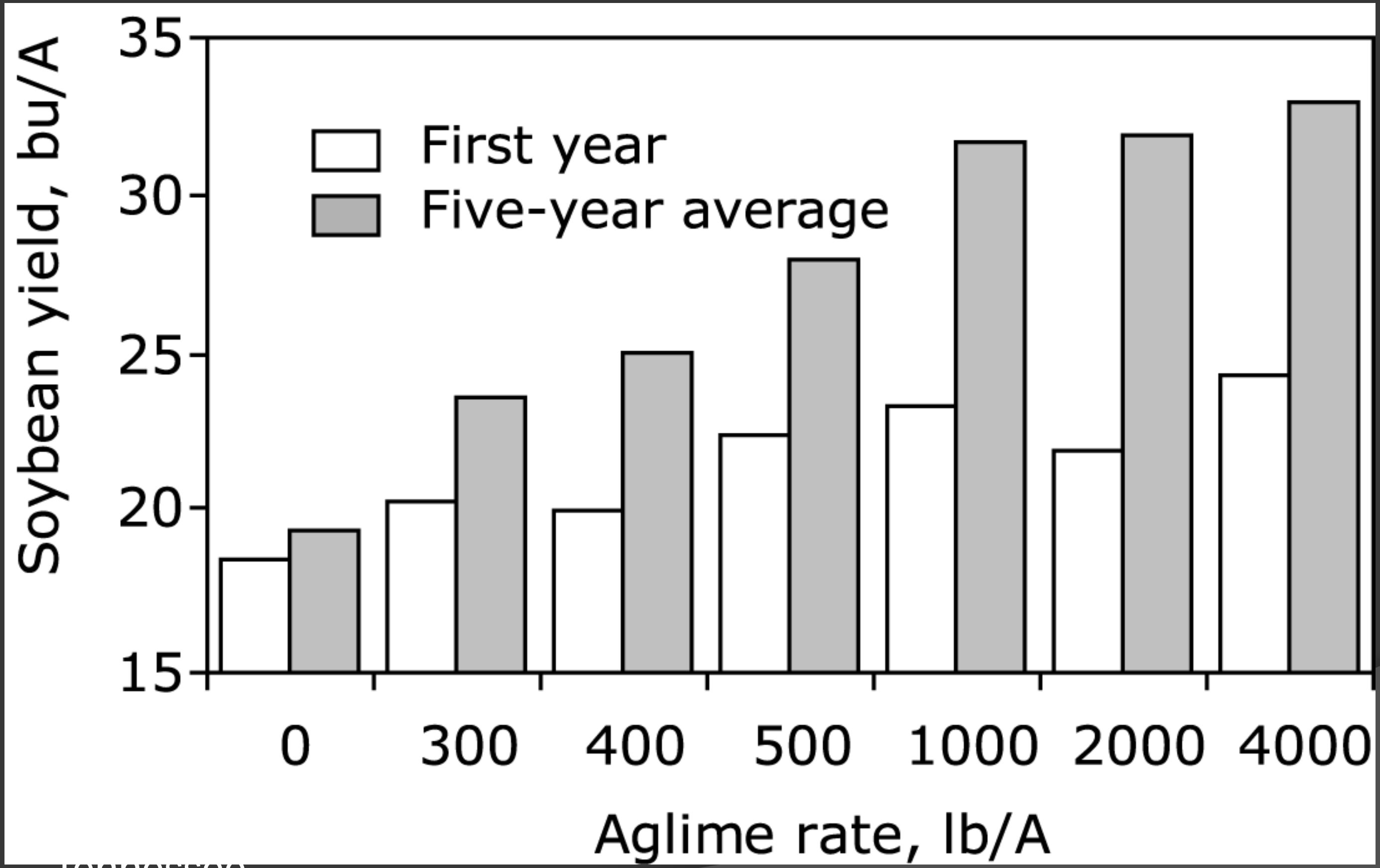
Liming Acid Soils Increases Yield Long Term



