CATION EXCHANGE CAPACITY

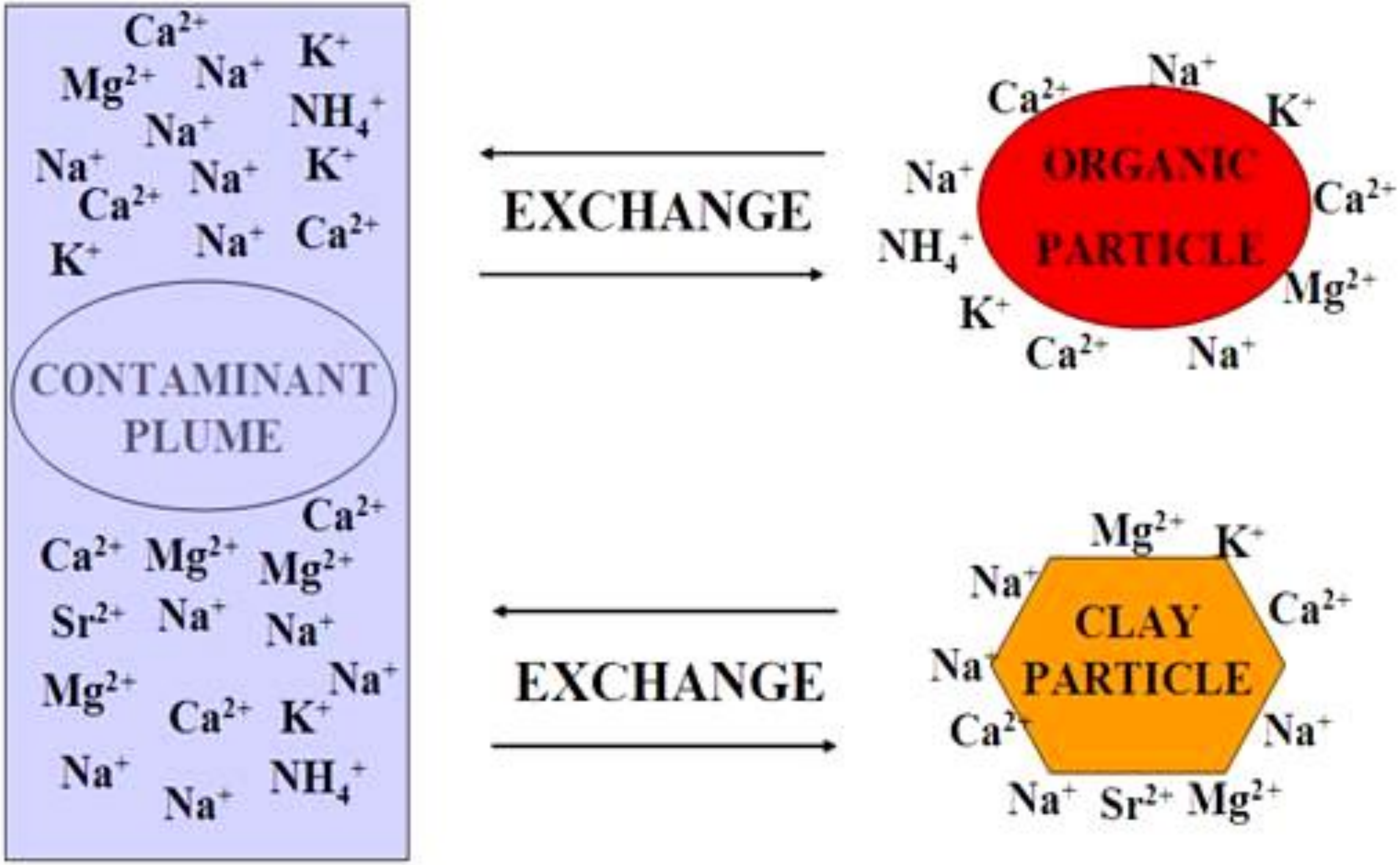
A MEASURE OF SOIL FERTILITY

WHAT IS CATION EXCHANGE?

