

# AUSTRALIAN SUGARCANE NUTRITION MANUAL



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This publication is proudly funded by Sugar Research Australia.  
ISBN-13: 978-0-949678-45-4

Errors identified for silicon third leaf critical values in table 12 on page 27 and potassium fertiliser guidelines for replant and ratoon crops in table 32 on page 60 have been corrected.



Sugar Research Australia Limited 2022 edition of the *Australian Sugarcane Nutrition Manual*, first published in 1994 by BSES Limited.

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Sugar Research Australia Limited acknowledges and thanks its funding providers, including levy payers (sugarcane growers and millers), the Commonwealth Government, and the Queensland Government (Department of Agriculture and Fisheries).

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# INTRODUCTION

**On-farm nutrient management has a key role in farm and industry sustainability, and in ensuring minimal off-site impacts occur.**

**The SIX EASY STEPS® nutrient management program is the foundation of the Australian sugar industry's nutrient/fertiliser guidelines.**

Developed over many years and regularly refined, these guidelines have been adopted by industry and accepted by governments as the most appropriate means of ensuring industry sustainability and environmental responsibility.

The key to sustainable sugarcane nutrition is the application of the correct nutrients in the recommended quantities at the right time at the right place (according to spatial and placement needs).

This manual updates the original *Australian Sugarcane Nutrition Manual* published in 1994. The manual is designed to be a practical guide and reference on most aspects of sugarcane nutrition. At the end of several chapters, a short summary highlights the major points in the chapter.

Because this manual is intended for all sugarcane growing areas in Australia, generalisations have occasionally been made. Local industry advisors can assist growers by combining regional knowledge with the principles of sugarcane nutrition explained here.

Soil health, nutrient management and environmental sustainability is one of eight research, development and adoption focused areas of the SRA Strategic Plan. You can read the full Strategic Plan and more on our current research investments via the SRA website.



## CHAPTER 1

# THE SOIL

Knowledge of the composition of soils and how they are formed assists with an understanding of fertiliser requirements.

Basic soil properties are easy to recognise in the field and can assist in the fundamental understanding of soils and their management. These properties include colour, texture, structure, depth and position in the landscape. In addition, soil chemical properties (usually identified from soil analyses) provide the basis for nutritional recommendations.

### SOIL FORMATION

Most soils are formed from parent materials that are weathered into increasingly smaller particles by processes that include the action of climate and organisms. Organisms such as worms, fungi, plants, algae, insects and bacteria are important in forming soil and in cycling nutrient materials that become available for plant growth.

Three main factors determine what types of soil are formed:

**TYPE OF ROCK:** Coarse-grained, quartz-containing rocks, such as granite and sandstone, produce sandy soils, while fine-grained rocks, such as basalt, produce loam or clay soils.

**CLIMATE:** High rainfall areas generally produce deeper and more leached soils than low rainfall areas.

**LOCATION:** Soils formed on the flood plains of streams often have a higher clay content than the lighter, sandy soils formed in elevated areas.

There are two broad groups of soil: residual soils and transported soils.

**RESIDUAL SOILS** are formed where a rock mass gradually weathers down and, after many thousands of years, develops a soil layer on its upper surface.

Examples include:

- i. The red volcanic soils in Bundaberg, Childers, Innisfail, Babinda and small sections of the Cairns area developed from basalt. In most cases, the unweathered parent rock may be found at varying depths below the surface.
- ii. The red schist soils of the hillside slopes in the Mossman, Edmonton and Mulgrave, south of Mena Creek (Innisfail), and El Arish areas. These soils are not volcanic in origin but are derived from schist rocks which were formed when sedimentary rocks were subjected to high pressure and/or temperature deep in the earth.



*Soils have a wide range of colours, textures and structures reflecting their different chemical, physical and biological properties.*

**TRANSPORTED SOILS** occur where the materials from which the soils develop are moved from their original site of formation, often by water, but also as the result of gravity. Examples of transported soils include those found in the Burdekin delta and the alluvial soils of the Barron, Mulgrave, Russell, Johnstone, Tully, Herbert, Pioneer, Burnett, Mary and Maroochy River catchments.

As an indication of the rate of soil formation, approximately 4 t/ha/year of soil is produced on basalt parent material in Queensland's wet tropics.

### SOIL COMPOSITION

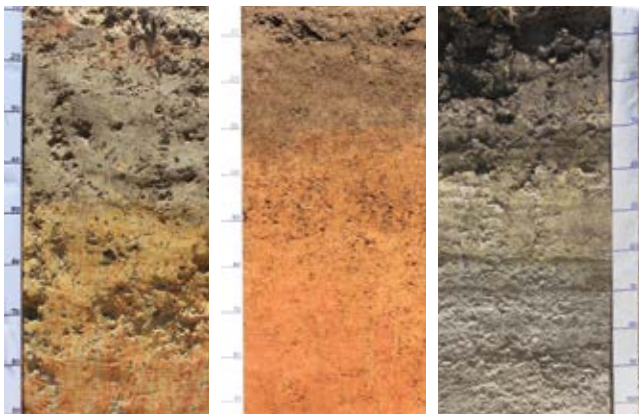
The five components of a soil are mineral matter (sand, silt and clay components that determine the soil texture), organic matter (plant material, humus and deceased organisms), soil water, soil atmosphere, and living soil organisms.

Soils differ in the proportions and arrangements of the five components, and in the extent and type of weathering.

## SOIL COLOUR

Soil colour is generally determined by the amount and state of organic matter, the amount and state of iron oxides, and the degree of aeration of the soil. Soil colours provide insights into some soil characteristics.

Dark-coloured soils generally have more organic matter than lighter-coloured soils. Some soils are black because of their constituent clay minerals. Well-drained soils have red colours. The more poorly-drained soils have paler colours (yellows and greys). Very poorly-drained soils range in colour from grey to blue-grey. A bleached horizon indicates that organic matter or iron has been leached from the horizon. Mottles are indicative of cyclical processes of waterlogging and drying. Moist soil tends to be darker than dry soil.



Soil colour reveals useful information about soil properties. Subsoil mottling (left) indicates regular waterlogging events; red clay loam soils (centre) are moderately fertile and well-drained; striated colours (right) reflect regular flood events and the accompanying deposition of material. Topsoils often have darker colour due to the presence of organic matter.

## SOIL TEXTURE

Soil texture is determined by the relative proportions of sand, silt and clay (mineral matter) in the soil.

### SAND

Sand particles are relatively coarse in size with diameters ranging from 0.05 to 2.0 mm. They do not bind together. Sands have a low ability to hold water, and nutrients are easily leached. They are well aerated, drain well and are easy to cultivate but are often very abrasive.

### SILT

Silt particles are finer than sand particles with diameters ranging from 0.05 to 0.0002 mm. They stick together, have a capacity to hold some water and nutrients, and have a smooth feel. Most silty soils are alluvial in origin. They tend to compact quite readily.



Clay is the powerhouse of the soil. It retains nutrients and water.

**TABLE 1 SOIL COLOURS AND RELATED CHARACTERISTICS**

COLOUR	CHARACTERISTICS	EXAMPLE
Black/dark	High organic matter and dark clay minerals	Black earth
Light grey	Low organic matter and highly leached	Grey sand
Red, brown and red-brown	Well-drained aerated conditions	Volcanic
Yellow and yellow-brown	Less well-drained conditions	Yellow earth
Grey and blue-grey	Waterlogged soils	Humic gley
Uniform colours	Old and well-formed soils	Volcanic
Stratified colours	Recently deposited young soils	Young alluvial
Mottled colours	Fluctuating waterlogged and dry conditions	Humic gley



## CLAY

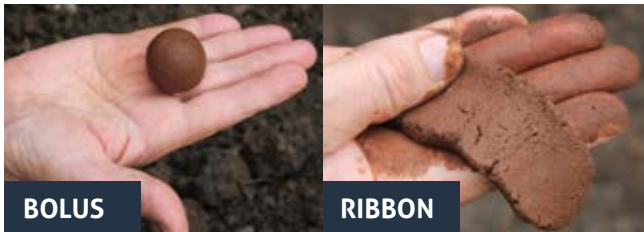
Clay soils have a high proportion of particles less than 0.0002 mm. Clays are capable of absorbing more water than silts due to their greater surface area. Clay soils can be fertile but are poorly aerated, waterlog easily and can be difficult to cultivate. They form hard masses when dry and are sticky when wet.

Soils are divided into 15 textural classes ranging from sand to heavy clay. One class, loam, contains approximately equal proportions of sand, silt and clay.

Texture influences the structural behaviour of soils. Soils with a high proportion of fine sand tend to be dense and hard-setting. Soils with a high proportion of silt tend to be crusty and cloddy, and surface-seal after rain or irrigation. Soils with relatively high clay content are generally easier to manage providing the clay percentage is not excessively high.

### Measuring soil texture

Field or hand texturing can be used to quickly assess the textural grade of a soil. A moistened, small handful of soil is kneaded into a ball called a bolus. The bolus is then squeezed between the thumb and forefinger to form a ribbon. The length of the ribbon characterises the soil textural class. Appendix 1 lists the 15 textural classes and their characteristics.



*The textural grade of a soil is a function of its relative amounts of sand, silt and clay. It can be deduced by the length of the unbroken ribbon resulting from squeezing some moistened soil (bolus) between the thumb and forefinger.*

## SOIL STRUCTURE

Soil structure is the natural aggregation of the primary soil particles (sand, silt and clay) into compound units called peds. Spaces between and within the peds are called macro-pores and micro-pores respectively. Moisture can be held in the micro-pores within the ped. The macro-pores allow drainage of excess moisture and the movement of air. Structure is governed by how the individual soil granules clump and bind together.

