Cation Exchange Capacity – It's Role in Crop Production

California Cooperative Rice Research Foundation

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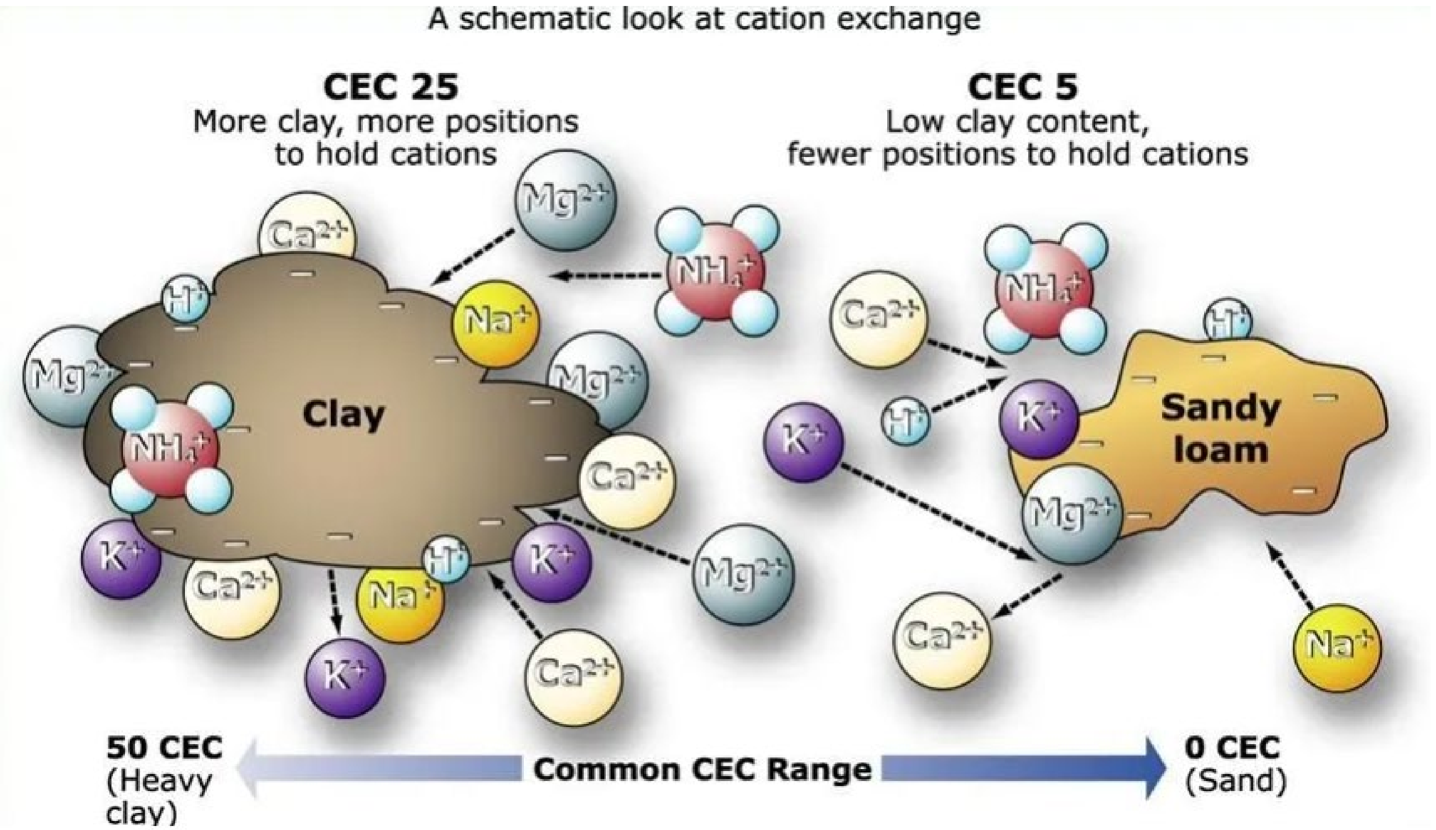
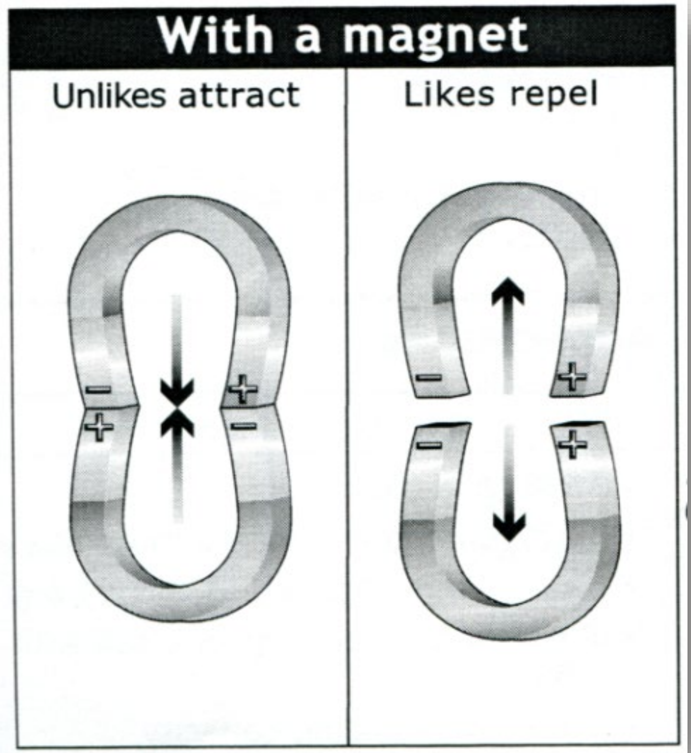


