HEALTHY SOIL, HEALTHY GRASS, HEALTHY STOCK - THE BALANCED APPROACH

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Abstract

Livestock performance is based largely on nutrition in terms of both quality and quantity. Part of the quality issue relates to the mineral content of the feed grown which is dictated primarily by the natural mineralogy of a given soil and historical fertiliser inputs. Within the framework of pastoral organic beef farming, there is the ability to alter the mineralogy of the soil so that the feed grown has the full range of macronutrients and micronutrients within the recognised optimum ranges for beef cattle. Because plant nutrient requirements differ to those of livestock the mineral levels found in pasture are commonly excessive to animal requirements for some elements such as potassium and sulphur, which themselves can impact on the bioavailability of other elements such as calcium and magnesium in the case of excessive potassium, and copper and selenium in the case of excessive sulphur. As few soils have all 17 essential elements required by both plants and animals in the right ratios, understanding and correcting the imbalances that occur at the soil level so that neither plant or animal productivity are compromised is a key tool available to organic beef producers. Trace element deficiencies can also be addressed through their inclusion in the organic fertiliser regime, and although often applied to the soil in inorganic forms, their uptake via the plant roots and subsequent translocation to the foliage in highly available organic complexes is the most natural way of providing grazing livestock with necessary minerals.

Key words: nutrition, minerals, soil, fertiliser, nutrients, elements.
1 Introduction

The old adage "You are what you eat", has a huge bearing not only on man and beast, but on all living entities including grassland swards. Much of the increase to grassland productivity has been brought about by the application of chemical fertilisers, yet for organic farmers, chemical fertilisers are generally outlawed in the standards of the various governing organic bodies.

The title of my paper emphasises the word 'healthy' which is a derivative of the word 'heal', which means to become well again, to be cured, or to be made sound again. It denotes a previous state of being unwell, sick and unhealthy, instead of vibrant and living to ones full potential. When it comes to examining soil health, many of our agricultural soils have become 'sick' through mismanagement and abuse over time and are in need of 'healing' to achieve their potential in terms of productivity. For the organic farming movement to achieve the goal of being able to feed a hungry world, methods must be employed which enhance both the productive value and health of the soil.

Soils vary considerably in their elemental make-up, depending largely on the parent material from which the soils are derived and the climatic environment that has dictated the amount of weathering and leaching that has occurred. However, over the past 100 years the human effect of soil management has had a huge impact on soil chemistry. There has been the depletion of organic matter through overuse of the plough and other forms of cultivation, plus the liberal applications of artificial nitrogen on many soils. There has also been the loss of topsoil and nutrient run-off as the result of bad management practices. On many intensively farmed areas we can also observe the build up of certain elements through excessive fertiliser inputs and conversely the loss of other elements through successive harvesting of nutrients that are sold off farm in plant and animal products, which are not being replaced.

When it comes to organic livestock farming, the health and welfare of stock is paramount for not just the public perception of organic farms, but also for economic viability. Nutrition plays a key role in animal health issues, in having both sufficient quantity of feed and having the correct type of feed. Grazing management of pastures will greatly affect the nutritive value of the feed in terms of energy, protein, fibre, sugars and carbohydrate content, and it can also affect the mineral content of pastures, with most elements diminishing on a percentage basis as the plants mature. The species composition of pastures can also greatly affect the above nutritive parameters of the feed, and plant species vary widely in their ability to extract different minerals from the soil. Another variable in the mineral content of pastures is seasonal differences caused by climatic changes, and although these effects are only minor, they need to also be considered.

Few soils provide an ideal balance of nutrients from which both plants and livestock will thrive to their potential without the addition of elements that are naturally deficient. Fertiliser applications to the soil are not only important for plant nutrition and increasing overall pasture productivity, but they can greatly influence the mineral content of the pastures, which will ultimately affect animal health and performance. Under conventional farming systems, fertiliser regimes tend to focus solely on plant productivity, and deficient elements are applied to either the soil or the crop. In the case of livestock, minerals are usually supplemented via the feed, drinking water, or as loose minerals for stock to lick, or they are given orally via drench, bolus, or capsule or can be given intravenously. If any major, minor or trace element is below the minimum desired level, then this will impact negatively on the productive potential of the farm. Under many organic systems, direct supplementation of minerals to livestock is not allowed, and the preferred method of supplementation is in the natural mineral balance of the feed grown, which in this case is pasture.

This paper will focus on some of the issues of soil chemistry and its relationship with temperate pasture productivity and mineral nutrition of beef cattle within an organic framework.

2 DISCUSSION

There are 16 essential elements for pasture plants and 17 essential elements for livestock. With the exception of carbon (C), oxygen (O), and hydrogen (H), which plants mainly harvest from the atmosphere, the other elements must all be extracted from the soil by the plant roots, and translocated into the foliage. These elements the plants take up from the soil are usually in inorganic forms, extracted from off the clay colloid or organic matter in exchange for hydrogen or hydroxyl ions. These elements are then translocated from the plant roots into the foliage where they occur in highly available organic
complexes for the grazing animal to absorb in the digestive process. If any of these essential elements occurring in inorganic forms in the soil are deficient or out of balance so that plant productivity is compromised, then the soil shortage is also likely to impede animal productivity. For the purposes of this discussion we will consider each element individually and some of the associated soil-plant-animal relationships. Each element falls into one of two groups, major elements and trace elements.

