SOIL COLLOIDS AND THE CATION EXCHANGE CAPACITY OF SOIL

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The solid particles in the soil occur in various sizes ranging from the very fine particles with diameters of < 2µm which constitute the clay fraction, to coarse fragments larger than 2 mm in diameter called gravel. A lot of the chemical reactions that occur in soils, happen on the boundary between the surfaces of soil particles and the water in the soil with its dissolved substances called the **soil solution**. In general, as the size of the solid particles decreases, **the surface area per unit mass** of the particles or the **specific surface area** increases. Since processes such as water retention and nutrient retention occur on the surfaces of solid particles, it follows that the ability of the soils to retain water and nutrients largely influence by the size of particles present in the soil. It is because of this that the texture of the soil is considered one of the important properties of the soil that helps in predicting the behavior of soils. Clay particles have a much greater influence on soil properties such as water and nutrient retention compared to the larger sand and gravel particles. Because of the great influence that very fine particles have on the physical and chemical behavior of soils, special attention is given to the study of the very fine solid particles in soils which are collectively called **colloids.**

Soil colloids are solid particles **with a spherical diameter of less than 1µm**. They are very fine solid particles of the soil that occur in the clay fraction of the soils. Because of their small size, **they have relatively large specific surface area.** In addition to their small size and large specific surface area, **soil colloids tend to have an electric charge on their surfaces.** In summary soil colloids are: (i) **very small particles** with a diameter of less than 1µm, which (ii) have **a large specific surface area** and (iii) which **tend to be charged**.

Soils colloid in soils are either **minerals, which are inorganic compounds** or **organic matter** usually consisting of complex organic compounds produced by the decomposition of organic materials, which are commonly **called humus**. The large specific surface area and presence of electric charges make the colloids very active components of the soil. The charge on the colloids tends to attract oppositely charged ions dissolved in the soil solution that is in contact with the surfaces of the colloids. **Negatively charged colloids attract positively charges ion or cations**, while **positively charged colloids attract negatively charges ions or anions.** In soils both positive and negative charged colloids exist. Some colloids have a mixture of positive and negative charges. However **most soil colloids are negatively charged**.

The inorganic colloids or minerals in the clay fractions, include layer silicate minerals such as kaolinite, vermiculite, smectite, micas and chlorites. The organic matter consists of complex organic compounds made in the soil collectively known as humus. The ability of a colloid to attract or retain cations on its negatively charged surface is called the **cation exchange capacity** (CEC). The CEC is a measure of the amount of negative charge present per unit mass of the colloid or colloidal material. The units for the CEC are **centimoles of positive charge per kilogram** (**cmol(+)/kg)** or **milli-equivalents per 100 grams (meq/100 g).** The meq/100g was formerly used and is still common in literature, while cmol (+)/kg is what is currently used. **It should be noted that X meq/100g is equivalent to X cmol (+)/kg**. (***See proof at end of this section of class notes)***

It should be noted that some soil colloids are positively charged. These colloids attract anion onto their surfaces. For such colloids the anion exchange capacity (AEC) can also be measured. The units for AEC are centimoles of negative charge per kilogram (cmol(-).kg^{-1}, or milli-equivalents per 100 grams.

Sources of Charge on Soil Colloids

There charge on soil colloids has two origins. The charges are classified as: (i) **variable charge or pH-dependent charge** and (ii) **permanent charge**. **Variable charge occurs both on organic colloids and on inorganic or mineral colloids**, while **permanent charge only occurs in minerals or inorganic soil colloids**.