Introduction to Important Terms

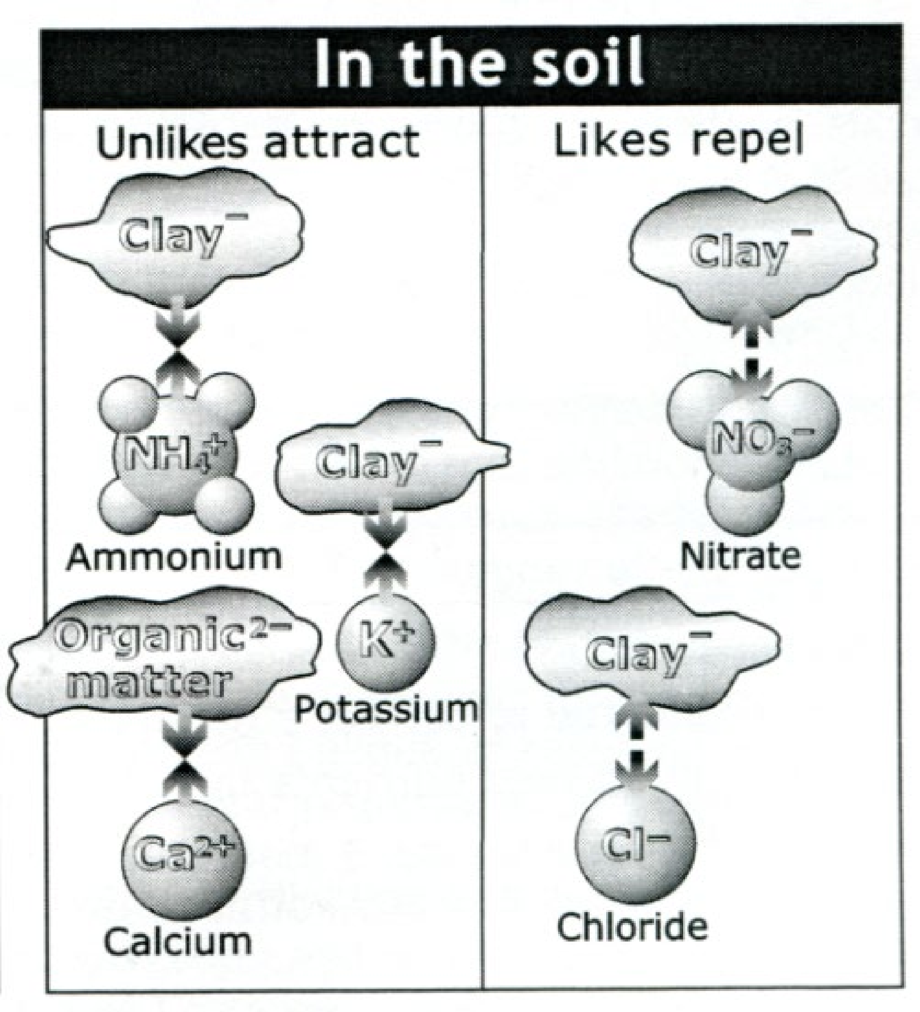
- **Cation – positively charged ion (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+})**
- **Anion – Negatively charged ions (OH^{-}, NO_3^{-})**
- **Soil Colloids – most chemically active fraction of the soils**
  - **Clay (mineral component of soil) or humus (organic)**