Tennessee

CLAY AND ORGANIC MATTER HAVE GREATEST INFLUENCE ON CEC

Clay	Organic matter
10-150 cmol(+)/kg	200-400 cmol(+)/kg

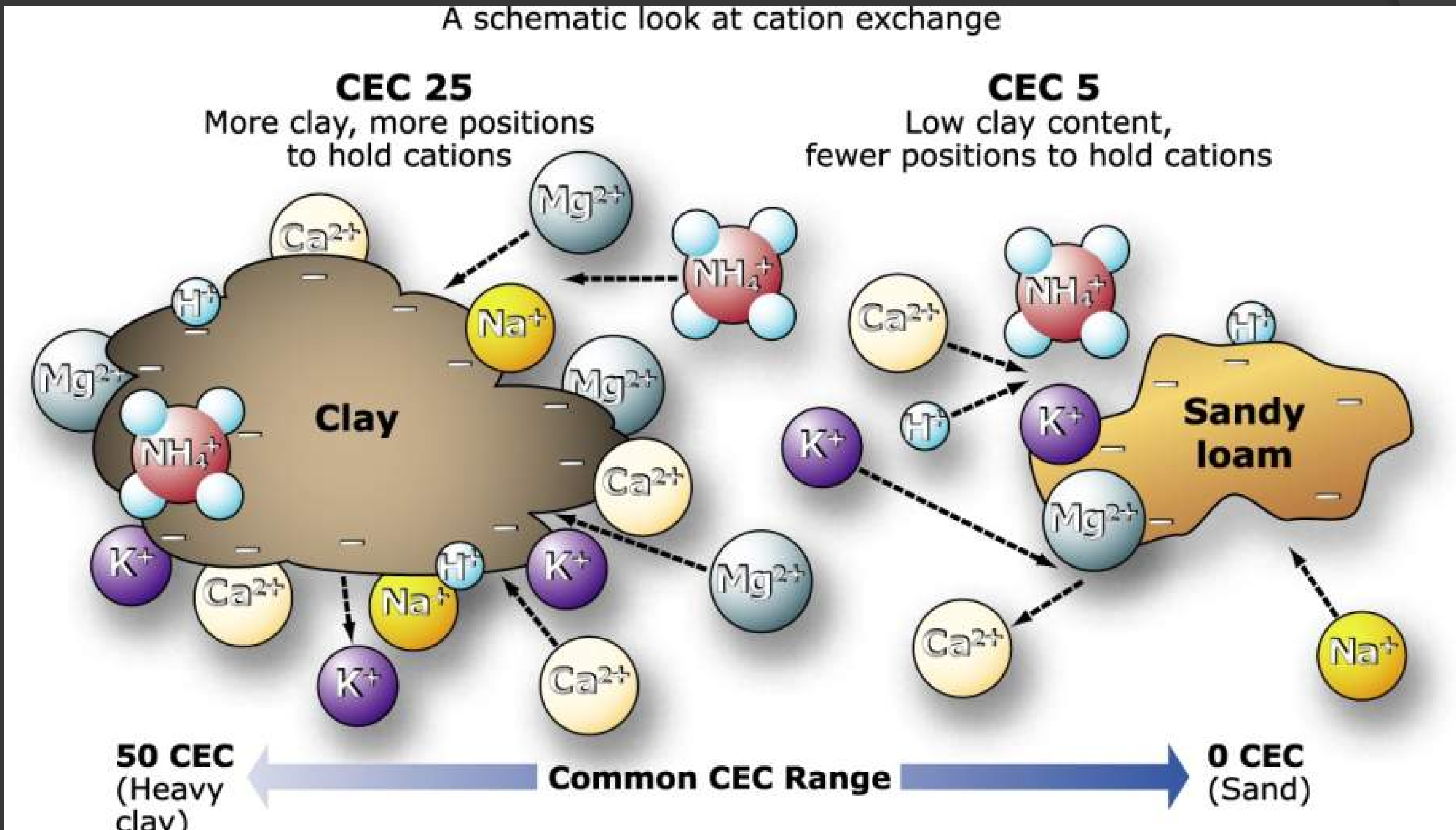
Organic matter has a higher CEC

Note: cmol(+)/kg = meq/100g

Positively Charged Ions Are Called Cations

Nutrient	Chemical Symbol	Ionic Form
Potassium	K	K^+
Sodium	Na	Na^+
Ammonium	NH_4	NH_4^+
Hydrogen	H	H^+
Calcium	Ca	Ca^{++}
Magnesium	Mg	Mg^{++}
Aluminum	Al	Al^{+++}