Soils can be described as friable, blocky, self-mulching, crumb, massive or structureless.

Soil structure influences water entry, water runoff, soil erosion, seedling emergence, water and air movement, root growth, biological activity and the soil's ability to hold nutrients.

Soil structure is categorised into four major classes based on the form or shape of individual aggregates.

### 1. PLATY

Platy structure is comprised of units formed into sheets or plates stacked horizontally on one another. The plates often overlap, greatly impairing water movement. Compacted soils often have a platy structure.

### 2. PRISMATIC AND COLUMNAR

Prismatic and columnar structures have units formed into vertical pillars or columns separated by vertical cracks that can be small or quite wide. These soils initially have good drainage via the vertical cracks. Drainage becomes poor when the peds swell due to water infiltration and the vertical cracks almost disappear.

### 3. GRANULAR CRUMB

Granular crumb structures contain sand, silt and clay particles grouped together in relatively small grains. Water can move relatively easily in these soils.

### 4. BLOCKY AND SUBANGULAR BLOCKY

Blocky and subangular blocky structures are soil units that bind together in blocks. Root penetration and the infiltration and movement of water are usually restricted in soils with these structures.

Soil structure development is broadly characterised as structureless (sand, single grain, granular – rapid water movement), moderate (blocky – moderate water movement) or strong (massive, prismatic, columnar – slow to moderate water movement).



*Blocky (left) and granular (right) soils have different clay contents and water-holding and nutrient-holding capacities.*



## EFFECTIVE DEPTH AND POSITION IN THE LANDSCAPE

### Effective depth

Effective depth is the depth of the soil that can be exploited by roots for water and nutrients or for physical support. The vast majority of sugarcane roots are found in the top 25cm of soil although some roots can reach depths of several metres.

### Position in the landscape

Position in the landscape refers to where various soil types are found relative to the landscape and other soils (Figure 1). The position can influence the physical characteristics (structure, texture) and chemical characteristics (colour, fertility) of the soil. For example, soils found at the bottom of the landscape are likely to be influenced by moist or waterlogged conditions whereas this would not be an influential factor on soils developing in an elevated position.

Soils at just a small elevation difference of a couple of metres can have markedly different properties including organic matter levels, nitrogen requirements, potential nutrient loss pathways, texture, colour and structure.

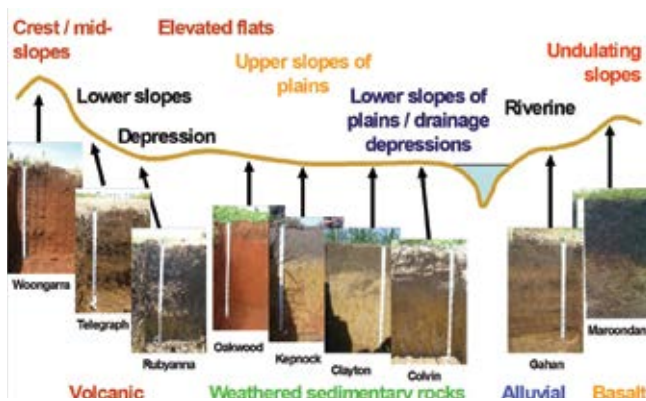


Figure 1: A regional landscape cross-section showing the relative position of different soil types

## SOIL CHEMICAL PROPERTIES

Soil chemical properties include, but are not restricted to, the following key items:

- cation exchange capacity
- phosphorus sorption
- organic matter and mineralisation
- soil pH
- soil salinity and sodicity
- plant nutrients.

### Cation exchange capacity (CEC)

Cation exchange capacity (CEC) is an inherent soil characteristic that influences nutrient availability, soil structure stability, soil pH and the action of fertilisers and ameliorants. It is a measure of the soil's ability to retain certain nutrients called cations. The most common cations

in the soil are potassium ( $K^+$ ), calcium ( $Ca^{2+}$ ), magnesium ( $Mg^{2+}$ ), sodium ( $Na^+$ ), aluminium ( $Al^{3+}$ ) and hydrogen ( $H^+$ ).

Cations are positively-charged and are attracted to, and reversibly bound onto, the negatively-charged clay and organic matter particles making the nutrients less likely to be leached out of the root zone. Cations in excess of the soil CEC value can be found in the soil solution. These are more likely to be leached than those cations adsorbed onto the soil via the CEC.

Other nutrients called anions including sulfate ( $SO_4^{2-}$ ), nitrate ( $NO_3^-$ ) and chloride ( $Cl^-$ ) are negatively-charged and are repelled, not attracted, by the negatively-charged clay and organic matter particles. They are usually found in the soil solution and can be readily leached from the root zone.

However, two anions, phosphate ( $PO_4^{3-}$ ) and silicate (most commonly  $SiO_4^{4-}$ ) often form insoluble complexes with iron, aluminium and manganese in acid (low pH) soils. In alkaline soils, these anions can also form relatively insoluble complexes with cations such as  $Ca^{2+}$ . When this occurs, they are unavailable for plant uptake. Acid and alkaline soils will be explained later in this chapter.

Root hairs increase the surface area of the root in contact with soil and aid in absorption of water and dissolved nutrient minerals (Figure 2).

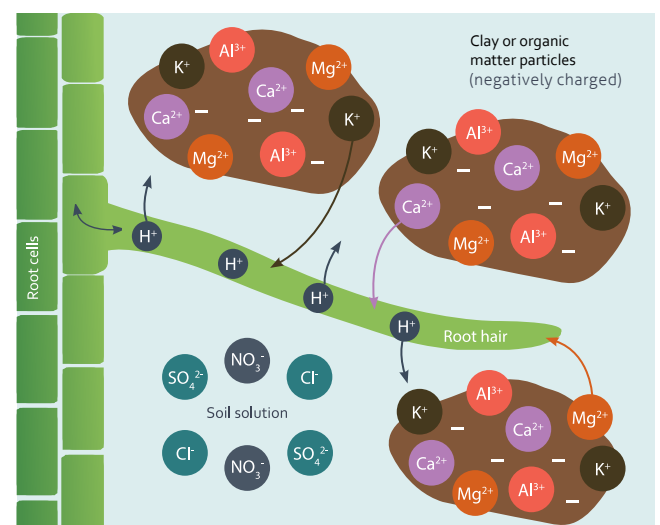


Figure 2: Illustration of cation exchange and nutrient uptake by plant root hairs

Because they are more weathered, soils in wetter tropical areas generally have lower CECs than soils found in cooler or drier areas. Soil CEC values vary depending on the organic matter content, the type of clay (kaolinite or montmorillonite) and the amount of clay. Soils with high levels of clay or organic matter usually have a high CEC and have a greater capacity to hold nutrients and water than sandy soils that have a low CEC. Organic matter has a higher CEC than clay.

Sometimes, the exchange capacity of a soil may be expressed as Effective Cation Exchange Capacity (ECEC).

The ECEC is assessed at the soil's natural pH whereas CEC measurements are made with a buffer solution at a particular pH value. The ECEC more closely reflects the real cation exchange capacity of a soil but can make direct comparison between soils more difficult.

CEC provides a buffer against soil acidification. Soils become more acidic when the "good" cations  $K^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$  are replaced by "bad" cations such as  $H^+$  and  $Al^{3+}$ .

It is difficult to substantially change the CEC of a soil.

### Phosphorus sorption

Phosphorus sorption (P-sorption) occurs in soil when phosphorus is bound onto soil particle surfaces or becomes chemically inactive when it forms relatively insoluble compounds. In other words, some of the phosphorus becomes "locked up" and unavailable for immediate plant growth. Depending on the type of soil, P-sorption can range from weak (e.g. in sandy soils) to strong (e.g. in volcanic and peat soils).

More information on P-sorption can be found in the chapter on phosphorus.

### Soil organic matter, soil organic carbon and soil health

Soil health refers to the capacity of the soil to function biologically, physically and chemically as a living ecosystem that sustains plant and animal life while not polluting the environment. The focus of soil health is on life, not an inert medium. Healthy soils teem with bacteria, fungi, algae, protozoa, beneficial nematodes, other microbes and larger organisms that interact to maintain a sustainable environment.

Soil health is generally closely linked to soil organic matter, and organic matter is associated with nutrient management.

