Chapter 3
Plant Nutrient Requirements

CONTENTS

3 Plant Nutrient Requirements

3.1 Introduction

Plants require nutrients for normal growth. These must be in a form useable by the plants and in concentrations that allow optimum plant growth. Furthermore, the concentrations of the various soluble soil nutrients must be properly balanced.

Learning outcomes
At the completion of this chapter, you should:
- Know which nutrients are essential for plant growth.
- Know which nutrients are required in large quantities.
- Understand the principles of the nutrient cycles for the major nutrients.
- Know which nutrients are required in smaller quantities.

3.2 Why do we need fertilisers?

Many Australian soils are old and weathered. In fact, many are considered the oldest soils in the world; and the nutrients have been leached, which has resulted in soils of low fertility. For example, average Australian soil phosphorus levels are 40% lower than English soils and up to 50% lower than North American soils.

Improved pasture species allow a much higher stock-carrying capacity; but to maintain this productivity, they require a higher level of soil fertility than do native pasture species.

Fertiliser applications are required to overcome the soil's inherent nutrient deficiencies and to replace the nutrients that are lost or removed from the soil by pasture growth, fodder cropping or conservation, and animal products, such as milk or meat.

Nutrient redistribution around the farm and the inherent ability of soils to 'retain' applied nutrients; so they are less available for plant uptake, are other reasons for fertiliser applications.

In addition to the loss of nutrients in fodder, grain, and animal products, a significant amount of nutrients can be lost off the farm in runoff from irrigation and rainfall - see Chapters 10.5.2 and 12.3. There are many factors that need to be considered in working out a profitable fertiliser program for a dairy farm. For details on nutrient planning see Chapter 15.

3.3 The essential plant nutrients

Seventeen nutrients are known to be essential for plant growth. For a nutrient to be classified as essential it must be:
- Essential for the plant to complete its life-cycle.
- Unique, not able to be replaced by another.
- Required by a substantial number of plant species, not just a single species or two.
- Directly involved in plant metabolism, that is, it must be required for a specific physiological function.

The essential nutrients can be divided into two categories:
- Major nutrients (macronutrients).
- Minor nutrients (micronutrients), often referred to as trace elements.

These are listed in Table 3.1. (See also Table D.1 in Appendix D.)

Table 3.1 The essential nutrients required by plants

MAJOR NUTRIENTS	MINOR NUTRIENTS (TRACE ELEMENTS)
Carbon (C)	Molybdenum (Mo)
Hydrogen (H)	Copper (Cu)
Oxygen (O)	Boron (B)
Nitrogen (N)	Manganese (Mn)
Phosphorus (P)	Iron (Fe)
Potassium (K)	Chlorine (Cl)
Sulphur (S)	Nickel (Ni)
Calcium (Ca)	Zinc (Zn)
Magnesium (Mg)	

Other minor elements, such as sodium, silicon, cobalt, strontium and barium, do not fit the criteria to be universally essential. These are called beneficial nutrients, as are the seventeen nutrients listed in Table 3.1, although the soluble compounds of some may increase plant growth. Other elements required for animal health, such as selenium, fluorine and iodine, have no known value to plants.

A deficiency in any one of the 17 essential nutrients will reduce growth and production, even though the others may be abundantly available. Optimum pasture production can only be obtained if all the requirements for plant growth are met. This fundamental principle is known as **"the law of the limiting"** or **"Liebig's Law of the minimum"** and often represented by the barrel with uneven staves as in Figure 3.1.

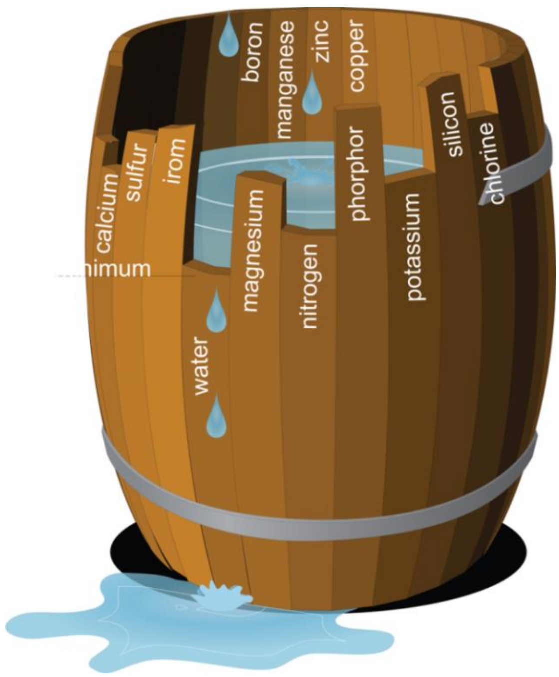

Figure 3.1 Liebig's Law of the Minimum.
(Source: http://www.greencare-concept.nl/eng/pagina/141/prevention-through-nutrition.html)

Liebig's Law of the minimum says:
"The yield of a plant is limited by a deficiency of any one essential element, even though all others are present in adequate amounts."

Even though Liebig's law is discussing essential nutrients, the same principle applies to all other facets of pasture management, for example soil moisture, soil structure, grazing management and ground cover. Pasture production will not reach full potential if any one management aspect is limiting even though plant nutrients are in adequate supply.

The first three major nutrients, carbon, hydrogen and oxygen, are non-mineral and generally considered to come from carbon dioxide in the atmosphere and from water. Combined, they make up 90% to 95% of the dry matter of all plants.

The remaining nutrients are found in the soil and are taken up through the root system of the plant. However, legumes (such as clovers, lucerne and medics) also have the ability to convert atmospheric nitrogen into a plant-available form - see Section 3.4.1.3.

3.4 The major nutrients or macronutrients

The macronutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium) are required in relatively large quantities by plants; measured by either a percentage or mg/kg. Plant growth may be retarded because:

- These nutrients are lacking in the soil.
- They become available too slowly.
- They are not adequately balanced.

3.4.1 Nitrogen

Nitrogen (N) is needed for all growth processes, as it is the major component of amino acids, which are the building blocks of proteins, enzymes and the green pigment chlorophyll. Chlorophyll converts sunlight energy into plant energy in the form of sugars and carbohydrates.

3.4.1.1 Nitrogen deficiency symptoms

Nitrogen deficiency symptoms include:

- Stunted growth.
- Yellowing or light-green colour in pastures (very occasionally orange and red pigments may dominate).
- Low protein content of grasses and crops.
- A lack of nodules or very small whitish nodules on clovers and other legumes.

Nitrogen is mobile in plants, so deficiencies show up in the oldest plant tissue first – see Chapter 8.6.2.1. Nitrogen deficiency in legumes and grasses has similar symptoms to a sulphur deficiency. However, sulphur is immobile in *most* plant species, so sulphur deficiencies typically show up in the youngest plant tissues first. An exception is in subterranean clover where sulphur is more mobile, so the deficiency shows up in young and old plant tissue.

3.4.1.2 The nitrogen cycle

Nitrogen is present in the soil in many different forms (Figure 3.2), including as a gas (N_2); as various oxides of nitrogen, such as nitrate (NO_3) and nitrite (NO_2); and as ammonia (NH_3), amines (formed from ammonia), or ammonium (NH_4). Organic matter is a major storage area for nitrogen. In fact, in most soils, more than 95% of the nitrogen is present in the organic matter.