2.1 Major Elements

Major elements include nitrogen, phosphorous, potassium, calcium, magnesium, sodium, sulphur and chlorine. Sometimes calcium, magnesium, sodium, sulphur and chlorine are referred to as minor or secondary elements, as they are not as critical to plant growth as nitrogen, phosphorous and potassium. Sodium and chlorine are not critical for many plants, and chlorine is often referred to as a trace element, even though the chlorine content in plants is usually higher than that of most of the other major elements.

2.2 Nitrogen

Under most organic farming systems, nitrogen is likely to be the most limiting nutrient factor for pasture productivity. Artificial forms of nitrogen are not allowed to be applied under organic rules, so nitrogen shortages are usually sufficed by animal manures and slurries, green manure crops, and legumes. Under permanent pasture situations, having a strong legume base to the pasture sward is critical, so that atmospheric nitrogen (N2) can be fixed by the rhizobia bacteria that inhabit root nodules and converted to NH3 and later to NH4 for use by the plant. Rhizobium bacterial strains are often host plant specific, and although many soils have native rhizobium species, their efficacy with alternative plant species can vary considerably. Consequently it is best for a farmer who is introducing new legume species onto the farm to also have the clover seed inoculated with the right rhizobium strain. There are also other micro-organisms in the soil that will fix atmospheric nitrogen in the soil that are not reliant on legume plants as hosts such as azotobacter, clostridium, beijerinckia, and blue-green algae.

Another important natural source of nitrogen for plants is organic nitrogen that is released from animal and plant residues, humus, soil microbes and other organic substances in the soil, through a process called mineralization by which micro-organisms convert the organic nitrogen into plant available inorganic forms of nitrogen. One major factor affecting the rate of mineralization of soil organic matter is the carbon:nitrogen (C:N) ratio, which varies from 20:1 to 100:1 for plant materials, with leafy materials being in the lower range and woody-fibrous material and straw being in the higher range. In contrast to this, soil micro-organisms have C:N ratios varying from 4:1 to 9:1, so that when these microbes mineralise the organic matter and release the nutrients locked up in it, they can create a nitrogen deficit for plants by using any available soil nitrogen for their own body needs, a process referred to as immobilization. This is important to consider when applying mulches, compost or straw to some soils, and also on vegetation based soils such as peat and muck soils. As the decomposition of organic matter continues, carbon is oxidised to CO2 and given off into the atmosphere, until eventually the C:N ratio is so narrowed that soil mineral nitrogen levels begin to build up in excess of microbial requirements, providing plants with necessary nitrogen. During the process of decomposition, complex proteins are broken down by microbes into amino acids, which are further broken down into ammonia (NH3), a process called ammonification. Some of this ammonia is then oxidised by nitrifying bacteria in the soil into nitrite (NO2), which is further oxidised into nitrate (NO3), a process called nitrification. Both ammonium and nitrate forms of nitrogen are available for plants to utilise, although some plants have a preference for ammonium nitrogen and others have a preference for nitrate nitrogen. Ammonium can be also be 'fixed' by clay minerals and ammonia can be fixed by organic matter into non-plant available nitrogen, which in a sense is held in storage.

Although soil tests are available that measure ammonium and nitrate levels, their interpretation and use in pasture situations is limited because soil nitrogen levels are constantly changing due to the biological and chemical processes going on. The amount of plant available nitrogen in pastures at any one time is therefore dependent on the following factors - the net release through organic matter mineralization, the nitrification of ammonium to nitrate, the denitrification of nitrate, nitrate lost through leaching, ammonium lost through volatilisation (gaseous loss into atmosphere), nitrogen absorbed by plants, additions of nitrogen from animal manures, additions from rainfall, nitrogen additions from free-fixing organisms, and nitrogen fixation into organic forms by micro-organisms.
The amount of nitrogen fixation, ammonification, and nitrification occurring in the soil is determined by external factors which are either climatic or they relate to soil physics and soil chemistry. Generally little nitrogen is fixed at soil temperatures below 7 °C, and if soils are water-logged due to poor drainage, the rate of nitrogen fixation will also be impaired. Compacted soils also inhibit these biological processes from occurring due to lack of oxygen. Soil pH is another critical factor, with pH levels in the 6.0-6.5 range regarded as ideal for most soil bacteria to function best, and other elements such as phosphorous, potassium, molybdenum and cobalt all need to be present in adequate levels for nitrogen fixation to occur. As soil fertility and grazing management have a huge bearing on the legume content of pastures it is imperative than these managerial practices are tailored to provide the best opportunity for legumes to thrive.

The nitrogen content of organic pastures is unlikely to be excessive to beef cattle from an animal health perspective unless high amounts of animal manures have previously been applied to the soil, in which nitrate levels in grasses could become an issue. The total nitrogen content of grazed pastures only needs to be between 2.0-2.6% (12.5-16% Crude Protein) of dry matter content for beef cattle, whereas lush green ryegrass/clover based pastures can often have twice these levels. The nitrogen content of pastures is likely to be affected more by the stage of plant growth and climatic constraints than by soil nitrogen levels, with short regularly grazed pastures having higher nitrogen percentages and also when plants come under moisture stress or grasses go to seed, the total nitrogen levels decline. The need to supplement beef cattle with extra protein in a pasture grazing situation is only likely to come about under very dry conditions or when stock are grazing long rank grasses. Retaining high legume components in the pasture sward will reduce the chance of this happening. The application of high amounts of N applied to a soil can reduce the uptake of some essential elements such as magnesium, selenium and iodine, but this scenario is unlikely to happen under most organic farming operations.

