



BASE SATURATION RATIOS – WHY THEY ARE NONSENSE!

The major soil testing laboratories including ARL, NZLabs and RJ Hills, report their soil test results for Calcium (Ca), Magnesium (Mg), Potassium (K) as Base Saturation Ratios. The amount of soil Ca, Mg or K is reported as the proportion (%) of the Cation Exchange Capacity (CEC) of the soil. On your soil test report they will likely be expressed as the Base Saturation percentage (BS%). Some fertiliser companies make prominent use of these results when formulating their fertiliser recommendations. What do these numbers mean and should they be relied upon?

[The positively charged nutrients Ca, Mg, K and Na are called cations, pronounced cat-ions, and are sometimes referred to as “Bases”. The ability of the soil to retain and store these ‘basic cations’ is called the Cation Exchange Capacity or CEC. The BS% is the proportion of the CEC taken up by a given cation. Thus the Ca BS% = Amount of Ca/CEC x 100. Note that Na, although a base cation, is not an essential plant nutrient and hence was not considered in this context].

Nutrient Ratios or Nutrient Quantity?

In the mid 1930s, two competing theories of soil fertility & plant nutrition emerged. One view, advocated in particular by Professor Albrecht, was that the ratio of the nutrients Ca, Mg, K was important, in terms of soil quality, plant health and plant growth. This is referred to as the **Ratio Theory**. The competing theory holds that the ratios of the nutrients, Ca, Mg and K are irrelevant. What is important is that a minimum quantity of each nutrient is present. This is referred to as the **Quantity Theory**.

Many trials on many crops have been conducted over the intervening years. Some example results are given in Figure 1 and show that the ratio of Ca/Mg in the soil has very little effect on crop yield. The same conclusion applies also to the ratios Ca/K and Mg/K.

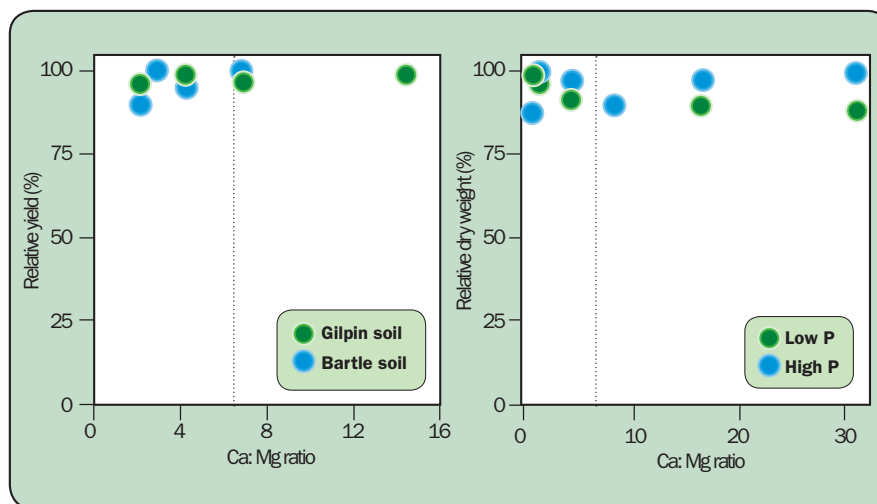


Figure 1: The effect of the soil Ca/Mg ratio in the yield of millet (on 2 soils) and on the yield of lucerne (at 2 levels of P) (from Kopitte and Menzies 2007).

Instead of expressing the ratio as simply the amount of Ca relative to the amount of Mg, the more normal procedure is to express the results as the amount of Ca, Mg or K as a proportion of the CEC. A soil was regarded as “ideal” if the Ca BS% was in the range 65–85%, Mg BS%, 6–12%, and K, 2–5%. Some results are shown in Figure 2.

[Expressed as simple ratios the ideal soil would have a ratio of Ca: Mg of about 7:1 (see Figure 1); Mg/K of 3.3:1 and Ca:K of 23:1].