Variable or pH dependent charge

Variable charge is associated with functional groups on the surface of organic and mineral colloids, which are able to dissociate or adsorb H^+ depending on the pH of the soil solution in contact with the soil colloids. In general when the pH of the surrounding solution increases, the functional groups release H^+ into solution resulting in the development of negative charges at the sites on the surfaces of the colloids where the H^+ ion was released. As the pH of the soil solution increases the magnitude of the negative charge on the surfaces of the colloids increase. On the other hand when the pH of the solution decreases of when it becomes more acid the negatively charged sites of functional groups adsorb H+ ions which result in decreasing the amount of negative charge on the soil colloids. Because this type of charge varies with the pH of the surrounding solution, it is referred to as **variable charge** or **pH- dependent charge**. As earlier mentioned **variable charge occurs on both organic colloids and on mineral colloids.**

Permanent Charge

The other source of charge which only occurs in mineral colloids is called permanent charge. During the formation of minerals, ions of similar size can occupy the same position in the structure of a minerals. Such ions are able to replace each other in the structure of the mineral when the mineral is forming. The replacement of one ion by another ion of similar size in the structure of a mineral at the time the mineral is forming is called **isomorphous substitution**. This is simply the replacement of one ion, by another of similar size in the structure of a mineral. If the ions that susbstitute each other have different charges or, the substitution may results in the development of a net positive charge or a net negative charge. For example if Al^{3+} replaces Si^{4+}, the new structure will have a lower sum of positive charges which will result in the structure having a net negative charge. This negative charge which results from isomorphous substitution is not influenced by the pH of the surrounding solution, but is a permanent property of the mineral. This type of charge is thus referred to as **permanent charge.** To emphasize the point, **organic colloids do not have permanent charge, they only have variable charge. Permanent charge only occurs in minerals,** while minerals also have variable charge.

Since soils contain both organic colloids and mineral colloids, the source of negative charge in soils consisting of minerals and humus is both variable charge and permanent charge. The total charge σ_t of soil colloids is thus the sum of variable charge σ_v and permanent charge σ_p. This summarized by equation 1.

$$\sigma_t = \rho_v + \rho_p \text{ ……… (1)}$$

Where: σ_t = is the total charge on colloids

σ_v = variable charge,
σ_p = permanent charge.

In soil the sources of charge are the mineral fraction and the organic fraction of the soil colloids. The total charge of soil colloids is thus a sum of the contribution of charge from the organic matter (om) and from the mineral (min). If the charge is negative then this is expressed as the CEC of the soil. This CEC of the soil can be expressed as a summation of the CEC of minerals in the soil and the CEC of the organic matter in the soil. This is summarized in equation 2.

$$\text{CEC}_{\text{soil}} = \text{CEC}_{\text{mineral}} + \text{CEC}_{\text{organic matter}} \quad ..... \quad (2)$$

If we recall that the two sources of charge are variable charge which changes with the pH of the surrounding solution and the permanent charge which does not change with pH, if that the CEC of the soil with depend on the pH as which it is measured. It will increase with increasing pH and decrease with reducing pH. Therefore whenever the CEC of a soil is reported, the pH at which it was measured has to be reported.

Table 1 shows the major constituents of the colloidal fraction of soils and their CEC measured at pH 7.0.

Constituent	Range of CEC values cmol(+)/kg	Average CEC cmol (+)/kg
Kaolinite	3 - 15	10
Vermiculite	120 -150	120
Smectite	80 - 120	80
Chlorite	20 - 40	30
Illite	20 - 40	30
Humus	100 - 300	200

Estimating the CEC of soil from percentages of clay and organic matter in the soil.

Using data in Table 1, one can estimate the CEC of soils if information is provided on the amount and type of clay present and the organic matter content. Example: ***Estimate the CEC of this soil at pH 7.0 of a soil containing 10 % clay which is kaolinitic and 2.5 % organic matter.***

Answer:

If the soil contains 10 % clay it means 100 g of dry soil contains 10 grams or 1kg of this soil contains 0.1 kg of clay. If the organic carbon content of the soil is 2.5 % it means 1kg of this soil contains 0.025 x 1kg, or that there are 0.025 kg of organic matter per kg of soil.