### ORGANIC MATTER AND ORGANIC CARBON

Soil organic matter makes up just a small fraction of the soil mass but is vital to the soil's chemical, physical and biological functions. It consists of plant residues, soil

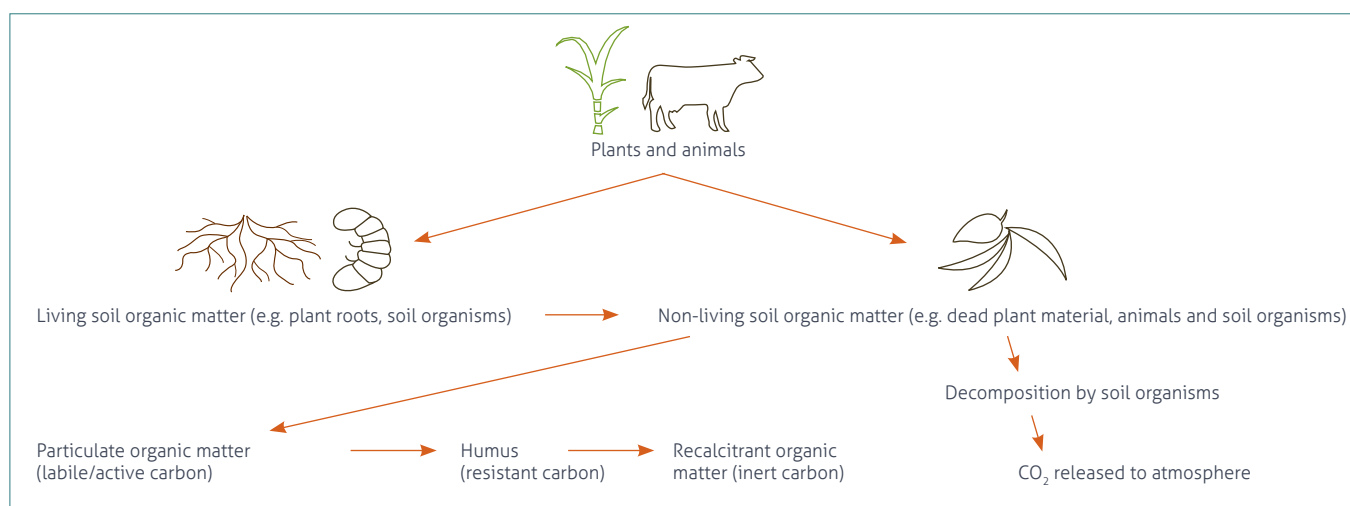


Figure 3: The organic matter cycle

TABLE 2 SOIL ORGANIC CARBON LEVELS OF AUSTRALIAN SUGARCANE GROWING DISTRICTS				
REGION	ORGANIC CARBON CATEGORY			
	VERY LOW-LOW < 0.8 %	MODERATELY LOW-MODERATE 0.8-1.6 %	MODERATELY HIGH-HIGH 1.6-2.4 %	VERY HIGH > 2.4 %
PROPORTION (%) BY ORGANIC CARBON CATEGORY				
Wet Tropics	6	49	28	17
Herbert	16	69	13	2
Burdekin	46	50	3	1
Central Queensland	26	64	9	1
South Queensland	14	58	19	9
New South Wales	2	12	26	60
<b>TOTAL INDUSTRY</b>	<b>21</b>	<b>54</b>	<b>15</b>	<b>10</b>

(Source: Nutrient Advantage® Laboratory data 1990 – 2002)

organisms and animal remains. Organic matter has high nitrogen (N) content. It usually contains a full range of essential plant nutrients that are slowly available for plant growth. Organic matter acts as a reservoir of plant nutrients, helps conserve moisture, improves the physical structure of the soil and provides a favourable environment for soil micro-organisms. It supports the diversity and growth of all living soil organisms. Healthy soils are dependent on the maintenance of soil organic matter.

Soil organic matter is composed of approximately 85% dead material, 10% living plant material and 5% micro-organisms.

It is difficult to determine the amount of soil organic matter directly in a laboratory. Total organic carbon is often used as a surrogate measure of a soil's organic matter content. Soil organic carbon comprises about 60% of the soil organic matter. Organic matter may be estimated using the following formula:

**ORGANIC MATTER (%) = ORGANIC CARBON (%) x 1.72**

Australian canegrowing soils generally have low organic carbon contents, usually in the range of 1 to 3% of the soil mass (Tables 2 and 3).

TABLE 3 AVERAGE SOIL ORGANIC CARBON LEVELS BY REGION	
DISTRICT	ORGANIC CARBON (%)
Wet Tropics	1.8
Herbert	1.2
Burdekin	0.9
Central Queensland	1.1
South Queensland	1.5
New South Wales	3.0

(Source: Nutrient Advantage® Laboratory data 1990–2002)

**IMPORTANCE OF ORGANIC MATTER**

Organic matter usually contains a full range of essential plant nutrients. However, they are unavailable to plants until the organic matter has broken down during a process called mineralisation. Organic nutrients are more slowly available than inorganic forms such as those contained in manufactured fertilisers.

Organic matter plays an important role in:

- improving soil structure and tilth
- increasing soil aeration
- assisting soil aggregation and the formation of peds
- improving the workability of the soil and other physical aspects
- supplying most soil nutrients, particularly nitrogen
- acting as chelates which help to increase plant availability of metal micro-nutrients
- allowing nutrients to be stored and slowly released, reducing losses by leaching and denitrification

- improving the soil's cation exchange capacity
- enhancing the buffering capacity and other chemical aspects of the soil
- increasing the soil's water-holding capacity
- reducing soil erosion
- providing a favourable environment for soil micro-organisms that have several important roles, including (i) the breakdown of chemicals such as herbicides that would otherwise become toxic if allowed to accumulate in the soil, (ii) reducing numbers of parasitic nematodes and increasing the population of beneficial nematodes, and, (iii) encouraging the growth of soil fungi that are involved in, among other things, nutrient cycling and disease suppression.

In other words, organic matter plays a critical role in soil health.

**MINERALISATION**

Mineralisation is the process of converting the organic forms of nutrients in the soil to inorganic forms. This includes mineralisation of organic N to ammonium-N which sugarcane plants readily absorb.

Mineralisation occurs when micro-organisms, such as fungi and bacteria, decompose organic material. The organisms use some of the energy released during organic matter decomposition along with some of the nutrients in the organic matter. When the organisms have used all the nutrients they need, the excess nutrients, including nitrogen, are released into the soil where they can be taken up by plants. When the organisms themselves die, their nutrients are, in turn, released back into the system.

Although organic matter contains about 5% nitrogen, the amount released in a growing season is usually insufficient for profitable sugarcane production. Additional nitrogen, normally applied as fertiliser, is needed to ensure productive and profitable crops.

**CALCULATING ORGANIC MATTER IN A BLOCK**

Soil organic carbon is reported as a percentage of the topsoil (0 – 10 cm). Using the equation, *organic matter (%) = organic carbon (%) x 1.72*, the organic carbon value can be converted to a meaningful organic matter weight for a paddock.

*Example*

**Q:** *What quantity of organic matter is in 1 hectare of topsoil (depth 0.1 metres) with an organic carbon level of 1.5% and a soil bulk density of 1.2 g/cm<sup>3</sup>?*

**A:** *Step 1: Weight of topsoil in 1 ha is 10,000 square metres (surface area) x 0.1 (topsoil depth) x 1.2 (bulk density) = 1,200 tonnes*

*Step 2: Weight of organic carbon in 1 ha is 1,200 (weight of topsoil) x 1.5 ÷ 100 (organic carbon level) = 18 tonnes*

*Step 3: Weight of organic matter in 1 ha is 18 (weight of organic carbon) x 1.72 (conversion factor) = 30.96 tonnes.*



## CROP MANAGEMENT AND SOIL CARBON

Soil organic matter is broken down and lost by mineralisation which is influenced by environmental factors such as temperature and moisture. Losses via mineralisation are increased by cultivation and other farm management practices. Soil type and position in the landscape are also factors associated with the accumulation or breakdown of organic matter. Except for the degree of cultivation, most of these factors are beyond the control of farmers.

The practices of growing a legume or other cover crop during the fallow, and retaining the tops and trash from green cane harvesting, aid in the conservation of organic carbon. However, it is unlikely that soil organic carbon can be increased substantially on a permanent basis through green manuring and/or green cane harvesting. In the sugarcane growing environment where decomposition rates are high, conditions are not conducive to raising organic carbon.

Nevertheless, organic matter levels can be stabilised with:

- reduced tillage
- maintenance of sugarcane trash blankets on the soil surface
- growing legume fallow crops
- preventing soil erosion
- adding imported organic matter sources such as mill mud, mill ash and bagasse.

In general, the most realistic outcome would be a cessation in the decline of organic matter levels, with a slow, steady improvement over the long term.

Table 4 illustrates the decline of soil organic carbon that occurs when land in its virgin state is brought into crop production.

Research in the Herbert River region has shown a similar trend. The average figures for topsoil pH and organic carbon across the Herbert were 5.2 and 1.5% respectively in uncultivated land, dropping to 5.0 and 0.7% respectively following cultivation.

TABLE 4 DECLINE OF ORGANIC CARBON WITH VEGETATION CLEARING AND CROPPING	
LOCATION	ORGANIC CARBON (%)
1 Rainforest (natural state) on Tully Sugar Experiment Station	2.91
2 Headland adjacent to the rainforest	1.62
3 Block adjacent to the headland	1.14

*The whole area was heavy rainforest until 1967.*

*The first sugarcane was planted in the block adjacent to the headland in 1969.*

*These soil tests were conducted in 1985. For research purposes, amendments were deliberately not added to the soil during that time.*



*Tully Sugar Experiment Station showing the sampling sites used to measure the change in fertility status of soil under cropping.*

Under normal conditions about 15 tonnes of dry sugarcane trash per hectare break down over about one year to form approximately 2.5 tonnes of organic matter. It is possible that this organic matter will, over sufficient time, completely disappear through decomposition.

The rate of organic matter breakdown depends on climate (breakdown is more rapid and extensive in the tropics), soil texture (breakdown is slower in clays than in sands), and crop husbandry (cultivation greatly promotes breakdown, as do applications of nitrogen fertiliser).

### SOIL ORGANIC CARBON POOLS

Although significant amounts of organic carbon are present in soils, some of it is relatively inert. Soil organic carbon is made up of four main fractions that vary in their rate of decomposition. These fractions may be described as plant residues, particulate organic carbon, humus carbon and recalcitrant organic carbon.

These distinct fractions vary in their chemical composition, stage of decomposition, rate of decomposition, and role in soil processes and soil health (Figure 4).

#### Plant residues

- Dissolved organic matter (soluble)
- Comprise shoot and root residues
- Broken down relatively quickly (weeks to years)
- Provide energy for soil micro-organisms.