Introduction to Important Terms

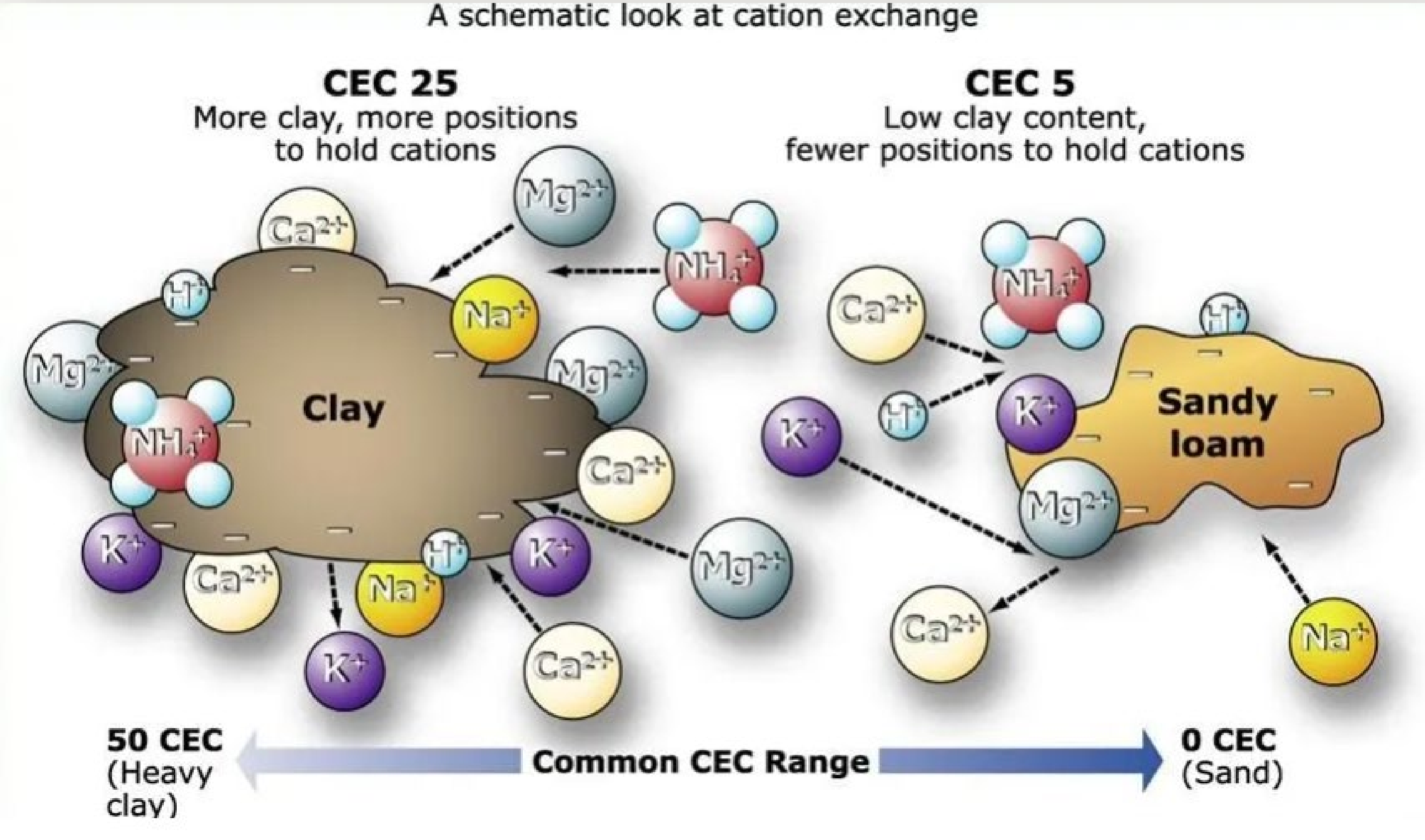
- **<u>Cation Exchange Capacity (CEC)</u> - The sum of exchangeable cations on soil colloids (clay and SOM) at a given pH that are attracted to soil solid phase negative charges.**
  - **the capacity of a soil to hold cations (or the susceptibility to leaching).**

- **<u>Adsorption</u> – electrostatic attraction to the outside of the colloid (think adhere); <u>NOT</u> the same as <u>absorption</u>**



CEC Relationships (Interpretations)

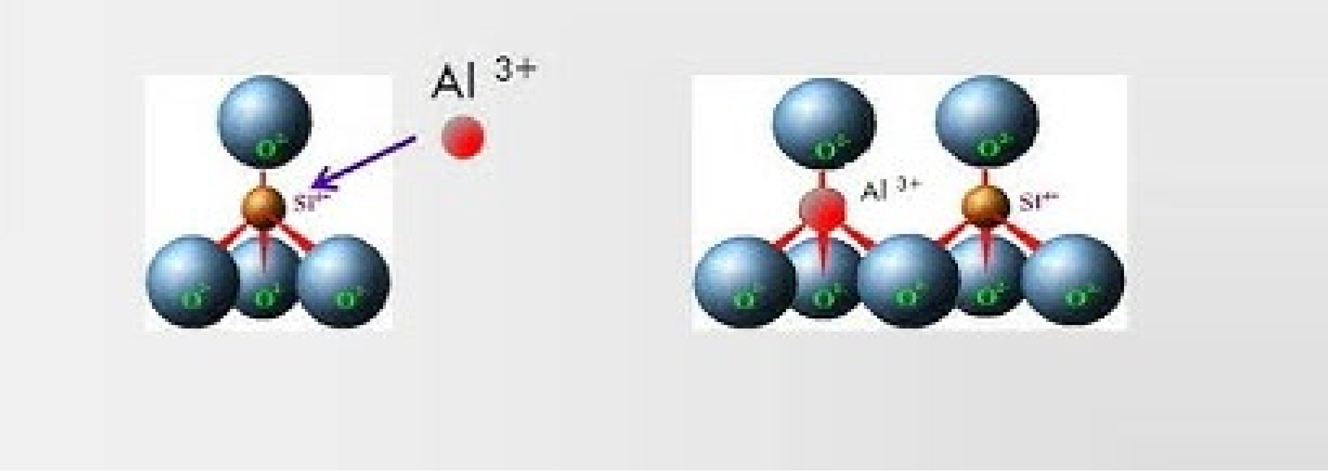
- Units of expression
  - meq/100 grams soil (old units)
  - cmolc/kg soil (new units, note 100 cmol = 1 mol)
  - 1 meq/100 g = 1 cmolc/kg