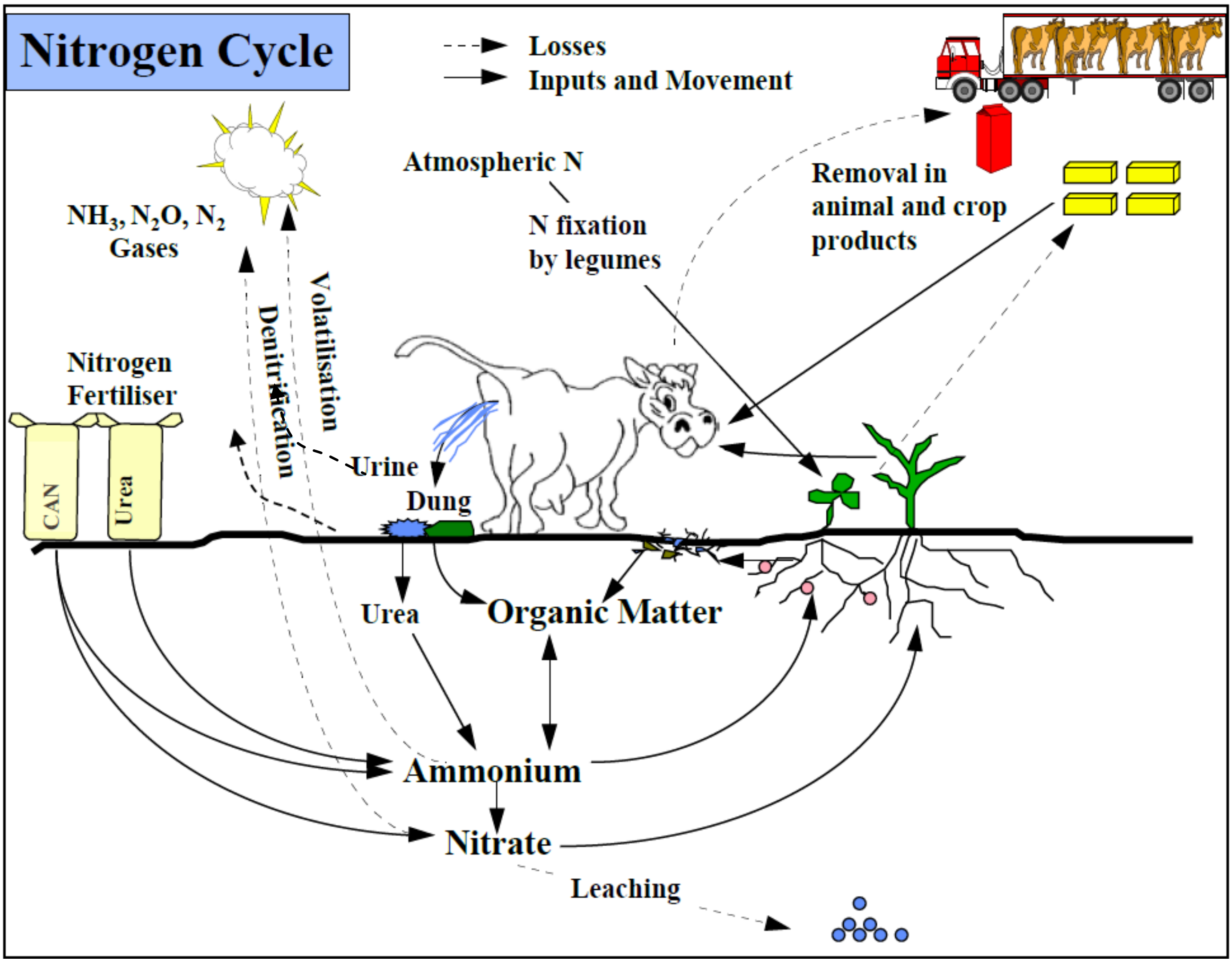

Figure 3.2 The nitrogen cycle of a dairy pasture

Plants can only use two of the many forms of nitrogen, namely, nitrate (NO_3) and ammonium (NH_4). Therefore, other forms of nitrogen need to be converted to either nitrate or ammonium before the plant can use them.

The conversion process is carried out by various soil micro-organisms, such as fungi and bacteria, and by chemical reactions in the soil - See Chapter 5.

Major losses of nitrogen occur through leaching, denitrification (breakdown of nitrogen compounds to less available forms), volatilisation (conversion of nitrogen to gaseous forms, which are lost to the atmosphere), and the removal of animal products and fodder (See Chapter 12.3)

Nitrogen is returned to the soil with varying levels of efficiency via animal manure and urine, bought-in feeds, nitrogenous fertilisers, and legumes (See the nitrogen cycle animation).

3.4.1.3 Where do legumes fit in?

The atmosphere is about 80% N, but plants such as legumes are able to use nitrogen from the air. They are able to do this by the development of small growths on their root system called nodules. These nodules contain bacteria called rhizobia, which can ‘fix’, or convert, nitrogen from the air into a plant-available form. This fixed nitrogen then becomes part of the pasture nitrogen cycle (see Figure 3.2). The nitrogen becomes available to grasses when the nodules or legume plants (roots, stems and leaves) die or are eaten by an animal then returned as dung or urine. The legume root nodules have a life span of up to 6 weeks, and new ones are constantly developing. The nodules are a pinkish colour when actively fixing nitrogen; however, they may be white (N deficient), green (when nodules become older) or brown (decomposing) if growing in suboptimal conditions.

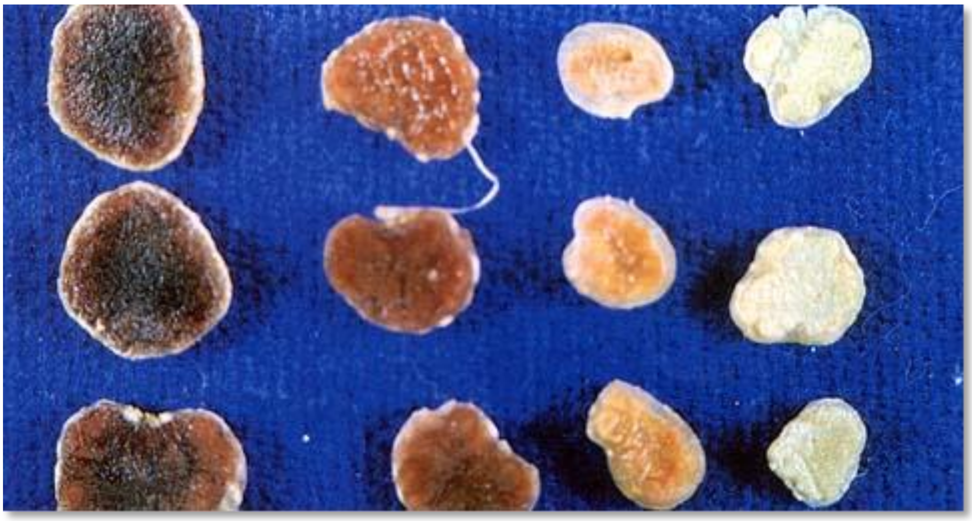

Figure 3.3 Nodules sliced in half, showing the pinkish colour (leghaemoglobin) indicative of healthy nodules in the centre, with old decomposing nodules on the left and ineffective white nodules on the right.
Source: http://www.dpi.nsw.gov.au/agriculture/pastures/pastures-and-rangelands/establishment/inoculating-legume-seed

In a ryegrass/clover pasture, 50 to 250 kg N/ha/year can be fixed by the clover, depending on such factors as the clover content of the pasture, soil fertility, and moisture availability. This is equivalent to applying urea (which is 46% nitrogen) at a rate of 109 to 543 kg of urea/ha/year. At a price of $500/tonne spread for urea, this is equivalent to about $55 to $270/ha/year. However, the amount of N fixed by clover in Australian dairy pastures is typically 50 kg N/ha/year or less due to the low legume content - see Chapter 12.2.1.

The rhizobia bacteria supply nitrogen compounds to the legume, and the legume supplies carbohydrates (energy) to the nitrogen-fixing rhizobia bacteria. If the soil environment is not ideal (for example, high acidity, lack of other nutrients, dry soils or salinity), these bacteria are adversely affected, which results in reduced nitrogen fixation and thus reduced pasture growth.

The various legume species often require 'inoculation' of the seed (mixing the seed with rhizobia bacteria) at sowing. Specific strains of the rhizobia bacteria are required for each of the major legume groups. For example, sub clovers require inoculant strain C, and white clover requires inoculant strain B.

It is essential to inoculate legume seeds when sowing into virgin, recently flooded, or newly cleared land because the soil will not have enough of the required rhizobia naturally present. Although it may not always be necessary to inoculate when resowing an old pasture, it is advisable.

Lime coating of the legume seed ensures that the soil environment surrounding the seed is more favourable (less acidic) for the rhizobia bacteria and young legume roots. In addition, several proprietary forms of coating (e.g. Prillcote® and Agricote®) contain ingredients to ensure longer survival of the inoculant if sowing is likely to be delayed. Insecticides can also be included in the coating to provide pasture plants with a degree of protection against some insect pests after germination (e.g. lucerne flea or red-legged earth mite).

3.4.2 Phosphorus

Phosphorus (P) helps run the 'power station' inside every plant cell and has a key role in energy storage and transfer. Phosphorus is necessary for all growth processes and for the nodulation of rhizobia bacteria and nitrogen fixation.

3.4.2.1 Phosphorus deficiency symptoms

Phosphorus deficiency symptoms include:

- Stunted growth, weak roots and shoots, fewer tillers.
- Depressed yields.
- Purple tints on small leaves.
- Small, dark green leaves on mature clover plants.

Growth of new pastures can be severely restricted when the soil is deficient in phosphorus. As animals derive their phosphorus requirements from pastures, animal production may also be affected by low phosphorus levels.

Phosphorus is a mobile nutrient within the plant and is moved to the actively growing tissue, such as root tips and growing points in the tops of plants – see Chapter 8.6.2.1. Therefore, deficiency symptoms occur first in the older leaves.

It is important that plants have an adequate supply of phosphorus to ensure recovery and regrowth after grazing. Likewise, newly sown pastures benefit from a supply of readily available phosphorus close to the germinating seed to help quickly develop a large root system.

3.4.2.2 The phosphorus cycle

When phosphorus fertiliser (for example, superphosphate) is applied to a pasture, the phosphorus enters a phosphorus cycle. As can be seen from Figure 3.4, the phosphorus can move around the system, as well as be lost from the system, via many different pathways. The P cycle is very complex, involving a great deal of interaction and chemical reactions in the soil.

The phosphorus in the soil can be taken up by plants, then consumed by animals and returned to the soil in ruminant dung. The phosphorus can also move about in the soil, changing in its chemical form and in its availability to plants.

Being hygroscopic (moisture-attracting) in nature, superphosphate granules attract moisture from the atmosphere, leading to the granule releasing P even in very dry conditions. Despite the movement shown in Figure 3.4, phosphorus in the soil is relatively immobile. Many chemical reactions take place when phosphorus is applied to the soil, and only a small proportion remains in solution and readily available to the plants (see Chapter 9.2.5). The remainder is 'bonded' (or 'fixed' or 'sorbed') in a less available form to the surface of the soil clay particles and organic matter. A proportion of this fixed phosphorus does become available over a period of time and is referred to as the soil phosphorus reserve – See Section 3.4.2.3.3 'Soil sorption'.