2.3 Phosphorous

Some soils are naturally high in phosphorous (P) whereas others are chronically deficient. The native phosphorous in soils mainly originates from apatite material, with the P present as tricalcium phosphate (rock phosphate). As soils develop and build up organic matter, a lot of the total soil phosphorous (up to 80% on some soils) is found in organic forms, which are not plant available, but organic P can become available by biological mineralization into inorganic P. Soils vary in their ability to store phosphorous, depending to a large extent on the amounts of clay, organic matter, iron, aluminium and calcium present, that ‘fix’ or ‘bind’ phosphorous into insoluble forms. Consequently on soils where a lot of phosphate ‘fixation’ occurs, only a tiny fraction of the total pool of phosphorous in the soil may become available for plant growth, and phosphorous deficiencies can become apparent even if the total amount of phosphorous in the soil is relatively high.

Like nitrogen, soil bacteria have a high demand for phosphorous, and carbon:phosphorous levels above 200:1 in the soil will result in immobilization of P rather than mineralization. Phosphorous levels in pasture can also vary seasonally, although not to the same extent as nitrogen, with levels being lower as plants mature over the summer period. In actively growing pasture, phosphorous levels below 0.35% of the dry matter indicate a phosphorous deficiency in the soil, whereas optimum soil test levels differ depending on soil type and the particular extraction method used.

On soils where phosphorous levels are deficient, large increases in productivity from both pasture and livestock can be expected from applied phosphorous.

Under organic standards, the most common forms of phosphorous allowed are rock phosphate, animal manures, and industrial by-products such as bone dust and some slag products. Natural rock phosphate sources vary in their suitability for direct application to the soil, and can be classified into one of two categories - reactive (RPR) and unreactive phosphate rocks, the latter only being suitable for processing. As a general guideline, RPR's should only be considered on acidic soils with a pH of 6.0 or below and where annual rainfall exceeds 800mm. There are three sources of rock phosphate that are highly reactive and suitable for direct application to the soil, these being Sechura RPR from Peru, North Carolina RPR from USA, Gafsa RPR from Tunisia, although the North Carolina source is not allowed by some organic standards because of the relatively high cadmium impurity. Two other commercial sources are Arad RPR from Israel, and Egyptian RPR, although the efficacy of both of these RPR's in some trials on pasture has shown their value to be questionable. RPR's generally are slow releasing, with no more
than 30% of the total P in them becoming available during the first year of application, with 30% of the remaining P becoming available each subsequent year.

Animal manures are another source of phosphorous, although if the manure comes from non-organically farmed sources, it may need to go through a period of composting before it is allowed. Industrial by-product sources of phosphorous and animal manures vary in their analyses, and different organic standards have restrictions on the use of some of these products. Unlike RPR's most of these sources of phosphorous are suitable for a wide range of soil conditions and pH.

There are a number of soil tests available for phosphorous, with the most common ones used being the Olsen P, Bray I and Bray II, Mehlich I and Mehlich III, Morgan, Saturated Paste, and Resin tests. Some methods are better at predicting phosphorous responses than others, but the laboratory repeatability of most tests is very high, and consequently if the figures have been calibrated against scientific trials or with herbage phosphorous levels on given soils they can be very useful. Seasonal changes caused by phosphate leaching/run-off are very small, whereas the greatest source of variability in soil testing is sampling variability due to the uneven distribution of phosphorous over a paddock through dung and urine deposits. It should also be noted, that if RPR fertilisers are being used, the Olsen P test will fail to adequately predict a phosphate response as this test uses a buffered pH solution of 8.5 which is too high for RPR to react.

Beef cattle require at least 0.3% P on a dry weight basis in the feed they consume, below which animals will not fatten and perform to their full potential. In chronically phosphorous deficient situations, cattle will be in a continual state of ill-thrift. An important consideration for breeding cows, is the calcium:phosphorous ratio which should be at least 1:1 to avoid milk fever related problems. Excessive phosphorous levels can restrict the availability of the trace elements iron, zinc and copper, but this is unlikely to happen under organic farms except on soils naturally high in phosphorous or on soils fertilised with excessive amounts of animal manures.

2.4 Potassium

Soils generally have large amounts of potassium (K), although the portion of total potassium in the soil that is plant available (solution and exchangeable potassium) is usually less than 2%, with the other 98% + being non-exchangeable potassium which is part of the make-up of soil minerals such as feldspar and micas, or held between the lattice layers in the clay. Through natural weathering processes, K ions can be released from this store and enter the soil solution where it can either be taken up by plants, leached out, or become exchangeable K, which in turn can become fixed into non-exchangeable potassium through migrating into vacant sites of the mineral lattice of the clay. The ability of a soil to store exchangeable cations like potassium, sodium, calcium and magnesium is referred to as the cation exchange capacity (CEC), or total exchange capacity (TEC), which is determined primarily by the amount and type of clay fractions a soil is composed of, the organic matter (humus) content, and the soil pH. The greater the CEC, the greater the ability of the soil to retain cations and reduce leaching losses. On low CEC soils such as sandy soils, potassium losses during periods of high rainfall can be quite high.

Pasture plants have a high requirement for potassium, which is typically 2-4% of the total dry matter content. In actively growing pasture, a potassium content below 2.5% of the total dry matter would indicate a possible potassium deficiency, which is more than treble the potassium content required by cattle. Potassium deficiency in grazing livestock would be extremely rare, whereas in pasture plants it is fairly common on low CEC soils and areas which have had a lot of hay and other crops harvested off them and which potassium has not been replaced. Soil analyses that measure exchangeable potassium should aim for 120-180 ppm for pasture, although this varies according to the CEC. Base Saturation percentages of potassium also will change according to CEC, but 3-4% on average CEC soils is a good place to start. On high CEC soils, 2% may be adequate, but as for all soil testing techniques, the interpretation of laboratory analyses should be calibrated with trial data, herbage levels and local knowledge of fertiliser responses.