CATION EXCHANCE CAPACITY



Negatively Charged Ions Are Called Anions

Nutrient	Chemical Symbol	Ionic Form
Chloride	Cl	Cl^-
Nitrate	N	NO_3^-
Sulfate	S	$SO_4^{=}$
Borate	B	$BO_4^{\equiv}$
Phosphate	P	$H_2PO_4^-$

CATION EXCHANGE CAPACITY (CEC)

THE TOTAL NUMBER OF EXCHANGEABLE CATIONS A SOIL CAN HOLD

(AMOUNT OF ITS NEGATIVE CHARGE)

SOIL

H^+
Ca^{++}
Mg^{++}
K^+
Al^{3+}
NH_4^+

$+ \quad 9\ NH_4OAc \longrightarrow$

SOIL

NH_4^+
NH_4^+
NH_4^+
NH_4^+
NH_4^+
NH_4^+
NH_4^+
NH_4^+
NH_4^+
NH_4^+

$+$

H^+
Ca^{++}
Mg^{++}
K^+
Al^{3+}
NH_4^+

$+ \quad 9\ OAc$

Solution

SOIL NH_4^+ NH_4^+ NH_4^+ NH_4^+ NH_4^+ NH_4^+ NH_4^+ NH_4^+ NH_4^+ NH_4^+ + 9 KCl → SOIL K^+ K^+ K^+ K^+ K^+ K^+ K^+ K^+ K^+ K^+ + 9 NH_4^+ + 9 Cl^-

Solution

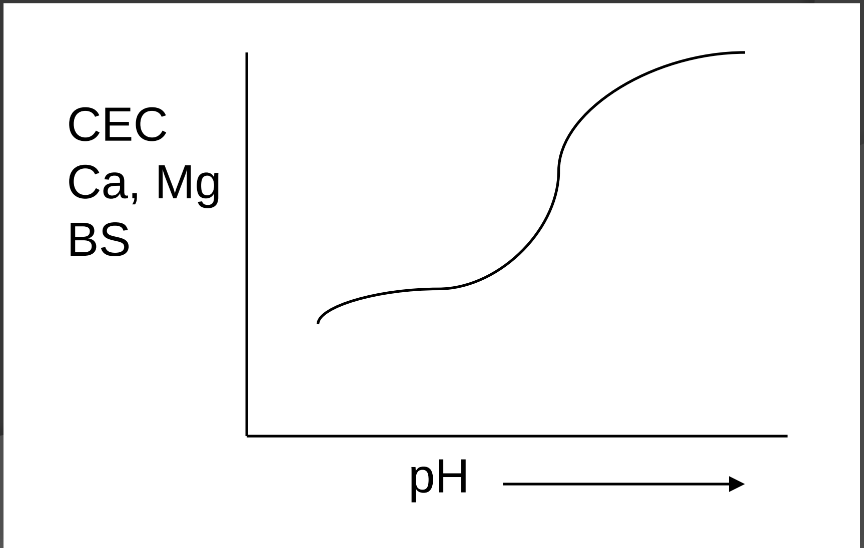
Filter and measure ammoniun
by steam distillation of ammo

Appendix Table 4.