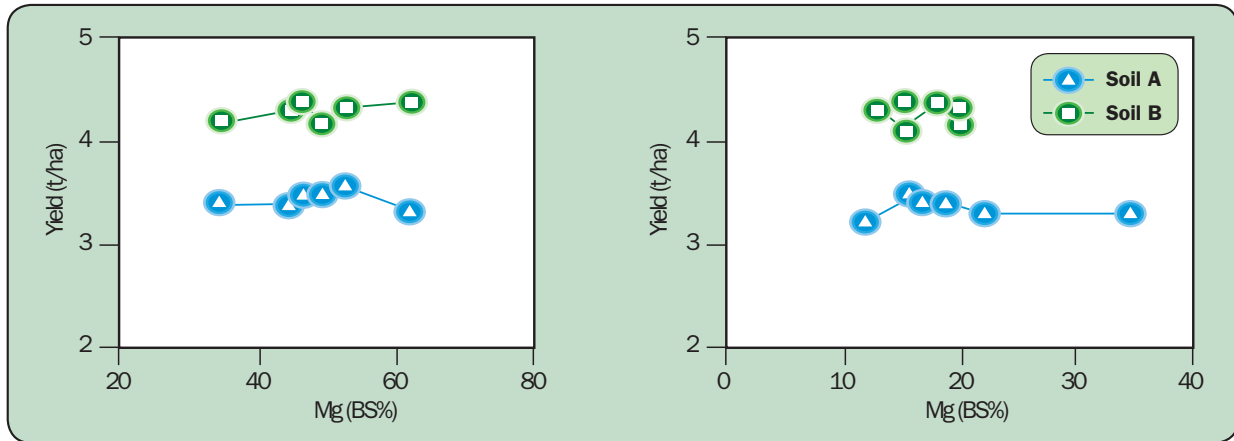


Figure 2: the Effect of Ca (BS%) and Mg (BS%) on the yield of lucerne on two soils (from Schulte and Keeling 1989).

Once again these results suggest that the BS% has little effect on plant yield. These are just a few of many examples and in their 1984 review of the literature, two American scientists summed it all up: *“The only conclusion one can reach from the results of growth chamber and field and the other studies is that there is no ideal base cation saturation or range of saturations where crop yield is maximised.”*

This conclusion alone should be enough to ensure that our New Zealand soil testing laboratories desist from producing these bogus results. But the story gets worse. There are other problems with this methodology.

[Important clarification: While changes in nutrient ratios have little effect on plant growth altering the amount of one nutrient relative to another can, in some circumstances, change concentrations of nutrients in the plant. For example, it is known that applying a heap of Ca (as in liming) can decrease the plant uptake of Mg and exacerbate the incidence of hypomagnesaemia (see Fertiliser Review: Special Edition. Liming and Soil Acidity). So too, excessive applications of potassium may decrease pasture Mg and Ca. (Fertiliser Review 16. Potassium: Malignant of Maligned?). But these effects are just as readily explained as due to an increase in the **quantity** of one nutrient without the need to invoke the **Ratio Theory** – see also Figure 6].

Defining soil pH

The BS% figures on your soil test report are based on measuring the CEC at pH 7. The reason for this is that it was believed in the early 1900s that the ideal soil had a pH of 7. There was no agronomic reason for this – it was simply ‘taken as read’ that a neutral soil (i.e. neither acid nor alkaline) was best for plants. For this reason the soil scientists at the time adopted the practice of measuring the CEC of the soil at pH 7. This is still the case today in most soil testing laboratories but it is no longer tenable given our current understanding of soil science.

[For a detailed discussion on the development of the concept and use of soil pH see Edmeades and Ridley 2003. Using Lime to Ameliorate Topsoil and Subsoil Acidity. [In] Handbook of Soil Acidity. Rengel Z (ed) Marcel Dekker 2003].