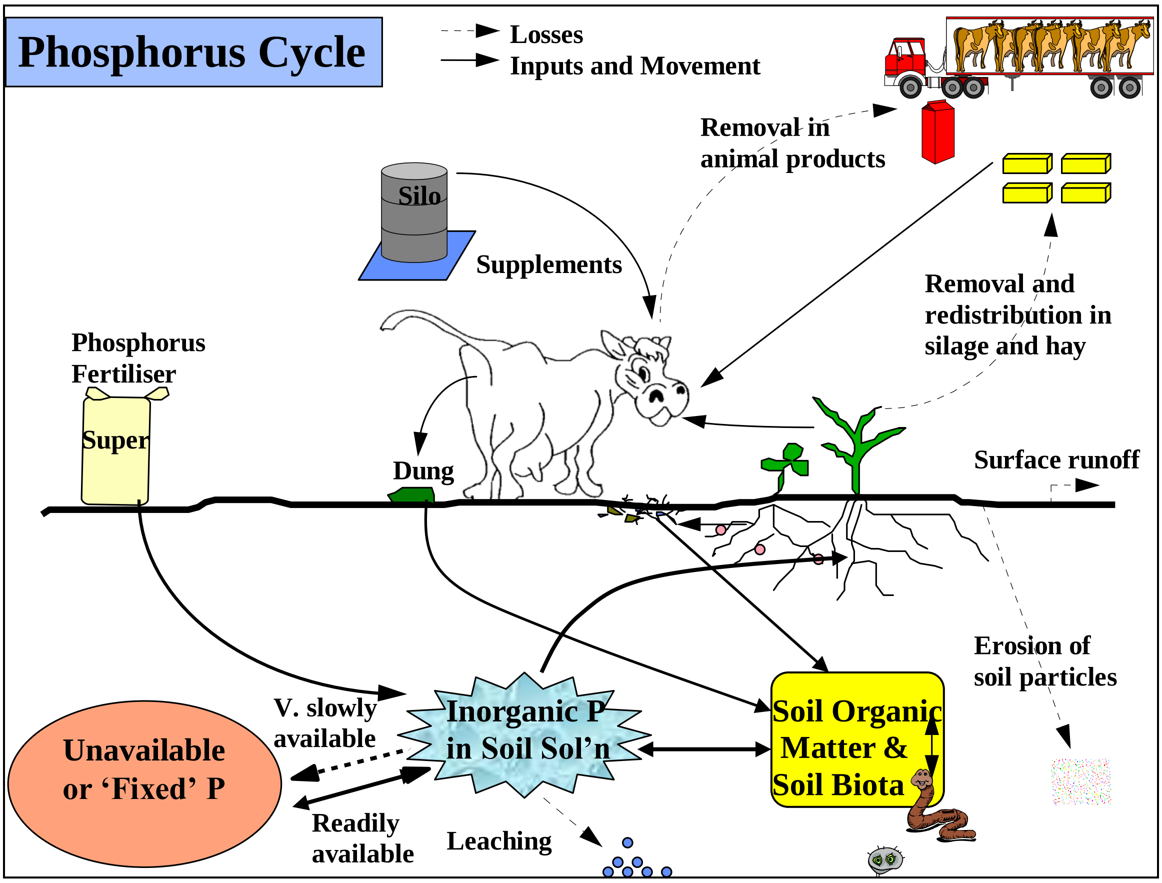

Figure 3.4 The phosphorus cycle of a dairy pasture

3.4.2.3 Losses of phosphorus

Phosphorus; supplied either as fertiliser applications or naturally from the soil, undergoes losses by various mechanisms. These losses occur by:

- Product removal.
- Redistribution of ruminant dung.
- Soil losses:
  - Leaching.
  - Surface runoff.
  - Soil sorption (fixation).
  - Erosion.

3.4.2.3.1 *Removal of phosphorus in plant and animal products*

Phosphorus is lost from the pasture in plant and animal products (milk and meat). Cutting hay or silage on a paddock and not feeding it back on the same paddock can very quickly 'mine' the paddock's fertility. Product removal off farm will result in a certain amount of phosphorus leaving the farm. Milk production results in much higher removal rate of phosphorus than does beef or wool production.

3.4.2.3.2 *Redistribution of faeces*

Large quantities of phosphorus can be removed or relocated within the growing pasture through the behaviour and management of the dairy herd. Cows graze pasture from all over the paddock but deposit a greater proportion of dung around gateways, stock camps, feedpads, shelter belts, water troughs, and other places where cattle gather. Dung dropped on the dairy yard and laneways can account for approximately 10% of total dung. The amount will vary according to how long the animals have been off pasture and their level of harmony in the dairy shed and yard. Cattle will deposit more dung and urine in the laneways, shed and yard if they are continually upset by dogs or operators. The nutrients contained in dung, urine, milk and those retained are listed in Table 3.2.

Table 3.2 Fate of nutrients consumed by lactating dairy cows.

NUTRIENT	% IN FAECES	% IN URINE	% IN MILK	% RETAINED
Nitrogen (N)	26	53	17	4
Phosphorus (P)	66	0	26	8
Potassium (K)	11	81	5	3

Source: During (1984).

Proportionally more of the phosphorus taken up by dairy cows when they graze pasture is retained by the cows and lost from the grazing area than is the case for potassium and nitrogen. Conversely, most of the potassium ends up in the urine. Table 3.2 illustrates just how little of what is eaten by a lactating dairy cow is actually retained. For information on cycling and losses of a wider range of nutrients see the article by Michael Russelle (2012).

3.4.2.3.3 *Soil losses*

Leaching: Despite the solubility of a single superphosphate granule in water, the phosphate ion is generally not leached (washed through the soil profile), as it is rapidly tied up in various forms soon after application. The amount of leaching that occurs in soils varies widely according to the type of nutrient, soil type, and amount of rainfall. Leaching is related to the amount of organic matter or the amount and types of clay minerals to which the phosphorus can adsorb (attach). Leaching is more of a problem in the sandy soil types (since they contain low amounts of organic matter and clay minerals), in areas of high rainfall, or when phosphorus is lost in surface runoff when fertiliser is applied just before a heavy rainfall event.

Phosphorus may also move down the profile in soils that are prone to cracking and in soils that have reached saturated levels of phosphorus.

We do not have accurate figures for this loss in most Australian soils under a pasture situation, but leaching of phosphorus is known to be relatively low in most soils types. Sulphur, boron and nitrogen are much more prone to leaching than phosphorus is.

Surface runoff on irrigated farms: As much as 11% of applied phosphorus can be carried away in irrigation water. See Chapter 10.5.2 for information on ways to reduce these losses.

Surface runoff on dryland farms: A small amount of applied phosphorus may be lost via surface water carrying away minute amounts of dissolved phosphorus in the short term; especially if highly water soluble fertiliser forms e.g. superphosphate are used. Most phosphorus lost in runoff is phosphorus present in pasture residues and other soil biota. This amount of dissolved phosphorus is much higher if a heavy rainfall occurs soon after applying the fertiliser. Research has shown that, on clay loam soils, the loss of P in surface runoff is reduced by 50% if rain falls 4 days after application and by 75% if rain occurs after 7 days, compared to when rain falls immediately after application.

The major effect of this loss is that phosphorus is carried to dams and lakes and, in combination with the plentiful supply of nitrogen in these areas, allows blue-green algal blooms to occur. Losses from phosphorus dissolved in soil moisture, especially following heavy rain, are dependent on the time since application of fertiliser, soil type, rainfall intensity, slope, etc. This is an area that has attracted much research with the **Phosphorus Environmental Risk Index (PERI)** now providing an indication as to the amount of phosphorus held in the soil that is adequate for pasture or crop production, with anything above this being excessive and at risk of leaching into waterways. See Chapter 10.5.2 for tips on how to reduce these losses.

Sorption by soil: Phosphorus tends to undergo sequential reactions that produce phosphorus-containing compounds of lower and lower solubility when applied to both acidic and alkaline soils. Therefore, the longer the P remains in the soil, the less soluble it is and the less available it becomes for plant uptake.

The primary factors governing the sorption of P in the soil profile include:

- Soil pH; the more acid the greater the retention,
- Distribution of soil particle sizes; soil texture with sandy soils having greater leaching ability,
- Presence of reactive iron (Fe) and aluminium (Al),
- Organic matter incorporation,
- Nature of adsorbed cations as well as anion adsorption.

When phosphorus is first applied to soil, a rapid reaction removes the soluble P from soil solution. Slower reactions then continue to gradually reduce P solubility for months or even years as the phosphate compounds age.

Imagine a fountain cascading down a series of steps with the steps indicating time and decreasing availability of P to plants. The soluble P, applied at the top, becomes much less available to plants over time due to an ever-increasing strength of P sorption by soil compounds such as iron, aluminium and manganese phosphate, from the top of the cascade to the bottom.

Soils high in organic matter or clay content have a stronger phosphorus-fixing capacity than do sandy soils. Some clay soil types (for example, krasnozems, or red soils) adsorb more phosphorus than other clay soils because of the type of clay mineral in the topsoil. Most of this adsorbed phosphorus is not available to the plant, although some may become available over time.

Soils with high aluminium and iron levels, such as red soils of volcanic origin, usually have a very high phosphorus-fixing (or sorbing) capacity. In these soils, the phosphorus reacts with the aluminium or iron to form relatively insoluble chemical compounds, which results in a higher proportion of applied phosphorus being locked up and unavailable to plants.

Soils vary widely in the amount of phosphorus (and other nutrients) ‘fixed’ in soils. The **Phosphorus Buffering Index** (PBI) has been developed and has been widely adopted across many states and industries to help with differentiating soil P-fixing ability - see Chapters 9.2.5.1 and 15.5.2.