#### Particulate organic carbon

- Defined as pieces of plant debris 0.053–2.000 mm in size
- Decomposes relatively quickly (years to decades)
- Provides an important source of energy for soil micro-organisms
- Plays an important role in maintaining soil structure and providing soil nutrients.

#### Humus carbon

- Is so decomposed that it can no longer be recognised as individual components

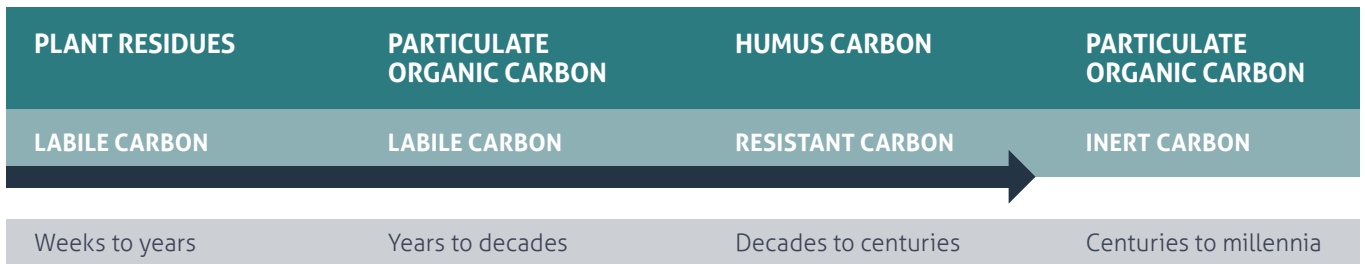


Figure 4: Organic Carbon Fractions and their decomposition rates (Adapted from Bell and Lawrence, 2009)

- Comprises older, decomposed material less than 0.053 mm in size
- The highly complex compounds that make up humus are able to resist further decomposition and, therefore, accumulate in the soil
- Usually found attached to soil minerals
- More resistant to decomposition by soil micro-organisms; decomposes more slowly (decades to centuries)
- Plays a role in all key soil functions
- Particularly important in the provision of nutrients.

**Recalcitrant (inert) organic carbon**

- Inert and resistant to decomposition (dominated by charcoal in Australian soils)
- Not associated with high soil microbial activity and rapid turnover of nutrients
- Decomposes over centuries to thousands of years
- Largely unavailable to micro-organisms
- Soils with a history of burning and highly weathered soils have a high proportion of recalcitrant organic carbon
- Important role in the exchange of cations and the soil’s water-holding capacity.

**LABILE CARBON AND SOIL HEALTH**

Soils that have the same total carbon content may have different proportions of labile carbon. Labile carbon comprises only a small part of the organic carbon fraction but is the major food source for soil microbes. It breaks down relatively quickly and is a significant source of plant nutrients. Changes in the amounts of labile carbon indicate changes in soil health as measured by soil biological activity, nitrogen mineralisation and overall fertility. As a soil becomes more biologically active, it has a greater potential for nutrient turnover and has improved soil structure.

Plant residues and particulate organic carbon cycle in the soil relatively quickly (weeks to decades), providing an active source of nutrition. Agricultural systems involving continuous cropping and management practices that accelerate the breakdown of organic material (such as burning sugarcane trash and cultivation) result in relatively low amounts of these two carbon fractions. Labile carbon changes substantially after each cultivation and is used as an indicator of the change in soil health.

**Carbon to nitrogen ratio (C:N) and soil organic matter**

The C:N ratio of organic residues influences the amount of soil nitrogen available to plants.

When the C:N ratio of organic residues is above 25, net immobilisation of nitrogen occurs as microbiological activity increases. Nitrogen will be consumed by micro-organisms and incorporated into their biomass at the expense of plant-available nitrogen. The microbes utilise the nitrogen for energy in digesting the organic matter. Residues will decompose slowly in this way.

As the C:N ratio of organic residues drops below 25 due to this microbial digestion and release process, breakdown will become more rapid. Nitrogen will become increasingly available as less nitrogen is utilised by the micro-organisms. However, some nitrogen immobilisation will still occur and not all of the nitrogen will be available to the plant.

At a C:N ratio of approximately 10 and below, nitrogen is optimally available without immobilisation being an overriding factor.

On average, plant material contains about 45% carbon and approximately 0.5 to 10% nitrogen. Sugarcane trash contains approximately 25 to 55% carbon and 0.3 to 0.5% nitrogen.

Average sugarcane trash blankets contain about 30 to 80 kg/ha of N. With relatively high C:N ratios (80 to 110:1), this nitrogen has limited plant availability, at least in the short term. Experiments and modelled outcomes initially showed that fertiliser nitrogen inputs could be reduced following the long-term adoption of green cane trash blanketing. However subsequent investigations showed that there was little evidence to support reduced nitrogen applications following three sugarcane crop cycles in the Wet Tropics.

Indicative C:N ratios of various organic materials are shown in Table 5 (over page).

**Soil organic carbon, greenhouse gas emissions and canegrowing**

Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) are the main greenhouse gas emissions associated with agriculture.

Soils are estimated to contain three times more carbon than the world’s vegetation. For every tonne of organic carbon

**TABLE 5 INDICATIVE CARBON:NITROGEN RATIOS OF SELECTED ORGANIC MATERIALS**

ORGANIC MATERIAL	UNITS OF CARBON PER UNIT OF NITROGEN (C:N RATIO)
Sewage sludge	5 - 16:1
Molasses	5 - 25:1
Poultry manure	5 - 25:1
Humus	10 - 25:1
Mill mud	14 - 23:1
Legume hay	15 - 19:1
Green compost	15 - 20:1
Mill ash	50 - 60:1
Sugarcane trash	80 - 110:1
Bagasse	100 - 150:1
Newspaper	170 - 800:1
Sawdust	200 - 700:1



As the C:N ratio of various products such as chicken manure, mill mud, mill ash, sugarcane trash, newspaper and wood chip/sawdust increases, net immobilisation of nitrogen rises as microbiological activity increases.

that is decomposed, about 3.7 tonnes of CO<sub>2</sub> are released to the atmosphere. Conversely, for every tonne of soil organic carbon created, about 3.7 tonnes of CO<sub>2</sub> carbon dioxide are removed from the atmosphere. Hence, soils are both a "carbon source" and a "carbon sink".

Nitrous oxide (laughing gas) has 310 times the global warming potential of CO<sub>2</sub>. Nitrous oxide emissions account for about 10% of global greenhouse gas emissions, with 90% of these emissions emanating from agricultural practices, usually under waterlogged and anaerobic conditions.

The soil and climatic conditions together with high nitrogen and organic carbon inputs typical of sugarcane production in Australia tend to create environments that are conducive to nitrous oxide production. Relatively high N<sub>2</sub>O emissions have been found to occur in some sugarcane areas, especially those with high organic carbon soils and predominance of wet/waterlogged conditions.

Methane has 21 times the global warming potential of CO<sub>2</sub>. In agriculture, methane is produced under waterlogged, anaerobic conditions and the decomposition of organic material. Methane emissions from sugarcane soils have been recorded.

### Soil health and soil quality

All the following functions interconnect to maintain healthy, productive, sustainable soils. It has been suggested that the term "soil quality" should be used to separate the combined chemical, physical and biological states of the soil. Sound nutrient management is a factor in maintaining and improving soil health.

### FUNCTIONS OF A HEALTHY SOIL

Soil management activities combined with the soil characteristics have an impact on soil health. Conducting farming operations that include controlled traffic, minimum tillage, and a legume or other non-grass species in the crop cycle to break the sugarcane monoculture is the basis for the maintenance and improvement of soil health. Soil properties that impact on soil micro-organisms include aeration, moisture, temperature, pH and the supply of nutrients.

### BIOLOGICAL FUNCTIONS OF A HEALTHY SOIL

- Decompose organic matter; maintain soil organic matter levels
- Maintain biological capacity for nutrient cycling and a resilient soil structure
- Suppress damaging populations of soil pathogens, weeds and other pests
- Enable the increase in populations of soil-beneficial microbes
- Produce hormones that aid plant growth.



**CHEMICAL FUNCTIONS OF A HEALTHY SOIL**

- Maintain nutrient-holding capacity; make retained nutrients available for plant growth
- Supply nutrients in the right proportions for plant growth
- Maintain optimum soil pH to support growth of plants and soil organisms
- Avoid toxic levels of nutrients, trace elements and pesticide residues.

**PHYSICAL FUNCTIONS OF A HEALTHY SOIL**

- Allow water to enter the soil; minimise runoff and erosion
- Store plant-available water
- Bind soil particles together for best soil structure
- Maintain friable soil structure for root growth and water extraction
- Provide an aerobic state under wet conditions.

Optimum soil nutrition is a key component of soil health. Soil testing to assess the soil’s fertility status is critical.



Soil health is a function of the physical, chemical and biological properties of the soil. The presence of earthworms is one indicator of sound soil health.

Table 6 illustrates the normal decline in soil fertility that occurs under agriculture if remedial actions (based on soil test results) are not taken. The headland data illustrate the losses that occur through mineralisation and leaching. The block data illustrate the additional nutrient losses associated with cultivation and cropping. This probably resulted from nutrient uptake and removal in the crop plus increased leaching loss because of a reduction in CEC associated with organic matter loss.

Research in the Herbert River region has shown a similar trend. The average figures for topsoil calcium, magnesium and potassium across the Herbert were 3.28 meq%, 1.41 meq% and 0.29 meq% respectively in uncultivated land, dropping to 1.52 meq%, 0.73 meq% and 0.20 meq% respectively following cultivation. The figure for topsoil pH was 5.2 in uncultivated land dropping to 5.0 following cultivation.