- The larger the CEC value the greater the capacity to hold nutrients

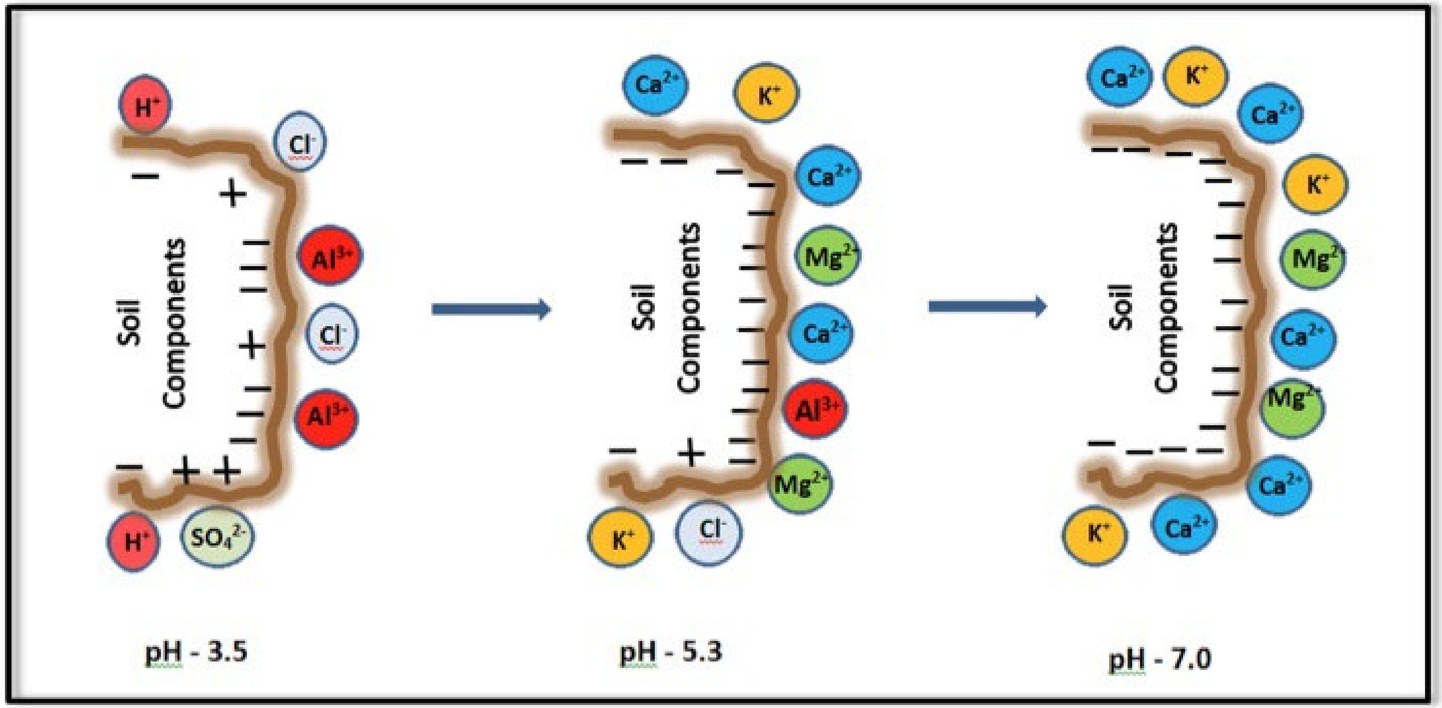
Where does the (–) charge come from?

- <u>Permanent Charge</u>
  - The negative charge of clay minerals resulting from isomorphic substitution.
    - When Al^{3+} replaces Si^{4+} (in Si tetrahedral sheet)
    - When Mg^{2+} or Fe^{2+} replace Al^{3+} (in Al octahedral sheet)
  - Uniformly distributed over the surface of the clay particles.
  - Not affected by soil pH.



Where does the (–) charge come from?

- <u>pH Dependent Charge</u>
  - Arises from the broken edges of clay particles layer silicates
  - The charge of these exposed edges depends on the soil pH
    - Low pH (abundance of H^+) results in positive charge or lower CEC
    - High pH (abundance of OH^-) results in negative charge or higher CEC
  - Significant source of CEC in 1:1 clays and OM



CEC Relationships (Interpretations)

- Indirectly indicates information about clay type, clay content, and organic matter content

Soil Texture	C.E.C. (Arkansas)	C.E.C. (Midwest)
	cmol$_c$/kg soil	
Loamy Sand	<3	3-20 (depends on SOM)
Sandy Loam	3-10	
Silt Loam	8-20	15-25
Clay loam - Clay	>18	20-50
Organic	>50	>50

Mineral	Layer	Layer charge	Spacing	CEC	pH-depend. Charge
			Angstroms	cmol$_c$/kg	
Kaolinite	1:1	0	7.2	**1 – 10**	**High**
Illite	2:1	1.0	10	**20 – 40**	**Low**
Vermic.	2:1	0.8	10-15	**120 – 150**	**Low**
Montmor.	2:1	0.4	Varies	**80 – 120**	**Low**
SOM	--	--	--	**100 – 300**	**High**