Cattle urine is very high in potassium due to the excess K found in pasture that is above the needs of grazing cattle, so that areas around water troughs, stock camps and other places animals congregate can become very potassium rich. Plants tend to luxury feed on potassium if it is available in the soil, and if the exchange sites in the soil have a higher than normal saturation in potassium, it can reduce the availability of other elements such as calcium, magnesium, sodium and boron. This is particularly important for breeding cows, as the likelihood of metabolic problems around calving are increased. It is
also significant in warmer climates as the potassium:sodium balance in animal cells affect water retention and dehydration. Pastures with K levels above 3.5% of the total dry matter are also less palatable to cattle, and if consumption is lowered, so too will the weight gain of growing cattle decline.

Types of potassium that can be applied to organic farms vary according to different standards. Some standards do not allow soluble sulphate or chloride forms of potassium to be applied to the soil, arguing that they are too soluble and plants luxury feed on the highly available potassium, creating an unnatural balance in the chemistry of the plant. Another reason some have outlawed naturally occurring potassium chloride products is the belief that chlorides kill of soil biota. However, the effect of chloride on soil biology when applied at low rates is likely to be negligible, and chloride is an essential element for plant growth. Ironically some standards allow potassium sulphate, which is often a processed form of naturally occurring potassium chloride, and the chloride issue could do with some revisiting by those groups which outlaw it, as potassium chloride is more concentrate and less expensive to the farmer than potassium sulphate. Naturally occurring compounds containing sulphate or chloride forms of potassium along with other elements such as magnesium and sodium as in the case of Sul-po-mag and Sylvinitie respectively are generally allowed to be used, as is ground feldspar.

2.5 Calcium

Calcium (Ca) levels vary considerably between soil types, with some soils having low levels, and others being very high, such as calcareous chalk-based soils. Calcium is usually applied to the soil as a liming material in the form of calcium carbonate (CaCO₃), or as part of rock phosphate based fertilisers. Its main benefit to pasture is to counter soil acidity, which is an ongoing issue with grazing animals due to the acidifying effects of dung and urine being returned to the soil. Calcium is also essential for soil organisms, and earthworms in particular thrive better in calcium rich soils. Legumes need sufficient calcium for protein production and nodulation to occur, and plants need calcium to fully utilise nitrogen, especially ammoniacal nitrogen. On some soils, iron and aluminium levels are excessive, and can be toxic to plant roots, as well as restricting the plant availability of other nutrients such as phosphorous. Calcium can help counter these toxicities, and in general calcium assists in providing the appropriate ‘balance’ and conditions for levels of other nutrients within the soil and plant to be ideally available. Another benefit of calcium is its flocculation effect on clay particles, thereby improving soil structure which is important for reducing poaching and pasture pugging incidence, enhancing root penetration, and increasing moisture retention and capillary movement. Calcium should be by far the most dominant cation occupying the exchange sites surrounding the soil colloid, yet its uptake by plants is comparatively low compared to potassium and sodium, because of its divalent bond to the colloid compared to the monovalent bonding of potassium and sodium. Legumes have a higher requirement for calcium than grasses, and having a higher legume component to the pasture sward will help raise the overall calcium status of forage.

Calcium is critical to cattle performance and weight gain, being the most abundant element in the body by weight. The calcium level in the herbage should be at least 0.4% of total dry matter, assuming phosphorous levels are similar. Calcium levels above 1.5% of total dry matter in pasture are rare, but are not problematic for cattle, except possibly with breeding cows, where high calcium levels in the feed can trigger milk fever problems.

Calcium can be applied to organic farms as lime, dolomite, marl, industrial lime by-products such as basic slag (depending on standards), reactive phosphate rock, and gypsum. Excesses of calcium through overliming can reduce the availability of phosphorous and boron and other cations - magnesium, potassium, iron, manganese, zinc and copper. It can also lead to excessively high levels of molybdenum in the forage which induces a copper deficiency in livestock. Some of these problems are inherent on calcareous soils.

2.6 Magnesium

Magnesium levels also vary considerably between soils, with some having huge magnesium reserves, whereas others can be naturally deficient. Most of the magnesium found in soils is mineral magnesium which is unavailable to plants, with plant available exchangeable and solution magnesium usually representing around 5% of the total magnesium level in soils. In plants, magnesium is essential for the process of photosynthesis, with magnesium being at the centre of the chlorophyll molecule.
Critical magnesium levels for legumes are higher than that of grasses, with white clover having a critical level of 0.12%, whereas grasses have a critical level 0.10% of total dry matter. Legumes can also suffer from magnesium deficiency when there is an oversupply of calcium saturating available sites around the soil colloid and the calcium:magnesium ratio in the soil becomes too wide.

In grazed pastures, magnesium deficiency problems will generally arise in cattle before it becomes apparent in pasture species. For breeding cows, maintaining magnesium levels in pasture above 0.20% of total dry matter will help alleviate the onset of hypomagnesaemia (commonly called grass staggers, magnesium tetany or grass tetany) after calving. Hypomagnesaemia usually happens during winter and spring growth, when plant magnesium levels are seasonally low, possibly due to the lack of sunshine which is an energy source plants use to draw elements up from the soil. The uptake of magnesium can also be seriously affected by excess of other cations, especially potassium and ammonium, so consequently it is not advisable to apply potassium or nitrogenous fertilisers immediately prior to calving. As legumes have higher levels of magnesium than grasses, having a higher clover content in the pasture sward will also help reduce the risk of hypomagnesaemia, and the feeding of hay/silage that is grown in summer months when magnesium levels are naturally higher will also help reduce susceptibility of livestock to this problem. Other classes of cattle can also suffer from magnesium deficiency, although the critical threshold is lower than that of recently calved breeding cows. Symptoms include nervous irritability, convulsions, scours and general ill-thrift, which can ultimately result in death, particularly in milk-fed calves around two months of age.