The modern understanding of soil pH is based on the concept of ‘fitness for purpose’. A few examples will be enlightening. We now know that plants cope differently with soil acidity. Lucerne (a legume) is very sensitive to soil acidity – it grows best at about 6.5. The optimal pH for our common forage legumes (white and red clover) is about 5.8 to 6.0. In contrast Lotus Major (another legume) thrives in very acid soil (pH 5.0). Similarly the “weed grasses” like browntop and paspalum out-compete ryegrasses in acid soils because they have inbuilt tolerance to acidity.

Soils also vary greatly in their chemistry. This means that at a given soil pH they are not equally acidic to plants. The best local example is peat. Pasture production (clover and ryegrass) is optimized on peat soils at pH 5.0–5.5 but a soil pH of about 5.8 to 6.0 is required on mineral soils. The reason is that peat soils contain less of the ‘nasties’ like aluminium (Al), which at low pH can be toxic to plants.

So, “fitness for purpose” in terms of soil pH, is a matter of matching the crop to the soil, or, matching the soil to fit the crop. Growing blueberries (very acid tolerant) on raw peat is a good match. Liming soils to pH 6.5 to grow lucerne is also a good match. What all this means is that there is no such thing as an “ideal soil pH” – it all depends on the soil and the intended crop and most certainly pH 7 is not ideal for most crops. This has large implications for the measurement of CEC and hence on the calculated BS%’s as we are about to learn.

Measuring CEC

A major revolution in our thinking took place in the 1970’s and 80’s. It was realized by scientists all over the world that soils have, to use the technical term, variable charge. What this means is that, as the soil pH increases, so to does the CEC.

Figure 3 shows the CEC of a group of New Zealand soils measured at pH 7 and at the pH of the soil in the field (which is always less than pH 7).

In all cases the CEC at pH 7 is greater than the CEC measured at the field pH. For this group of soils the average CEC (pH 7) is 26 compared to 12 at CEC (field pH) approximately a 2 fold difference and as has been noted, the BS% is calculated as the percentage of the CEC occupied by either, Ca, Mg or K. Thus, for this set of soils, the Ca BS%'s (based on CEC at pH 7) are about half that of the Ca BS%'s (based on the CEC at field pH) (i.e. 34% versus 67%) (Figure 4).

If we accepted the Ratio Theory and the criteria that an ideal soil is one with Ca (BS%) of 65–85%, we would conclude that all of these soils are Ca deficient and would recommend some form of Ca, most likely lime. This would be bad advice because the soil pH levels and the soil Ca levels of these soils do not indicate the need for either increasing the soil pH or adding Ca.

Maybe this set of soils is unusual. Figure 5 shows the relationship between Ca (BS%) (based on CEC at pH 7) and the Ca (BS%) (CEC at the field pH indicated in the graph as the effective CEC or ECEC) for a set of 97 New Zealand top soils, collected to represent all the major soil groups. Once again it is clear that the current standard method used to calculate Ca (BS%) underestimates the 'true' Ca (BS%). About 50% of these soils would have been diagnosed as Ca deficient assuming the ideal Ca (BS%) of 70% even though they have appropriate soil pH and soil Ca levels.

