Cation Exchange

Cation Exchange Capacity (CEC)

Base Saturation

Ca:Mg Ratio

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What is a Cation and Cation Exchange?

- Cation
  - Positively charged ion
    - Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}, Na^{+}, Zn^{2+}, Mn^{2+}, H^{+}, Al^{3+}
- Exchange
  - Trading of one cation for another
    - Soil colloid ⇔ soil solution
    - Soil colloid or soil solution ⇔ plant root

What is Cation Exchange (cont.)?

- Cation adsorption strength
  - Cations are held with different strengths on the soil exchange sites
  - More strongly held cations accumulate as soils weather over a long time period

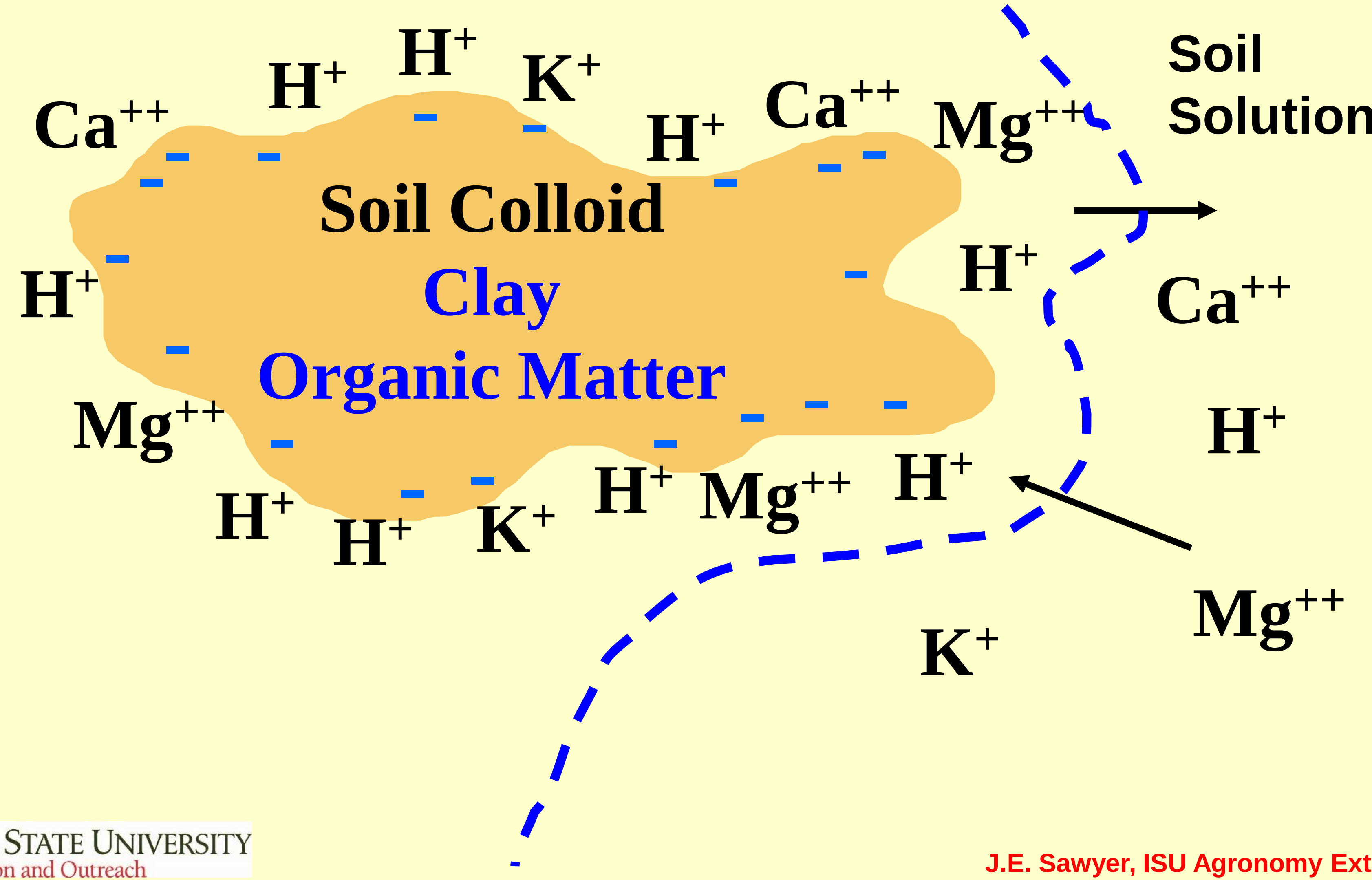
$$Al^{3+} > H^{+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$$

"Acidic Cations" "Basic Cations"

What is Cation Exchange Capacity (CEC)?