These chemical changes reflect the acidification of the soil and a decline in organic matter. Bulk density increased and soil porosity decreased, highlighting the negative impacts of compaction and a breakdown of soil structure.

**Soil pH (acidity and alkalinity)**

Soil acidification is a natural process that increases with agricultural practices. Acidity in soils is caused by excessive hydrogen and aluminium ions on the cation exchange sites. Ammonium nitrogen is converted to nitrate and hydrogen ions in the soil. If nitrate is not taken up by plants, it can leach from the root zone leaving behind hydrogen ions which increases soil acidity.

Depending on the level of acidity, acid soils can lower the availability of some plant nutrients, and reduce soil microbial activity particularly of legume Rhizobia bacteria that fix nitrogen from the air. Aluminium toxicity may occur in very acidic soils resulting in retarded root growth.

Four major reasons cause soils to become acidic: the type of soil parent material, rainfall and subsequent leaching of nutrients from the soil, the decay of organic matter, and the harvest of crops resulting in the removal of nutrients.

Hydrogen ions are required for numerous chemical interactions. However, in large quantities i.e. in acidic soils, they displace some essential plant nutrients adsorbed on soil clay and organic matter resulting in a fertility imbalance in the soil. Conversely, alkaline soils may have insufficient hydrogen ions for many chemical reactions to readily occur.

Soil acidity and alkalinity are described by the symbol pH. pH values are measured on a scale of 0 to 14. A reading of 7 is neutral. Pure water is neutral. Acidity increases as the pH reading falls below 7. Alkalinity increases as the pH reading rises above 7.

**TABLE 6 DECLINE OF FERTILITY WITH VEGETATION CLEARING AND CROPPING**

LOCATION	CALCIUM (meq%)	MAGNESIUM (meq%)	POTASSIUM (meq%)	pH (1:5 WATER)
1. Rainforest (natural state) on Tully Sugar Experiment Station	3.40	1.97	0.465	5.56
2. Headland adjacent to the rainforest	2.14	0.87	0.225	5.53
3. Block adjacent to the headland	0.50	0.18	0.178	5.18

Whole area was heavy rainforest until 1967.

First sugarcane was planted in the block adjacent to the headland in 1969.

These soil tests were conducted in 1985. For research purposes, amendments were deliberately not added to the soil during that time.

The pH scale is logarithmic; a pH of 1 is 10 times more acidic than a pH of 2, and 100 times more acidic than a pH of 3, and so on. So, a sugarcane growing soil with a pH of 4.5 is 10 times more acid than a soil of pH 5.5 even though the difference is only one unit on the pH scale.

Figure 5 shows the pH scale and the position on the scale of some everyday materials.

In soil test reports, two measures of acidity are commonly given: pH in water (pH<sub>water</sub>) and pH in calcium chloride solution (pH<sub>CaCl<sub>2</sub></sub>). pH<sub>water</sub> is mostly used in soil tests in the Australian sugar industry although pH<sub>CaCl<sub>2</sub></sub> is used for alkaline soils in the Burdekin region.

Most of the sugarcane-producing soils in Australia are naturally acidic with values between 5.2 and 6.0 on the pH scale. The notable exception is a large area of alkaline soil in the Burdekin.

### SOIL pH AND AVAILABILITY OF NUTRIENTS

Soil pH has a major influence on the availability of plant nutrients, as illustrated in Figure 6. The availability of each nutrient is indicated by the width of the bars.

Under very acid soil conditions, the major elements are largely unavailable, or “locked up” in the soil, while some of the minor or trace elements (iron, manganese, boron, copper, zinc) are released.

Soils with pH greater than 5.5 are desirable for plants because concentrations of aluminium, which is more soluble at low pH and toxic to many plants, are minimised above this value. Increased acidity (lower pH) causes reduced availability of nitrogen, potassium, calcium, magnesium, phosphorus and sulfur, while micro-nutrients such as copper and zinc will become more available. Under acidic conditions, aluminium is present in its soluble form and is toxic to most plants but particularly to legume crops. Consequently, regular additions of lime are essential if legume crops are included into the farming system on acid soils. However, Australian sugarcane varieties are reasonably tolerant to high levels of aluminium and soil acidity.

Low pH reduces the already low cation exchange capacity (CEC) of tropical soils and causes the soil CEC to be dominated by the acidic hydrogen and aluminium cations

CONCENTRATION OF HYDROGEN IONS COMPARED TO DISTILLED WATER	1/10,000,000	14	Liquid drain cleaner		
	1/1,000,000	13	Bleach; oven cleaner; caustic soda		
	1/100,000	12	Quicklime (calcium hydroxide)		
	1/10,000	11	Household ammonia products		
	1/1,000	10	Detergent; soap powder; antacid		
	1/100	9	Toothpaste; green tea; calcium carbonate; olive oil; hair dye; soap		
	1/10	8	Sea water; baking soda; eggs; pancreatic acid		
	1	7	Pure water; blood; tears; faeces; mill mud; mill ash; sugars		Neutral
	10	6	Milk; urine; saliva; fish; sugarcane juice; rain; wasp sting		
	100	5	Molasses; black coffee; tea; skin; sweat; bananas; chicken; bee sting		
	1,000	4	Tomato juice; beer; soda water; acid rain; hydrogen sulfide		
	10,000	3	Soft drinks; cider; apples; orange juice; grapefruit; wine; pastries		
	100,000	2	Vinegar; lemon juice; lactic acid; acetic acid; citric acid; Coca Cola		
	1,000,000	1	Stomach acid		
	10,000,000	0	Battery acid; sulfuric acid; hydrochloric acid; nitric acid		Increasing acidity

Figure 5: pH scale and indicative pH of some common substances

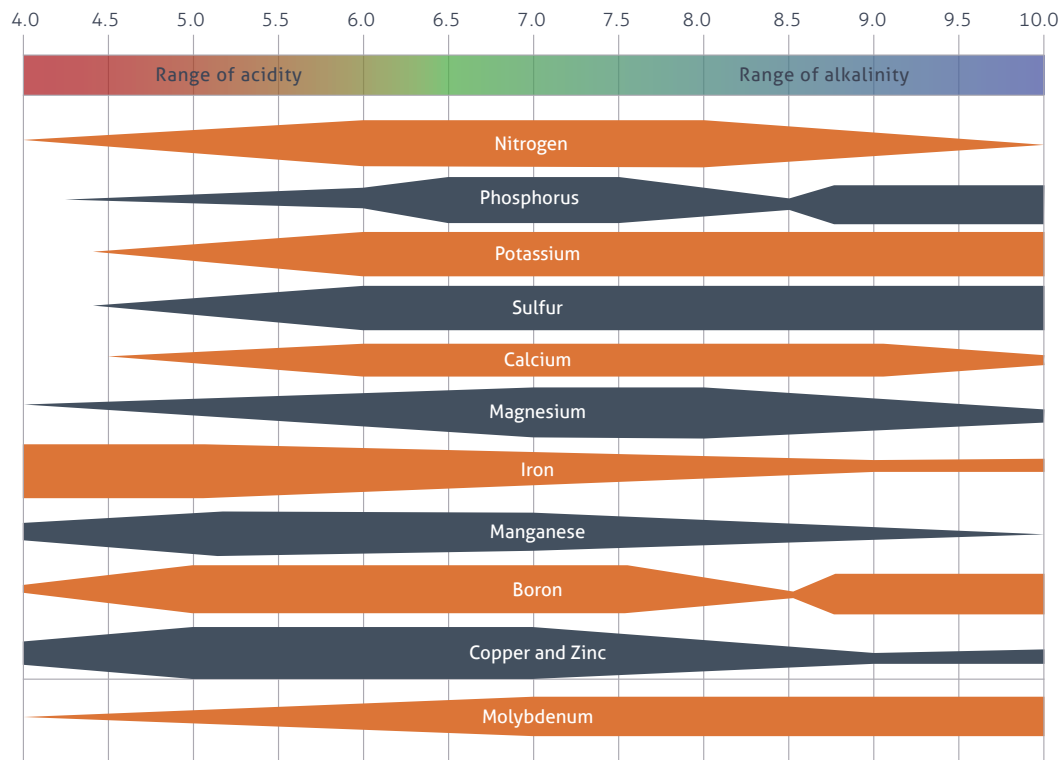


Figure 6: The influence of soil pH on nutrient availability

( $H^+$  and  $Al^{3+}$ ). This reduces the storage capacity for nutrients such as calcium, magnesium and potassium and can be critical, particularly on sandy soils with low CEC. Soil acidification is a natural process which is made worse by the use of nitrogen fertilisers and the removal of sugarcane to the factory (Table 6). Regular use of liming materials will reduce soil acidity, neutralise acidity arising from the use of nitrogen fertiliser, and replace calcium and magnesium (if using, for example, magnesium lime or dolomite) withdrawn in the harvested crop.

The ideal pH range for the overall availability of all nutrients is between 5.5 and 7.0. All commercial soil tests include the pH reading.

#### CHANGING SOIL pH

Calcium and magnesium carbonate-based (lime) products will increase soil pH while supplying calcium and magnesium. While containing calcium, gypsum (calcium sulfate) will not change soil pH. Further information can be found in the chapter on calcium.

To lower soil pH, sulfur-based products will produce sulfuric acid. Under some conditions, the conversion rate of the sulfur may take up to several months.

#### Soil salinity and sodicity

Excess sodium can cause soils to be saline, sodic or a combination of both known as saline-sodic. If not rectified, these situations will lead to crop losses or even death.