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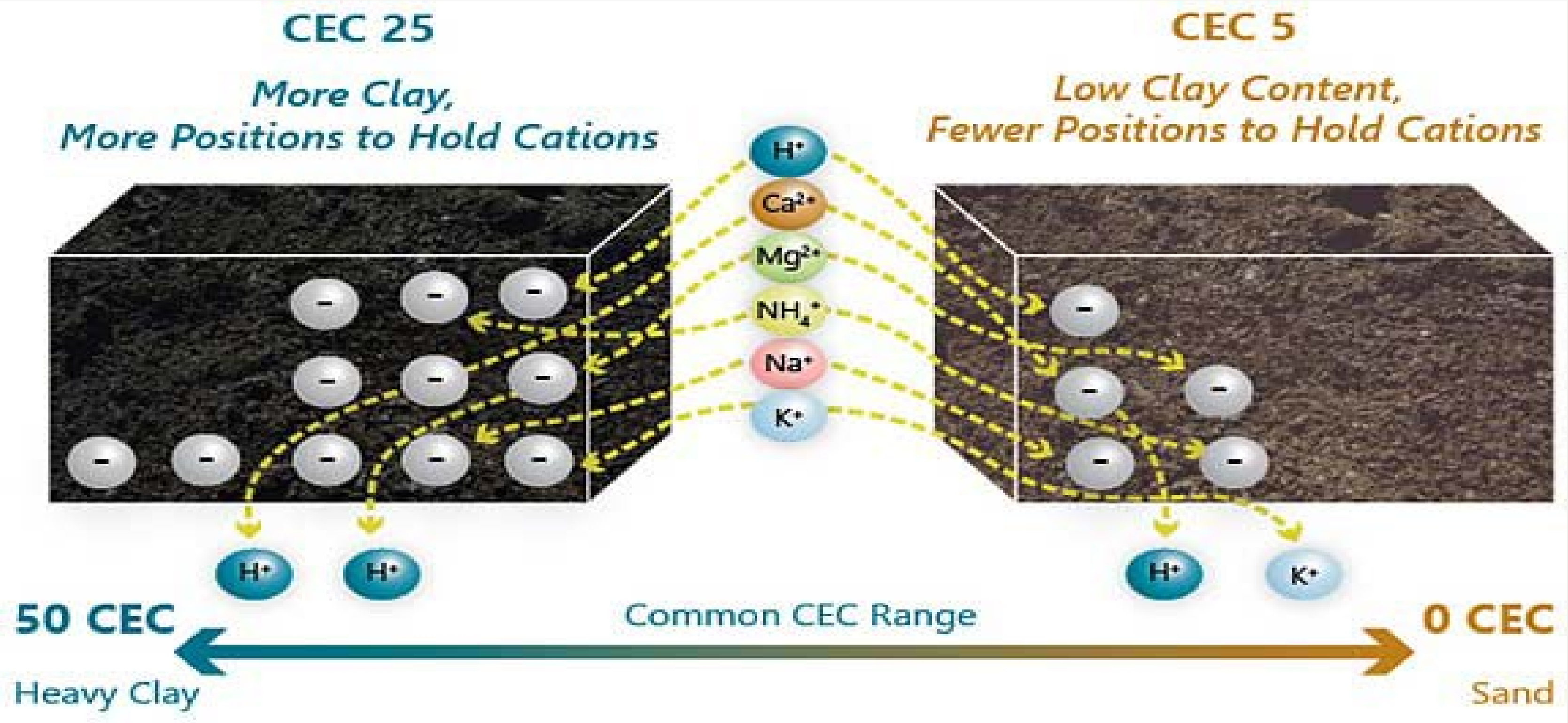


SOME PRACTICAL APPLICATIONS	
Soils with CEC 11-50 Range	Soils with CEC 1-10 Range
• High clay content • More lime required to correct a given pH • Greater capacity to hold nutrients in a given soil depth • Physical ramifications of a soil with a high clay content • High water-holding capacity	• High sand content • Nitrogen and potassium leaching more likely • Less lime required to correct a given pH • Physical ramifications of a soil with a high sand content • Low water-holding capacity

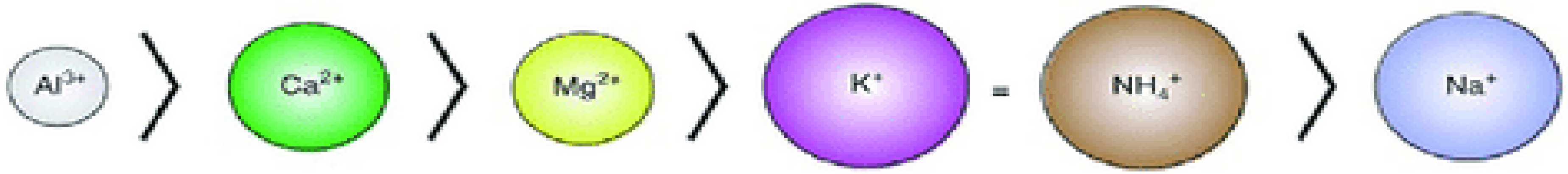
Residual herbicides and CEC

- Often rate are based on soil texture
  - Rate increased with increasing clay content (CEC).

COMMAND 3ME MICROENCAPSULATED HERBICIDE USE RATE	
SOIL TEXTURE	*BROADCAST RATES PER ACRE**
Coarse (light) soils: (sand, loamy sand, sand loam)	11-14 oz. (0.25-0.33 lb. ai)
Medium soils: loam, silt, silt loam, sandy clay, sandy clay loam	17-21 oz. (0.4-0.5 lb. ai)
Fine (heavy) soils: silty clay, clay loam, silty clay loam, clay	21-34 oz. (0.5-0.8 lb. ai)