- The replacement of one adsorbed cation by another cation from solution
  - Colloid–A + B = Colloid–B +A

- Soil colloids (clay/humus) usually have a negative (–) charge and attract cations (+) on or near their surface

- Other cations in soil solution that approach the held cation may be able to replace it or exchange for it



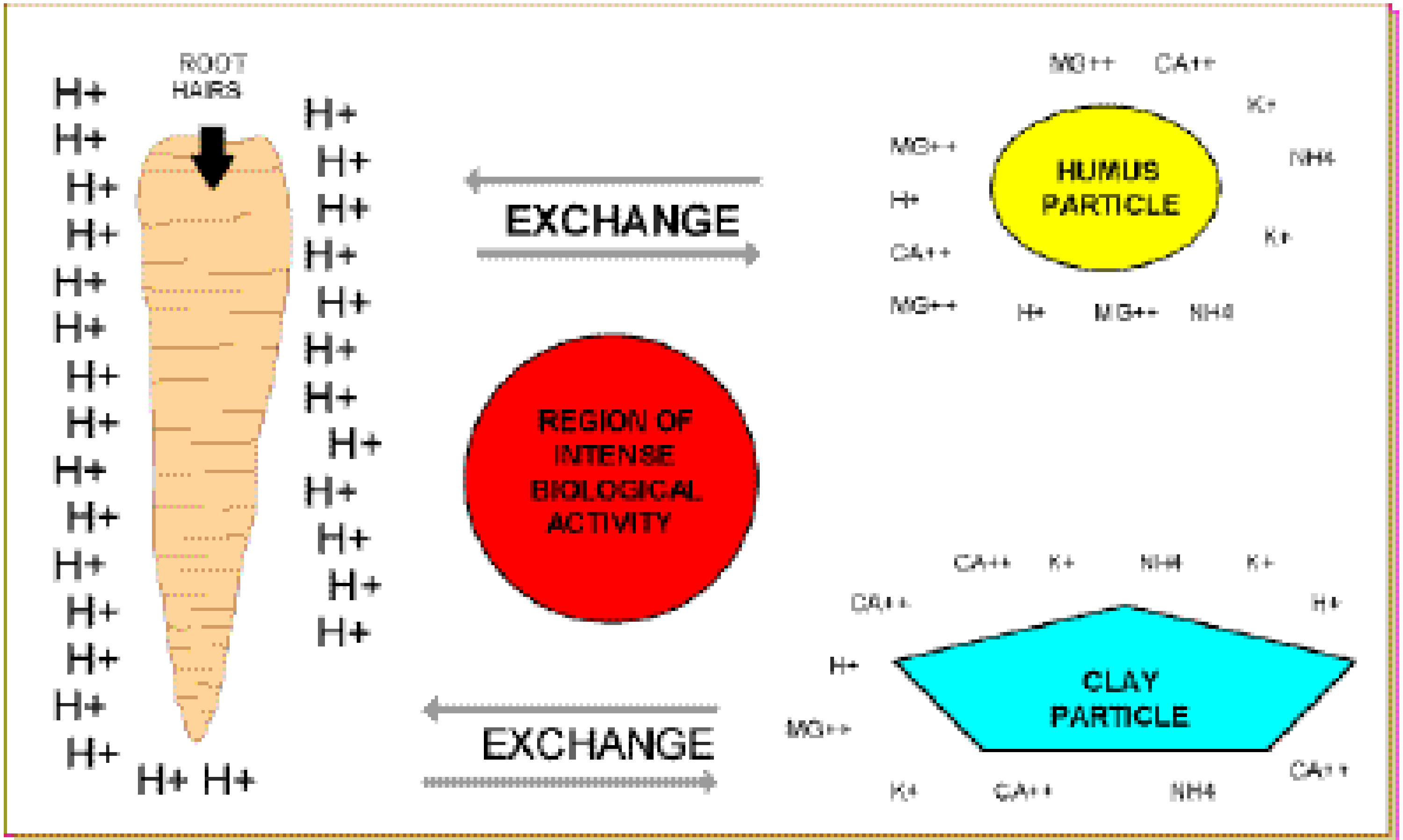
Ca^{2+} K^{+}
Mg^{2+} Na^{+} NH_4^{+}
Na^{+}
Na^{+} Na^{+} K^{+}
Ca^{2+}
K^{+} Na^{+} Ca^{2+}
CONTAMINANT PLUME
Ca^{2+}
Ca^{2+} Mg^{2+} Mg^{2+}
Sr^{2+} Na^{+} Na^{+}
Mg^{2+} Na^{+}
Ca^{2+} K^{+}
Na^{+} NH_4^{+}
Na^{+}
EXCHANGE
ORGANIC PARTICLE
Na^{+} Ca^{2+} K^{+} Na^{+} Ca^{2+} NH_4^{+} Mg^{2+} K^{+} Ca^{2+} Na^{+}
EXCHANGE
CLAY PARTICLE
Mg^{2+} K^{+} Na^{+} Ca^{2+} Na^{+} Ca^{2+} Na^{+} Na^{+} Sr^{2+} Mg^{2+}