The CEC due to the mineral fraction or kaolinite is equal to the charge associated with the amount of kaolinite present in a kg of soils.

$$\text{CEC}_{\text{due to kaolinite}}/\text{ kg soil} = \text{CEC /kg kaolinite*kg kaolinite in the soil/kg soil}$$

$$\text{CEC}_{\text{due to kaolinite}}/\text{kg soil} = (10 \text{ cmol (+)/ kg kaolinite})*(0.1 \text{ kg kaolinite/kg soil})$$

$$\text{CEC}_{\text{due to kaolinite}} = 1 \text{ cmol (+)/ kg soil}$$

$$\text{The CEC}_{\text{due to organic matter}}/\text{kg soil} = (\text{CEC/kg organic matter}) * (\text{kg organic matter/kg soil})$$

= (200 cmol (+)/kg OM) *(0.025kg OM/ kg soil)

CEC $_{\text{due to OM}}$ = 5 cmol (+)/kg soil

The CEC of soil = (CEC $_{\text{due to kaolinite}}$ + CEC $_{\text{due to OM}}$)

= (1+ 5) cmol(+)/kg soil

= 6.0 cmol (+)/kg soil

<u>Therefore the CEC of the soil is about 6.0 cmol (+)/kg soil</u>.

The type of clay present in a given soils can also be estimated if one knows CEC of the soil measured at pH 7, the amount of clay in the soil and the amount of organic matter on the assumption that the soil contains one type of clay mineral.

Example. ***A soil with a CEC of 15 cmol (+)/kg soil, contains 37 % clay and 3.5 % organic matter. Estimate the CEC of the clay present in this soil and indicate the type of clay that is probably present in this soil.***

1. Calculate the CEC due to O M in this soil>
   CEC $_{\text{OM}}$ = (kg OM/kg soil)* (CEC $_{\text{OM}}$/kg OM)
   kg OM/Kg soil = (3.5/100) * 1 kg soil = 0.035 kg
   CEC $_{\text{due to OM}}$ = (0.035kg OM*200 cmol (+)/kg OM)
   CEC $_{\text{due to OM}}$ = 7 cmol (+)/kg soil
   Estimate the CEC $_{\text{due to clay}}$ = (CEC $_{\text{soil}}$ – CEC $_{\text{due to OM}}$)

   CEC $_{\text{due to clay}}$ = (15 - 7) cmol/kg soil

The CEC due to clay in this soil = 8 cmol (+)/kg soil

The CEC of the clay = (CEC due to clay/kg soil) / (kg clay/kg soil)

= (8 cmol(+)/kg soil) (0.37 kg clay/kg soil) = 21 cmol (+)/kg clay

The CEC of the clay is 21 cmol(+)/kg

<u>Based on the data in Table 1 the type of clay that is most likely to have this CEC is Illite or Chlorite</u>

Proof that X meq/100g = X cmol.(+)/ kg soil

1 equivalent of charge = 1 mole of charge; or 1eq = 1 mole (c)

1 meq = 1 x10^{-3} eq = 1 x 10^{-3} mol(c) = 1 mmol (c)

1meq/ 100 g soil = 1 x 10^{-3} mol (c)/ 100g

1meq/ 100g soil = (1meq/100g)*(10^{3}g/kg) = **10 meq/kg soil**

10 meq/kg soil = 10*1x10^{-3} mol (c)/kg soil = 10^{-2} mol (c)/kg soil

Since 10^{-2} = centi, 10 meq/kg soil = 1 cmol(c)/kg

Therefore: 1 meq/100g soil = 10 meq/kg soil = 1 cmol(c)/kg soil

Hence: 1 meq/100g soil = 1 cmol(c)/kg soil or X meq/100g = X cmol(c)/kg

The Cation Exchange Capacity of Soils and Related soil Properties

From the foregoing notes, we know that soil colloids are usually charged and tend to attract oppositely charged ions or counterions present in the soil solution to their surfaces. We have also established that most soil colloids are negatively charged and as such tend to attract cations to their surfaces. These cations that are electrostatically attracted to the surfaces of soils colloids are usually retained or held on the colloid surfaces temporarily, and can be replaced by other cations in the soil solution. For this reason these cations are said to be **exchangeable as they are not retained of held permanently on the surfaces of colloids**. The amount of exchangeable cations that a unit mass of soil or material can a given pH is the cation exchange capacity of the soil or material. It is a measure of the amount of negative charge present on the surfaces a unit mass of soil or material at a given pH. The pH is mentioned because the quantity of variable charge on colloid varies with the pH of the surrounding solution.