Lyotropic Series

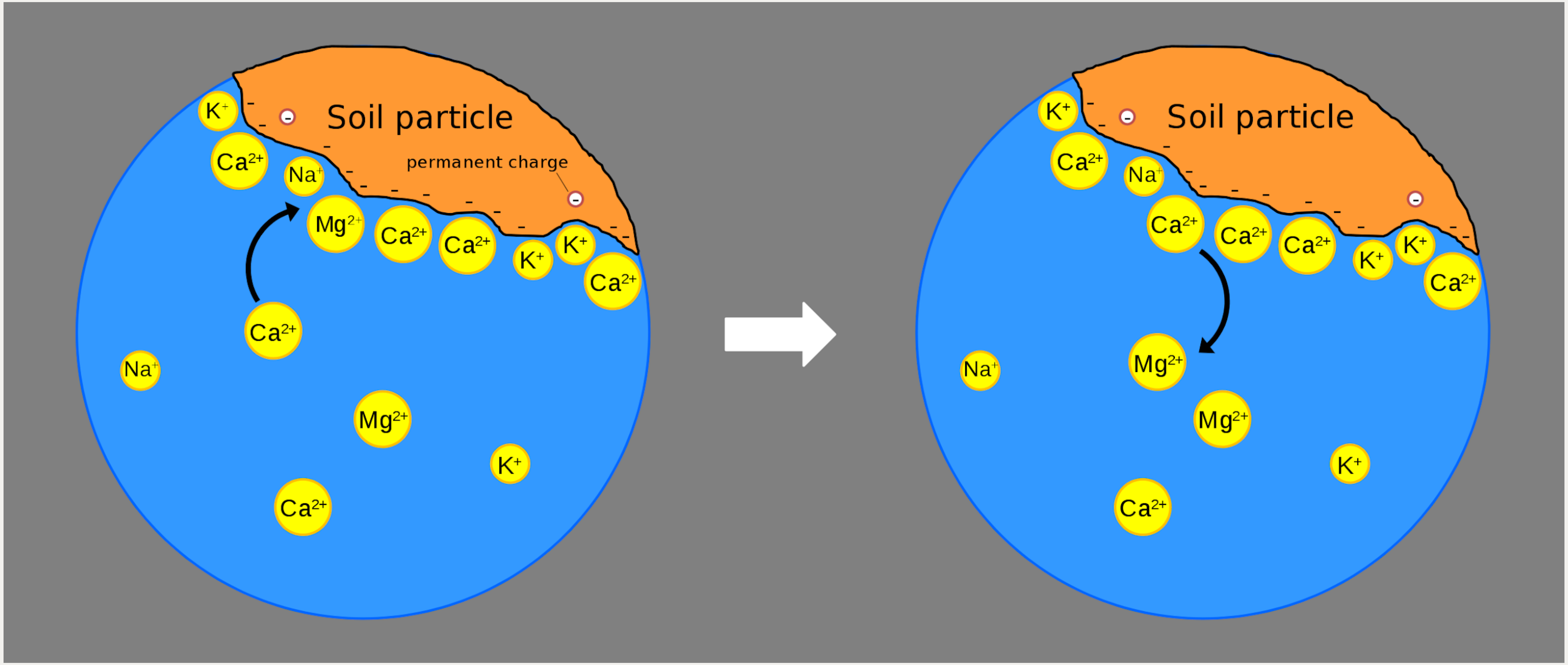
- **The strength of cation adsorption to a cation exchange site**
- **Order determined by cation properties**



Radius	Unit	Na^+	K^+	NH_4^+	Mg^{2+}	Ca^{2+}	Al^{3+}
Non-hydrated	nm	0.095	0.133	0.143	0.066	0.099	0.050
Hydrated	nm	0.360	0.330	0.330	0.430	0.410	0.480

- **Ion charge ($3^+ > 2^+ > 1^+$)**
- **Ion size, *larger hydrated size creates more distance between the opposite charges***
- **Charge density, Combination of ion size and valence**

