CATION EXCHANGE CAPACITY & BASE SATURATION

This note explains how Cation Exchange Capacity (CEC) and Base Saturation can help assess soil fertility.

Hill Laboratories differs from some other testing laboratories in New Zealand, in that we include analysis of a soil's Cation Exchange Capacity and Base Saturation as part of our Basic Soil Analysis. We do this because we believe that it provides important additional information for assessing soil fertility.

Cations and Anions

Before explaining CEC, it is first necessary to provide a general explanation of the behaviour of nutrients in the soil. Plant nutrients usually exist as ions - that is, they carry an electrostatic charge. The positively charged nutrients are known as **cations**, and those with negative charges are known as **anions**.

The most important of these nutrients are:-

Cations (+)		Anions (-)	
Calcium	Ca^{2+}	Nitrate	NO_3^-
Magnesium	Mg^{2+}	Phosphate	$H_2PO_4^-$, HPO_4^{2-}
Potassium	K^+	Sulphate	SO_4^{2-}
Sodium	Na^+	Chloride	Cl^-
Hydrogen	H^+		
Aluminium	Al^{3+}		

(Not surprisingly, the interaction of anions with soil is markedly different to that of cations. This note is only concerned with cations, and does not discuss the behaviour of anions.)

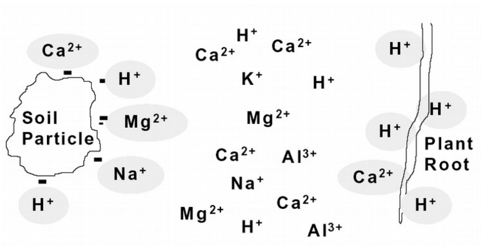
Exchangeable Cations – The Fraction Available to Plants

Cations can be bound to the soil to varying degrees. At one extreme, they may be an integral part of the soil, strongly bound to silica and essentially unavailable to growing plants. At the other extreme, they may be fully soluble – not interacting with the soil to any significant extent.

Between these two extremes are the **exchangeable cations,** which are weakly bound to soil particles. Soil particles carry net negative electrostatic charges as a result of the processes of soil weathering, and organic decomposition. These sites of negative charge are most predominant in the humus fraction of the soil, and on the edges of clay particles. They are 'neutralised' by the weak bonds that they form with the positively charged exchangeable cations. The bonds between soil particles and exchangeable cations are not permanent, and are continually broken and reformed, as the cations move within the water surrounding soil particles. The bonding of these cations largely prevents their loss by leaching, but is not so strong that plants cannot extract them from the soil. In fact, plant roots absorb exchangeable cations by 'swapping' them for hydrogen cations (H^+).

What Is Cation Exchange Capacity?

The **cation exchange capacity** of a soil is a measurement of its ability to bind or hold exchangeable cations. In other words, it is a measure of the number of negatively-charged binding sites in the soil.



Cation Exchange Capacity Helps to Characterise Soils

The cation exchange capacity helps characterise the soil type under consideration. For example, because organic matter in the soil is a major source of negative electrostatic sites there is a strong correlation between CEC values, and the amount of organic matter present in the soil.

Typical CEC values for different soils are as follows:-

Rating	CEC (me/100g)	Comment
Low	5 - 12	Soil very low in organic matter. Typical of sandy soils.
Medium	12 - 25	Pumice soils often in the range 13-18; lower fertility mineral soils in the range 15-25.
High	25 - 40	High fertility soils may be in the range 25-35. Also may have high clay content.
Very High	40 +	Values typically found in peat soils. Consolidated peats typically in range 40-65; raw peat may be as high as 100.

The CEC results provide advisers with an insight into the type of soil they are dealing with, as well as providing secondary information for use in formulating a fertiliser programme. **This can be especially important if they did not collect the samples themselves, and they are making their recommendation without seeing the property.**

Example

Consider the CEC values for these four soil samples:-

Sample Name	CEC (me/100 g)
Wet Gullies	54
Contoured Block	12
Back Hills	17
Front Flats	27

The CEC results indicate that the sample "Wet Gullies" contains a substantial amount of organic matter, and is very possibly a consolidated peat.

The "Contoured Block" has very little organic matter, suggesting that the top soil was not fully replaced (with implications for nutrient supply and the water holding properties of the soil.)

The remaining two samples have more normal CEC values, with the "Front Flats" being likely to be the more fertile soil of the two.

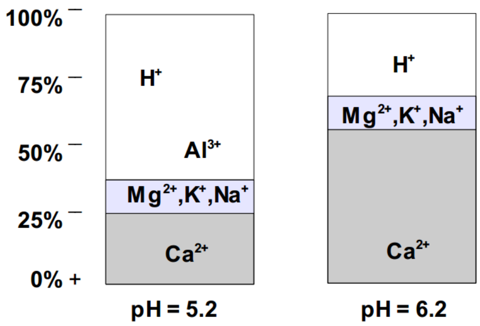
Means of Expression

CEC is expressed as millequivalents of positive charge per unit mass i.e. me/100g. Some texts use the term centimoles per kilogram, which is numerically equivalent i.e. 1 me/100g =1 cmol/kg.

What Is Total Base Saturation?

The exchangeable cations can be divided into two groups:

Bases	Cations which are alkaline (non-acid) and therefore raise the soil pH	Ca^{2+}, Mg^{2+}, K^+, Na^+
Acids	Cations which increase soil acidity and therefore lower pH	H^+, Al^{3+}



Every CEC binding site must have a cation bound to it, to maintain electroneutrality. The soil pH will be affected by whichever cations predominate on these exchange sites. The more base (non-acid) cations present, the more alkaline the soil (ie. the higher soil pH will be), whereas the more acid cations present, the more acidic the soil (ie. the lower the pH).

