CATION EXCHANGE PROPERTIES OF SOILS

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ION EXCHANGE

- The interchange between an ion in solution and another ion on the surface of any charged material such as clay or organic matter

- In most soils, 99% of soil cations can be found attached to micelles (clay particles and organic matter) and 1% can be found in solution.

- Cations in the soil (mainly Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) whereas anions include NO_3^{-}, SO_4^{2-}, PO_4^{3-} .

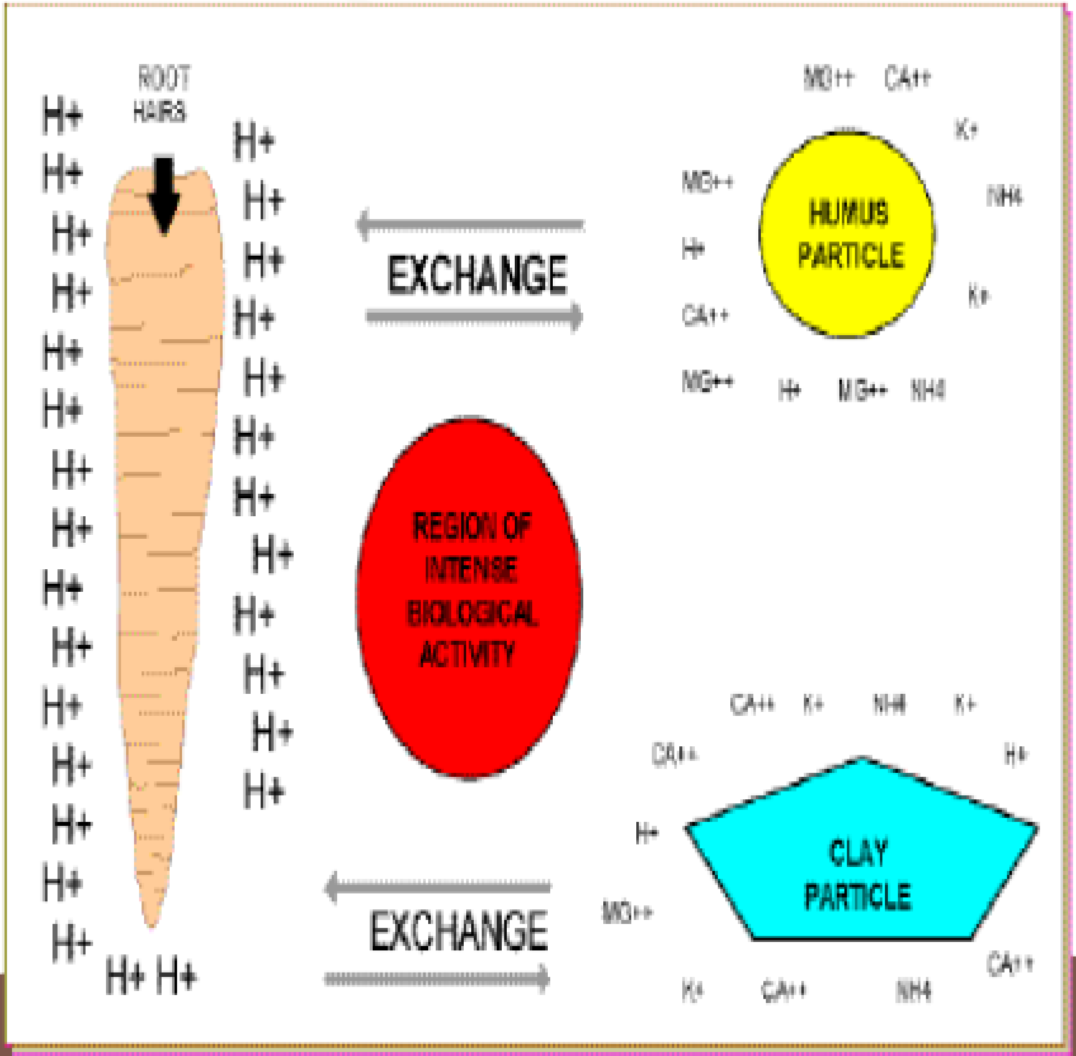

Table 2. Representative values and common ranges of cation exchange capacities of clay minerals and humus.