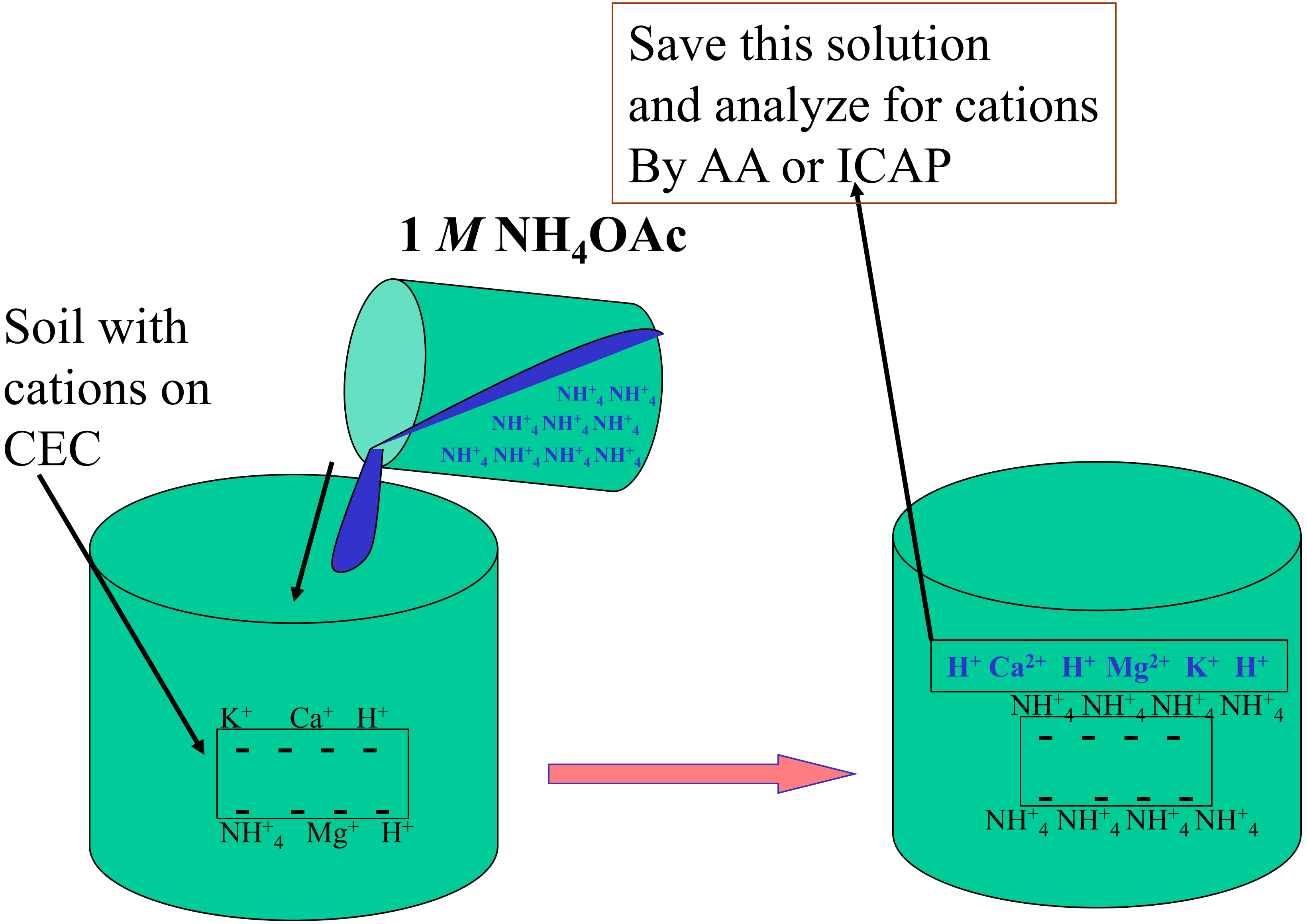
Cation Exchange



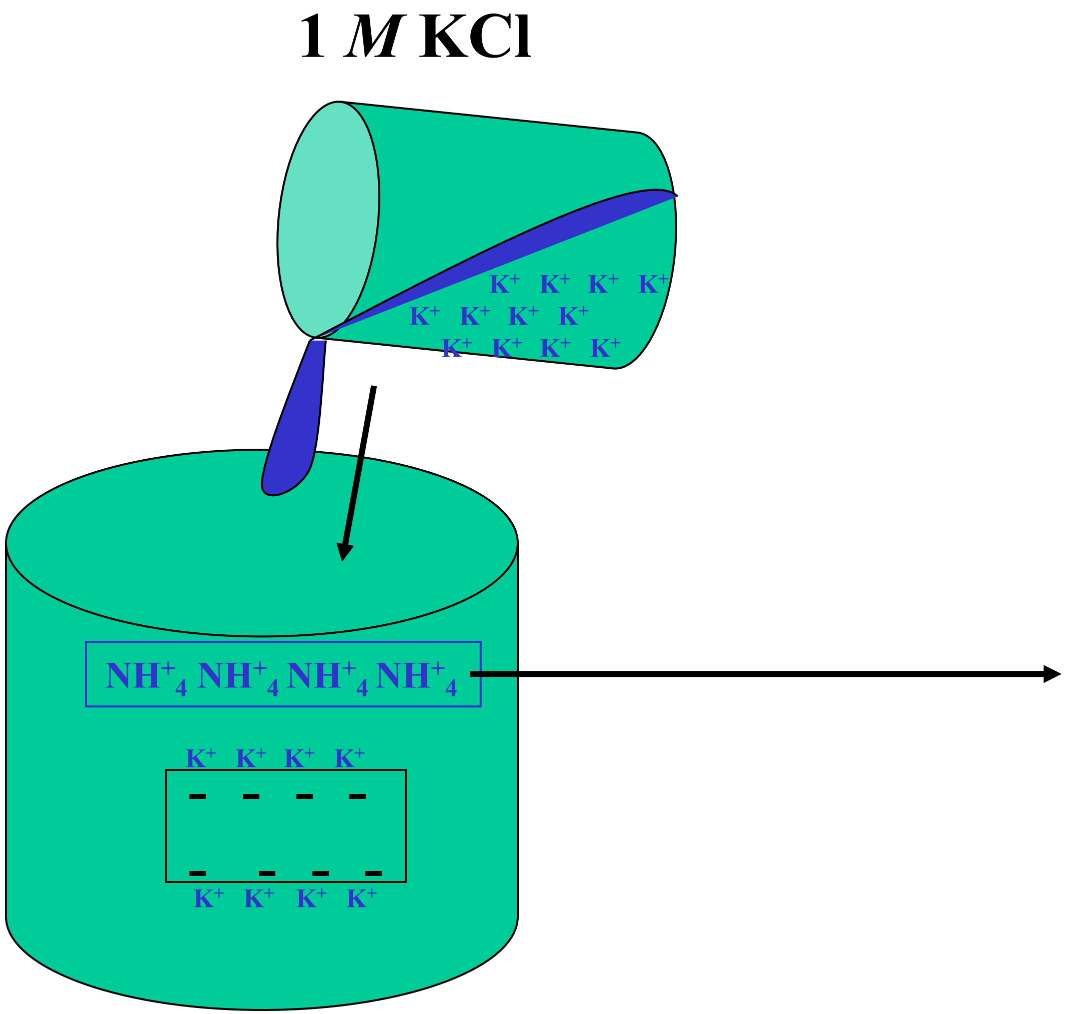
CEC and Soil Test Reports

- Most labs estimate soil CEC using ‘cation summation’
  - <u>Basic Cations</u>: Ca + Mg+ K + Na
  - <u>Acidic Cations</u>: H + Al
- Provides good estimate
- True determination of CEC is time consuming