Mississippi State University Plant & Soil Sciences Dept. Soil Genesis Laboratory				Chemical Analysis						County: Washington Series: Sharkey - Site 1	
Depth (inches)	pH H_2O	pH KCl	Organic Matter(%)	Ca	Mg	K	Na	H	Al*	Total**	Base Sat. (%)
				------------Exch. Cations (m.e./100g soil)------------							
0-5	4.98	4.49	3.68	24.81	13.00	1.82	0.28	17.47	0.36	57.38	69.55
5-10	4.85	4.07	1.71	25.16	14.16	1.46	0.59	17.72	2.25	59.09	70.01
10-20	4.76	4.06	1.71	26.92	15.27	1.38	0.95	17.31	2.06	61.83	72.00
20-25	5.10	4.43	1.35	24.59	14.95	1.13	1.85	12.06	0.44	54.60	77.88
25-30	5.55	4.95	1.21	26.05	15.78	1.01	2.52	9.37	0.07	54.73	82.88
30-40	6.85	6.37	0.74	24.19	16.99	0.85	3.88	4.69	0.01	50.60	90.73
40-50	7.33	6.80	0.80	28.65	21.57	1.06	5.19	3.96	0.01	60.43	93.45
50-60	7.46	6.98	0.72	45.46	22.30	1.16	5.36	3.19	0.01	77.47	95.88
60-70	7.55	7.04	0.60	80.33	23.30	1.08	4.73	3.06	0.03	112.50	97.28
70-80	7.54	7.03	0.57	63.70	21.30	1.04	4.67	3.04	0.01	93.75	96.76
80-90	7.56	7.06	0.57	28.92	21.61	1.17	4.84	3.14	0.01	59.68	94.74

Generally……as soil pH increases

- **CEC of highly weathered soils increases (“pH dependant charge”)**
- **The percentage of CEC sites occupied by Ca and Mg increases**
- **Base saturation, therefore tends to increase**



Soil Tests Serve Two Basic Functions

- Provide a starting point for developing fertilizer and lime program
- Monitor the production system to keep the fertilizer program on track

Basic Cation Saturation Ratios (BCSR)

- Sometimes used as an indicator of nutrient availability
- Idea originated New Jersey in 1940s,
  - 65 to 75% for Ca^{++}
  - about 10% for Mg^{++}
  - 2.5 to 5% % for K^{+}
  - & remainder for H^{+}