- The total number of exchangeable cations a soil can hold
  - Source of CEC
    - Negative sites on clay and organic matter
    - Sand and silt do not contribute negative sites
  - Amount of CEC
    - Varies by amount and type of clay and organic matter
  - Importance
    - Holds plant essential cation nutrients available in soil

What is Cation Exchange Capacity (CEC)?



What is CEC (cont.)?

- CEC can give general clues to soil properties

- Soils with low CEC
  - High sand content
  - Low organic matter
  - Less lime needed to change pH
  - Leaching of N more likely
  - Low water holding capacity

- Soils with high CEC
  - High clay or organic matter
  - More lime needed to change pH
  - Greater capacity to hold nutrients
  - High water holding capacity

What is CEC (cont.)?

- Approximate CEC of various soil textures

Soil Texture	Light Color	Dark Color
sandy loams	< 8	8 - 15
silt loams & loams	8 - 15	15 - 25
silty clays/clay loams	15 - 25	25 - 40
organic soils	---	50 - 100

What is CEC (cont.)?

- CEC allows soil to act as a buffer
  - Buffer means resistance to change
  - Helps us manage crop nutrients
    - Large cation nutrient storage
    - Slow drawdown of nutrients by crops
    - Allows management flexibility and crop safety
  - However, at same time
    - Large amounts of lime and fertilizers needed to change pH and soil test levels

What is CEC (cont.)?

- "Classic" laboratory measurement
  - Saturation with ammonium
  - Expensive and time consuming
- Laboratory estimation
  - Summation of exchangeable cations
    - Determined from ammonium acetate or Mehlich-3 extraction and soil buffer pH_b
    - Less expensive and quick

Problem with CEC Estimation

- An estimate only
  - Not direct measurement
- Ca^{+2} from free $CaCO_3$ in calcareous soils inflates CEC value when Ca is extracted with neutral ammonium acetate or Mehlich-3 extractants

Estimate of CEC

- Summation of exchangeable bases and exchangeable acidity
  - Exchangeable bases from cation determination
    - K^+ meq/100g = (ppm K) ÷ 390
    - Ca^{++} meq/100g = (ppm Ca) ÷ 200
    - Mg^{++} meq/100g = (ppm Mg) ÷ 120
    - Na^+ meq/100g = (ppm Na) ÷ 230
  - Exchangeable Acidity Estimated from Buffer pH
    - meq acidity/100g = 12 x (7.0 - pH_b)

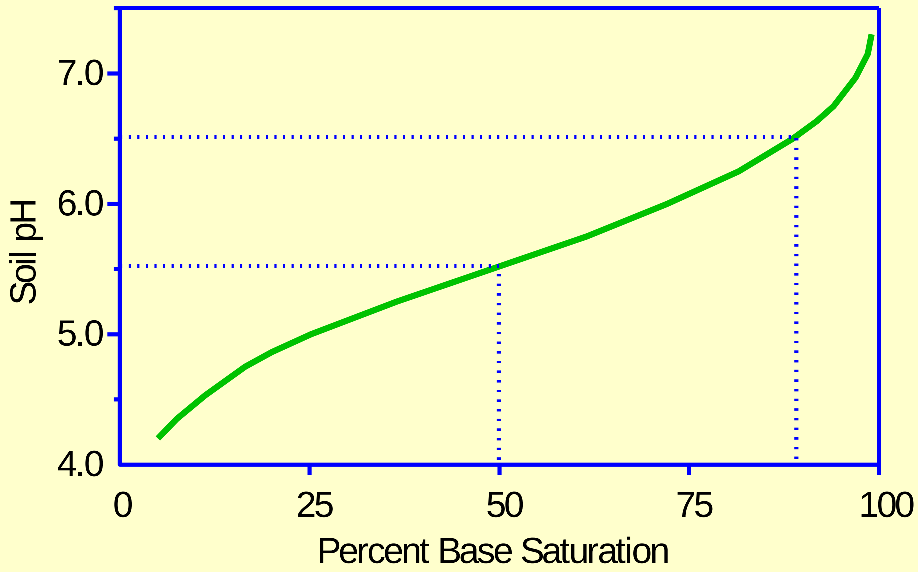
Estimate of CEC

- Example CEC Summation Calculation

120 ppm K ÷ 390	= 0.31 meq K/100g
975 ppm Ca ÷ 200	= 4.88 meq Ca/100g
210 ppm Mg ÷ 120	= 1.75 meq Mg/100g
(7.0 - 6.8 pH_b) x 12	= 2.40 meq H/100g
CEC	= 9.34 meq /100g