CATION EXCHANGE

- Adsorbed cations resist removal by leaching water, but can be replaced (exchanged) by other cations by **mass action** (competition for the negative site by large number of cations)

- **Takes place on surfaces of clay and humus colloids, and plant roots**

- Cations most numerous on exchange sites are Ca^{+2}, $Mg+^{2}$, H^{+}, Na^{+}, K^{+}, Al^{+3}, NH^{+4}



ROOT HAIRS
H+
EXCHANGE
HUMUS PARTICLE
MG++
CA++
K+
NH4
REGION OF INTENSE BIOLOGICAL ACTIVITY
EXCHANGE
CLAY PARTICLE

CATION EXCHANGE

- Proportions of cations are constantly changing as ions are added/lost from:
  - Minerals or additions of lime, gypsum, fertilizers
  - Lost by plant absorption or leaching

- Water moving through the soil will lose soluble cations to the soil and pick up other cations replaced from exchange sites by cations being absorbed
  - K^{+}, NH^{+4}, Ca^{2+} do not move far before they are re-absorbed or used by plants

CATION EXCHANGE

- Different ions move at different speeds
  - Well vegetated soils lose less N than bare soils
  - Less S is needed so losses are not significant
  - Non-organic soils have little loss of phosphates
  - Chlorides easily leach with water

LEACHING LOSSES (kg/ha) OF CATIONS AND ANIONS

SOIL TYPE	Ca	Mg	K	N	S
IL-Prairie	101	52	1	86	12
Bare Soil	374	104	45	---	---

CATION EXCHANGE

- Rate of movement of cations decreases as adsorption increases

- $Na^+ < K^+ = NH_4^+ < Mg^{2+} = Ca^{2+} < Al < H^+$

- Liming the soil to correct acidity is a cation exchange reaction

CATION EXCHANGE CAPACITY

- The quantity of exchangeable cation sites per unit of weight of dry soil
  - Measured in centimoles$_c$ of cations per kilogram of dry soil (cmol$_c$/kg)
  - Centimoles$_c$ is used rather than weight because the number of negative sites in a given soil does not change, but the weights of the adsorbed cations do change
  - One centimolec means 1/100 mole of charged units (ex. Ca^{2+} = 2 centimole$_c$)