	Cation Exchange Capacity	
Clay mineral or humus	Representative value	Common range
	meq/100 g or cmol (+) kg^{-1}	
Kaolinite†	8	3–15
Chlorite	30	15–40
Illite	30	15–40
Montmorillonite	80	60–100
Allophane†	100	50–200
Vermiculite	125	80–150
Humus†	200	100–300

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CEC Expression and Calculations

- Cation exchange capacity (CEC) of a soil is measure of the negative charge on the solid phase balanced by exchangeable cations.
- Higher the CEC of soil the more cations it can retain.
- Soils differ in their capacities to hold exchangeable cations
- Cations that usually occur in normal soil are Ca> Mg> K > Na
- Acid soils have Al and H, sodic soils high Na , Calcareous soils high Ca,Mg
- Exchange takes place on equivalent basis between the soil solution and colloidal surface
- One equivalent of an anion / cation, exchanges with one equivalent of another ion
- Negative charge is usually expressed in milli equivalents per 100 grams (me/100 g) of soil or cmol (+) charge per kg (SI unit)
- Two are numerically equal - 1 me/100 g is equal to 1 cmol (p+) kg^{-1} soil

Equivalent- concept

- One equivalent of an ion may be defined as the quantity of that ion that contains one mole of charge (6.023×10^{23} charges)
- So, one equivalent of H^+ equals one mole of H
- Quantity of Ca^2 that contains 6.023×10^{23} charges is 1/2 mole of Ca
- Ca has two positive charges
- One equivalent of Mg equals 1/2 mole of Mg
- One equivalent of Al equals 1/3 mol of Al since Al has 3 $^+$ charges

Gram equivalent weight

- Gram equivalent weight is the equivalent weight expressed in grams
- Equivalent wt. is the Atomic Wt./Valence
- Equivalent Wt of Na^+ and K^+ is Atomic wt. /1 since ions have one charge
- Equivalent Wt of Ca^{++}/Mg^{++} is Atomic wt./2 since ions have two charges
- Equivalent Wt of Al^{+++} Atomic wt. /3 since Al has three charges

Milli equivalent weight

- Equivalent is a large unit for clays and humus
- Milli equivalent is commonly used and convenient
- Milli equivalent (me) equals 1/1000 of an equivalent.
- 1 me of Na 23/1 = 23 mg
- 1 me of K 39/1 = 39 mg
- 1 me of Ca is 40/2 = 20 mg
- 1 me of Mg is 24/2 = 12 mg
- 1 me of Al is 27/3 = 9 mg

Cation content expression - milli eqivalent and parts per million

- A soil with 1 me/100g CEC can hold
- 23 mg Na/ 100g
- 39 mg K /100g
- 20 mg Ca/100g
- 12 mg Mg /100g
- 9 mg Al/100g

In terms of ppm (parts per million)