Erosion of soil particles: Since phosphorus binds quickly to soil particles (in other words, becomes particulate P), it is obvious that soil erosion can result in phosphorus losses. Such erosion losses can occur along stream banks; via tunnel, gully or sheet erosion; from newly renovated or laser-graded irrigation areas; and from severely pugged pastures or sacrifice paddocks. The quantity of P lost by erosion is usually low but may be a significant contributor to the environmental problem of eutrophication (high levels of nutrients) causing unwanted and large growth of water weeds or an algal bloom of, say, blue-green algae.

Recent research has provided some indication of the extent of this loss and is providing some guidelines for reduction of P losses. Obviously, any management that reduces loose soil particles entering waterways will achieve this. Accurate figures for this loss of phosphorus are difficult to assess for individual farms. It is small but should be reduced or completely stopped, if possible.

3.4.3 Potassium

Potassium (K) is needed for a wide range of important processes within the plant, including cell wall development, flowering and seed set. Potassium has a key role in regulating water uptake and the flow of nutrients in the sap stream of the plant. It helps legumes fix nitrogen and also helps the plant to resist stress from weather, insects and diseases.

3.4.3.1 Potassium deficiency symptoms

Potassium deficiency symptoms include:

- Reduced growth (possibly up to a 50% drop in yield of some crops before deficiency symptoms appear).
- Yellowing and whitish spots along the outer margin of clover and lucerne leaves, which subsequently develop a necrosis, or deadening, of the outer leaf margins – see Figure 3.5
- In grass, a pale-green colour, which may be followed by a pronounced yellowing to browning off, beginning with the tips of older leaves (called chlorosis, or tip burn). These symptoms are not sufficiently different from nitrogen deficiency or frost effect to allow them to be used alone to identify a K deficiency in grass.
- Excess salinity may also cause brown, necrotic leaf margins, but this occurs mostly in the younger leaves.

Figure 3.5 Lucerne leaves showing varying degrees of potassium deficiency. *Source:* David Hall.

Potassium is very mobile in the plant, and deficiency symptoms initially occur in the older leaves – see Chapter 8.6.2.1. Deficiencies are most obvious at times of peak potassium demand; in other words, Spring. Potassium deficiencies may not appear if a combination of nutrient deficiencies, such as phosphorus and potassium together, are limiting growth.

Grasses tend to be more deeply rooted and have more fibrous roots than clovers and therefore can compete more strongly for potassium. A symptom of potassium deficiency is a grass-dominant pasture that often has an abundance of weeds. Older urine patches may show good grass or clover growth; if clover is present in the pasture, as 80% to 90% of the potassium in pasture consumed by stock is excreted in urine.

Deficiencies of potassium are most likely to occur on lighter sandy soils and regular ‘day’ paddocks and particularly in paddocks that have been repeatedly cut for hay or silage.

3.4.3.2 The potassium cycle

Potassium in the soil-pasture system (Figure 3.6) is cycled in a similar way to phosphorus. Animals grazing pastures recycle most of the potassium they take in as urine. However, they concentrate this potassium return around water troughs, stock camps and yards. Hay-making and silage-making are the major ways that potassium reserves are removed or redistributed – See Appendix H for nutrient contents of feeds.

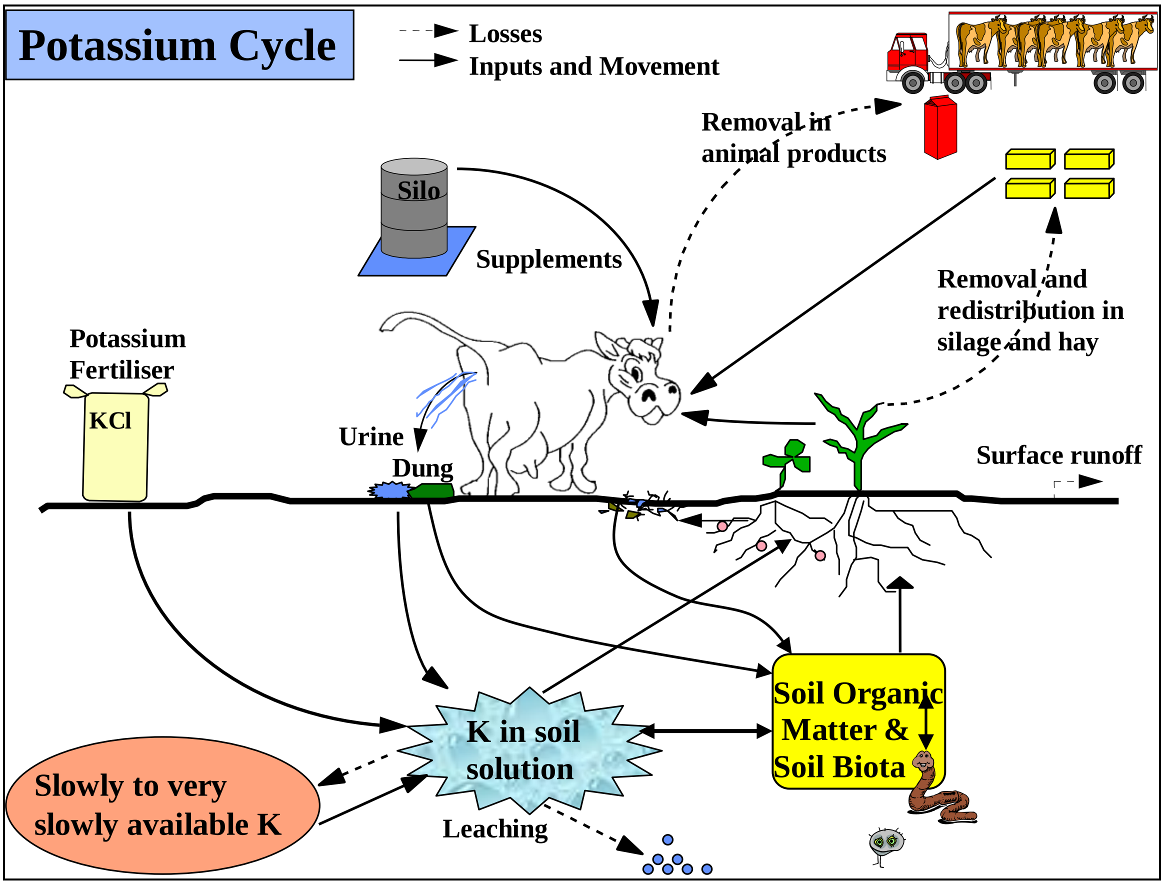

Figure 3.6 The potassium cycle of a dairy pasture

Unlike phosphorus, when potassium is applied as a fertiliser it does not react with the soil to form insoluble compounds. However, like phosphorus, potassium does not form any gases that could be lost to the atmosphere like nitrogen does. The soil's cation exchange properties and mineral weathering influence its behaviour in the soil. Potassium, unlike P and N, causes no off-site environmental problems, such as eutrophication, when it leaves the soil system.

Potassium can be temporarily held in clay particles as exchangeable potassium and becomes available for plant uptake when it moves back into the soil solution. Dry soil immobilises potassium, thereby reducing its availability temporarily. Waterlogging also reduces K uptake due to lack of oxygen. Unlike the P in single superphosphate, if K is applied to dry soils, it will not be utilised until rain or irrigation occurs.

Potassium is found in four forms in the soil: mineral non-exchangeable potassium, non-exchangeable potassium, exchangeable potassium, and potassium in soil solution (water-soluble potassium) - see Figure 3.7. The total amount of K present in each form will depend on the potassium content of the parent material, extent of weathering and leaching, redistribution by plants (fodder) and animals, and the amount of applied potassium.

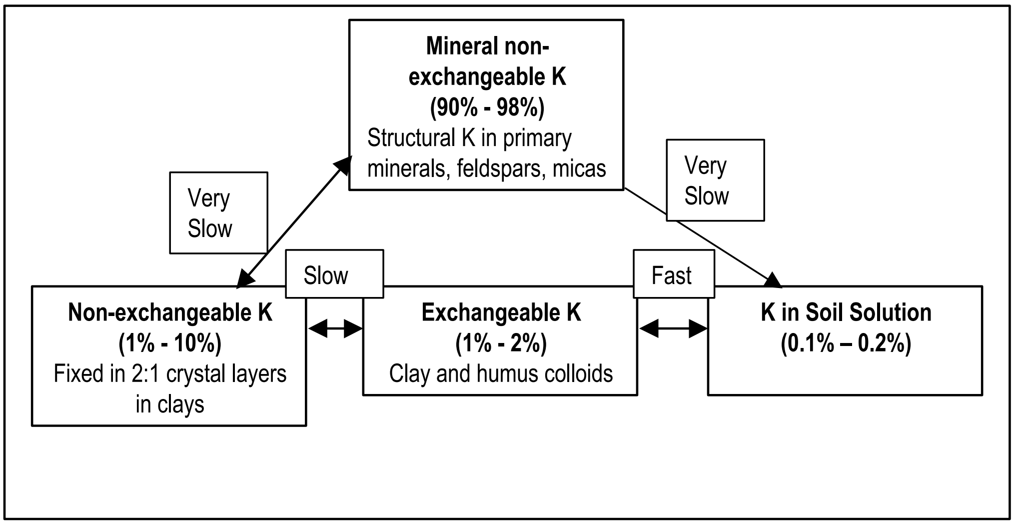

Figure 3.7 Forms of potassium in the soil and their plant availability.

Approximately 90% to 98% of the total soil K is in the non-exchangeable form, although some becomes available very slowly due to weathering. In the non-exchangeable form it is part of the internal structure of clays, mineral particles and parent rock material. This form is not available for plant uptake. Approximately 1% to 2% is in the exchangeable form and is lightly bound or held (retained) on the surface of clay particles and organic matter. This form becomes available rapidly and easily to plants when it exchanges with other cations and moves back into the soil solution. Hence, it is referred to as '**exchangeable K**' when it is measured in a soil test - see 'Exchangeable potassium' in Chapter 9.2.9.5. Approximately 0.1% to 0.2% is in the soil solution and readily available for uptake by plants. Both the soil solution and exchangeable potassium are measured in a soil test as '**available K**' - see Chapter 9.2.6.