Among the many ions that occur in soil solutions, there are six ions that dominate as exchangeable cations. These are: **Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+} and H^{+}.** The first four cations, namely; Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}, are referred to as **exchangeable bases**, while the last two cations namely Al^{3+} and H^{+} are referred to as **exchangeable acids**. Although the first four cations are called exchangeable bases, they are not actually bases and do not behave as bases in water. On the other hand, exchangeable Al^{3+} and $H^{+,}$ which are called **exchangeable acids** actually are acids and behave as acids in water. This will be made clear when we discuss **soil acidity**.

The CEC of the soil is usually expressed as the quantity of exchangeable cations held by a unit mass of soil. The quantities of the cations are expressed in units of equivalents of positive charge per unit mass of soil. As earlier mentioned the units may be milli-equivalents or millimoles of charge per 100 grams or centimoles of charge per kilogram. We earlier established that X meq/100g is equal to X cmol (+)/kg. What is important is to know the relationship between the units of charge of a given cation to the mass of that cation and the vice-versa or the reverse which the relationship between the mass of a given cations to its units of charge.

In this course you are **expected to know by heart** (i) the atomic masses of the six elements (**Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+} and H^{+})** and (ii) their **charges or valency**. The reactions that occur between cations attracted to the surfaces of soil colloids and the cations in the bulk soil solution are exchanges reactions involving charges. A cation on the soil hold with a given charge can be replaced by any other cations with an equivalent positive charge. So the cation exchange reactions involved cations with equivalent charges. The quantity of mass of a given cation that is able to replace another cation of known charge will depend on the mass or weight of the cation that carries the same charge. The concept of **equivalent weights** or **equivalent mass** of cations is therefore important. The **equivalent weight of a cation involved in a cation exchange reaction is simply that mass of that cation that carries one mole of positive charge.** The equivalent weight or mass of a cation is found by dividing the atomic or molar mass of the cation by the valency of the cation. This is summarized in equation 3.

$$Equivalent\ mass\ of\ cation\ = \frac{Molar\ mass\ of\ cation\ (g)}{Valency\ of\ cations} \quad \text{……. (3)}$$

A cation exchange reaction occurring between a colloidal material X, holding exchangeable Ca^{2+} with K^{+} ions in solution, resulting in the replacements of the Ca2+ ions by the potassium ions can be represented by equation 4.

$$XCa^{2+} + 2\,K^{+} \leftrightarrow X2K^{+} + Ca^{2+} \quad .... (4)$$

Figure 1 show the distribution of exchange cations between the surface of soil colloids and the ions in the bulk soil solution.

