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Chemistry

CATIONS and CATION EXCHANGE CAPACITY

Key points

- Cation exchange capacity (CEC) is the total capacity of a soil to hold exchangeable cations.
- CEC is an inherent soil characteristic and is difficult to alter significantly.
- It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification.
- Soils with a higher clay fraction tend to have a higher CEC.
- Organic matter has a very high CEC.
- Sandy soils rely heavily on the high CEC of organic matter for the retention of nutrients in the topsoil.

Background

Cation exchange capacity (CEC) is a measure of the soil's ability to hold positively charged ions. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilisers and other ameliorants (Hazleton and Murphy 2007).

What are exchangeable cations?

The clay mineral and organic matter components of soil have negatively charged sites on their surfaces which adsorb and hold positively charged ions (cations) by electrostatic force. This electrical charge is critical to the supply of nutrients to plants because many nutrients exist as cations (e.g. magnesium, potassium and calcium). In general terms, soils with large quantities of negative charge are more fertile because they retain more cations (McKenzie *et al.* 2004) however, productive crops and pastures can be grown on low CEC soils.

The main ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) (Rayment and Higginson 1992), and are generally referred to as the base cations. In most cases, summing the analysed base cations gives an adequate measure of CEC ("CEC by bases"). However, as soils become more acidic these cations are replaced by H^{+}, Al^{3+} and Mn^{2+}, and common methods will produce CEC values much higher than what occurs in the field (McKenzie *et al.* 2004). This "exchange acidity" needs to be included when summing the base cations and this measurement is referred to as effective CEC (ECEC).

Measuring CEC

Different laboratories use various methods to measure CEC, and can return contrasting results depending on the fraction of the soil measured. In Western Australia, some laboratories measure CEC directly and others calculate it as CEC by bases. Cation exchange capacity is commonly measured on the fine earth fraction (soil particles less than 2 mm in size). In gravelly soils the effective CEC of the soil as a whole is diluted, and if only the fine (clay) fraction is analysed, reported CEC values will be higher than actual field values.

Measuring CEC involves washing the soil to remove excess salts and using an "index ion" to determine the total positive charge in relation to original soil mass. This involves bringing the soil to a predetermined pH before analysis. Methods, including pre-treatment, for measuring CEC and exchangeable cations are presented by Rengasamy and Churchman (1999) and described in detail by Rayment and Higginson (1992).

Units

CEC is conventionally expressed in meq/100 g (Rengasamy and Churchman 1999) which is numerically equal to centimoles of charge per kilogram of exchanger (cmol(+)/kg).

Management implications

Soil type and CEC

The CEC of soils varies according the clay %, the type of clay, soil pH and amount of organic matter. Pure sand has a very low CEC, less than 2 meq/100 g, and the CEC of the sand and silt size fractions of most soils is negligible. Claying sandy soils for managing water repellence increases the CEC of the surface layers by a small amount depending on type and amount of clay added. Typically CEC is increased by less than 1 meq/100 g.

The most commonly occurring clay in Western Australian soils, kaolinite, has a CEC of about 10 meq/100 g. Other clays such as illite and smectite have CECs ranging from 25 to 100 meq/100 g. Organic matter has a very high CEC ranging from 250 to 400 meq/100 g (Moore 1998). Because a higher CEC usually indicates more clay and organic matter is present in the soil, high CEC soils generally have greater water holding capacity than low CEC soils.

Soil pH and CEC

Soils dominated by clays with variable surface charge are typically strongly weathered. The fertility of these soils decreases with decreasing pH which can be induced by acidifying nitrogen fertiliser, nitrate leaching and by clearing and agricultural practices (McKenzie *et al.* 2004). Soil pH change can also be caused by natural processes such as decomposition of organic matter and leaching of cations. The lower the CEC of a soil, the faster the soil pH will decrease with time. Liming soils (see Soil Acidity fact sheet) to higher than pH 5 ($CaCl_2$) will maintain exchangeable plant nutrient cations.

Nutrient availability and CEC

Soils with a low CEC are more likely to develop deficiencies in potassium (K^+), magnesium (Mg^{2+}) and other cations while high CEC soils are less susceptible to leaching of these cations (CUCE 2007). Several factors may restrict the release of nutrients to plants. Some groups promote the controversial idea of managing cation ratios, claiming ideal ratios for Ca:Mg or Ca:K. For plant nutrition, a more critical factor is whether the net amount of Ca or K in the soil is adequate for plant growth. The addition of organic matter will increase the CEC of a soil but requires many years to take effect.

Figure 1 illustrates how CEC can change with depth. The sum of the base cations provides an estimate of the CEC of each soil layer. The surface 10 cm has a CEC of 4.6 meq/100 g because of a high organic content. At 10–30 cm depth, the organic content of the sand is very low, hence the low CEC. The CEC of the subsoil layers are governed by the clay content, 61%, 51% and 34% respectively. The dominant clay in this soil is kaolinite so CEC values remain low.

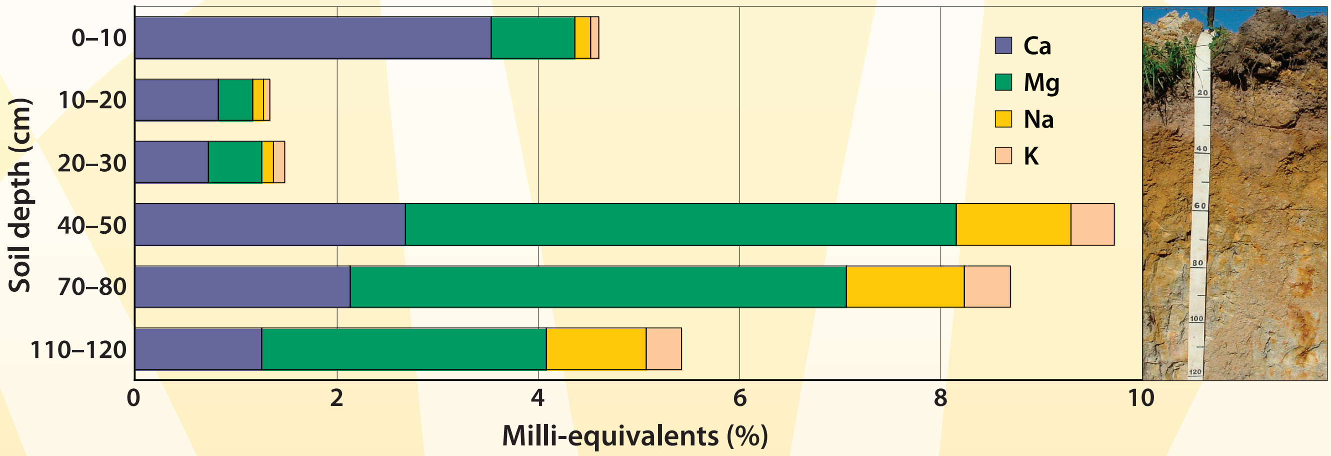

Figure1: *Sandy duplex soil, with clay at 40 cm. Note the high CEC of the clay below 40 cm, and the impact of organic matter on the sand's CEC.*

Further reading and references

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