Cation Exchange Capacity

FACT SHEET 4

The cation exchange capacity (CEC) of a soil is closely related to the soil minerals and texture. It is an inherent characteristic of a soil primarily determined by the parent material. Soils with higher clay content tend to have a higher CEC and organic matter has a high CEC

CEC explained

The soil may be considered as a weak electrical system consisting of positively charged ions, called cations and negatively charged ions, called anions. The surface of clay particles and organic matter are inherently negatively charged. The cation exchange capacity (CEC) is a measure of that negative charge and therefore that soils ability to balance and hold positively charged elements, exchangeable cations.

The CEC of a soil is an inherent characteristic of a soil and other than the addition of organic matter is difficult to alter with management. It indicates the total capacity of a soil to hold positively charged cations by electrical attraction. The CEC of a soil is related to the type and amount of clay present.

The negatively charge particles of clay and humus are called colloids which consist of thin flat plates which provide a comparatively large surface area. This large surface area provides the capacity to potentially hold a large amount of cations. Soils with a high CEC are considered inherently more fertile.

The unit of measurement of the CEC is milliequivalents per 100g of soil (meq/100g) or centimoles of positive charge per kg soil ($cmol^+/kg$). Both measures are numerically equal.

The dominant ions associated with the CEC are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+). These are often referred to as the base cations.

In more acid soils other cations, mainly hydrogen (H^+) and aluminium (Al^{3+}) are more prevalent and when adding these to the base cations the measurement is referred to as the Effective CEC (ECEC).

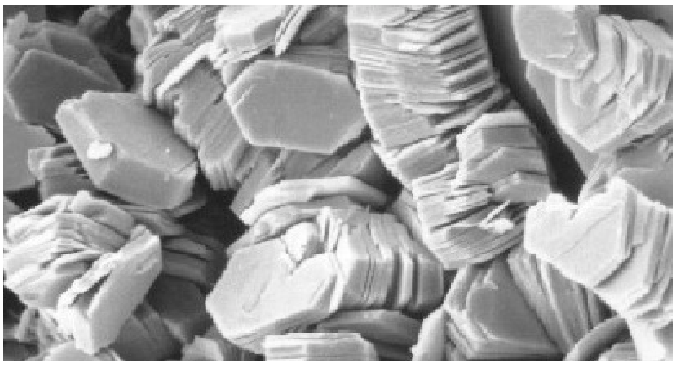

Figure 1: Electron microscope image of kaolinite clay layers

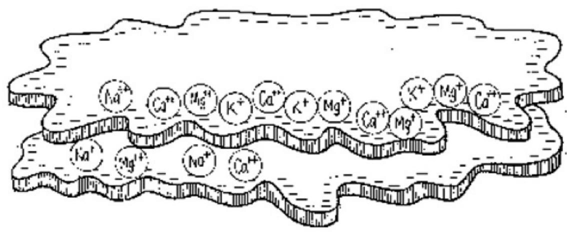

Figure 2: Positively charged cations are attracted to the negative charge on the surface of clay layers of soil colloids.

Clay soils with a high CEC (<20 meq/100g) are considered inherently more fertile than lighter sandy soil with low CEC (2-3 meq/100g).

Table 1: Ideal proportions of major cations of the CEC in heavy and light soils

Cation	Heavy Clay (meq/100g)	Light sandy (meq/100g)
Calcium	75	60
Magnesium	12	20
Potassium	3	8
Sodium	2	3

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Soil texture and soil CEC

Soil with a high clay content or high organic matter will generally have a high CEC. The structure of the clay layers and high surface area provide a greater capacity to attract and hold cations.

The CEC varies with the type of clay present. The chocolate montmorillonite clay soils have the highest CEC. Highly weathered clays such as kaolinite found in kraznozem soils have variable surface charge and are generally more acidic which has the effect of lowering the CEC.

Sand particles are inert and the absence of electrical charge limits the capacity to exchange cations. The only option to improve CEC in sandy soil is with the addition of organic matter. Organic matter has a very high CEC, potentially ranging from 250-400 meq/100g.

Table 2: Likely range of CEC levels for some local soil types with low and high levels of soil organic matter.

Soil	Low OM ($cmol^+/kg$)	High OM ($cmol^+/kg$)
Kraznozem	6	20
Chocolate	10	40
Podzolic	3	10
Sand	0.5	5

The CEC is a characteristic of soil not easily changed with management

Measurement of CEC

Cation Exchange Capacity is measured on the fine particle fraction of soil, particles <2mm diameter. The total CEC is the sum of the measure of the exchangeable cations in meq/100g OR cmol+/kg. The higher the CEC the greater the capacity of that soil to hold nutrients.

The balance of cations for a given soil may be more important than the amount of each element present. The ideal proportions of cations for different soil types are provided in Table 1.

The Ca:Mg ratio is most important. In heavy clay soils a Ca:Mg ratio of 6:1 is considered ideal and in sandy soil a 3:1 ratio is acceptable.