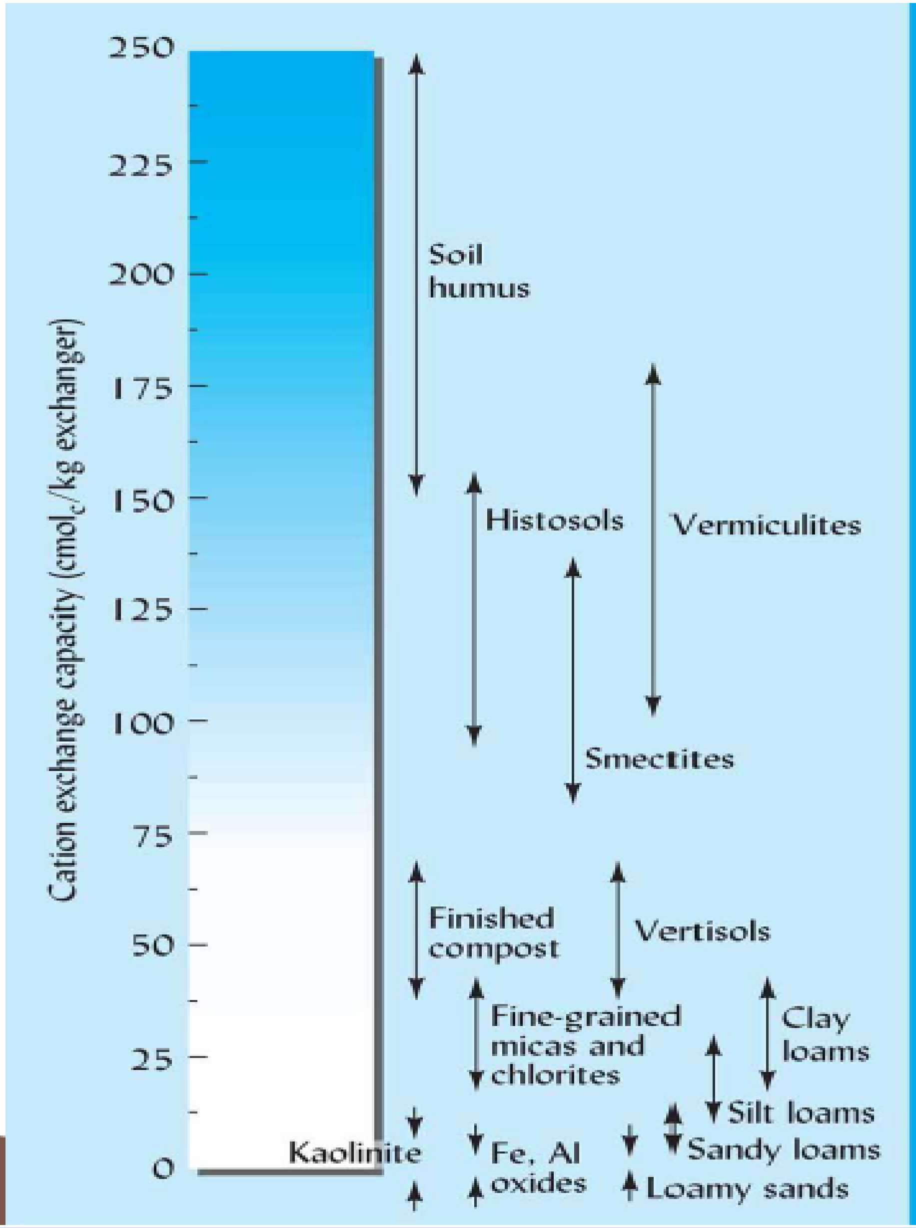
Atomic wt/valency X 10 = ppm

- 1 me of Na = 230 ppm
- 1 me of K = 390 ppm
- 1 me of Ca = 200 ppm
- 1 me of Mg = 230 ppm
- 1 me of Al = 90 ppm

Table 1. Gram-equivalent- and gram-milliequivalent-weights of the more important cations and anions in soils and of two compounds.

Cation or compound	Gram-atomic-weight or gram-formula-weight	Valence or total number of cation charges in compound	Gram-equivalent-weight	Gram-milliequivalent-weight †
	g		g	
H^+	1	1	1.0	0.001
Na^+	23	1	23.0	0.023
K^+	39	1	39.0	0.039
NH_4^+	18	1	18.0	0.018
Ca^{2+}	40	2	20.0	0.020
Mg^{2+}	24	2	12.0	0.012
Al^{3+}	27	3	9.0	0.009
NO_3^-	62	1	62.0	0.062
$H_2PO_4^-$	97	1	97.0	0.097
SO_4^{2-}	96	2	48.0	0.048
$CaCO_3$	100	2	50.0	0.050
$CaCl_2$	110	2	55.0	0.055

† Or one milliequivalent of an ion or compound weighs in grams.



Ranges in the cation exchange capacities (at pH 7) that are typical of a variety of soils and soil materials.