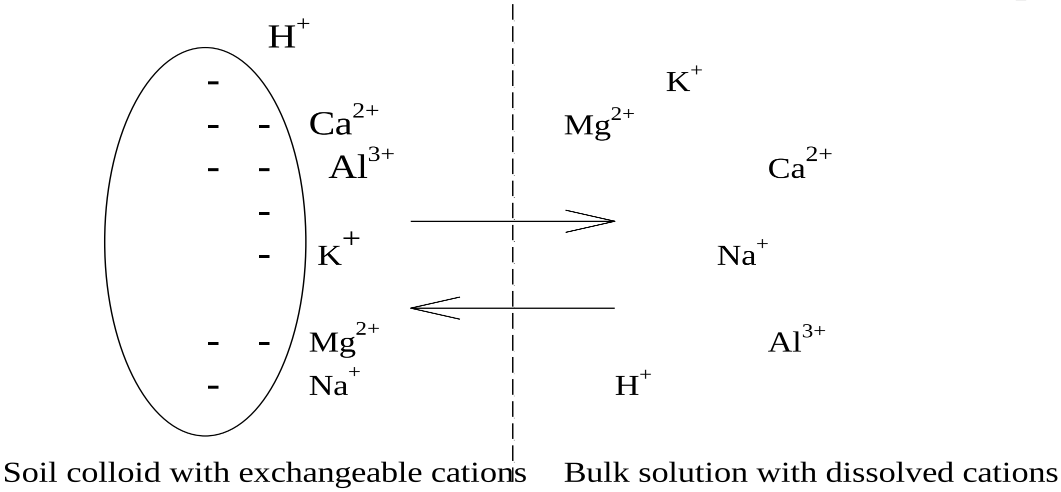

Figure 1. Illustration of cation exchange reaction between ions in the soil solution and exchangeable cations held on soil colloids.

Table 2 below gives the molar masses, valency, and equivalent masses of the six most common exchangeable cations in soils.

Table 2. Molar masses, valency and equivalent masses of most commons exchangeable cations in soils

Cation	Molar mass (g)	Valency	Equivalent mass (g)	milliequivalent mass (mg)
H^{+}	1.0	1	1.0	1.0
Al^{3+}	27.0	3	9.0	9.0
Ca^{2+}	40.0	2	20.0	20.0
Mg^{2+}	24.0	2	12.0	12.0
Na^{+}	23.0	1	23.0	23.0
K^{+}	39.0	1	39.0	39.0

The quantities of exchangeable cations held by the soils can be calculated using the knowledge of the equivalent mases of the cations if the equivalents charges of the cations in the soil are given. For example given that a soil contains 0.23 cmol (+) Na/kg and 0.16 cmol (+) K/kg, calculate the masses of (i) sodium and (ii) potassium in grams present in a kilogram of soil as exchangeable cations.

a. The mass of sodium in a kilogram of the soil.
   0.23 cmol (+) Na/ kg soil = 0.23 x 10^{-3} moles (+) Na/kg soil x 23g Na/ mole (+) Na
   =0.23 x 10^{-2} x 23g Na/kg soil = 0.0529g Na+/ kg soil

   The soil contains 0.0529 g of Na^{+} per kilogram as exchangeable cations.

To check whether this answer is correct, we can try to find out what 0.0529 g Na+ corresponds to in terms of moles of positive charge per kilogram of soils.

Moles of (+) charge = (mass of cations (g)/kg soil) /(equivalent mass of cation(g))
= (0.0529g Na+/kg soil)/(23 g Na^+/ mole (+))
= 2.3 x 10^{-3} moles (+) Na/kg soil
= 0.23 x 10^{-2} moles (+) Na/kg
= 0.23 cmol (+)/kg soil.

0.0529 g Na^+ has is equivalent to 0.23 cmol (+)Na/kg soil

b. the mass of potassium in grams present in 1 kg of the soils as exchangeable K is;

0.16 cmol (+) K/kg soil = 0.16 x10^{-2} moles (+) x 39 g K/ mole (+) K

= 1.6 x 10^{-3} x 39 g K/kg soil

= 0.0624 g K/ kg soil

The soil contains 0.0624 g K as exchangeable cations.

To check if this is correct we find out what 0.0624 g K+ corresponds to in moles of charge

(0.0624g K+/kg soil)/ (39g K/ mole (K^+))

=1.6 x 10^{-3} mole (+) K/kg soil

= 0.16 x 10^{-2} mole (+)K/kg soil

= 0.16 cmol(+)/kg soil

0.0624 g of exchangeable K is equivalent to 0.16 cmol (+) K/kg soil.