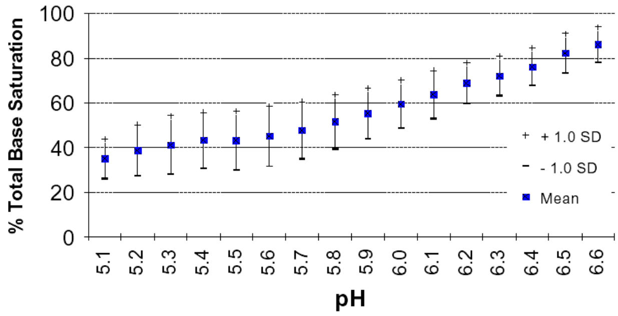
The **Total Base Saturation** is the fraction of the negative binding sites occupied by bases. For example, a base saturation level of 75% means that three out of every four sites is occupied by basic cations. (The remaining 25% of the sites must therefore be occupied by acid cations). Total Base Saturation is simply calculated by summing together the levels of calcium, magnesium, potassium, and sodium found in the soil; then expressing this sum as a percentage of the CEC value.

$$\text{Total Base Saturation} = \frac{Ca + Mg + K + Na}{CEC}$$

Is Lime Required?

Most pastoral and horticultural crops prefer neutral to slightly acid soil conditions; and it is often necessary to raise soil pH levels (when they are too acidic), by applying lime.

There is a strong correlation between total base saturation and soil pH. The next graph shows the mean values and standard deviation of total base saturation versus pH for a sample of 7,500 pasture soils processed by this lab.



Total base saturation therefore gives a **second perspective** on the soil's acidity or alkalinity, and on the need for liming.

***Note**: Usually the base saturation level and the pH value will indicate a very similar soil acidity level. Sometimes, there will be a discrepancy between the two. Because the Base Saturation result involves a more rigorous and complete extraction of the soil than the pH test, it is the more reliable test of the two to consider when making liming decisions.*

Knowing the CEC and total base saturation will also yield a lime requirement, by calculating the amount of calcium necessary to achieve a target total base saturation (usually 75%). The calcium is expressed as kg/Ha Calcium Carbonate, assuming 90% purity.

As the pH tends to show more seasonal variation than total base saturation, this calculation is regarded as being a more reliable lime requirement test than one based on pH alone.

Individual Base Saturation Levels

Individual base saturations can also be used to gauge the balance of cations within the soil. For a soil where the pH should be in the range 5.8 – 6.5, the following base saturation levels can be regarded as being 'ideal'.

Potassium	2% - 5%
Calcium	50% - 75%
Magnesium	5% - 15%
Sodium	1% - 2%

As with all soil test interpretations, however, attempting to achieve the ideal level may not be economic or practical given the quite wide ranges described. For different crops, on varying soil types, these 'ideal' levels may differ. (For example, 30% – 50% Ca for a peat soil is more appropriate than the range 50% – 75%).

For high value crops, where the cost of fertiliser is not a major concern, then working towards the optimum individual base saturation levels does have some merit.

Alternate Methods for Measuring CEC

Methods for CEC use extractants that are either ***buffered*** (usually at pH 7 using ammonium as the exchanger cation, although overseas labs may also use barium as the exchanger cation at pH 8.2) or ***unbuffered*** (field pH).

- Buffer CEC methods provide a measure of the **potential** CEC of a soil at that pre-defined pH. When a soil is extracted at an elevated pH (e.g. 7.0), the higher pH 'induces' some weakly acidic compounds to dissociate and the liberated H+ ions are measured as exchangeable (or extractable) acidity. This provides an insight into the reserves of acidity in the soil, and it is this 'latent acidity' that is neutralised when lime is applied. The CEC value by this method will remain relatively constant irrespective of liming history, although the relative % Base Saturation (and pH) will increase with liming (as shown previously diagrammatically).
- Unbuffered methods allow the exchange to take place at the actual pH of the soil, and are often referred to as the field pH CEC or the Effective Cation Exchange Capacity (ECEC). The ECEC will usually be a lower value than a buffered CEC value, as it does not include the latent acidity described above. ECEC will therefore always have 100% Base Saturation (or the sum of the exchangeable bases Ca, Mg, K and Na), unless the soil pH is less than 5.5 (when true exchangeable acidity can exist in the form of aluminium ions). When lime is applied to soils, the carbonate will neutralise some of the latent acidity and the liberated calcium ion will bind to the newly created exchange site. This will result in an increase in the ECEC, but the % Total Base Saturation remains unchanged at 100%. Therefore, the % Base Saturation concept with ECEC is of little value as an agronomic tool.

Some overseas labs use extrapolation equations from the measured soil pH(water) to estimate the % Base Saturation at pH 7, then back-calculate the residual acidity that way. These methods are probably suitable for the soils where they were developed, but tend to underestimate the residual acidity (and therefore CEC) in New Zealand soils.

Conclusions

CEC and base saturation data is particularly useful in highlighting differences in soil fertility between samples from the same farm; and in determining lime requirements.

As a number of different methods are used to measure CEC, it is very important to only compare CEC (and % Base Saturation) values for soils where the same laboratory method has been used. Hill Laboratories believe the buffered (pH7) CEC method provides the most useful information for charactersing the fertility and nature of soils. As well, it is more cost effective to only offer a single method to report individual cations and CEC (from the same ammonium acetate extractant), and these cation results can be used to populate the soil test fields in Overseer for nutrient budgteing purposes. Other methods of measuring cations and CEC do not provide any additional agronomic value to farmers or advisors.