Remember

1 meq/100g = 1 cmo+l/kg

The CEC of a soil is the sum of each cation measured in meq/100g. It is not valid to add measures of other units to calculate CEC. Often soil tests only report cation values in mg/kg (or ppm and 1 mg/kg = 1 ppm). In this case to convert meq/100g (or cmol+/kg) to mg/kg the following conversion factors apply;

Calcium (Ca)	1 meq/100g = 200 mg/kg
Magnesium (Mg)	1 meq/100g = 122 mg/kg
Potassium (K)	1 meq/100g = 390 mg/kg
Sodium (Na)	1 meq/100g = 230 mg/kg
Aluminium (Al)	1 meq/100g = 90 mg/kg
Hydrogen (H)	1 meq/100g = 10 mg/kg

To convert mg/kg to kg/ha multiply by 2.24. An example calculation is provided in Table 3.

Table 3: Example conversion calculations from mg/kg (from a local soil test) to meq/100g to kg/ha for the base cations

Cation	mg/kg (A)	ConvFac (B)	Meg/100g (A/B)	kg/ha (Ax2.24)
Ca^{2+}	582	200	2.91	1304
Mg^{2+}	168	122	1.38	376
K^+	59	390	0.15	132
Na^+	27	230	0.12	59
Total CEC 4.56				

Note:- To calculate ECEC include Al and H in the calculation

To then express each of the exchangeable cations as a percentage of the CEC divide the value of each cation in meq/100g by the total CEC and convert to a percentage. An example of the process using the values from Table 3 is provided in Table 4.

Table 4: Example calculation of the exchangeable cations as a percentage of the Total CEC (figures from Table 3).

Cation	mg/kg (A)	Meg/100g (B)	% CEC (B/C) x 100)
Ca^{2+}	582	2.91	63.8
Mg^{2+}	168	1.38	30.2
K^+	59	0.15	3.3
Na^+	27	0.12	2.6
Total CEC (C) 4.56			

In the example above the key ratios are;

Ca:Mg ratio	= 63.8 / 30.2	= 2.1:1	(Ideal > 3:1)
Mg:K ratio	= 30.2 / 3.3	= 9.2:1	(Ideal 2-6:1)
K:Na ratio	= 3.3 / 2.6	= 1.3:1	(Ideal 4-5:1)

The ratios of exchangeable cations can provide important indicators of the structural stability of clay soils. The higher the Ca:Mg ratio and lower the Na % the more likely the soil will be a self mulching clay. Self mulching clays will have a Ca:Mg ratio of at least 2 to 4:1 and Na less than 3%. Clay soils with a low Ca:Mg ratio tend to have poor structure. Where it is less than 2:1 it is also more likely to disperse.

Dispersion characteristics of clay soils are covered in more detail in Factsheet 9 of this series.

The exchangeable sodium percentage (ESP) gives an indication of the potential for a clay soil to disperse. In the example in Table 4 the ESP is 2.6. Where the ESP is greater than 5 a clay soil will be more prone to dispersion on wetting, particularly if salinity (EC) is low.

Order of attraction of cations

Cations are of various sizes and have different positive charge attached. The greater the positive charge the more tightly bound the cation will be to the negatively charged soil colloid. Aluminium, with 3 positive charges is held more tightly than calcium and magnesium which both have 2 +ve charges and are held more tightly than the single charged potassium, sodium and hydrogen.

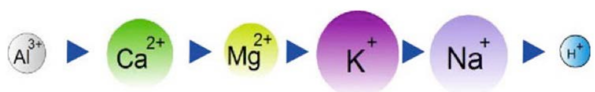

Figure 3: Order of strength of attraction by cations.

The relative strength of the electrical attraction of these positively charged cations and the strength of the colloids negative charge contribute to the soils cation exchange capacity. As these elements move from the colloid to the soil solution these cations are referred to as exchangeable.

CEC and acidity

In the strongly weathered clays typical of many Northern Rivers soils these clays can have variable negative charges on their surface. Soil fertility declines as aluminium and hydrogen bind with more of these negative charged sites decreasing the CEC. As the pH increases the number of negative charges on the soil colloid increases and can be occupied by the more desirable base cations.

Exchangeable cations

The term 'exchangeable' associated with cations describes the ability of cations to change their location in the soil. To exchange from their attachment with the negatively charged clay layers or organic matter on the soil colloid to the soil solution. The following figures illustrate the relative difference between a more fertile clay soil with a high CEC and a lower fertility soil with fewer negative charges and lower CEC.