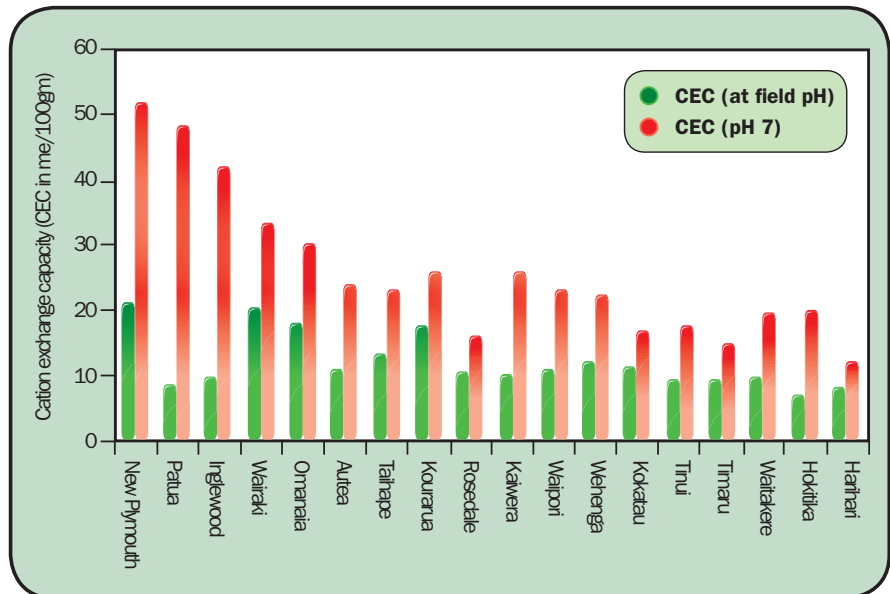


Figure 3: The soil cation exchange capacity (CEC) of a group of soils measure at pH 7 and at the field pH.

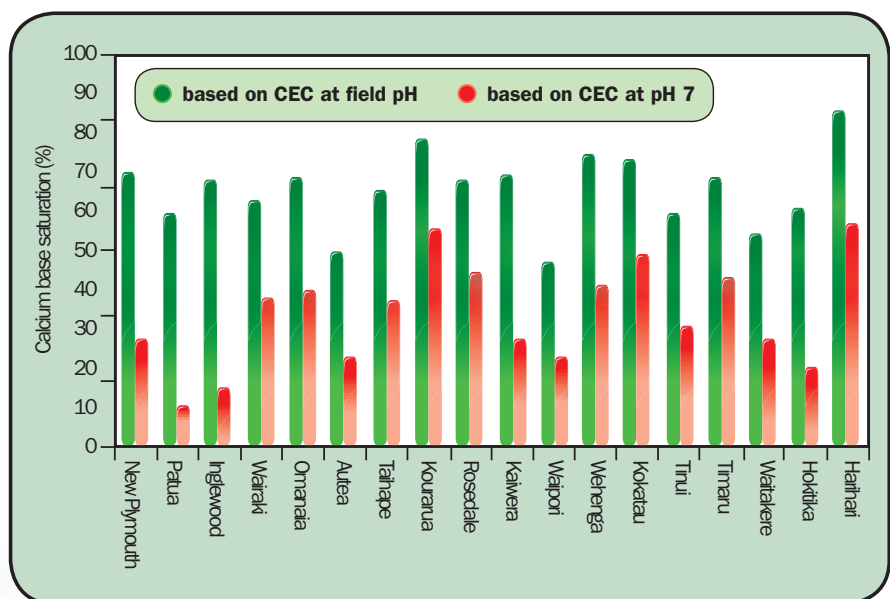


Figure 4: The calcium (Ca) base saturation ratio (BS%) of a group of soils based on the CEC at pH 7 and the field pH.



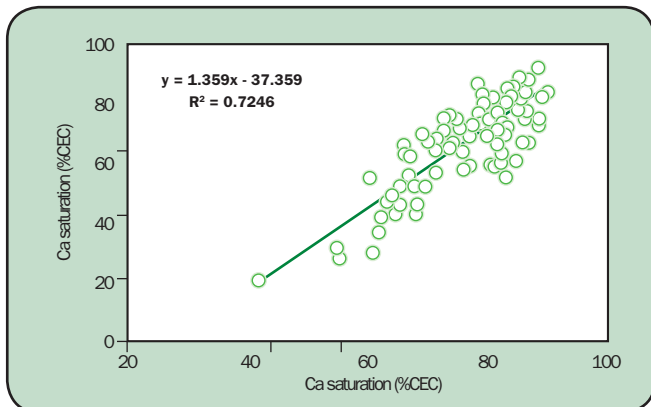


Figure 5: The relationship between Ca saturation (% CEC measured at pH 7) and Ca saturation (% CEC at field pH i.e. the effective CEC of ECEC) for a set of 97 New Zealand topsoils.