3.4.3.3 Losses of potassium

The potential for fixation or leaching of potassium depends largely on the soil clay content and its mineralogy; the level of soil organic matter; and the climate, particularly rainfall or irrigation levels.

In sandy soils low in clay, potassium largely remains in the soil solution and can be leached below the plant root zone and potentially into the ground water. Such lighter soils, especially in high-rainfall districts or under high irrigation levels, are more prone to potassium deficiencies due to this leaching effect.

Heavy soils (such as clays) or soils high in organic matter are usually high in potassium. However, some can be low in potassium.

3.4.3.4 Responses to potassium fertilisers

In rainfall-dependent pastures, soil testing and test strips provide an excellent prediction of likely potassium responses. If a response is to be seen, it will occur in the spring following an autumn or early winter application because of the rapid demand for potassium in spring. The value of soil testing versus plant tissue testing for potassium needs to be assessed in light of soil texture and extent of the following rainfall. Light textured (sandy) soils can leach the soil potassium below the pasture root zone, so in these situations plant testing will be more reliable.

It must be recognised that dairying is an intensive system and significant rates of potassium are being removed, so responses to potassium may occur sometime in the future.

3.4.3.5 Animal health implications

High rates of potassium fertilisers can cause low plant calcium and magnesium levels, which may induce the metabolic disorders hypocalcaemia (**milk fever** – see Section 3.4.5.2) and hypomagnesaemia (**grass tetany** – see Section 3.4.6.2) respectively. It is important to understand that dairy cows can acquire the grass tetany disorder from grazing pastures that contain excessive potassium; whether from fertiliser or inherent levels, in particular from effluent fields that accumulates in some cases very high soil potassium levels. For more information about grass tetany follow the links:

- http://www.dairyaustralia.com.au/Animals-feed-and-environment/Animal-health/Animal-health-fast-facts/Downer-cows/Grass-tetany.aspx
- http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0013/111334/Grass-tetany-in-cattle.pdf
- http://www.dpiw.tas.gov.au/inter/nsf/WebPages/RPIO-4ZM89P?open

3.4.4 Sulphur

Sulphur (S) is required for the formation of several amino acids, proteins, and vitamins and for chlorophyll production. It also helps the plant to resist stress from weather, insects and diseases.

3.4.4.1 Sulphur deficiency symptoms

Sulphur deficiency symptoms include:

- Plants appear stunted.
- Plants tend to become spindly with thin stems and petioles on legumes.
- Small, pale, yellow-green leaves with lighter coloured veins.
- Poor development and low numbers of nodules on legumes.

Plants severely deficient in sulphur show similar symptoms to nitrogen deficiency. The major difference between sulphur deficiency and nitrogen deficiency is that sulphur is immobile within the plant, and deficiency symptoms appear first in the younger leaves, whereas nitrogen deficiency affects the older leaves first. This is true for grasses, however S is more mobile in subterranean clover so the whole plant rather than young leaves typically becomes lemon yellow and, if the deficiency is severe, clover leaves cup upwards. When sulphur levels are low, grasses, because of their larger root system, will compete very strongly for the available sulphur, to the detriment of the legumes. This results in a grass-dominated sward and reduced pasture quality.

3.4.4.2 The Sulphur cycle

The sulphur cycle is shown in Figure 3.8. Significant amounts of sulphur are removed through meat and plants harvested for fodder, but only small amounts are removed through milk - see Appendix H.

In the past, sulphur deficiencies have been rare because most farmers used low-analysis fertilisers, such as single superphosphate, which contains high levels of sulphur (11%) – see Chapter 11.3.1. However, if high-analysis fertilisers, such as triple superphosphate and Diammonium Phosphate (DAP) are used, then the potential for sulphur deficiencies may increase because these fertilisers contain much lower levels of sulphur. For example, triple superphosphate contains only 1% S.

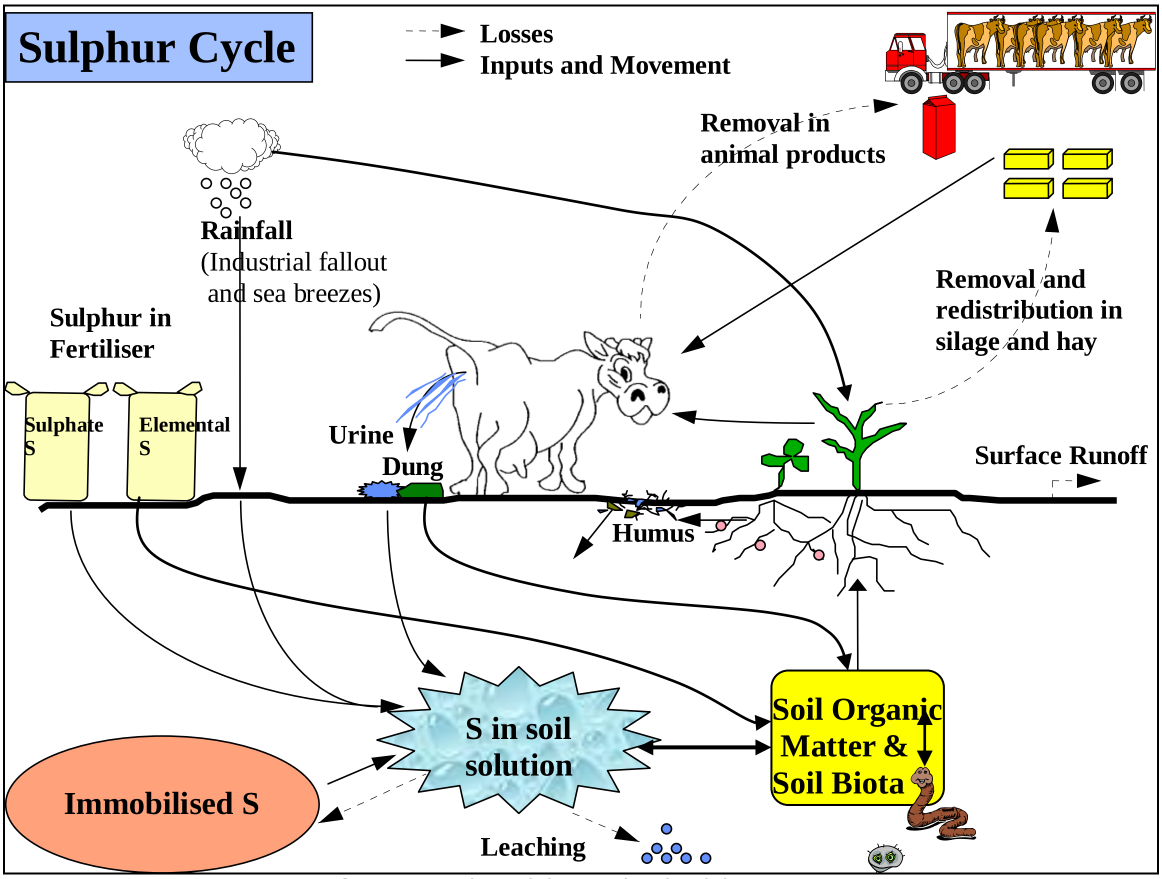

Figure 3.8 The sulphur cycle of a dairy pasture

Most sulphur in soils is derived from soil organic matter and must be mineralised (converted to the inorganic sulphate form, SO_4^{2-}), before it can be taken up by the plants. In this form, it is very soluble and may be more readily leached, particularly from sandy soils or in high rainfall conditions or under high levels of irrigation. In some soils, the sulphate is adsorbed on (fixed to) soil particles, which reduces leaching. This adsorbed sulphur becomes available as it is released back into the soil solution - see Chapter 9.2.7.

3.4.4.3 Forms of sulphur

Two forms of sulphur are used in fertilisers. They are sulphate sulphur (SO_4^{2-}), such as in superphosphate, and elemental sulphur (S elemental). Sulphate sulphur (SO_4^{2-}) is readily available for plant uptake and more effective on very deficient soils. The elemental form (S elemental) must be converted by bacteria in the soil to the sulphate form before it is readily available to the plant. Therefore, this more slowly available form of sulphur (S elemental) may be more suitable on sandy soils that have less organic matter and are susceptible to leaching. Where a soil test reveals a sulphur deficiency, then the sulphate form (SO_4^{2-}) will provide a quicker response.

Elemental sulphur (S elemental) applied at a rate of up to about 30 kg/ha has negligible effect on soil properties but, if applied in large quantities (over 800 kg/ha), can lower the pH of soils. The extent of pH reduction and reaction rate is influenced by the pH buffering capacity of the soil and the original pH level. The rate at which elemental sulphur converts to sulphate sulphur depends on the type of sulphur applied, particle size of the material, soil temperature, soil moisture content and population levels of the sulphur-oxidising bacteria.

If soil sulphur levels are high, then it is usually a lower-cost option to use a low-sulphur phosphorus fertiliser, such as triple superphosphate.

3.4.5 Calcium

Calcium (Ca) is usually in adequate supply for plant growth. It is involved in the proper functioning of growing points (especially root tips), maintaining strong cell walls, and seed set in clovers.