AMOUNTS OF EXCHANGEABLE CATONS IN SOIL

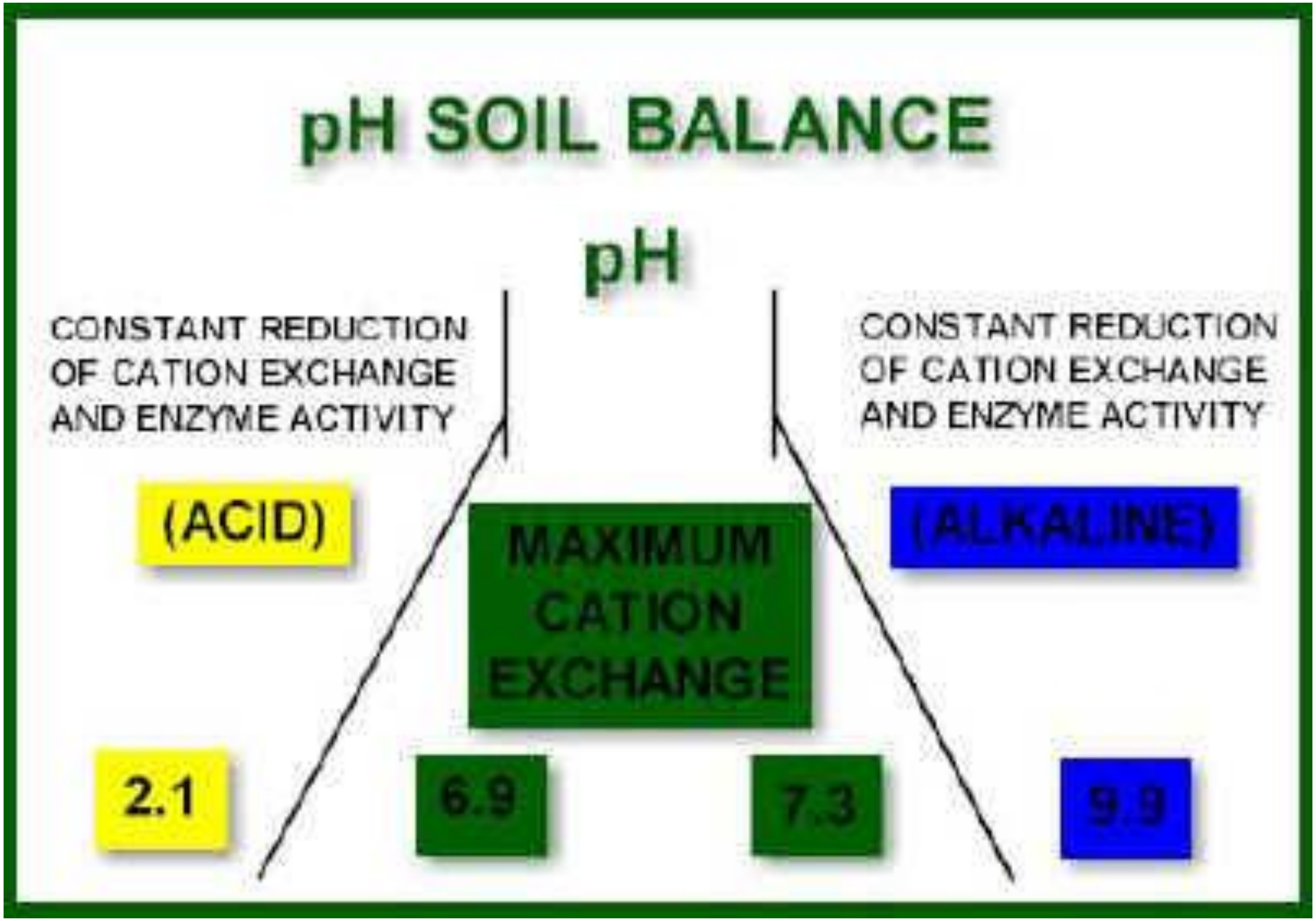
SOIL	CEC	Ca	Mg	K	Na	H & Al
Sandy Soil (pH=6.4)	5	1.9	1.2	0.3	Trace	1.8
Silt Loam (pH=6.7)	25	17.1	3.1	0.4	0.1	4.7
Organic layer (pH=3.6)	106	5.8	6.5	0.5	1.3	91.6
Sandy Loam (pH=3.5)	24	2.7	0.6	0.06	0.02	20.6
Clay (pH=4.9)	26	8.1	2.1	0.6	0.1	15.6
Volcanic Loam (pH=5.3)	103	6.7	1.2	0.4	0.4	94.9

NORMAL RANGE OF CEC VALUES BY SOIL GROUPS

SOIL GROUP	EXAMPLES	CEC (meg/100g)
Light Colored Sands	Plainfield/Bloomfield	3-5
Dark Colored Sands	Maumee/Gilford	10-20
Light Colored Loams and Silt Loams	Clermont/Miami	10-20
Dark Colored Loams and Silt Loams	Sidell/Gennessee	15-25
Dark Colored Silty Clays	Pewamo	30-40
Organic Soils	Carlisle Muck	50-100

IMPORTANCE OF CATION EXCHANGE

- Causing and correcting of soil acidity and basicity
- Altering soil physical properties
- Purifying or altering percolation water
- Ca, Mg, and K are supplied to plants from exchangeable forms


pH SOIL BALANCE
pH
CONSTANT REDUCTION OF CATION EXCHANGE AND ENZYME ACTIVITY
CONSTANT REDUCTION OF CATION EXCHANGE AND ENZYME ACTIVITY
(ACID)
MAXIMUM CATION EXCHANGE
(ALKALINE)
2.1
6.9
7.3
9.9