Determination of the CEC of Soils

As was earlier mentioned, the CEC of the soil various with the pH of the solution that is in contact with the soil when the CEC is being measured. It is therefore important and necessary that the pH at which the CEC of the soil was measured is indicated when the values of the CEC are reported. There are many methods of determining the pH. The two most common methods of determining the pH are: (i) determining the CEC of the soil at the actual value of the pH as occurs in the field (ii) the CEC of the soil when the pH value is adjusted to pH 7, which may be different from the field pH value of the soil. The CEC of the soil measured at its actual or natural pH, is also called the **Effective Cation Exchange Capacity** (ECEC). The CEC reflects the CEC that one would expect the soil to exhibit in the field at its natural pH. The CEC measured at pH 7, is that is used to compare the CEC of soils at a standardized or uniform pH value of 7.0. This CEC is called the pH measured in 1 N Ammonium acetate buffered at pH 7.0. It is a standard method for comparing the CECs of different soils or different materials and is commonly used for classifying soils after soil mapping exercises. The disadvantage with this method is that the CEC measured does not reflect the actual CEC of the soil in the field, for soils whose actual pH values in the field differ from pH 7.0. For agronomic purposes or for the activities where the main aim is to assess the suitability of soils for crop production the Effective Cation Exchange Capacity (ECEC) is the more appropriate method.

The ECEC is therefore what is most commonly used when evaluating the suitability of soils for crop production. Because of the importance of the ECEC in agriculture, we will briefly describe how it is measured in the lab.

To determine the ECEC of soils involves measuring to properties of the soil. These are (i) **the exchangeable acidity of the soil** and (ii) **the sum of the exchangeable bases in the soils**. As earlier defined the **exchangeable acidity** is the sum of positive charge due to exchangeable Al^{3+} and exchangeable H^{+}, while the **exchangeable bases** is the **sum of positive charges due to Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}.** The **ECEC** is thus **a summation of the exchangeable acidity and the exchangeable bases,** where the exchangeable cations are expressed in cmol (+)/kg soil or meq/100g. The formula is summarized below as equation (5).

$$\text{ECEC} = (\text{Exchangeable acidity} + \text{sum of Exchangeable bases}) \ldots (5)$$

Equation 5 can also be expressed as equation 6.

$$\text{ECEC} = \text{Exch}\,(Al^{3+} + H^{+}) + \text{Exch}\,(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})\ldots\ldots\ldots.(6).$$

The Exchangeable acidity of soils is negligible or close to zero in soils with pH values of 5.0 or greater. It is however significant in soils with pH values of less than 5.0. In soils with pH values of 5.0 or more the ECEC is approximately the same as the sum of exchangeable bases. In soils with pH less than 5.0 the ECEC that the exchangeable acidity and exchangeable bases are measured.

Determination of Exchangeable acidity

If the soil has a pH values of less than 5.0 the exchangeable acidity is determined by weight 10 gram air dry soil from the fine earth fraction. This is placed in a 200 mL conical flask to which 50 mL of 1NKCl solution is added. The top of the conical flask is closed using parafilm and the flasks are placed on a mechanical shaker. The samples are shaken for 30 minutes and then filtered in new 20 ml conical flasks. The filtrate obtained in the flasks are titrated using 0.1N NaOH to the phenolphthalein end point. The volume of NaOH solution used multiplied by the concentration of the NaOH is used to calculate the equivalents of exchangeable acidity present in the soil, which is expressed in meq/100 g soil or cmol (+)/kg soil. After determining the exchangeable acidity the solution used to determine the exchangeable acidity can further be used to determine the amount of exchangeable aluminium. The difference between exchangeable acidity and exchangeable aluminium gives exchangeable H+.

Determination of sum of exchangeable bases

To determine the sum of exchangeable bases 10 gram of air dry fine earth fraction of soils is weighed and placed into a conical flask to which 50 mL of 1N ammonium acetate solution buffered at pH 7.0 is added. The tops of the conical flasks are sealed with parafilm, placed on a mechanical shaker and shaken for 30 minutes. After shaking the suspension is filtered into new conical flasks. The filtrate obtained contains Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} displaced from the soil colloids into the solution by the NH4+ ions added to the soil as 1N NH4-acetate solution. The concentrations of these cations in the filtrate are determined using an Atomic Absorption Spectrophotometer (AAS). The amounts of each of the exchangeable bases are expressed in meq/100 g soil or cmol(+)/kg soil. The sum of these calculated and presented as the sum of exchangeable bases.