#### SALINE SOILS

Salinity is caused by an excess of soluble salts in the soil. The most common salt in problem areas in the sugar belt is sodium chloride (table salt). As soil salinity increases, plants find it increasingly difficult to extract water from the soil. This induced water stress is evident in sugarcane by premature wilting and scorching of the leaves, restriction in growth, and in severe cases, death of the plant. Sugarcane is regarded as a relatively salt-sensitive plant, and there are varietal differences in salt tolerance.

High levels of salt can also create an imbalance of plant nutrients in the soil.

The salt is soluble and can be leached with water through the soil profile. Saline soils are generally more friable than sodic soils. Saline soils are usually associated with salt water intrusion of low-lying lands along the coast, either by inundation by sea water or a rise in the water table.

#### RECLAMATION OF SALINE SOILS

- Ensure salinity of irrigation water is within recommended levels
- Improve surface and subsurface drainage to promote leaching of accumulated salts
- Prevent inundation of saline water to the crop area
- An application of gypsum may be beneficial once drainage has been improved.





Saline soils are usually associated with salt water intrusion which can cause death of sugarcane. Affected areas can be reclaimed by providing adequate surface and subsurface drainage, preventing salt water intrusion, and leaching the accumulated salt through the soil profile.

### SODIC SOILS

High soil sodium levels cause the breakdown of soil structure which affects both aeration and water penetration. In sodic soils, sodium replaces a large proportion of the other cations calcium, magnesium and potassium. The clay particles are dispersed by the presence of high levels of sodium attached to them. The clay particles can remain suspended in water or they can flocculate and settle. Sodium-dominated soils with an exchangeable sodium percentage (ESP) greater than 6% are unstable when wet and will disperse. Clays that disperse readily fill up pore spaces and reduce permeability to both air and water. Sodium in this form is referred to as exchangeable sodium, high levels of which cause breakdown of the soil structure, giving rise to areas called soda patches. A soil ESP figure in excess of 15% indicates severe structural deterioration in most soils.

Sodic soils slump and disperse when wet. They have poor water entry and are difficult to cultivate and manage.

Sodic soil water is not saline as in saline soils. Sodic soils are poorly aerated and nutrient uptake is restricted.

Soils may be sodic for a number of reasons including the existence of naturally high sodium levels in the soil and irrigating with poor quality water.



In the Burdekin sugarcane growing region, the presence of certain vegetation such as beefwood and *Eucalyptus alba* and *E. papuana* is an indicator of natural soil sodicity. (Photo: Evan Shannon, Farmacist)



Severe sodicity has caused heavy deterioration of soil structure resulting in major soil erosion. A nodule of calcium carbonate (circled) is an indicator of high sodicity in alkaline soils. (Photo: Evan Shannon, Farmacist)

### RECLAMATION OF SODIC SOILS

- Improve surface and subsurface drainage to promote leaching of displaced sodium salts from the soil profile
- Ensure that sodium and/or bicarbonate levels in irrigation water do not exceed recommended standards
- Apply gypsum or mill ash to promote replacement of sodium on the clay particles by calcium, and to improve soil structure (Table 7).

EXCHANGEABLE SODIUM PERCENT (ESP %)	GYPSUM RATE (t/ha)*	
	ALL REGIONS EXCEPT BURDEKIN	BURDEKIN
<5	0	0
5 - 10	2	5
10 - 15	4	7.5
>15	6	10

\* Burdekin has a different rate due to the region's different clay type. Other regions have mostly 1:1 clays (non-swelling clays) while the Burdekin has 2:1 clays (swelling clays) which are more difficult to ameliorate.

The quality of gypsum can vary widely. Products from some natural deposits are much less soluble than others. In the photograph below, the subsoil core from an amelioration trial clearly shows undissolved gypsum that was applied at 10 t/ha in a narrow ripper tyne slot approximately 30 cm into the acid subsoil five years previously. Gypsum crystals are still visible.



Gypsum quality influences its effectiveness. The picture shows undissolved gypsum in a subsoil soil core five years after application. (Photo: MSF Sugar)

Under Australian legislation, gypsum is categorised into grades 1 to 3 that have lower concentrations of sulfur and calcium respectively. The particle size of a gypsum product is important. Products that have low solubility must be fine enough to be useful as an ameliorant. The particle size must be stated on the label of registered gypsum products. Most naturally-occurring gypsums are coarse, meaning it takes them longer to dissolve than finer products. Fine gypsum may be important where it is dissolved in irrigation water or when a quick response is required.

**SALINE-SODIC SOILS**

Saline-sodic soils contain excessive levels of salt in the soil water plus large amounts of sodium attached to the soil particles.

**CONDUCTIVITY**

Conductivity is a measure of the total amount of soluble salt compounds in the soil solution. It does not identify the individual dissolved salts but does provide a reasonable indication of the salinity problem that is likely to occur.

Water that contains salt can conduct electricity. The more salt in a solution, the easier it is to conduct electricity. The potential of a solution to pass an electric current is called electrical conductivity (EC) or specific electrical conductivity (SEC). The higher the salt concentration, the larger the EC or SEC reading.

Plant growth will suffer if excessive quantities of soluble salts are present. The higher the salt concentration around the root system, the more difficult it is for plants to draw water from the soil. Saline soils often contain concentrations of ions such as sodium and chloride at levels that become toxic to plants.

Table 8 sets out the impact of soil salinity on sugarcane yield for cultivars of different salinity sensitivity.

**Plant nutrients and nutrient deficiency**

The most important way in which plant roots take up nutrients is by absorbing them from the soil solution. The actively growing cells of the root tips and in the root hair zone acquire those elements needed by the plant.

Plants are deficient in a nutrient if they cannot get enough of that nutrient from the soil for normal growth. There are several reasons for nutrient deficiency:

- Not enough nutrient in the soil
- Sufficient nutrient in the soil but "locked up" and therefore not available to the plant in sufficient quantities for normal growth
- Restricted plant growth prevents adequate nutrient uptake (caused by, for example, drought, waterlogging, heavily compacted soil, very cold weather, grub damage).

**TABLE 8 IMPACT OF SOIL SALINITY ON SUGARCANE YIELD (ECe –0.5 m DEPTH)**

YIELD LOSS CLASS	NONE	SLIGHT	MODERATE	SEVERE
YIELD LOSS (%)	0	0–10	10–20	>20
Moderately sensitive–sensitive cultivars				
ECe (dS/m)	0–1.0	1.0–2.0	2.0–3.0	>3.0
Sensitive cultivars				
ECe (dS/m)	0–0.5	0.5–1.0	1.0–1.5	>1.5



## OLD LAND-NEW LAND EFFECT

The decline in soil fertility with crop production is sometimes referred to as the "old land-new land effect". When land is converted from its natural state to food or fibre production, the inherent chemical, physical and biological fertility reduces if no intervention is taken.

Evidence of the old land-new land effect can be seen when previously uncultivated land immediately next to a cropped block is brought into production. The visual improvement in yield is normally quite obvious. However, after a period of continual cropping, yields on that "new land" come back to match the rest of the block.

The decline of organic carbon, soil pH and several nutrients with vegetation clearing and cropping is illustrated in Tables 4 and 6 above. Over the same period, soil copper and zinc levels also fell while exchangeable aluminium and exchangeable acidity levels increased to the detriment of soil health. At the same time, there was a potential deterioration in soil biology and soil structure.

## What happens to fertiliser applied to the soil?

A number of processes occur to applied fertiliser. Many factors (such as crop management, soil type, weather conditions, fertiliser placement and timing) govern the extent of each process. Each nutrient is subject to the processes to differing degrees.

- **Mining.** Fertiliser is taken up by the crop and removed from the field at harvest. When nutrient input is less than nutrient removal by the crop, mining of that nutrient occurs.
- **Nutrient pool contribution.** Fertiliser nitrogen reacts with organic matter and soil minerals to become part of the soil reserve that can potentially be used for future crop growth.
- **Gaseous losses.** Fertiliser nitrogen can be lost to the atmosphere as a gas through volatilisation and denitrification.
- **Run-off losses.** Fertiliser can move from the field on sediment through soil erosion and dissolved in water during run-off events.
- **Leaching losses.** Fertiliser can leach downwards with water movement below the root zone.

Of all the essential plant nutrients, nitrogen undergoes the most complex interactions. Nitrogen is subject to all of the above five processes. In addition, nitrogen fertiliser comes in three different forms – nitrate, ammonium or urea. To be available to plants for growth, nitrogen must be converted to the nitrate or ammonium forms. Further information can be found in Chapter 8.





CHAPTER 2

# SUGARCANE GROWTH

## HOW SUGARCANE MAKES SUGAR

All plants absorb carbon dioxide gas from the atmosphere through the leaves. The carbon dioxide taken in by the leaves and the water taken up by the roots are converted by sunlight harvested by the leaves into sugars, other organic molecules for use by the plant, and oxygen. This process is called photosynthesis, the source of all plant growth.

Photosynthesis can be summarised like this:



The sugarcane leaf is the factory where sugar is produced. The stalk is the storage facility for sugar.