It should be clear that the standard method used to calculate BS%’s underestimates the “real” BS% and as a consequence will result in excessive applications of Ca in particular and also Mg and to a lesser extent K. This conclusion is supported by research which shows that the Ratio Theory when used as a basis for making fertiliser recommendations, results in the use of some nutrients which are in fact not required.

In other words it increases costs for no economic gain¹.

[¹An example of this can be found in Fertiliser Review No 4 which relates to the use of the Ratio Theory as applied by Quantum Laboratory of Waipukurau. Superior Minerals Ltd who operate out of Dunedin also offered bad advice to a farmer based on the Ratio Theory – see the Court Case: Superior Minerals Ltd v Lindsay Watts, 2005, Dunedin].

TAKE HOME MESSAGE

The jury is well and truly out on this issue. Albrecht’s Ratio Theory is flawed for the following reasons:

1. There is no such thing as an ideal ratio of Ca, Mg and K either in terms of plant growth or in terms of soil quality.
2. The concepts of soil pH and soil acidity have changed over time. The idea that the ideal pH is 7.0 is no longer tenable.
3. Calculating BS% using the CEC measured at pH 7 grossly underestimates the true BS%.
4. Basing fertiliser advice on the Ratio Theory results in misleading advice.

Postscript

The most recent review of the literature² on this topic concludes:

“The data do not support the claims of the BCSR [the Base Cation Saturation Ratio theory], and continued promotion of the BCSR will result in inefficient use of resources in agriculture and horticulture.”

[²Kopittke, P. M and Menzies, N.W. 2007: A Review of the Use of Basic Cation Saturation Ratio and the “Ideal” Soil. Soil Science Society of America. 71 (2) March–April 2007, 259–265].

The last point is interesting: not only is the theory flawed but its continuing use results in incorrect fertiliser advice – it introduces inefficiencies. So why does it persist?

It is understandable that the Ratio Theory is so enthusiastically adopted by those who are selling Ca-based products (e.g. dicalcic lime, fine lime, slurry lime, flour lime). The Ratio Theory is simply magic because almost invariably it will say the soil Ca level is low and limiting production and hence my new magical Ca product is the ideal solution!

Also this theory is used by the “quack brigade” who want a point of difference in the market place; something that looks new and exciting relative to the main-stream. It especially suits those given to conspiracy theories, as in: “Science has overlooked this great volume of wonderful research – the world has gone mad – I am the only one who knows the truth etc.....”

Finally, and most worryingly to me, the Base Saturation Ratio results are provided by soil testing laboratories whose owners should know better. In discussing this serious matter with Dr Roger Hill of Hill Laboratories³ I was told that they continue to provide these Base Saturation Ratios results because their clients request them. I would have thought that Hill Laboratories, and the others like them, have an obligation to tell their clients that these tests have no interpretive value and can result in misleading advice.

[³See also my Open Letter to Dr Hill in Fertiliser Review No 25].



THE QUANTITY THEORY

There is an extensive body of research, both local and international, which shows that plant growth is driven not by the **ratio** of nutrients but by the **quantity** of each nutrient. Figure 6 shows the generalized relationship between pasture growth and soil Mg for New Zealand soils. No further pasture growth occurs once the minimum quantity of Mg is present in the soil (about 8–10 Mg units). Note also that the pasture Mg concentration continues to increase with increasing quantities of soil Mg.

The same also applies to soil K (Figure 7). Pasture production increases with increasing soil K up to about 8–10 units. Once the minimum quantity of soil K is reached there are no further increases in pasture growth.

These examples show that the **Quantity Theory** works – plant growth, in this case clover-based pasture production, increases until a minimum quantity of a given nutrient is present, thereafter increasing amounts of the nutrient have no further effect on production.

It is for this reason that the **Quantity Theory** has been adopted world-wide, and in New Zealand scientists have invested much time, effort and taxpayers money⁴ to define the *production functions* which relate pasture production to the quantities of soil P, K, Sulphate S, Organic S and Mg, and of course soil acidity (pH), across the range of soils in New Zealand. This is what is meant by calibrating the soil test and the extent to which the various soil tests we use in New Zealand have been calibrated is shown in Table 1.