Calculation of ECEC

The ECEC of the soil is calculated by adding the values of the exchangeable bases to the values of the exchangeable acidity as indicated in equation 5. Once the value of the ECEC has been determined a number of other soil properties related to the ECEC can be calculated.

Chemical Properties of the Soil related to the CEC

There are a number of important soil properties that are related to the CEC of the soil. They include: (i) the **Base saturation** (BS) (ii) the **Aluminium saturation** and (ii) the **Exchangeable Sodium Percentage (ESP)**.

Base Saturation Percentage (BSP)

The base saturation or base saturation percent is the ratio of the sum of exchangeable bases to the CEC of the soil expressed as a percentage. The formula for calculating the base saturation is given as equation 7.

$$\%\, Base\ saturation = \frac{Sum\ of\ exchangeable\ bases\ (cmol(+).kg\ soil^{-1}}{CEC\ or\ ECEC\ of\ soil\ (\ cmol(+).kg\ soil^{-1}} * 100 \text{ .....(7)}$$

The base saturation is a measure of the proportion of exchangeable sites occupied by exchangeable bases. Note that 3 of the exchangeable bases (Ca, Mg and K) are plant nutrients while Na is not. A high base saturation is usually an indicator of better soil fertility. High base saturations are desirable for crop production compared to lower base saturation as long as Na is not the dominant exchangeable base.

Aluminium saturation

Aluminium saturation is the ratio of the amount of exchangeable aluminum to the CEC of the soil expressed as a percentage. It is a measured of the proportion of exchangeable sites occupied by exchangeable aluminium. The formula for calculating the aluminium saturation is given as equation 8.

$$Aluminium\ saturatio\ (\%) = \frac{Exchangeble\ Al^{3+}\ cmol(+).kg\ soil^{-1}}{CEC\ (\ cmol(+).kg\ soil^{-1}} * 100 \text{.......(8)}$$

Exchangeable aluminium is part to the acidity of soil and in addition is toxic to plants when present in high concentrations. It is not a plant nutrient but a potentially toxic ions which adversely affects root development and thus contributes to the infertility of soils. High levels of aluminium saturations are generally undesirable for crop production while low levels are generally desirable.

Exchangeable Sodium Percentage (ESP)

The ESP is the ratio of the amount of exchangeable sodium to the CEC of the soil expressed as a percentage. It is an indicator of the proportion of exchangeable sites in soil that are occupied by sodium ions. The formula for calculating the ESP is given as equation 9**.**

$$\text{ESP } (\%) = \frac{Exchangeable\ Na^{+}.cmol(+).kg\ soil^{-1}}{CEC\ (cmol(+).kg\ soil^{-1}} * 100 \text{ ....(9)}$$

Sodium is not a plant nutrient. High amounts of exchangeable sodium promote the dispersion or separation of soil colloids that hold soils aggregates together resulting in the collapse or breakdown of soil aggregates. When soil aggregates breakdown many of the macropores and mesopores in the soil become clogged by the colloids resulting in the reduced aeration and water flow when the soil is wet. The soil also becomes hard and massive when dry, making it very difficult to cultivate. The clogging of the pores also make the soils more prone to water erosion when it rains or when soils are irrigated. High levels of exchangeable sodium are therefore undesirable for crop production, road construction and construction of buildings. Soils with ESP values of 15 % or more are classified as **Sodic. Sodic soils have undesirable physical properties**.

Exchangeable bases as nutrient sources for plants

Among the exchangeable cations in soils, are three plant nutrients, calcium, magnesium and potassium. The cationic form of these three elements are the chemical form that plants are able to take up or assimilate. In other words the exchangeable forms of calcium, magnesium and potassium are readily available forms or the **bioavailable forms** of these three nutrients that plants can use. Therefore the exchangeable forms of these three elements are a measure of the amounts of plant available nutrients in the soil. It is therefore important to know to determine the quantities of these nutrients in a given soil from data on the CEC of the soils

Assignment 4 will help you get some practice in working with concepts covered in this topic.