or approximate

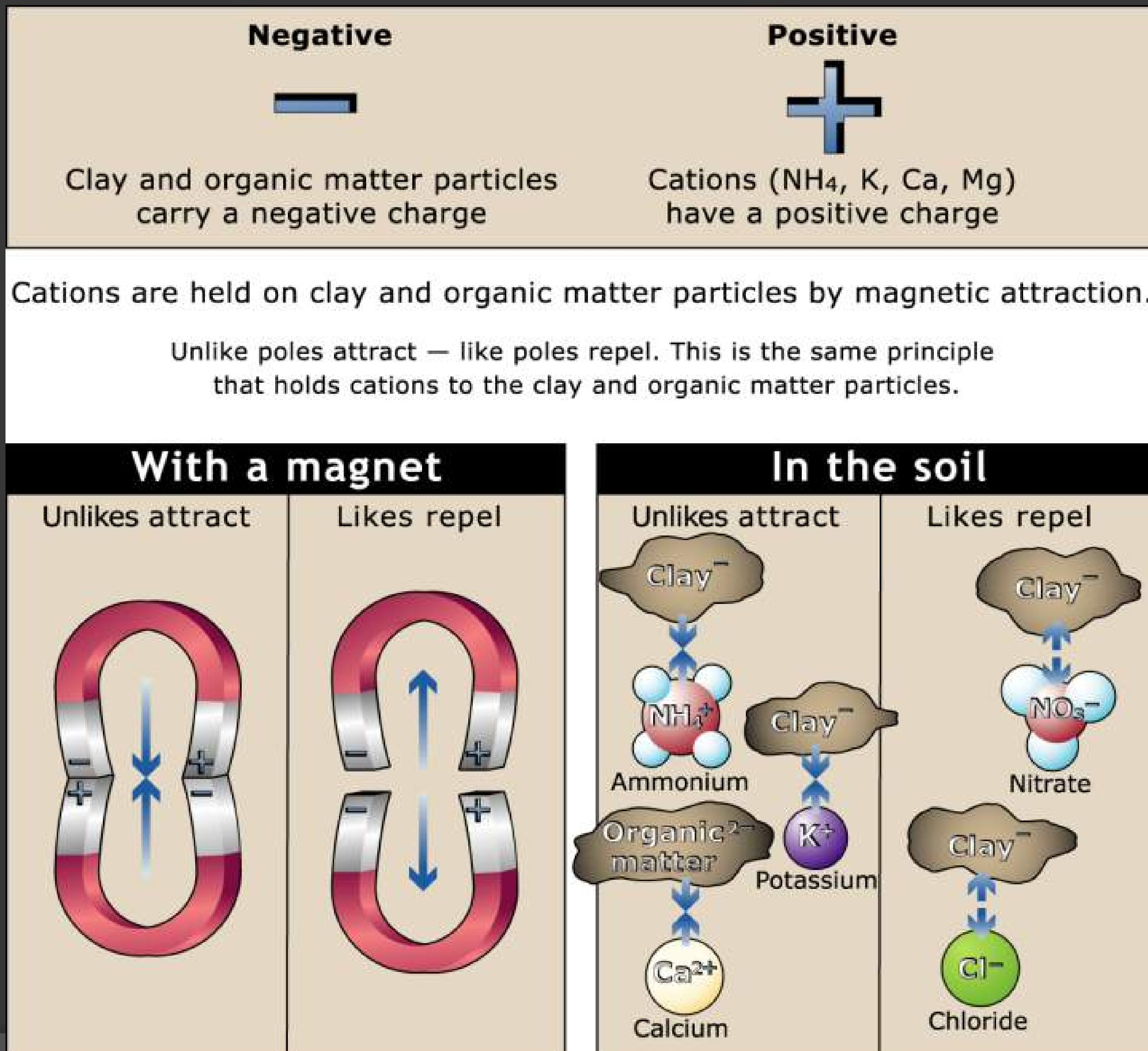
7:1 for Ca/Mg

15:1 for Ca/K

3:1 for Mg/K

Soil Fertility Handbook. 1998 Keith Reid, editor. Ontario, Canada

- “Crop growth has not been adversely affected over a wide range of Ca:Mg:K ratios or percentages”
- …Ca:Mg “ratios ranging form 267:1 to 1:1 had no significant influence on yields” of either alfalfa or trefoil


Negative
Positive
Clay and organic matter particles carry a negative charge
Cations (NH_4, K, Ca, Mg) have a positive charge
Cations are held on clay and organic matter particles by magnetic attraction.
Unlike poles attract — like poles repel. This is the same principle that holds cations to the clay and organic matter particles.
With a magnet
Unlikes attract
Likes repel
In the soil
Unlikes attract
Likes repel
$Clay^-$
NH_4^+
Ammonium
$Clay^-$
$Organic^{2-}$ matter
K^+
Potassium
Ca^{2+}
Calcium
$Clay^-$
NO_3^-
Nitrate
$Clay^-$
Cl^-
Chloride