3.4.5.1 Calcium deficiency symptoms

Deficiency symptoms are rare because calcium is common in the earth's surface. It is also a component in many fertiliser products and in lime and gypsum. Soils low in calcium usually have associated adverse conditions, such as low pH and high aluminium, iron, and manganese - see 'Exchangeable calcium' in Chapter 9.2.9.3. In very rare situations, heavy applications of potassium may induce a calcium deficiency, particularly on very acid soils, possibly resulting in hypocalcaemia, or milk fever.

Deficiency symptoms can also occur in strongly acidic peaty soils, where the calcium content may be less than 0.1%.

3.4.5.2 Animal health implications

Milk fever is caused by low levels of calcium in the blood stream of cattle. This often occurs at or soon after calving when the cow's requirements for calcium are high. When high rates of potassium (for example, muriate of potash - MOP) and nitrogenous fertilisers that produce ammonium ions (for example, DAP) are used together, the potassium or ammonium ions interfere with plant root uptake of calcium, thereby raising the risk of inducing milk fever - see Figure 3.9. However, nitrogenous fertilisers applied on their own do not cause this problem.

For more information about milk fever follow the links:

- http://www.dpi.vic.gov.au/agriculture/pests-diseases-and-weeds/animal-diseases/beef-and-dairy-cows/milk-fever-hypocalcaemia-in-cows
- http://www.dairyaustralia.com.au/Animals-feed-and-environment/Animal-health/Animal-health-fast-facts/Downer-cows/Milk-fever.aspx
- http://www.daff.qld.gov.au/27_15479.htm
- http://www.dairyaustralia.com.au/Levy-investment/Case-studies/Transition-cow-management.aspx

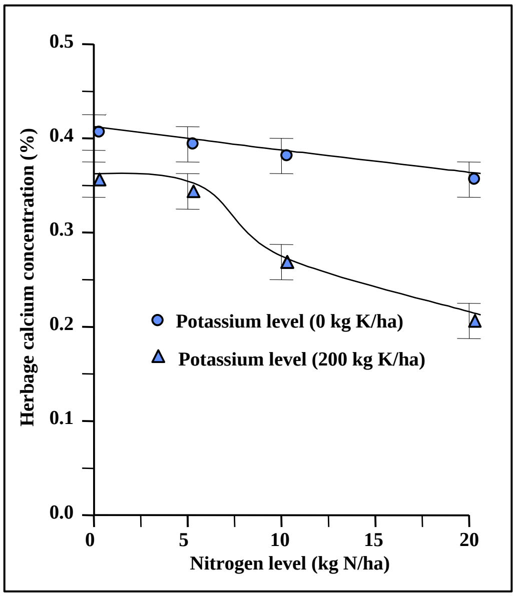

Figure 3.9 Effect of DAP plus MOP on calcium concentration in pasture.
Source: Bolan (1998).

3.4.6 Magnesium

Magnesium (Mg), like calcium, is usually present in sufficient quantities in the soil for plant growth; and pasture deficiencies are rare. It is an essential component of chlorophyll and is required for the transport of phosphorus around the plant.

3.4.6.1 Magnesium deficiency symptoms

Magnesium deficiency symptoms, rarely seen in most Australian states include:

- Yellowing of leaves while the leaf veins remain green.
- Abnormally thin leaves.
- Older leaves mainly affected and affected first.

Magnesium is mobile within the plant, and a deficiency presents itself in the older leaves first.

The main source of magnesium for pasture deficiencies is dolomite (a compound mineral of calcium carbonate and magnesium carbonate containing 8% to 13% Mg).

As with calcium, magnesium plays an important role in the cation exchange capacity in the soil - see ‘Exchangeable magnesium’ in Chapter 9.2.9.4. However, magnesium is more exchangeable than calcium, and the magnesium ion is more soluble and susceptible to leaching.

3.4.6.2 Animal health implications

In most pasture situations, magnesium is present in adequate quantities for plant growth. However, the level of magnesium in the grass may be too low to meet the animals’ requirements and may lead to a condition known as **grass tetany**. Pasture magnesium levels are highest in summer and lowest in late winter and early spring. Grasses, which contain less magnesium than legumes do over most of the year, are usually dominant in late winter and early spring. Thus, grass tetany has typically occurred in late winter and early spring. Also, low temperatures and wet soils can reduce magnesium levels in forage.

However, high application rates of potassium fertilisers or dairy shed effluent can result in a **luxury consumption** of potassium. In other words, the plant takes up more soluble K than it requires and no yield increase occurs. This high concentration of plant potassium can often result in a lower proportion of other nutrient cations in the plant, such as calcium, sodium and, in particular, magnesium. These low magnesium levels may induce hypomagnesaemia, or grass tetany, in cattle. With more farmers applying more potassium and potassium blends in early spring, there appears to be anecdotal evidence that grass tetany is becoming more prevalent in the following autumn.

Grass tetany may also be caused by applying high rates of nitrogenous and potassium fertilisers, thus releasing ammonium ions and potassium ions together – see Figure 3.10. The ammonium and potassium ions both compete with the uptake of magnesium ions by the plant root, thus resulting in a lower magnesium concentration the plants. The use of nitrogenous fertilisers on their own does not cause this problem.

Also, animals consuming pasture or fodder high in potassium concentration can often upset the magnesium movement through the rumen and intestinal walls, consequently inducing a magnesium deficiency leading to grass tetany.

The cation exchange section of your soil tests can be used to determine the ratio of magnesium to potassium in the tested paddocks - see ‘Exchangeable magnesium’ in Chapter 9.2.9.4.

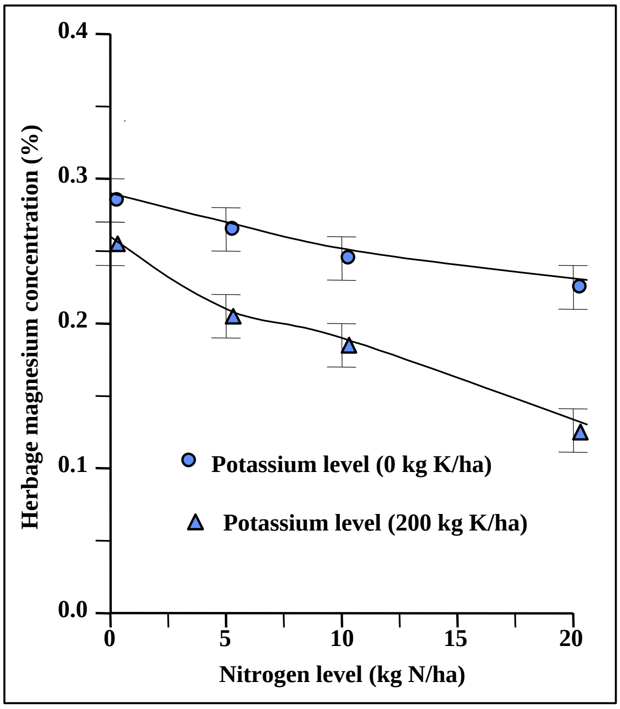

Figure 3.10 Effect of DAP plus MOP on magnesium concentration in pasture.
Source: Bolan (1998).

Grass tetany can be largely prevented by feeding animals a magnesium supplement at a rate of 60 grams/head/day mixed with hay or a grain supplement, or dusted on pasture. The main sources of magnesium used in this way are Granomag, Magox or Causmag (magnesium oxide containing 50% to 56% Mg) and Epsom salts (magnesium sulphate containing 9.6% Mg).

For more information on grass tetany, refer to the web links listed in Section 3.4.3.5.

3.5 Minor nutrients or trace elements

Although only required in small amounts, minor nutrients (micronutrients, or trace elements) are essential for plant growth. These nutrients often act as catalysts in chemical reactions. It is possible to have toxicities of trace elements, as well as deficiencies.

The micronutrients essential for plant growth are listed in Table 3.1. (See also Table D.1 in Appendix D.) Particular trace element deficiencies are generally restricted to specific soil types or localities.

Many products in the market place extol the virtues of trace elements that are 'absolutely needed' by plants. Some companies use soil tests to determine whether trace elements are deficient in the soil. On the basis of many field and laboratory experiments and much experience, the Department of Primary Industries Victoria has found that soil tests are not a reliable method of detecting a trace element deficiency. Plant tissue tests (see Chapter 8.4) are far more reliable for assessing what was available for plant uptake, but even these are not always correct and must be taken at the appropriate times of the year to increase their accuracy and reliability. In addition, recommendations should be based on research conducted in Australian soils or on Australian plants, not on overseas data.

Some of the micronutrient deficiencies in plants can cause nutrient deficiencies in the animals that graze those plants. In some cases (for example, copper and manganese), these micronutrients are also essential for plant growth. In other cases (for example, selenium), they are not required by the plant. Thus, in many cases of animal nutrient deficiency, it may be better to treat the animal rather than to apply fertilisers to pastures to overcome the problem. It is therefore important to discuss trace element issues with your local veterinarian.

Though plant testing is the recommended method for testing for trace element disorders in plants, it is usually unreliable for trace element requirements for animal nutrition. Testing body fluids (blood, urine, saliva) and tissues (liver, bone) is often required to determine whether animals have a trace element disorder. Seeking veterinary advice in addition to, or instead of, plant tissue testing is recommended.

This manual only touches on the complex issue of trace elements and their deficiency and toxicity implications. Several high-quality publications containing colour photographs of deficiency and toxicity symptoms and descriptions are recommended for additional reading. See the References at the end of this chapter.

Some of the more common trace elements likely to be deficient in Australian soils are discussed in this section.

3.5.1 Molybdenum

Molybdenum (Mo) is essential for the health of the rhizobia bacteria associated with the legume root nodules that are responsible for atmospheric nitrogen fixation.