IMPORTANCE OF CATION EXCHANGE RELATIONSHIPS

- Exchangeable pools of Ca, Mg, and K are major sources of plant nutrients

- **Amount of lime required to raise pH increases as CEC increases**

- Cation exchange sites hold cations and slow their losses due to leaching

IMPORTANCE OF CATION EXCHANGE RELATIONSHIPS

- Cation exchange sites hold K and NH_4 fertilizers

- Cation exchange sites adsorb metals preventing groundwater pollution:
  - Examples: Cd, Zn, Ni, Pb

RELATIONSHIP BETWEEN CEC AND FERTLIZATION PRACTICES

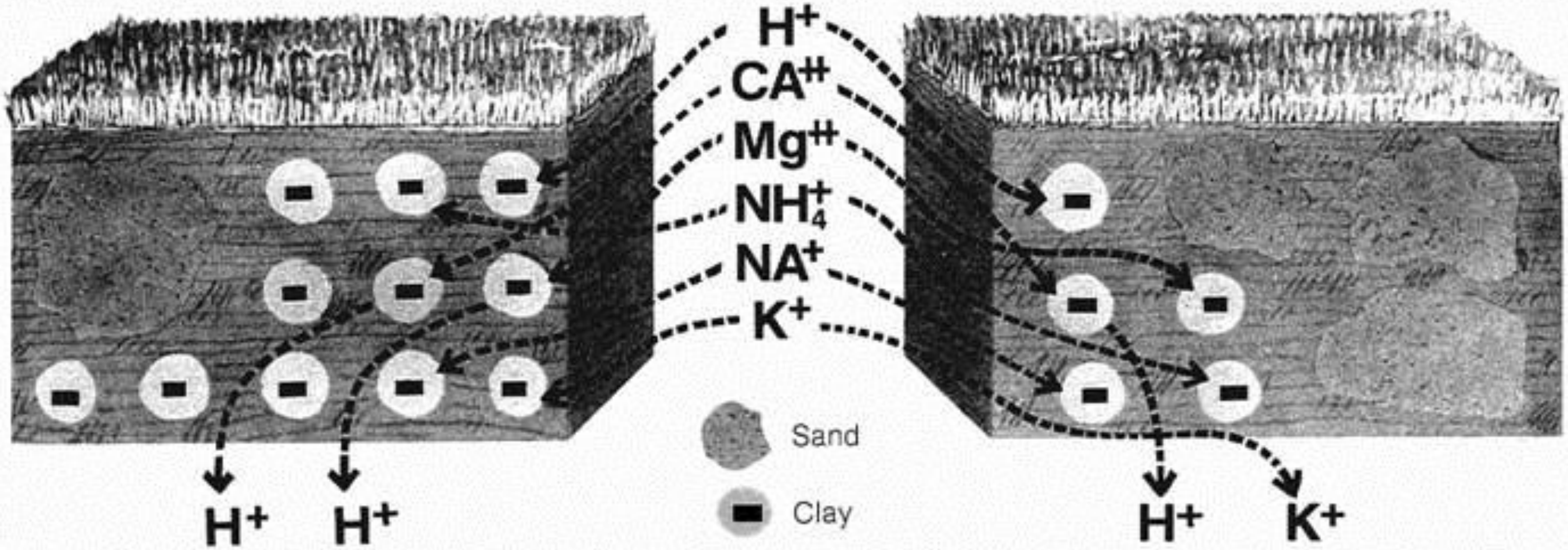
- Soils with high CEC and high buffer capacity change pH much slower than low CEC soils

- High CEC soils do not need to be limed as often as low CEC soils

- Fall fertilization of N and K on low CEC (<5 meg/100 g) soils/sandy soils can result in leaching. Spring fertilization is better

A SCHEMATIC LOOK AT CATION EXCHANGE

CEC 25	**CEC 5**
MORE CLAY, MORE POSITIONS TO HOLD CATIONS	LOW CLAY CONTENT, FEWER POSITIONS TO HOLD CATIONS



50 CEC (Heavy Clay) ← **Common CEC Range** → **0 CEC** (Sand)

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

RELATIONSHIP BETWEEN CEC AND FERTLIZATION PRACTICES

- Higher CEC soils (>10 meg/100g) experience little cation leaching

- Fall applications of N and K is appropriate

- **Soil drainage will have a greater effect on fertilization practices on soils with high CEC**

SUMMARY

- Cation Exchange Capacity (CEC) of a soil determines the number of cations that the soils can hold
- In turn, this can have a significant effect on the fertility management of soils