[⁴The database that was set up by the then MAF Soil Scientists at Ruakura in the early 1990s, summarising all the field trials conducted around New Zealand over the period 1940 to 1990 consists of 2255 P trials, 1100 S trials, 804 K trials, 48 Mg trials and 127 lime trials. Assuming current costs this represents an investment of about \$60m].

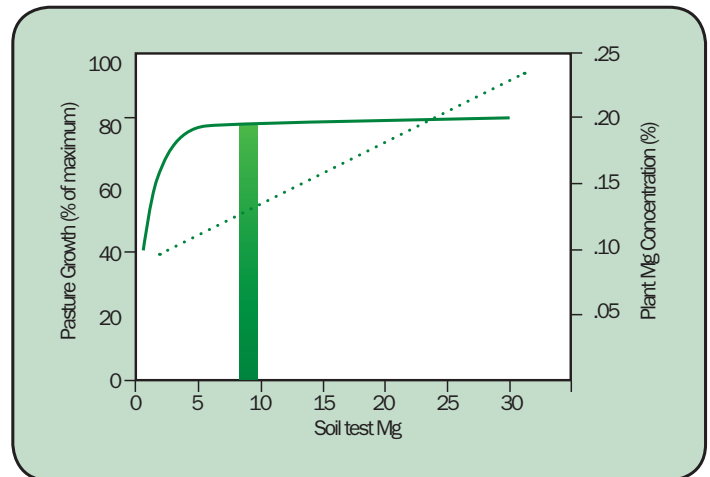


Figure 6: The generalized relationship between pasture production and soil Mg and pasture Mg concentration (From Morton and Roberts 2009).

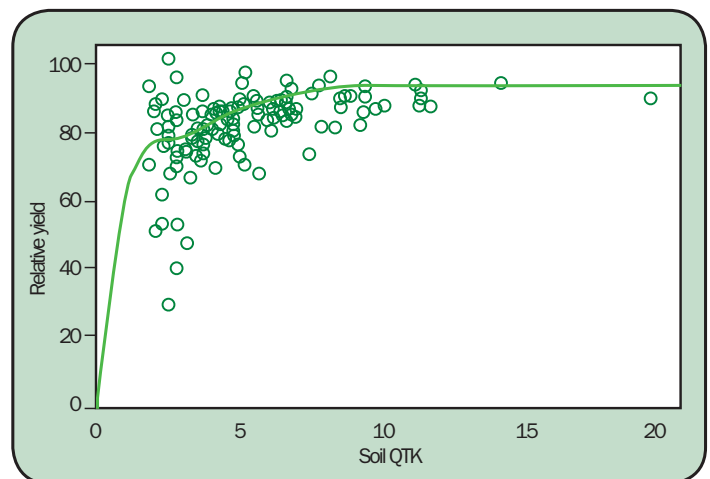


Figure 7: Relationship between pasture production and soil K (From Edmeades et al 2009).



Soil test	Extent of calibration
pH	widely
Olsen P	widely
Quick test K	widely
Quick test Mg	widely
Sulphate S	widely
Organic S	widely
Quick test Ca	limited ¹
Quick test Na	limited ²
Available Al	limited ³
Available N	limited ⁴
Resin P	limited ⁵
Available Co	limited ⁶

Notes 1) Calcium deficiency in New Zealand is unknown because our soils are young (not highly leached) and because traditionally super (20% Ca) and lime (40% Ca) have been used.
 2) Sodium (Na) is not required for plant growth.
 3) Aluminium toxicity only occurs on soil with pH less than 5.5.
 4) Only used on cropping soils.
 5) Only used where RPR is applied and even then difficult to interpret without a knowledge of the type and particle size of the RPR remaining in the soil.
 6) A better option is to have a mixed-pasture sample analysed for Animal Health Profile which includes Co, Se, Cu and Mo.

Table 1: Common soil tests used in New Zealand and the extent of their calibration.