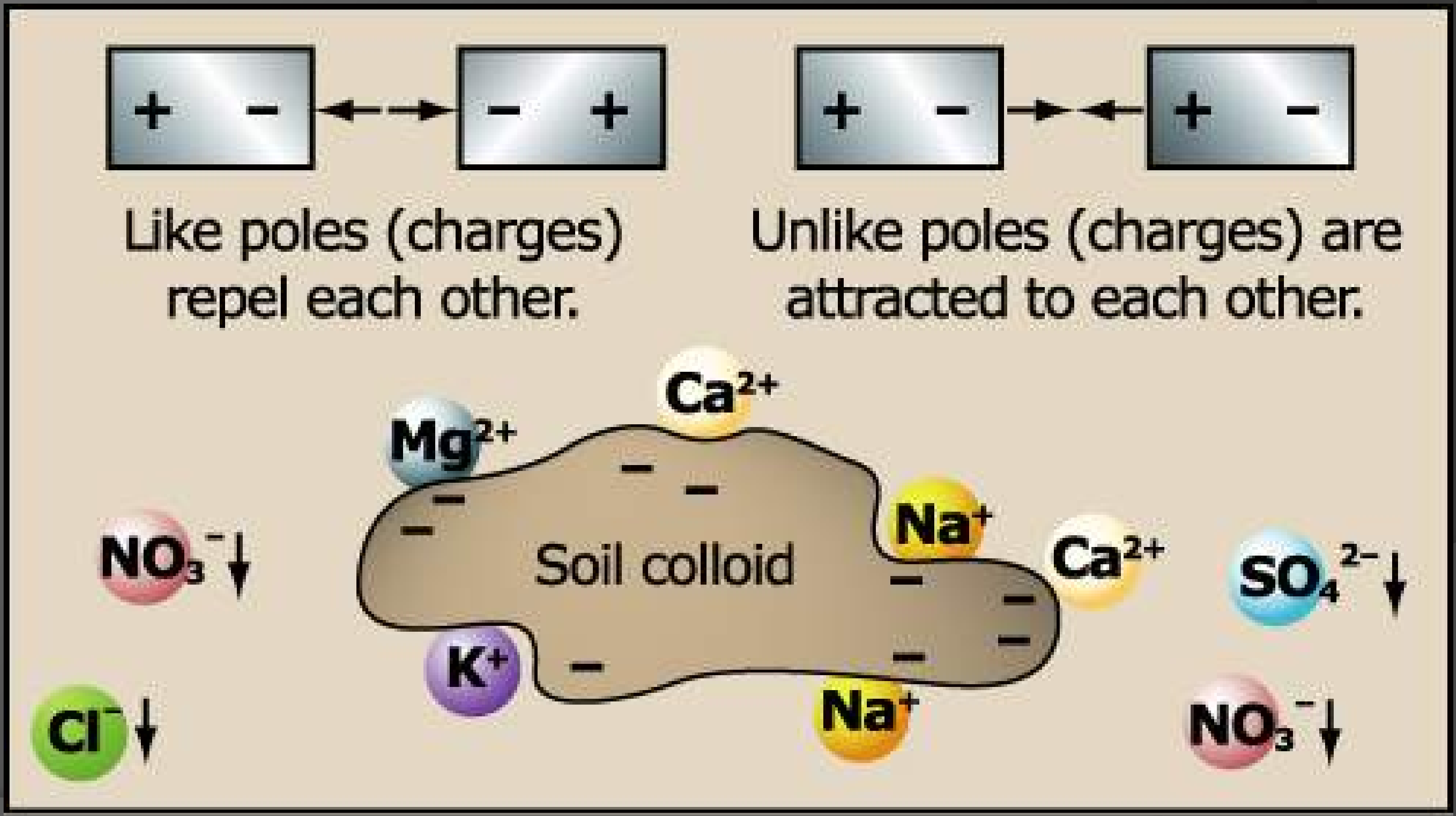
POSITIVELY CHARGED IONS ARE CALLED CATIONS

Nutrient	Chemical symbol	Ionic form
Potassium	K	K^+
Sodium	Na	Na^+
Ammonium	NH_4	NH_4^+
Hydrogen	H	H^+
Calcium	Ca	Ca^{++}
Magnesium	Mg	Mg^{++}

NEGATIVELY CHARGED IONS ARE CALLED ANIONS

Nutrient	Chemical symbol	Ionic form
Chloride	Cl	Cl^-
Nitrate	N	NO_3^-
Sulfate	S	SO_4^{2-}
Borate	B	BO_4^{3-}
Phosphate	P	$H_2PO_4^-$, $H_2PO_4^{2-}$

NEGATIVELY CHARGED COLLOIDS ATTRACT CATIONS



Cation Exchange Capacity (CEC)

The total number of exchangeable cations a soil can hold (amount of its negative charge)

Base Saturation Determination

- Calculation of percentage of CEC occupied by the basic cations:

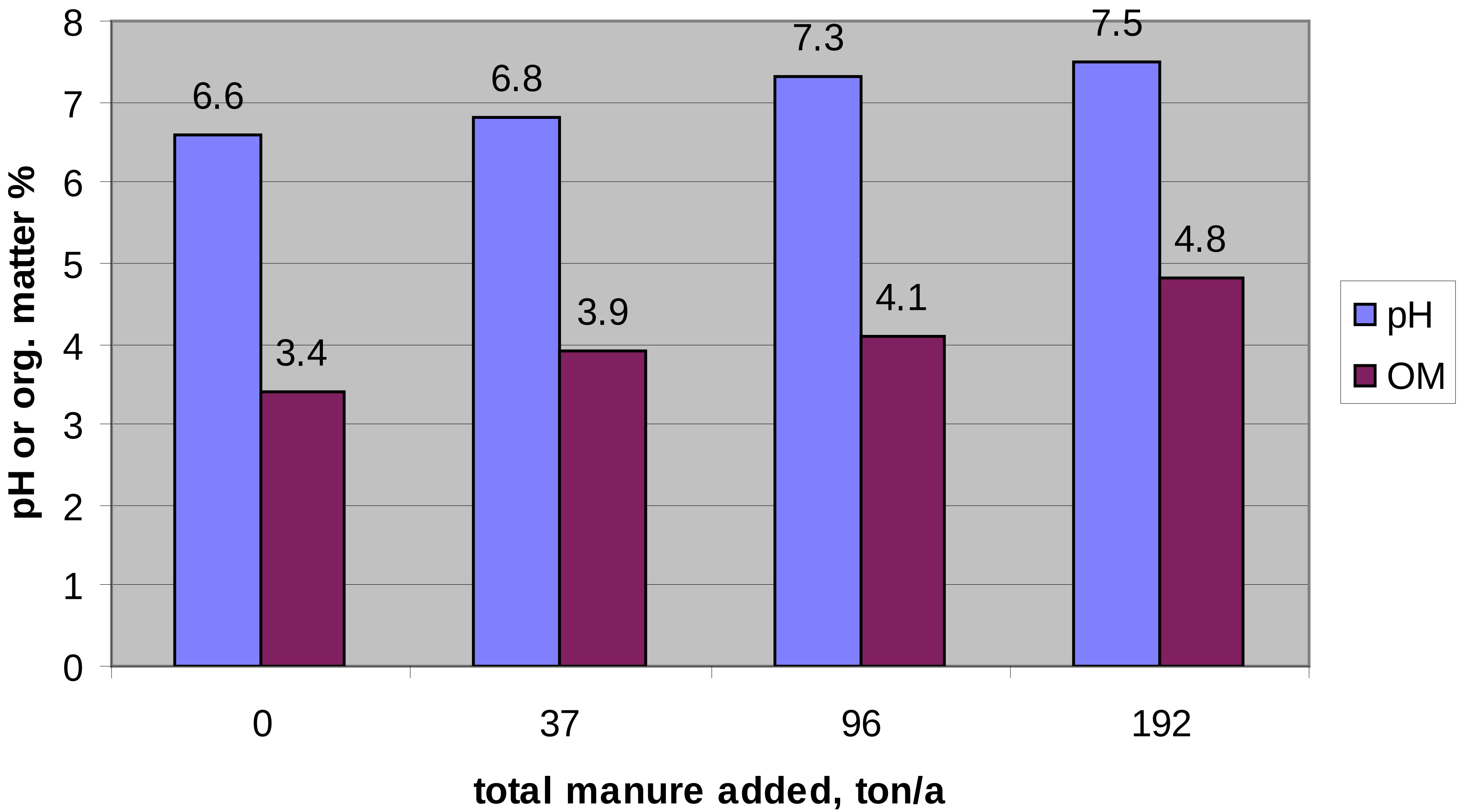
  $$BS=(Ca + Mg + K + Na)/CEC \times 100$$

- If base saturation is, for example, 60 percent, then acid saturation (Al^{3+}, H^+) is 40 percent
- Percent saturation of any cation is the percentage of the CEC occupied by that cation

Haby and others, 1990.
Soil Testing and Plant Analysis

- Many crops respond to Ca when the saturation drops below 25%
- Kaolinitic clays satisfy crop requirements at lower Ca saturations than montmorillonite, which requires a Ca saturation of 70% or more

Fig. 3. Influence of nine years of manure additions on soil pH and organic matter levels, Beresford, SD, 2011.



ORGANIC MATTER BENEFITS SOIL IN MANY WAYS:

- Improves physical condition
- Increases water infiltration and holding capacity
- Improves soil tilth and structure
- Decreases erosion losses
- Increases soil CEC
- Reduces compaction
- Supplies plant nutrients

Soils high in organic matter hold N in organic compounds which are not readily available for plant use.

Fertilizer N must be applied to non-legume crops to assure adequate N availability.

Corn Responds to Lime on Low pH soils