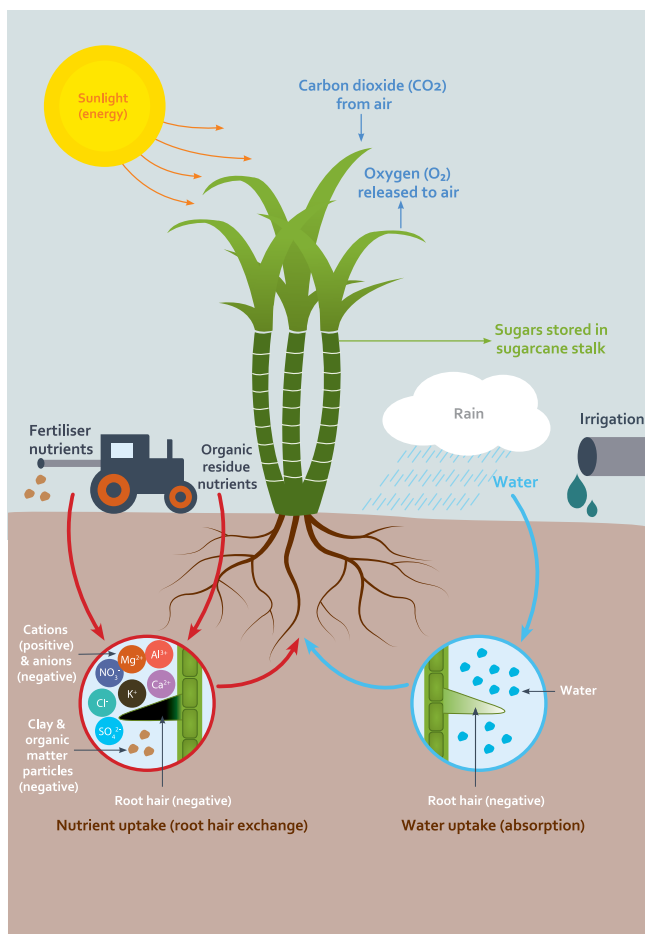


Figure 7: The process of photosynthesis and water and nutrient uptake by plants

## ESSENTIAL PLANT NUTRIENTS: WHAT SUGARCANE REQUIRES

Sixteen chemical elements (nutrients) are known to be essential for the growth of all plants. In addition, silicon, is regarded as a beneficial element for sugarcane production.

The 17 nutrients can be divided into five groups:

- Non-mineral nutrients provided from air and water
- Primary nutrients
- Secondary nutrients
- Trace elements
- Beneficial element

### SUGARCANE NUTRIENTS

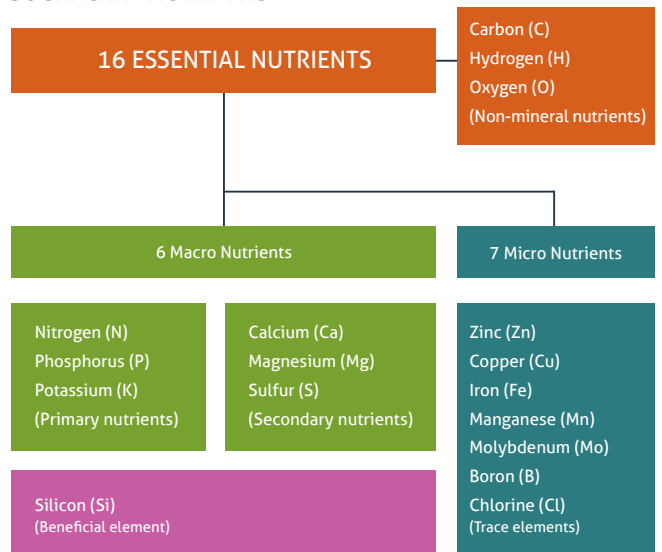


Figure 8: Nutrients for sugarcane production

Other elements such as sodium, cobalt, selenium, fluorine and iodine are taken up by plants but are not required for plant growth.

Carbon, hydrogen and oxygen make up 90% to 95% of the dry matter of plants. The other 13 essential nutrients, obtained from the soil by the root system, make up the remaining 5% to 10% of the dry weight.

Carbon is the primary constituent of most plant molecules. Carbon is fixed through photosynthesis when carbon dioxide from the air is converted into carbohydrates which are used to store and transport energy within the plant.

Hydrogen, which is obtained from water, is necessary for the production of sugars and plant growth. Hydrogen ions are vital for photosynthesis and for respiration.

Oxygen is acquired in many forms including carbon dioxide and oxygen (mainly from the air via the leaves), and water, nitrate, dihydrogen phosphate and sulfate (mainly from the soil water via roots).

## HOW SUGARCANE TAKES UP WATER AND NUTRIENTS

Water is the single most limiting factor in plant growth. Water provides the plant with the hydrogen needed for producing essential carbohydrates (sugars), as well as providing the internal transportation medium for the entire plant. Water is taken up by the cells of the fine root hairs.

Nutrients are leached from rock particles and organic matter to the soil solution. Nutrient levels in the soil solution can be increased by cation exchange. The root hairs pump hydrogen ions ( $H^+$ ) into the soil. These hydrogen ions displace cations attached to negatively-charged clay particles. Those cations are then available for uptake by the roots (Figure 7).

Sugarcane obtains most of its nutrients and water from the soil by absorption through the roots. Water uptake by a plant is like drinking water through a straw: the water is pulled up from the roots to the leaves because of the suction influence of water being lost from the leaves by transpiration (similar to evaporation). The dissolved nutrients are taken up with the water.

Inside the root cells, the concentration of minerals is greater than in the soil surrounding the roots. This difference

creates root pressure which is osmotic pressure within the root cells that cause sap to rise through the plant stem to the leaves. Osmosis forces water up from the root through the xylem as more water and minerals are absorbed into the root from the soil.

Plant roots do not change their direction of growth towards bands of buried fertiliser. The roots cannot detect where the fertiliser is. However, if the roots pass into a band of fertiliser, they show greater branching while in the band to take advantage of the zone of nutrients.

Nutrients are taken up by plants in the ionic (carrying a net electrical charge) form (Table 9).

The beneficial element, silicon, is taken up in the form of soluble monosilicic acid,  $Si(OH)_4$ .

## BASIC PRINCIPLES OF SUSTAINABLE NUTRIENT MANAGEMENT

Four basic principles need to be followed when nutrient inputs are determined. The principles apply to both plant and ratoon cane.

1. Apply nutrients when they are needed.
2. Do not apply nutrients when they are already present in sufficient quantities in the soil.
3. Do not apply one nutrient at the expense of another (or others).
4. Be sceptical of gimmicks that promise unrealistic benefits.

A combination of soil testing, leaf analysis and the assessment of crop response is the best way of determining which nutrients, and the quantity of each, that need to be

**TABLE 9 FORMS OF ESSENTIAL NUTRIENTS TAKEN UP BY PLANTS**

ELEMENT	SYMBOL	FORM ABSORBED BY PLANTS
Nitrogen	N	$NH_4^+$ (ammonium) and $NO_3^-$ (nitrate)
Phosphorus	P	$H_2PO_4^-$ (dihydrogen phosphate) and $HPO_4^{2-}$ (hydrogen phosphate)
Potassium	K	$K^+$
Calcium	Ca	$Ca^{2+}$
Magnesium	Mg	$Mg^{2+}$
Sulfur	S	$SO_4^{2-}$ (sulfate)
Copper	Cu	$Cu^{2+}$
Zinc	Zn	$Zn^{2+}$
Boron	B	$H_3BO_3$ (boric acid) and $H_2BO_3^-$ (borate)
Manganese	Mn	$Mn^{2+}$
Iron	Fe	$Fe^{2+}$ (ferrous) and $Fe^{3+}$ (ferric)
Molybdenum	Mo	$MoO_4^{2-}$ (molybdate)
Chlorine	Cl	$Cl^-$ (chloride)

applied to maintain soil fertility, achieve balanced nutrition, prevent the build-up of luxury amounts of particular nutrients, and produce profitable crops.

Soil testing is best done at the end of the previous sugarcane crop cycle, immediately after harvesting the final ratoon crop and prior to the establishment of the new crop. This will enable development of a nutrient management plan covering the next crop cycle (plant crop and four ratoon crops). Additional sampling should be carried out for fifth and subsequent ratoon crops.

Analysis of leaf samples will reveal the adequacy of nutrient uptake by the crop.

### BALANCED NUTRITION

Balanced nutrition implies that all essential plant nutrients need to be present at appropriate concentrations in the soil to enable optimum crop growth and yields. Cane and sugar yields will be reduced if any one of the essential nutrients or silicon is in short supply, even though there may be ample supplies of all the others.

All nutrients should be present in the soil-crop system in adequate quantities (as determined by a soil test) to ensure potential crop yield is possible to be attained. This concept of balanced nutrition is illustrated in Figure 9.

The total volume of the barrel indicates the maximum yield possible. All the staves of the barrel (nutrients) must be present at their correct height (*adequate quantity: diagram a*) for the barrel to hold the maximum volume of water (maximum sugarcane yield).

Plant growth is limited by the nutrient in short supply just as the level of water in the barrel is limited by the shortest stave (*diagram b*). However, adding more nutrient than is required will not make the barrel bigger; it will not grow more sugarcane (*diagram c*).