Factors influencing Cation exchange capacity

Organic Amendments

- ❖Acidification
- ❖Organic matter

Excessive Irrigation

- ❖Acidification

Burning of plant residue

- ❖Change in mineralogy
- ❖Organic matter content
- ❖Fertilizer Application

Liming increases CEC

- ❖Deportation of charged sites on oxides, hydroxides
- ❖carboxylic or phenolic OH groups

Factors influencing CEC (contd)

- Concentration and number of ions
- Strength of ion held on the colloidal complex

Al > Ca > Mg > K > NH_4^+ > Na^+ > H^+

Held tight → Easily replaced

- Soil pH greatest influence since H^+ ions are the most active in cation replacement
- Type of colloids and organic matter

Kaolinite	3-15
Montmorillonite	100-150
Fe and Al Oxides	3
Organic matter (Humus)	150-250
Amorphous minerals	5-350

CEC in soil management

- Soils with high CEC have more of negative charge, adsorb, retain more cations, water and hence more fertile with lesser deficiencies of Mg, K and other nutrients
- High CEC soils require less frequent irrigations because of greater water adsorption/retention
- Split application of fertilizers and soil amendments required in low CEC soils to prevent leaching loss of nutrients
- Incorporation of fertilizers/amendments applied needed to prevent run off loss due to slow infiltration rate
- Sandy soils with low CEC tend to acidify faster due to leaching of base cations
- High CEC soils require more lime rates as compared to lower CEC to attain optimum pH
- Frequency of lime application more in low CEC soils

Selected cations and anions commonly adsorbed to soils colloids and importance in plant nutrition and environmental quality

Cation	Formula	Comments	Anion	Formula	Comments
Ammonium	NH_4^+	Plant nutrient	Arsenate	AsO_4^{3-}	Toxic to animals
Aluminum	Al^{3+} etc.[a]	Toxic to many plants	Borate	$B(OH)_4^-$	Plant nutrient, can be toxic
Calcium*	Ca^{2+}	Plant nutrient	Bicarbonate	HCO_3^-	Toxic in high-pH soils
Cadmium	Cd^{2+}	Toxic pollutant	Carbonate*	CO_3^{2-}	Forms weak acid
Cesium	Cs^+	Radioactive contaminant	Chromate	CrO_4^{2-}	Toxic pollutant
Copper	Cu^{2+}	Plant nutrient, toxic pollutant	Chloride*	Cl^-	Plant nutrient, toxic in large amounts
Hydrogen*	H^+	Causes acidity	Fluoride	Fl^-	Toxic, natural and pollutant
Iron	Fe^{2+}	Plant nutrient	Hydroxyl*	OH^-	Alkalinity factor
Lead	Pb^{2+}	Toxic to animals, plants	Nitrate*	NO_3^-	Plant nutrient, pollutant in water
Magnesium*	Mg^{2+}	Plant nutrient	Molybdate	MoO_4^{2-}	Plant nutrient, can be toxic
Manganese	Mn^{2+}	Plant nutrient	Phosphate	HPO_4^{2-}	Plant nutrient, water pollutant
Nickel	Ni^{2+}	Plant nutrient, toxic pollutant	Selenate	SeO_4^{2-}	Animal nutrient and toxic pollutant
Potassium*	K^+	Plant nutrient	Selenite	SeO_3^{2-}	Animal nutrient and toxic pollutant
Sodium*	Na^+	Used by animals, some plants, can damage soil	Silicate*	SiO_4^{4-}	Mineral weathering product, used by plants
Strontium	Sr^{2+}	Radioactive contaminant	Sulfate*	SO_4^{2-}	Plant nutrient
Zinc	Zn^{2+}	Plant nutrient, toxic pollutant	Sulfide	S^{2-}	In anaerobic soils, forms acid on oxidation

[a] Important aluminum cations include Al^{3+}, $AlOH^{2+}$, and $Al(OH)_2^+$.

Anion Exchange

- ❖ Mostly observed in sesquioxide clays with a net positive charge
- ❖ Anion exchange is less common in soils and there is heavy loss of anions through leaching
- ❖ Anions Nitrate, chloride, carbonate, bicarbonates, sulphate etc are adsorbed and retained by anion exchange
- ❖ Anion exchange increases with decrease in pH

References

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