Molybdenum is also directly involved in nitrogen metabolism and specifically implicated in the electron-transfer system (for example, nitrate reductase and enzyme nitrogenous reactions). Molybdenum is the least abundant of the trace elements in the soil and the least required by plants with the exception of nickel.

3.5.1.1 Molybdenum deficiency symptoms

Molybdenum deficiency symptoms may look similar to a nitrogen deficiency (see Section 3.4.1.1), and legumes will have green or grey to white nodules rather than the pinkish-coloured nodules of healthy plants.

Consequently, a lack of molybdenum will reduce the nitrogen-fixing ability and growth of legumes. In effect, molybdenum-deficient plants cannot properly metabolise nitrate nitrogen, even though their tissues may contain considerable amounts of nitrates.

Molybdenum is not sorbed by soil when soil pH (1:5 $CaCl_2$) is greater than 5. Sorption occurs when soil pH is below 5, with sorption increasing as soil pH increasingly falls below 5. Therefore, deficiencies are more likely in acid soils. The application of lime increases soil pH improving the effectiveness of naturally occurring molybdenum present in soil, thereby increasing availability for plant uptake. However, peat soils, which are usually acidic, should not require additional molybdenum, as these soils usually have high levels of molybdenum held within the organic matter. The application of lime to the peaty soils in the Koo-wee-rup area of southern Victoria has been sufficient to rapidly increase the availability of molybdenum and sometimes induce a copper deficiency in livestock.

Correcting a molybdenum deficiency can be by the application of a fertiliser to the soil or in water. Fertiliser products such as superphosphate can be used that have molybdenum added. However if lime is being applied the increase in soil pH may increase the solubility of soil molybdenum preventing any further application.

Applications of 50 to 200 g Mo/ha every 3 to 10 years are required for correcting pastures deficiencies and 50 to 60 g Mo/ha every 5 to 7 years are required on responsive soils for field crops. However, a plant tissue test (see Chapter 8.4) may show that Mo is not required at the 'due time'.

3.5.1.2 Animal health implications

A complex relationship exists between copper, molybdenum, and the sulphates in animal nutrition.

Copper and molybdenum are mutually antagonistic in plant uptake; that is, if one is applied, uptake of the other may be reduced. Conversely, an oversupply of copper can induce a molybdenum deficiency in animals, particularly on lighter-textured soils or when animals are stressed.

Molybdenum toxicity (molybdenosis in ruminants) is not thought to be significant in plants, but excessive molybdenum levels in plants (forage crops) or high rates of molybdenum applications in fertilisers can sometimes induce copper deficiency in livestock. There are complex reactions in the animal's rumen involving molybdenum, sulphur and copper; generally forming a complex product with copper becoming unavailable to the animal. Often these conditions can be subclinical and difficult to diagnose. Therefore copper:molybdenum ratios of animal diets should be monitored and maintained with suitable ranges (5:1 to 10:1).

Sulphate can also sometimes restrict molybdenum uptake by plant roots when the two nutrients are applied together. A high molybdenum content in plants can be dramatically lowered by the addition of sulphates. To avoid copper deficiency in grazing animals, it is generally recommended that copper should be applied when molybdenum is being applied in a fertiliser. However, if plant levels of copper (as determined by a plant tissue analysis; see Chapter 8.4) are at satisfactory levels or higher, then molybdenum can be applied without copper.

In addition, molybdenum should not be applied to pastures limed within the past 12 months, as the combination of applied molybdenum plus the molybdenum released from the soil by the lime may raise the molybdenum levels enough to cause copper deficiencies in livestock.

3.5.2 Copper

Copper (Cu) is required for the formation of enzymes for chlorophyll production, nutrient processing and the plant's exchange of water and oxygen for carbon dioxide. It is also required for seed setting of legumes. Plant responses (in other words, additional growth) due to copper are rare. Like most trace elements excessive quantities of copper can interfere with the uptake of other trace elements like iron; therefore producing iron deficiency symptoms.

3.5.2.1 Copper deficiency symptoms

Copper deficiency symptoms are not very specific in plants, although 'dieback' is common, showing up first in the young growth. Copper deficiencies commonly occur in highly leached acid sands (such as coastal sandy and sandy loam soils), in loams from sandstone, in peat soils, and in highly calcareous alkaline soils. Heavy clay type soils are least likely to be copper deficient.

Copper deficiencies can be correctly by either soil or foliar applications. Copper can be applied as an impurity in some common phosphorus fertilisers, but generally copper is broadcast onto pastures annually using superphosphate with copper as an additive. Broadcasting copper fertiliser is less effective than incorporation as a band into the soil prior to planting, due to its immobility. Because copper is immobile it remains in the soil for plant uptake.

Foliar applications of copper sulphate (bluestone) can be effective in correcting copper deficiency in an existing crop or pasture, however caution should be exercised as the mixture can burn under adverse environmental conditions (e.g. hot dry windy conditions).

Rates of 1.5 to 2 kg Cu/ha applied as fertiliser every 3 to 6 years are required for deficient soils.

3.5.2.2 Animal health implications

Problems with copper are more commonly associated with animal deficiencies than with plant deficiencies. Because animals have a higher copper requirement than plants do, animals may become deficient at copper levels that are sufficient for normal plant growth. Imbalances with excessively high trace elements in the soil (e.g. iron, molybdenum – see Section 3.5.1.2) can induce copper deficiencies in animals with the animal showing typical unthrifty symptoms increasing as body reserves are depleted.

Copper deficiency symptoms are also more obvious in livestock than in plants. The symptoms appear as hair or coat abnormalities (red-coated animals tend to be pale-red or orange), retarded growth and skeletal defects, infertility, and diarrhoea.

It may be necessary to treat the animals directly, particularly if copper deficiency symptoms are evident in livestock.

3.5.3 Zinc

Zinc (Zn) is associated with the formation of chlorophyll and of several enzyme systems required for protein synthesis. It also has a regulatory role in the intake and efficient use of water by plants.

3.5.3.1 Zinc deficiency symptoms

Zinc remains in the older green leaves as it is poorly mobile, so as the deficiency increases symptoms will appear in the middle to younger leaves, deficiency symptoms include:

- Small bronze spots on older leaves of legumes; as spots enlarge, leaves develop a mottled appearance.
- Branching of small, dark green, distorted leaves in the centre of legume plants (called the 'little leaf syndrome' and noted at Yanakie, South Gippsland).
- White stripes in younger leaves of grasses (See Figure 3.11)

Figure 3.11 Showing white stripes; typical of zinc deficiency symptoms in young maize plants
Source: David Hall

Typically, zinc deficiency is associated with leached acidic sandy soils, alkaline soils with considerable calcium carbonate content, and soils with high organic matter. Deficiencies may be temporarily induced by cold, wet weather and have been noted to disappear with the onset of warmer weather.

Zinc deficiency affects millions of hectares throughout Australia. It is associated with many crops and pastures grown across a wide range of soil types, including coastal pastures along eastern and Western Australia and large areas of alkaline cracking soils throughout the dairying regions of all states within Australia. Deficiencies are uncommon in pastures in southern Victoria except on the alkaline coastal soils.

Zinc availability is related to pH; and in the north-west and Goulburn Valley areas, zinc availability is often low on heavily cut laser levelled paddocks after landforming, particularly if they are planted to maize and other fodder crops. In this situation, alkaline subsoils become exposed.

Zinc deficiencies can be successfully corrected by either soil or foliar applications. As zinc is immobile in the soil, placement of zinc close to the developing root system is important. Zinc can be applied to the soil in smaller amounts as a component of some pre-plant fertilisers (e.g. Granulock Z which contains 1% Zn), or in higher concentrations lasting for many years (e.g. zinc sulphate monohydrate which contains 35% Zn). Zinc can also be applied to existing pastures using superphosphate with zinc added. Foliar applications of a zinc sulphate or a chelated form can be applied to an existing crop or pasture to correct an existing deficiency or soil conditions that have reduced the availability of zinc.

3.5.4 Manganese

Manganese (Mn) has several plant-growth functions. It is closely associated with iron, copper and zinc as a catalyst in plant-growth processes; is essential for rapid germination; and plays a role in enzyme systems in seed and new tissues.

3.5.4.1 Manganese deficiency symptoms

Manganese deficiency symptoms include:

- Yellowing between the veins of young leaves due to immobility in plants.
- Eventually spots of dead tissue may drop out, leaving a ‘ragged’ leaf.
- Stunting of growth.
- Reduced flower formation.

> The main factors affecting manganese availability are soil pH and seasonal variability.

The more alkaline the soil, the more likely deficiencies will occur. Conversely, very strongly acidic soils can accumulate toxic levels of manganese – see Section 3.5.4.2. Occasionally, a manganese deficiency can be induced by excessive liming on these acid soils.

Manganese deficiency is more often associated with coastal calcareous soils and deficiencies are more likely to occur in highly alkaline soils with high organic matter.

Due to the seasonal availability of manganese, symptoms may be more prominent in the cooler wetter months and disappear during the warmer months – see Figure 3.12

There is no evidence in Australia of manganese deficiency affecting pasture growth; however it is more common on alkaline cropping soils during the cooler months. Manganese deficiency in pastures can be treated by applying manganese sulphate.

3.5.4.2 Manganese toxicity symptoms

Manganese toxicity symptoms include:

- In sensitive plants (Lucerne and clover), symptoms of toxicity appear in late autumn, initially as a light brown discolouration of the leaf margins, which later become reddish. Waterlogging or root rot can produce similar symptoms, so a plant tissue analysis may be necessary to determine the true problem.
- The plant may die in cases of severe toxicity.