Base Saturation

- Definition
  - Percentage of total CEC occupied by basic cations
    - Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+},Na^{+}, Zn^{2+}
  - Soil pH is generally related to % base saturation



Example Base Saturation Calculation

Base Saturation = (total meq of cation bases ÷ CEC) x 100

$$\frac{(K + Mg + Ca)}{CEC} \times 100$$

Example:

meq Ca	=	4.88
meq Mg	=	1.75
meq K	=	0.31
meq H	=	2.40
CEC	=	9.34

$$\text{Base Saturation} = \frac{(4.88 + 1.75 + 0.31)}{9.34} \times 100 = 74\%$$

Example Cation Saturation Calculation

Cation Saturation = (meq of cation ÷ CEC) x 100

Example:

		Cation Saturation
meq Ca	= 4.88	(4.88/9.34) x 100 = 52%
meq Mg	= 1.75	(1.75/9.34) x 100 = 19%
meq K	= 0.31	(0.31/9.34) x 100 = 3%
meq H	= 2.40	(2.40/9.34) x 100 = 26%
CEC	= 9.34	

Base Cation Saturation for Formulating Fertilizer Recommendations???

- Basic Cation Saturation Ratio (BCSR)
  - Theory
    - Maximum yields achieved by creating an ideal ratio of Ca, Mg, and K
    - Originated in New Jersey (Bear et al., 1945)
    - Eight years of work with alfalfa on acidic soils with lime amendment
    - Modified by Graham (Missouri, 1959) into ranges (no research data, interpretation only)

Problems with BCSR Concept!

- Research database for support is lacking
- Research shows that optimum yield occurs outside of ideal range, that is, no “ideal range” or “ideal saturation level”
- Often generates recommendations that are prohibitively expensive and not justified by agronomic research
- No justification to alter Ca:Mg ratios
  - **IF** there is a deficiency of Ca or Mg, apply nutrient to correct deficiency rather than altering ratio

BCSR Compared To Soil Test K Interpretation

	Optimum	Base Saturation Concept		
CEC	Concept	2 %	3%	5%
meq/100g	- - - - - - - - - - - - -	ppm STK	- - - - - - - - - - - - -	
3	161-200	24	35	59
6	161-200	47	70	117
12	161-200	94	140	234
18	161-200	130	210	351
24	161-200	188	280	468
30	161-200	235	350	585

Ca:Mg Ratio Calculation

Cation Ratio = meq cation A ÷ meq cation B

Example:

meq Ca = 4.88	
meq Mg = 1.72	
meq K = 0.31	
meq H = 2.40	
CEC = 9.31	

Cation Ratio

Ca:Mg = (4.88 ÷ 1.72) = 2.8:1

Relationship Between Soil Ca:Mg Ratio and Crop Yield

- Ca:Mg ratio range where greenhouse and field research has shown no detrimental yield effects

0.5 Ca : 1 Mg to 50 Ca : 1 Mg

(2 times more Mg to 50 times more Ca)
(on a meq basis)

Typical Ca:Mg Ratio of Iowa Surface Soils

Soil Type	pH	CEC	Ca	Mg	K	Ca:Mg Ratio
		- - - - - meq/100g - - - - -				
Primghar	5.8	32.7	22.4	7.4	0.5	3.0
Sac	6.0	29.8	20.6	5.5	0.6	3.7
Kenyon	5.9	14.0	8.5	2.6	0.2	3.3
Dinsdale	5.9	20.5	14.6	4.2	0.4	3.5
Muscatine	6.1	28.3	20.4	7.1	0.4	2.9
Napier	6.6	27.6	23.5	3.2	0.6	7.3

Magnesium is not “bad” for a soil

- Essential element
- Mg^{++} divalent cation that helps with soil structure

Effect of broadcast potash and sulpomag on corn yield, Webster soil.

Year	Control	KCl	$KMgSO_4$
		bu/acre	
1967	146	160	161
1968	148	161	160
1969	144	139	144
1970	108	130	124
1971	147	157	160
1972	129	150	152
1973	115	129	129
1974	120	133	130
8-yr avg.	132	145	145

Fertilizers applied at 160 lb K/acre annually
Sul-po-mag supplied 199 lb S/acre annually
J. Webb, 1978.

$KMgSO_4$ supplied 98 lb Mg/acre annually and 784 lb Mg/acre across 8 years

Questions?