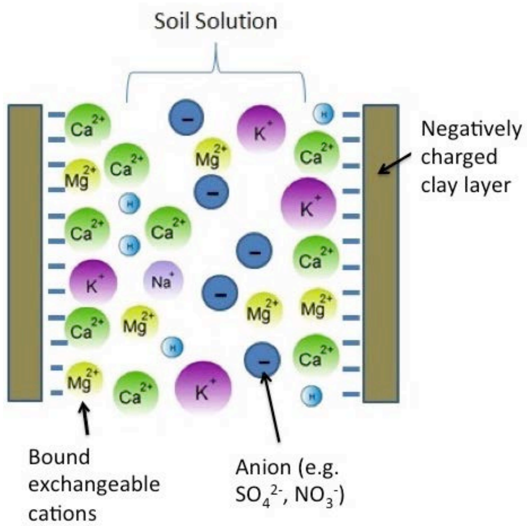

Figure 4: The relatively greater capacity of clay soils with a high CEC to hold nutrients.

Ion exchange in soil is a dynamic process. Cations in the soil solution (or exchangeable) may be taken up by plants or microbes or may potentially bind with anions to form compounds or reattach to soil colloids.

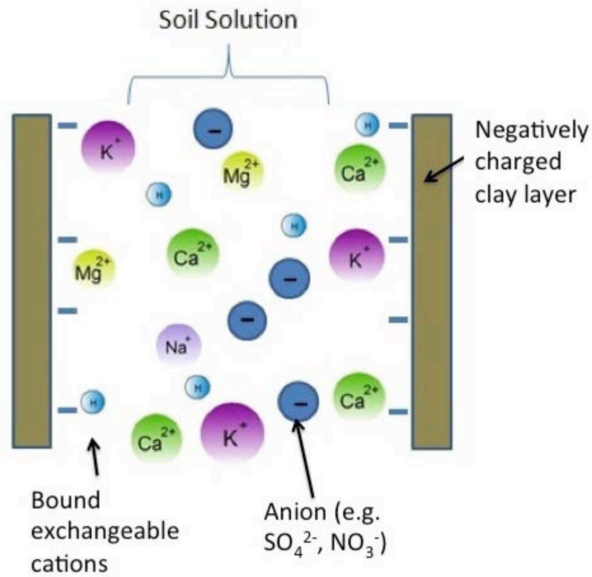

Figure 5: The relatively lower capacity of a soil with a low clay content and low CEC to hold nutrients.

Cation Exchange Capacity

Significance for soil health

Where the exchangeable cations are present in the correct ratio calcium is dominant and Ca:Mg is >2:1. Calcium has the effect of increasing the space between clay layers in the colloid. It also flocculates clay where small particles are broken up and held together in fewer, larger aggregates. This allows more air space in soil and allows better water infiltration. Where the Ca:Mg ratio is unbalanced and magnesium dominates, the opposite occurs in soil. The spaces between clay layers is reduced resulting in limited air space and soil water infiltration potential.

The correct Ca:Mg balance also favours microbial activity and plant nutrient uptake since calcium is an important carrier of nutrients both in soil and plant tissue.

The exchangeable character of cations means that while the exchange capacity (CEC) is relatively stable the composition, relative proportion, percentage of the different cations occupying sites on the colloid can be altered. Where the magnesium % is in excess the addition of calcium can displace magnesium ions from the colloid.

Similarly sodium can be displaced by calcium. The sodium is ionised in the soil solution and flushed or drained in soil water. This is essentially the process of leaching. Where soil has a low CEC and high sodium a large amount of the cations present are in the soil solution, not bound to soil particles. These ions are susceptible to leaching. Soils with high CEC have fewer cations in the soil solution and are less susceptible to nutrient loss by leaching.

The CEC of a soil can only be improved in one of two ways. In acidic weathered soils the addition of lime will raise the pH by removing hydrogen ions. Alternatively, the addition of organic matter may increase the CEC. Deep rooted perennial pastures, green manure crops, addition of compost, mulch or manures are all effective management actions to increase soil organic matter.

This is the fourth of a series of 12 Factsheets which cover a range of topics regarding soil processes

Calculating lime requirement

The following describes an example of the process for calculation of the lime requirement to improve the soil condition with the aim to achieve Ca at 70% CEC.

Step 1 Determine the desired level of Ca

= CEC (from a soil test) x 400 x 70%

= 5.9 x 400 x 0.70

= 1,652 kg/ha = desired Ca level

If current level (from a soil test) = 1,432 kg/ha

Step 2 Calculate deficiency

Desired level – Current level = Deficiency

Deficiency = 1,652 – 1,432 = 220 kg/ha Ca

Step 3 Calculate Lime requirement

Lime as calcium carbonate = $CaCO3$

Lime = 40% calcium therefore

220 kg/ha Ca ÷ 0.40 % Ca in lime

Lime required = 550 kg lime/ha

Notes:

- the ideal proportion of Ca of the CEC will depend on your soil type
- on heavy clay soils with low levels of calcium it may not be economic to add lime
- the same process applies to the application of dolomite (16% Ca + 10% Mg) and gypsum (20% Ca + 16% S). Check the composition of the product you plan to apply in relation to other nutrient levels on your soil test.

More Information

This factsheet has been prepared by Judi Earl
Agricultural Information & Monitoring Services
Email: judi@aimsag.com.au Phone: 0409 151 969

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