To maintain or build magnesium levels in the soil on organic farms, options to consider are dolomitic limestones, magnesite or serpentine rock. Fineness of grinding of these products is essential to their efficacy, and their suitability is limited to acidic soils. On calcareous soils, magnesium sulphate containing compounds such as kieserite or Sul-Po-Mag can be considered.

2.7 Sodium

Sodium was once believed to be essential for animals only, and not plants, but we now know plants do utilise sodium, although their requirement for it vary. Sodium can substitute potassium for some functions in the plant, and pasture responses to applied sodium have been recorded where soil sodium levels are low. Pasture responses to sodium have been observed through improved palatability of pastures on low sodium soils, resulting in better utilisation and more even grazing, and consequently overall productivity can be increased.

On the reverse side of things there are many soils where sodium levels are toxic to plants as seen in saline and sodic soils, although plant species vary considerably in their tolerance of high levels of sodium. Ryegrass, strawberry clover and kikuyu grass species are relatively tolerant to high salt concentrations in the soil, whereas red and white clover are sensitive. Irrigation waters high in dissolved salts of calcium, magnesium and sodium can become saline over time. As the proportion of sodium increases in the soil, the soils lose their structure and become lifeless and resistant to water permeability, causing plants to often exhibit signs of drought. Gypsum can be used to lower soil salinity.

Pasture plants will die long before sodium toxicity will ever become an issue for cattle on grazed pasture, although a high sodium saturation of the CEC of a soil will affect the availability of other critical elements such as calcium and magnesium which can result in animal maladies if not remedied. Most sodium problems in livestock relate to its shortage, particularly in inland coarse textured soils where there is a relatively high rainfall, and also when stock are grazing plants that are poor in translocating sodium from the soil into their leaves, which is common among many sub-tropical grasses. A deficiency of sodium in their forage causes cattle to dehydrate through a lowering of cellular osmotic pressure, resulting in extreme thirst (which is also symptomatic of excessive sodium levels). Sodium is also required for saliva production, and low sodium levels can lead to poorer digestion, loss of appetite and weight, and in breeding cows it can also result in lower milk production. More pronounced signs of sodium deficiency are an unthrifty haggard appearance, lustreless eyes, a rough hairy coat, shivering, inco-ordination, weakness, and cardiac arrhythmia which can lead to death.

For beef cattle a minimum sodium level in the herbage of 0.10% of total dry matter should be aimed for, to avoid the need for other forms of sodium supplementation. Crushed rock salt under most organic standards is allowed both as a free-feed mineral lick, and also as a sodium fertiliser for top-dressing onto pastures. For lactating breeding cows, the sodium level in pasture should be at least 0.15% total dry matter.
2.8 Sulphur

Sulphur deficiencies are becoming more common as the amount of sulphur dioxide in the atmosphere which was a major cause of ‘acid rain’ declined due to the drop off of coal as an energy source and as industrial countries have become more environmentally conscious of the hazards of air pollution. The quantities of atmospheric sulphur falling annually vary from region to region. Most of the sulphur in the soil (usually greater than 90%) is contained in the organic matter and is unavailable to plants, but becomes available to plants as sulphate sulphur (SO4) through mineralization. Under permanent pasture, organic matter levels can accumulate, during which time considerable amounts of sulphur can be withdrawn from circulation which may last many years. It is during this build up phase in particular that sulphur deficiencies in pastures become most acute.

Sulphur is an essential component of the amino acids cysteine and methionine which are constituents of proteins, and therefore all living things require sulphur. In plants where sulphur is deficient, protein synthesis is slowed down and in the case of legumes, the amount of nitrogen fixation is limited. Grasses are more efficient utilisers of soil sulphur than legumes, so that in incipient sulphur deficiency, clovers are affected earlier than grasses, and the resultant yellowing of pastures can sometimes be mistakenly thought to be nitrogen deficiency. Sulphur rich soils appear to have markedly greater nitrogen utilisation, and it seems that sulphur has a stimulating effect on the nitrifying bacteria in the soil.

Soil test figures for optimum SO4 sulphur levels are highly variable depending on time of year and rainfall prior to sampling, and organic sulphur levels are often used in conjunction with SO4 sulphur levels to better predict a sulphur response. Some soils which have been mechanically altered, or are badly compacted can have large quantities of sulphates accumulating in them. Other soils which are anaerobic or water-logged, have SO4 reduced to hydrogen sulphide (H2S) by micro-organisms which in turn can be lost or combine with iron to form iron sulphides. These transformations are often observable when the soil is dug up, as is the unpleasant smell of some of the sulphides that are formed. When these soils are drained, the sulphuric acid formed during the oxidation of sulphide can create serious acidification. A similar thing occurs with the oxidation of elemental sulphur into SO4, which is sometimes used in significant quantities to acidify a soil that is too alkaline. Thiobacillus spp are the most important soil micro-organisms involved in biological oxidation of sulphur, although other bacteria, fungi, and actinomycetes are also capable of oxidising elemental sulphur. Soils that are classically low in sulphur tend to be coarse textured, low in organic matter, inland from the coastal areas and a long way from large industrial centres.