Please note that unless a soil test has been widely calibrated it is of very little diagnostic value.



BALANCED NUTRITION

One of the alluring features of the **Ratio Theory** is that it sounds good because it refers to nutrient BALANCE. This appeals – it sounds more benign, more natural and somehow less excessive. It is of course an illusion as has been discussed.

So is there such a thing as balanced soil and plant nutrition? Is it sensible to strive for “balanced soil fertility?” The answer is most definitely **YES**.

Pastures (and other plants are no different) require 16 nutrients for optimal growth and to complete their normal life cycle (Table 2). As discussed elsewhere (see Fertiliser Review 16), some come from the air (carbon and nitrogen – the latter for legumes only), some come from the water (hydrogen and oxygen) and the others must be supplied via the soil (N (grasses only), P, K, S, Ca, Mg, Cu, B, Fe, Mn, Mo and Zn).

Major nutrients	Minor nutrients
Carbon (C)	Copper (Cu)
Hydrogen (H)	Zinc (Zn)
Oxygen (O)	Boron (B)
Nitrogen (N)	Manganese (Mn)
Phosphorus (P)	Iron (Fe)
Sulphur (S)	Molybdenum (Mo)
Potassium (K)	Chlorine (Cl)
Calcium (Ca)	
Magnesium (Mg)	

Table 2: The 16 essential plant nutrients and their chemical symbols.

Of these, Ca, Mg, (except pumice soils), Cu (except on peat soils), B, Fe, Mn and Mo (except sedimentary soils) are abundant in most New Zealand soils. No need to add them as fertiliser. That leaves: P, K, S, Mg (pumice soil), Mo (sedimentary soils). These are the nutrients we typically add as fertiliser. There are three others that may be added to the fertiliser not because the pasture needs them but because they are needed by the animal. These are Na, Co and Se.

So we can define a “**balanced soil**” as one which contains the minimum **quantity** of all these nutrients such that pasture growth and animal health is optimized. The qualification, “minimum” is important because there is no need to farm above the optimal nutrient levels – there is no economic gain and it means unnecessary enrichment of the waterways with nutrients.

How is the minimum quantity determined? For those nutrients which have adequately calibrated soil tests (i.e. P, K, S, Mg) sufficient fertiliser needs to be added to bring the soil test levels up to the optimal range.

There are some nutrients for which there are no calibrated soil test, such as Mo, Mn, Zn and Fe. For these nutrients, clover-only tests are required to check that they are adequate and/or not excessive for pasture, an in particular, clover production. And to make sure that the animal is getting sufficient Mg, Na, Cu, Co and Se and not excessive levels of possible ‘nasties’ like K, Mo and Mn, mixed-pasture samples are required.

Is this not too difficult, too costly or too academic? Not at all, we do it every day – it is essential for a science-based farming operation.



HILL LABORATORIES AGAIN

In Fertiliser Review 25 I published an open letter to Dr Roger Hill of Hill Laboratories. In that letter I was critical of the on-going introduction and use of soil tests which were not adequately calibrated. Specifically I mentioned the Resin test, the Mehlich Test and the use of Base Saturation Ratios.

Hill Laboratories have responded, albeit indirectly. In their Quarterly Newsletter (No. 12, December 2010) we find the statements:

“A recent publication claimed commercial soil testing laboratories should only offer soil tests that had been fully calibrated against field trials”.

and;

“The Resin test has been researched considerably with conclusions confirming its usefulness in such circumstances [i.e. where RPR is used].”

For the record, the Resin test has been calibrated on 6 sites (compare: Olsen P 2255 trials, Sulphur 1100 trials, QTK 804 trials, QT Mg 48 trials, soil pH 127 trial). Furthermore, it has only been calibrated against one type of RPR (Sechura) which is no longer available in New Zealand. Given that RPRs are different this means the Resin Test can only be interpreted by a) assuming that the RPR that has been used is the same as Sechura, and b), even then you need to know the particle size distribution of the remaining RPR residues. Hardly what I would call *researched considerably*.