Although rare, manganese toxicity can occur during the warmer months in high rainfall, acid soils (<4.3 pH $CaCl_2$) inherently high in manganese. Figure 3.12 shows the variation in manganese availability with seasonal conditions.

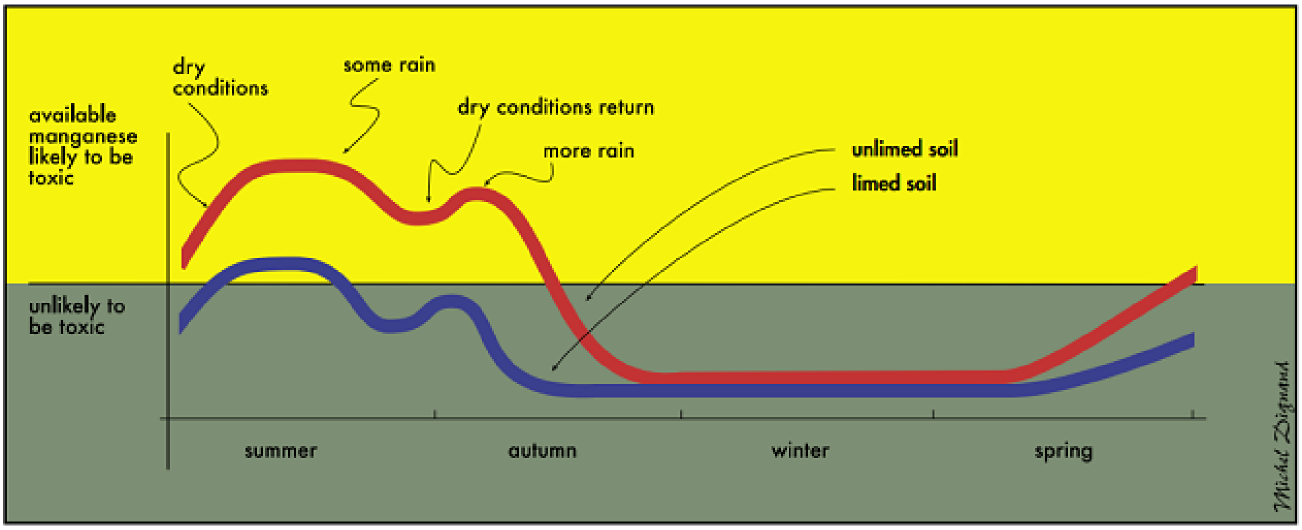

Figure 3.12 Variation of manganese availability with season.
Source: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/167209/soil-acidity-liming.pdf

Manganese toxicity has been found in the northern tropical regions of Australia where high rates of acidifying fertiliser have been used on already acid soils. In these regions, there can be a five-fold increase in manganese availability during the warmer wetter months, and possible toxicity.

Manganese toxicity is also more likely when grazing lupins as they can accumulate high concentrations of manganese. Soil compaction and waterlogging (both of which result in inadequate soil aeration) can produce manganese toxicity in plants; especially in more susceptible crops like canola, lucerne, phalaris and annual medics. – See Table 3.3.

Table 3.3 Tolerance to manganese (Mn), and critical levels* of manganese for pasture plants.

TOLERANCE TO MANGANESE (Mn)	PLANT SPECIES	PLANT CRITICAL LEVEL* OF Mn (mg/kg)
Highly sensitive	lucerne, barrel and burr medics	200 - 400
Sensitive	white and strawberry clovers	400 - 700
Tolerant	sub clover	700 - 1000
Highly tolerant	most pasture grasses	> 1000

***** The critical levels of manganese in this table are the levels in the youngest fully developed leaf that are sufficient to cause a 10% decline in growth.

Source: NSW Agriculture Agfact AC.19 Soil Acidity and Liming.

Manganese toxicity can be reduced by working lime into the soil to a depth of 100 to 150 mm and by correcting waterlogging and soil compaction.

3.5.4.3 Animal health implications

Livestock are susceptible to both manganese toxicities and manganese deficiencies.

A lack of manganese is commonly associated with infertility in cows and impaired growth and bone development. There have been no confirmed cases of manganese deficiency in grazing animals in Australia.

Deficiencies in livestock can be corrected with manganese supplements. Check manganese levels via a plant tissue analysis of mixed herbage if concerned about manganese deficiency in livestock - see Chapter 7.3.2)

3.5.5 Iron

Iron (Fe) is associated with the production of chlorophyll and helps to carry oxygen around the plant cells. Iron is also involved in reactions that convert nitrates to ammonia in the plant.

3.5.5.1 Iron deficiency symptoms

Iron deficiency symptoms include:

- Chlorosis (yellowing) between the leaf veins of the youngest leaves.
- Tips and margins of leaves remain green for the longest time.
- Affected leaves curve upwards.
- Stunting and abnormal growth.

Iron is very immobile in the plant. Thus, deficiency symptoms affect the youngest leaves first.

Deficiencies usually occur on high-pH calcareous soils, waterlogged soils or in soils that have been heavily limed. The correction of iron deficiencies is generally through the application of foliar iron fertilisers; iron sulphate or iron chelate. If iron is applied to the soil it can be converted to an unavailable form, particularly when applied as iron sulphate.

3.5.6 Boron

Boron (B) is mainly involved in the movement of sugars throughout the plant and in seed production in legumes. It is also an important nutrient in the metabolism of nitrogen, carbohydrates, and hormones and is involved in the uptake and efficient use of calcium in the plant.

Boron may induce both toxicities and deficiencies in Australia.

3.5.6.1 Boron deficiency symptoms

Boron deficiency symptoms include:

- Distorted and chlorotic leaves with darker pigmentation along the leaf margins.
- Red and yellow discolouration, particularly in sub clover.
- Poor growth.
- Low seedset.

Deficiencies often tend to disappear after rainfall since plant roots may be unable to access soil boron in dry soils. Lucerne is the main crop in which boron deficiency has been identified in Australia

> Boron deficiencies may occur in humid regions, in highly leached acid sands, in organic (peaty) soils, and in calcareous (alkaline) soils and becomes less available in poorly drained soils.

Occasionally, liming may heighten a boron deficiency. Boron deficiency can be induced in turnip fodder crops by lime application, usually at 3.5 t/ha or higher during seedbed preparation. Boron starts to be sorbed by soil at pH (1:5 $CaCl_2$) values greater than 7-8, with sorption thereafter increasing as pH values increase.

If plant tissue analysis (see Chapter 8.4) indicates a deficiency, then apply boron with a fertiliser application and retest in 2 to 3 years. Seek expert advice to determine the appropriate boron types and application rates. A problem with boron is that amounts required to overcome a deficiency and amounts causing toxicity for plant production are relatively close; so avoid applying too much fertiliser boron. Once induced, toxicity is difficult to ameliorate.

3.5.7 Chlorine

Chlorine (Cl) is thought to stimulate carbohydrate metabolism, some plant enzymes, chlorophyll production, and the water-holding capacity of plant tissues. Chlorine seems to be more important for animals than for plants. Deficiencies of chlorine seldom occur as the chloride ion is continually replenished via rain water, the amount increasing with rainfall quantity and closeness to the sea.

3.5.8 Nickel

Nickel (Ni) is a naturally occurring element found in soil, water, air and biological materials. Its availability in soils is very pH dependant, with the nutrient becoming soluble and therefore plant available when less than pH 6.5 (water). Because nickel is required by plants in such small concentrations (0.1 to 5 mg Ni/kg dry weight) detection of plant deficiencies is difficult in the field.

Nickel is a very mobile nutrient within plants with large proportions being rapidly translocated to seeds from shoots. Nickel has the following roles in plants:

- As a component of the enzyme urease, it is involved in nitrogen metabolism
- Involved in nitrogen translocation within plants
- Involved in bacterial enzymes; including nitrogen fixation.
- Involved in the seed germination and vigour
- Influences plant disease resistance

Nickel is unlikely to become deficient in soils due to its small plant requirement and natural presence throughout most soils. A nickel deficiency, however, could be exacerbated by excessively high applications of other nutrients (zinc, copper, manganese and iron); root damage by nematodes; and cold wet conditions. Nickel is present in cow's milk at 0.1 mg Ni/L and in normal circumstances would not be required as a separate dietary component. However, if it is not present in the animal in sufficient quantities, the main adverse effect is a reduced feed intake and reduced growth.

3.6 Summary

- Nutrients are necessary for plant growth.
- There are two categories of plant nutrients: macronutrients and micronutrients.
- The major nutrients, or macronutrients, supplied by the soil are nitrogen, phosphorus, potassium, sulphur, magnesium and calcium.
- The minor nutrients; also referred to as micronutrients or trace elements, supplied by the soil are molybdenum, copper, zinc, manganese, iron, boron, nickel and chlorine.
- Fertilisers are required to overcome nutrient deficiencies and to replace the nutrients that are lost or removed from the soil and pasture.
- Nutrient cycling (soil-plant-animal) involves nutrients:
  - Being brought onto the farm in various forms.
  - Undergoing ongoing reactions in the soil.
  - Being consumed by animals via the plants.
  - Being lost to the farm system by various means.
- Nutrients are required for a number of tasks associated with plant growth.
- A deficiency in any one of the 17 essential nutrients will reduce pasture growth and animal production.
- Various trace elements are deficient in some dairying areas.
- Although grazing animals receive most of their essential nutrients from pasture; plants and animals have different essential nutrient needs. In regard to trace elements, it is sometimes better to treat animal nutrient deficiencies directly rather than supply the nutrient indirectly through the pasture.

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