Sources of sulphur fertiliser allowable by most organic standards include naturally occurring sulphates, the most common being gypsum (calcium sulphate), and also elemental sulphur. Elemental sulphur has the advantage of not being subject to leaching like sulphates, although like RPR's the particle size has a huge bearing on release rate, with particle sizes less than 150 microns being most suitable to address a deficiency.

Healthy pasture needs at least 0.25% sulphur in dry matter content, but can sometimes have levels three times higher. Sulphur deficiency in beef cattle can occur when sulphur levels drop below 0.18% of DM, although it may take several months for this to become apparent, by which time pasture productivity will be suffering severely. Sulphur excesses and toxicity is a more common problem in cattle grazing pasture. Sulphur levels above 0.45% of dry matter in grazed pasture can reduce the bioavailability of copper and selenium in cattle. There is an inter-relationship between sulphur and molybdenum, as molybdenum can also affect copper bioavailability in cattle if too high, yet the beneficial effects of molybdenum on clover nodulation is greatly enhanced in the presence of adequate sulphur. Conversely excessive sulphur can compete with molybdenum uptake in plants.

2.9 Chlorine

Chlorine is an essential element for both plants and livestock, although deficiencies in grazed pasture is unknown, and if it does occur it is likely to be only found in extreme inland areas. Chlorine toxicity can occur on some coastal soils affected by sea water and in areas where irrigation water is used that is high in chlorides. Excessive chlorine can induce nitrogen and sulphur deficiencies due to competition with nitrate and sulphate uptake. Most pastures have chloride contents ranging from 0.2-2.0% of total dry matter. Chloride sensitivity between plant species vary considerably, and is often aligned to sodium.
tolerance due to the combination of sodium and chloride to form salt. Chloride in the soil is not absorbed by minerals, and is easily leached in free-draining soils, but can concentrate in poorly drained soils.

For cattle, having a minimum chloride level of 0.15% in the feed is essential, although around calving, having a high chloride level can help reduce dietary cation-anion difference (DCAD) levels reducing the likelihood of milk-fever related problems. Chloride based fertilisers such as potassium chloride (muriate of potash) and salt, can provide chloride in a chloride deficient situation, although there are some standards which disallow these natural forms of chloride, believing chloride negatively impacts on soil microbiology. Under healthy grazed pasture, rich in organic matter, such an effect is likely to be very temporal and negligible.

3 Trace Elements

Trace elements or micro-nutrients are only required by plants and animals in minute quantities compared to major elements. Their occurrence in nature is generally only as very small proportions of mineral rocks, and consequently for practical application to address a soil deficiency, they are either applied as a processed mineral such as cobalt or zinc sulphate, or as a contaminant found in other products such as molybdenum in Sechura RPR. Once applied to the soil and accessed by plant roots, these minerals become complexed in the plant tissue, and are highly available for livestock to absorb in a completely natural form.

3.1 Boron

Boron is a critical element for plants, particularly leguminous plants, whereas grass species tend to be more tolerant of low soil boron levels. Animals do not require boron, although boron can have some minor influences on calcium availability, and reducing nitrate levels in plants. Boron enhances cell division, carbohydrate and water metabolism, translocation of sugars, protein synthesis, and has a major bearing on seed production. On boron deficient soils, clover seed productivity is greatly reduced. Boron deficiency is more likely to be found in coarse textured soils, due to its susceptibility to be leached through the soil profile as boric acid (H3BO3), the form of boron predominantly found in soil solution. Boron is readily complexed by organic matter, and deficiencies are accentuated during dry periods and from liming of soils where both the higher pH and increased calcium concentration decrease boron uptake by plants.

There is a fine line between boron deficiency and boron toxicity in plants and boron should only be applied after a boron deficiency has been diagnosed through soil or herbage analysis. Boron toxicity is more likely to occur in low rainfall areas or where irrigation water is high in boron. Pasture productivity will be compromised well before any negative effect on livestock will be observed in grazing situations. Colemanite and ulexite are both combinations of calcium and sodium borates, and are the nearest to natural boron based fertilisers suitable for use in organic situations, although they vary in their solubility and hence suitability for direct application to pastures.

3.2 Iron

Iron is generally present in soils in higher concentrations than any other nutrient, although soils vary considerably in their total iron content. The vast bulk of this iron is unavailable to plants, and plants themselves only require very small amounts of iron, so to find iron deficiencies in pastures or grazing animals is extremely rare. Plants require iron as a catalyst for the synthesis of chlorophyll and iron is also present in a number of critical enyzymes. Where deficiencies in pastures do exist, it is generally not the lack of iron in the soil, but an induced iron deficiency from other factors such as too high pH, or excessive bicarbonates, calcium, phosphorous, manganese, copper, cobalt or zinc. Such effects are also often seasonal, and usually addressed by means of iron sulphate or chelated sprays onto foliage. Iron sulphate mixed with organic manures can also be used to correct deficiencies, and naturally occurring iron carbonates are a third option, although their effectiveness on high pH situations would be minimal.
More often iron toxicities are found in soils, particularly in very low pH soils or in poorly drained situations. Excessive iron can interfere with manganese, zinc, copper, phosphorous, cobalt and calcium adsorption. For pasture growth, iron levels below 60 ppm dry weight can indicate a deficiency in the plant, but it should be noted that the herbage sample must be completely free of soil, which if present will artificially elevate the iron level.