I suggest that Hill Laboratories put a caveat on their Resin P results as follows:

The Resin test has not been widely calibrated in New Zealand and can only be meaningfully interpreted where Sechura RPR has been used and the particle size of the residual RPR in the soil is known.

The Hill Laboratory Newsletter justifies their use of the Mehlich 3 test on the grounds that it is a multi-element extractant, meaning that from one extract from a given soil, many nutrients (major and minor) can be measured. This is true, and it is very convenient for the laboratory, because it greatly reduces the processing time. BUT what you are not told is that the results from this test are virtually meaningless agronomically – the numbers on your soil test report do not necessarily relate to the plant availability of these nutrients in the field; In other words, they have very little agronomic and hence interpretive meaning.

The Newsletter also explains that the Mehlich 3 test has been offered at Hill Laboratories for some years now *aimed largely at avocado growers in conjunction with their leaf tests*. If this is so then why is this test offered to pastoral farmers?

I suggest that Hill Laboratories put a caveat on their Mehlich 3 results as follows:

We advise that the Mehlich 3 results given in this report have not been calibrated in New Zealand and should only be used by avocado growers in conjunction with their leaf tests.

Hill Laboratory's Newsletter is more forthcoming in talking about the Base Saturation (BS%) approach. It says: *“there are many scientific references relating to the subject it is critical to have an understanding of how the BS% has been calculated i.e. the CEC method used.”* It goes on to conclude. *“It does provide useful second tier information however, particularly in situation of very high or low CEC soils e.g. golf greens.”*

What does this mean? Yes there are many scientific references related to the BS% approach. Most conclude it does not work and should not be used!

What is *“useful second tier information”*? I think it is time for Hill Laboratories to come clean on this one. I suggest the following caveat on all these results as follows:

Hill Laboratories advise great caution when using the BS% approach. There is much scientific research which shows that this approach is technically flawed and results in misleading fertiliser advice. It may be useful on golf greens.





CLIMATE CHANGE AND THE ETS

I am in the skeptic camp when it comes to the question of **dangerous human-induced global warming**. Although it is out of my normal field of expertise I have taken the time to get up to speed on the issue for several reasons. First, it is undoubtedly the most important contemporary science issue confronting civilization. Second, I have been writing about the dangers of commercializing and politicizing science for some time now and it has occurred to me on many occasions that a consequence of this dangerous path could be a major scam involving science. Given the “hockey stick” story and what has emerged from “climate-gate”, I believe the time and the issue is with us. And we have our own local example in NIWA-gate – the story of our official temperature record (see the paper referred to below).

Given the importance of this issue I have written a paper entitled “The Reasons Why I am a Climate Skeptic.” It has been critiqued by climate scientists on both sides of the debate and no-one has found fault with my reasoning and logic.

The paper is available at www.agknowledge.co.nz (Just log into the “Members” area – no cost – and an index will lead you to the paper). You will find much else besides, including my publications on the dangers of commercializing science and the full collection of my review papers on the nutrient requirements (P, K, S, Ca, Mg and Na) of New Zealand pastures.



THE PRICE OF INDEPENDENCE

Most farmers who call me for assistance with their pasture nutrition or fertiliser problems tell me that they do so because I am independent – I am not involved in selling fertiliser products and not aligned to any science institution. This role is analogous to that of a lawyer who is “called to silk”. Back in antiquity the Queen (or King) appointed senior lawyers to provide her (him) with advice, independent of commercial, institutional or political considerations. They became known as the Queen’s Councilors or QC’s. The tradition continues to this day.

One reason why lawyers and especially QC’s can command high fees is because they have a captured market – everybody must use the law. The market for independent science skills is very different – there is no law to say farmers must use science on their farm.

As an independent scientist I am reliant on farmers who value that independent science voice and are prepared to pay for it. So help me to help you make the best fertiliser decisions for your farm: doug.edmeades@agknowledge.co.nz or ph 07 834 0316 or visit the website www.agknowledge.co.nz.



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