CEC Extraction Procedure



CEC Extraction Procedure



Save this solution and analyze for NH_4^+ to Determine soil CEC

Example of Soil Base Saturation and CEC Calculations

- 10 grams soil
- 50 mL of 1 *M* NH_4OAc (extractant #1)
  - Ca = 241mg/L = 6.03 $cmol_c$ Ca/kg
  - Mg = 102 mg/L = 4.19 $cmol_c$ Mg/kg
  - Na = 29 mg/L = 0.63 $cmol_c$ Na/kg
  - K = 63 mg/L = 0.81 $cmol_c$ K/kg
- 50 mL of 1 *M* KCl (extractant #2)
  - NH_4 = 485 mg/L = 13.47 $cmol_c$ NH_4/kg
- CEC = 13.47 $cmol_c$ /kg
- Base Saturation = 87%

Base Saturation and Cation Saturation Ratios

- **<u>Base Saturation</u> - The percentage of the soil CEC occupied by a basic cations (Ca^{2+}, Mg^{2+}, Na^{+}, & K^{+})**
- **Ideal 'Basic Cation Saturation Ratio' Concept**
- **Soil Fertility Philosophy, max yields can be achieved only when the basic cations are in some optimal ratio**
- **Does not involve P, S, N, and micronutrients**

Optimum Suggested Ratios

Cations	Ideal Saturation
	% of CEC sites
Ca	65 – 85%
Mg	6 – 12%
K	2 – 5%

Basic Cation Saturation Ratio

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Nutrient	Bear et al. (1945)	Graham (1959)	Baker & Amacher (1981)
		Base Saturations (%)	
Ca	65	65 – 85	60 – 80
Mg	10	6 – 12	10 – 20
K	5	2 – 5	2 – 5
		Base Cation Saturation Ratios	
Ca:Mg	6.5:1	5.4:1 – 14.1:1	3.0:1 – 8.0:1
Ca:K	13:1	13.0:1 – 42.5:1	12.0:1 – 40.0:1
Mg:K	2:1	1.2:1 – 6.0:1	2.0:1 – 10.0:1

Is the BCSR Concept Valid?

- The majority of research indicates high yields can be produced across a wide range of cation ratios
- There are some valid points to this concept, but soil nutrient management strictly by the BCSR is not recommended

Source: Rehm (2009) North Central Regional Ext Publ. #553.
http://www.extension.umn.edu/distribution/cropsystems/DC6437.html

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SOIL ANALYSIS

Client : Nutrien Ag Solutions, Inc. (Elton)	Grower :	Report No: 23-331-0644
		Cust No: 20006
		Date Printed: 11/28/2023
		Date Received : 11/27/2023
		PO:
		Page : 2 of 3

Lab No: 49337 **Field:** **Sample ID:** #2

Test	Method	Results
Soil pH	1:1	
Buffer pH	SMP	
Phosphorus (P)	M3	8 LB/ACRE
Potassium (K)	M3	134 LB/ACRE
Calcium (Ca)	M3	1128 LB/ACRE
Magnesium (Mg)	M3	384 LB/ACRE
Sulfur (S)	M3	30 LB/ACRE
Boron (B)	M3	0.6 LB/ACRE
Copper (Cu)	M3	2.0 LB/ACRE
Iron (Fe)	M3	518 LB/ACRE
Manganese (Mn)	M3	394 LB/ACRE
Zinc (Zn)	M3	2.2 LB/ACRE
Sodium (Na)	M3	136 LB/ACRE
Soluble Salts		
Organic Matter	LOI	2.1%
Estimated N Release		86 lbs/acre
Nitrate Nitrogen		

SOIL TEST RATINGS

Calculated Cation Exchange Capacity

8.7 meq/100g

%Saturation

	%sat	meq
K	2.0	0.2
Ca	32.4	2.8
Mg	18.4	1.6
H	43.7	3.8
Na	3.4	0.3

K/Mg Ratio: 0.10

Ca/Mg Ratio: 1.76

SOIL FERTILITY GUIDELINES

Crop : Rice **Yield Goal :** 200 bu/acre **Rec Units:** LB/ACRE

LIME (lbs)	LIME (tons)	N	P_2O_5	K_2O	Mg	S	B	Cu	Mn	Zn	Fe
4000	2	200	58	117	0	12	1.0	0	0	3.4	

Crop : **Rec Units:**

Comments :

Rice

- Calculated CEC

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	$cmol_c$/kg soil	
Loamy Sand	<3	3-20 (depends on SOM)
Sandy Loam	3-10	
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Clay loam - Clay	>18	20-50
Organic	>50	>50

- Sandy loam *or* silt loam, low fertility, leach prone (K, NO3)
- Low pH, kaolinite, lime would improve fertility, increase CEC, reduce leaching
- Use low rate of residual herbicides

Cations	Ideal Saturation
	% of CEC sites
Ca	65 – 85%
Mg	6 – 12%
K	2 – 5%

Thank you

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Field Day August 28, 2024