For livestock, iron is principally recognised as an essential component of haemoglobin, but it is also critical for a number of other body functions. In grazed pasture, cattle can consume large amounts of iron by ingesting soil, particularly where the pasture has been trampled into the dirt, and subsequently consumed, which can consequently induce copper, cobalt, manganese and zinc deficiencies. Critical levels for cattle are below 40 ppm, but iron deficiency is unlikely to occur in grazing situations because of soil consumption. Iron absorption and utilization by cattle can be affected by the copper content of the feed as the ability to utilise iron is directly controlled by a copper containing enzyme called ferroxidase.

### 3.3 Manganese

Manganese is essential for many functions in plants including photosynthesis, nitrogen metabolism and assimilation and enzyme activation. The availability of manganese to plants is dependent on a number of factors including soil pH and calcium levels, soil moisture, aeration and temperature. Excessive manganese is often found in very acid soils and soils subject to water-logging, and as plants vary in their tolerance and requirements for manganese, it is difficult to give broad-brush critical figures. Manganese levels in soils vary considerably depending on soil type and organic matter content. The uptake of manganese by plants can be depressed by high levels of available iron, copper, zinc and phosphorous.

In cattle, signs of manganese deficiency include impaired growth, skeletal abnormalities, reproduction problems including abortion, and deformities and abnormalities in new-born calves. Critical manganese levels in pasture are around 25 ppm of dry matter for breeding cows both for reproductive performance and foetal development. Very high levels of manganese can restrict the availability of cobalt which in turn could affect Vitamin B12 metabolism. The most common method of fertilising for manganese is using manganese sulphate, as manganese oxide is not very effective in high pH situations where manganese deficiency is most common.

### 3.4 Copper

Copper is essential in many plant processes including photosynthesis, protein and carbohydrate metabolism, and is also present in several enzymes. In pastures, clover species are more sensitive to copper deficiency than grasses, where both the clover plant and the rhizobia nodule bacteria are affected by copper deficiency. Visual symptoms in clovers are reduced growth, with plants growing more erect than normal, with pale green leaves that cup upwards as if affected by drought, and root nodules that are white and slender rather than pink in colour. Copper deficiencies occur worldwide on many different soils, but tend to be more acute on high organic or high pH soils. Most of the copper in soil solution is complexed with organic matter, and copper deficiency can be further antagonised through over-liming of soils, or where high levels of nitrogen or phosphorous have been applied. An over abundance of iron or zinc can also detrimentally affect the uptake of copper. Copper toxicity in pastoral soils is unlikely to occur unless the pastures are grown on previously contaminated sites, or on areas where horticultural crops that are subject to multiple copper sprays such as hops, apples or vineyards were once planted.

Cattle deficient in copper show a general ill-thrift, and in severe situations exhibit rapid weight loss, diarrhoea, rough hair coat or loss of hair, hair pigmentation, calving problems, reproductive problems, weak bones and fractures, and calves born with congenital rickets and anaemia, or even born dead. For cattle, the minimum dietary requirement for copper cannot be established without also considering other interfering elements including molybdenum, sulphur, iron, phosphorous, zinc and cadmium. Molybdenum is the most common antagonist to copper in cattle, and this situation is often brought about through liming, in which molybdenum works in reverse to copper, being more available as the pH rises.

Copper sulphate is the most common copper fertiliser used to address deficiencies in the soil, although copper metal dusts and copper chelates can also be effective. Although bovine copper poisoning form top-dressing with copper is unlikely when applied at normal rates (up to 0.5-2 kg/ha
elemental copper per application), if sheep are also being grazed, care should be taken to ensure copper sulphate is washed off grass before they graze, as sheep are relatively sensitive to copper poisoning. In cases of extremely high molybdenum, iron or sulphur levels in the feed, the application of copper to the soil may not be sufficient to address the copper deficiency in cattle, and attention needs to focus on reducing the antagonistic element. In pasture, once copper levels have reached 11 ppm of dry matter, there is little benefit in applying more copper to the soil.

3.5 Zinc

Zinc is involved in most of the enzyme systems within plants, and it also promotes auxin (indole acetic acid) production which is a natural plant hormone necessary for cell elongation and water utilization. Zinc is closely involved in the nitrogen metabolism of plants, and in zinc deficient plants protein synthesis and protein levels are reduced, and amino acids and amides can accumulate. Zinc deficiency in plants can be induced by over-liming, poor drainage, or excessive phosphorous levels. Calcareous soils are particularly prone to zinc deficiency, and zinc deficiency is likely to affect legumes before it will affect grasses. High zinc levels in the soil can suppress pasture productivity, particularly on areas where copper levels are down.

Zinc deficiency in cattle may occur when pasture zinc levels drop below 25-30 ppm of dry matter. Zinc is found in a number of enzymes in cattle, and tends to accumulate in the bones, hair, skin and testicles, although zinc is found in every tissue of the body. The application of zinc sulphate to the soil is the most common way of addressing zinc deficiency. Cattle have a high tolerance to zinc concentrations, and should not suffer from zinc toxicity in grazing situations, as plants will die before this will occur.

3.6 Cobalt

Soils vary substantially in their cobalt content, with deficiencies occurring mainly in highly leached sandy soils, acid soils of volcanic origin, calcareous soils, and peaty soils or other soils high in organic matter. Cobalt is not regarded as essential for pasture plants, but it is essential for the fixation of nitrogen by rhizobium bacteria on legumes, although the amount of cobalt required is miniscule. The importance of cobalt is primarily for the grazing animal, and deficiencies in cattle result in lack of appetite, lack of growth and poor reproductive ability. A critical level of cobalt for young cattle is about 0.08 ppm of dry matter in the herbage, whereas adult cattle can tolerate lower levels. Cobalt availability to plants is sensitive to soil pH and moisture conditions, with water-logged and acid soils having higher cobalt levels. Liming can substantially reduce cobalt availability, as can excessive iron and manganese levels. Plant species also vary considerably in their cobalt content, with higher cobalt levels usually found in legumes, and also seasonal variations occur with lower cobalt levels generally found in spring and summer.

The common method of fertilising with cobalt is to apply cobalt sulphate at around 400 gm/ha, although higher rates of 1-2 kg/ha have been used in severe situations. Cobalt behaves like other heavy metals - iron, manganese, copper and zinc - in that it tends to form chelate compounds with the soil organic matter, and in deficient situations, the availability of applied cobalt for rapid plant uptake is sometimes limited to 2-3 months before dropping off to an equilibrium. Late spring applications of cobalt sulphate are often useful to elevate the cobalt levels when most required by calves over the time of year when cobalt levels are lowest in the pastures. Animals generally have a high tolerance to cobalt toxicity, and cobalt levels have to be extremely high before plant growth is compromised. Cobalt toxicity in plants can be alleviated by the application of iron.

3.7 Molybdenum

Molybdenum is an essential element for both plants and animals, although in grazed pasture, cattle are unlikely to ever be deficient in molybdenum. In pastures, molybdenum is mostly required by clovers for the formation of the enzyme nitrogenase which controls the fixation of atmospheric nitrogen by bacteria. Molybdenum is also essential for the formation of another enzyme, nitrate reductase, which controls the first stage in the conversion of nitrate nitrogen to amino acid and protein nitrogen. The involvement of molybdenum in nitrogen metabolism of plants, is probably why molybdenum deficiency
Symptoms in legumes mimic nitrogen deficiency, with plants being stunted, pale green in colour, and sometimes withered.

As previously mentioned, liming increases molybdenum availability, and it is important to consider the pH of the soil before applying molybdenum, as applying lime will often address a molybdenum deficiency. Although applying lime is undoubtedly more expensive than applying molybdenum, the antagonism of excessive molybdenum with copper availability in cattle once a low pH has been rectified is an all too common problem on many soils. If the pH is at an optimum level and molybdenum deficiency is still evident, then molybdenum should be applied annually until molybdenum is in the desired range. Soil moisture can also affect molybdenum availability, with greater uptake by plants when soils are saturated, compared to drier periods. Molybdenum availability to plants can also be affected by other elements such as phosphorous and nitrogen, which increase availability, whereas sulphur and manganese can reduce availability.

The best way to diagnose molybdenum deficiency and also to predict any copper antagonism is through herbage analysis, although it should be borne in mind that molybdenum levels are higher over winter-spring, whereas copper is lowest during this period. Molybdenosis (molybdenum toxicity) in cattle (sometimes also called heart or peat scours) usually occurs when the copper:molybdenum ratio drops below 4:1 in the herbage, and on some soils the molybdenum level can be too high for the application of copper sulphate to soil to adequately remedy the problem. The most common forms of applying molybdenum fertiliser are as ammonium and sodium molybdates, although molybdenum contaminations can be found in other fertiliser materials such as Sechura RPR and Basic Slag.

3.8 Selenium

Selenium has no known value to plant growth but is an essential element for animals. Soils vary considerably in their selenium status, from being chronically deficient to toxic in different parts of the world. Cattle require at least 0.05 ppm selenium in their feed, with a maximum toleration of 5 ppm. Selenium deficiency causes white muscle disease, scours, ill-thrift, poor growth rates, infertility, calving problems, and retained placenta in cattle. Vitamin E and selenium can have a synergistic effect in reducing white muscle disease in calves, and mastitis incidence in milking cows. Sulphur can reduce selenium availability, and liming can improve availability. Commercially available limestone chip based selenium prills containing 1% sodium selenate applied annually to the soil has proved an effective and safe method of addressing selenium deficiency in pastures.

3.9 Iodine

Like selenium, iodine has no value to plants, although it has been suggested that iodine is required by earthworms. Cattle require at least 0.15 ppm iodine in their feed, with a maximum toleration of 50 ppm. Chronic iodine deficiency causes goitres to develop around the neck, but sub-clinical problems associated with infertility and calf mortality are common. Addressing iodine deficiency in the soil through the application of potassium iodate or iodide to the soil is largely ineffective because of iodine loss from volatilisation. For organic farmers unable to give iodine direct to stock, seaweed meal top-dressed onto silage, or liquid seaweed extracts high in iodine given orally to stock are feasible options.

4 CONCLUSION

To achieve the goal of having healthy organically grown beef cattle farmed in pastoral situations, a knowledge of the mineral content of the pastures being consumed and the mineral status of the soil from which plants draw their nutrients from is important. No one element essential for life processes can be considered any more important than the other essential elements. All are necessary for growth, production and reproduction and must be supplied to the plant or animal in quantities sufficient for these life processes to be sustained. Because of the interrelationships of all essential elements and their effect on one another, they must be maintained in relative amounts in proportion to each other. A deficiency or excess of one critical element may cause the deficiency or excess of another. As every action causes a reaction, fertiliser regimes need to be thoughtfully implemented so as to create an optimum equilibrium.
and harmony for life's processes to operate within the grassland ecosystem. Single or major element focused fertiliser regimes that ignore the minor and trace element statuses in the soil will upset the delicate balance of life, and for the past few decades under conventional farming systems has served the veterinary and pet food industries well. For the organic movement to avoid the same pitfalls, a preventative strategy of using the diagnostic services provided by laboratories for comprehensive soil and plant analyses, together with a knowledge of the chemistry involved, will provide a fulcrum upon which the balance can swing.

5 BIBLIOGRAPHY