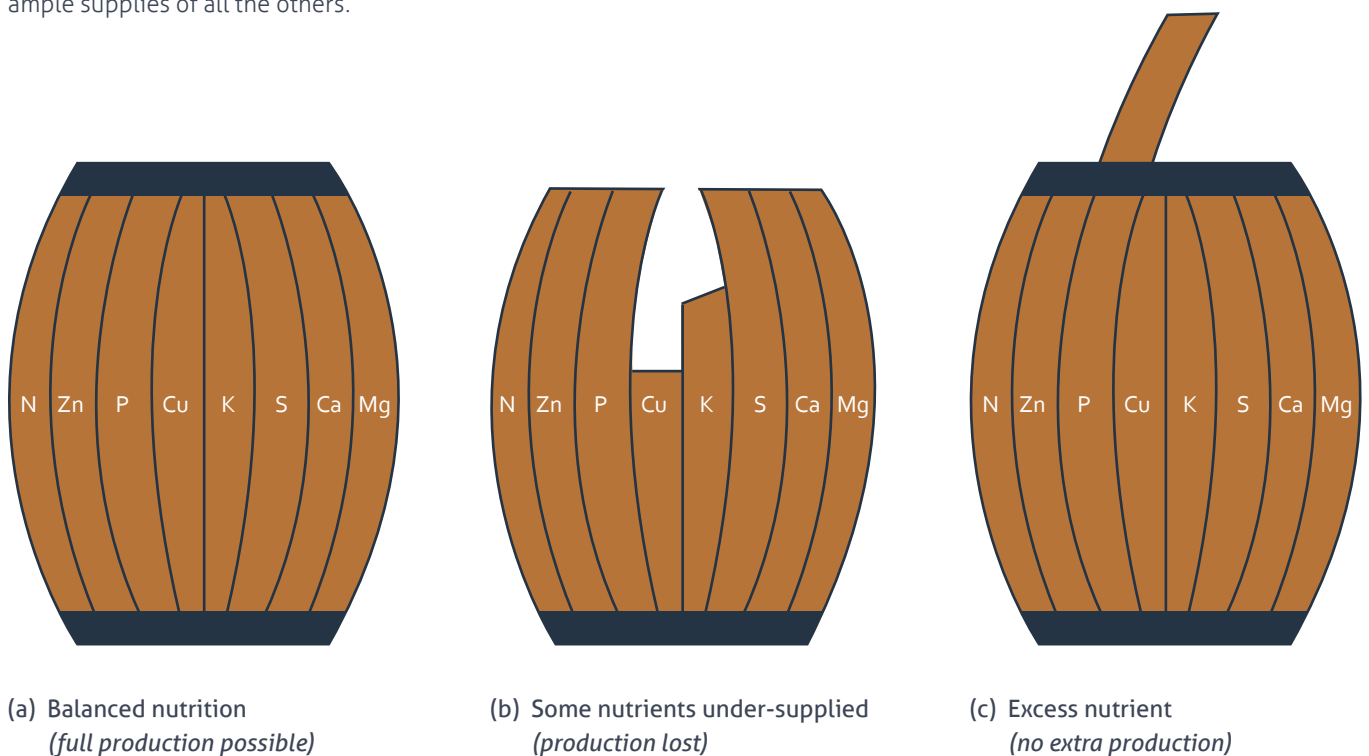


Figure 9: Staves of a barrel analogy illustrating the need for balanced nutrition – Liebig’s Law of the Minimum



## CHAPTER 3

# THE SIX EASY STEPS<sup>®</sup> NUTRIENT MANAGEMENT GUIDELINES

*Canegrowing, the environment and sustainability*

Modification of the traditional nutrient-management guidelines for sugarcane production in Australia is ongoing. The need for change occurred with a realisation that nutrient management should no longer target only sugarcane yields but should be aimed at sustainability.

This research has also resulted in the nutrient management guidelines being more soil-specific by taking account of basic soil attributes such as colour, texture, position in the landscape and chemical properties (*Chapter 1*). These modified guidelines have been incorporated into a grower-friendly nutrient management program entitled the SIX EASY STEPS approach to improved nutrient management.

### THE MEANING OF SUSTAINABILITY AND BEST-PRACTICE NUTRIENT MANAGEMENT

Nutrient management in the sugar industry must be aimed at sustainability. This means that profitable sugarcane production needs to be achieved in combination with the maintenance of on-farm soil fertility and minimal off-site impacts.

Best-practice nutrient management means having the best chance of success in minimising the risk of losses in productivity (loss of yield), profitability (loss of income), nutrients (leaching, runoff and/or gaseous losses) and soil resources (erosion and fertility losses).

Farm-specific nutrient management plans based on SIX EASY STEPS enable the adoption of best-practice nutrient management in sugarcane production.

### THE SIX EASY STEPS PROGRAM

The SIX EASY STEPS program is an integrated nutrient management tool that enables the adoption of best-practice nutrient management on-farm. It consists of:

- STEP 1. Knowing and understanding our soils**
- STEP 2. Understanding and managing nutrient process and losses**
- STEP 3. Regular soil testing**
- STEP 4. Adopting soil-specific nutrient management guidelines**
- STEP 5. Checking on the adequacy of nutrient inputs**
- STEP 6. Keeping good records to modify nutrient inputs when and where necessary.**

The overall objective of the program is to provide guidelines on how to implement balanced on-farm nutrition with the ultimate aim of optimising productivity and profitability, without adversely influencing soil fertility or causing off-farm effects.

### THE IMPORTANCE OF THE SIX EASY STEPS PROGRAM

The SIX EASY STEPS program is a framework that enables the adoption of best-practice on-farm nutrient management. It is not a recipe but rather a framework which enables farm and management differences to be taken into account when decisions are made about nutrient inputs.

It recognises that appropriate nutrient inputs for a particular farm should be based on the knowledge of the soils on the farm and the nutrient processes and risks of nutrient losses associated with those soils. This fundamental understanding should be used in combination with soil testing, leaf analysis and record keeping to deliver benefits in productivity, profitability and environmental responsibility.



*Employing the SIX EASY STEPS nutrient management guidelines will assist the sugar industry to maximise profitability while minimising adverse environmental impacts, including on water quality.*

## SIX EASY STEPS AND THE ENVIRONMENT

The SIX EASY STEPS program is based on the premise that sustainable nutrient management aims at profitable sugarcane production in combination with environmental responsibility. In terms of the environment, it considers both the on-farm effects (maintenance of soil fertility for future generations) and off-site effects (nutrient losses through various mechanisms and channels). Fundamental to this is the principle that soils should be managed according to their basic properties, the processes that occur within soils, and the interaction of applied nutrients with soils.

Best-practice nutrient management and environmental responsibility go hand-in-hand and are entirely compatible: what's best for minimising on-farm nutrient impacts on the environment is also best for farm profitability.

### The Great Barrier Reef and cane growing

The proximity of the industry in the catchments that drain to the Great Barrier Reef means the industry is acutely aware of its responsibility in minimising adverse impacts on water quality. The implementation of the SIX EASY STEPS

Guidelines – applying the environmentally-sensitive nutrients nitrogen and phosphorus at the recommended rates at the appropriate time in the correct manner – will maximise yield while minimising the off-site impacts of nutrient loss.

Current Queensland Government environmental legislation and management strategies mandate that SIX EASY STEPS recommendations for nitrogen and phosphorus must be implemented on sugarcane farms in much of the industry.

## SIX EASY STEPS GUIDELINES

Nutrient management guidelines are tailored for each sugarcane growing region in Australia.

The regional SIX EASY STEPS Nutrient Management Guidelines are available from the SRA website in the "For Growers and Millers" section. Recommendations for each nutrient are provided in the respective chapters in this manual.

## CHAPTER 4

# SOIL ANALYSIS

Soil testing is absolutely essential to provide the foundation of a reliable, profitable fertiliser program. It serves as a basis for determining specific nutrient inputs for a particular block of sugarcane by identifying the chemical and nutrient properties of a soil.

### OBJECTIVES AND BENEFITS OF SOIL TESTING

Soil sampling assists in determining the most suitable fertiliser products and application rates. Besides identifying nutrient imbalances or deficiencies, a soil test can also forecast upcoming nutritional issues. Since the introduction of the Queensland State Government Reef Regulations in 2010, it has been mandatory for growers in some districts to analyse soil samples from blocks to be planted to sugarcane.

Soil testing is important to:

- identify nutrient deficiencies (or excesses) and determine the nutrient status of the soil
- monitor changes in soil chemical properties
- calculate crop nutritional requirements and develop the most effective and profitable nutritional program for every block over the entire farm
- monitor and forecast future nutritional or soil management issues (e.g. acidity, sodicity, salinity)
- save money on fertiliser costs by only applying what the crop needs
- maintain water quality and healthy soil properties.

### TIMING OF SOIL TESTING

The recommended time to sample is straight after harvesting the last ratoon crop before the soil is cultivated. This strategy provides the most accurate information on the current nutrient status of the soil. It will allow any remedial action (such as the addition of lime, a calcium-magnesium blend or gypsum) to be taken well before the establishment of the fallow or next crop cycle.

Sampling after cultivation may affect the nutrient analysis, making it difficult to accurately determine the appropriate nutrient inputs.



*Analysing the soil is the foundation of sound nutrient management practice.*

### HOW TO SOIL SAMPLE

An auger, soil tube or spade can be used to take soil samples. Samples should be taken to a depth of 200 mm. However, if salinity and/or sodicity is suspected, samples should be taken in 200 mm intervals to a depth of at least 800 mm.

The greatest potential for error in soil testing is in obtaining the sample. Soil samples must be representative of the area to be assessed. This can be achieved by following these guidelines:

- avoid unusual areas such as old drainage lines, windbreaks, near trees, regularly used tracks etc.
- avoid sampling in the position of old fertiliser bands
- avoid areas differing in crop growth, soil type, drainage or past management practices (liming, fertilising, mill mud application etc.), or sample these areas separately if they are a significant proportion of the block
- sample the area on a grid or zig-zag pattern to obtain at least 15–20 subsamples. (The most common mistake is taking too few sub-samples to adequately represent the area being tested, particularly on very large blocks)
- thoroughly mix the subsamples in a clean plastic bucket, fill the soil sample bag, and discard the remaining soil



- alternative sampling strategies include using electrical conductivity (EC)-generated maps (Figure 10) to guide sample collection points. This enables in-field variability to be taken into account, and in-field zones to be sampled separately. In particular, it allows for variable rate applications of ameliorants and, potentially, nutrients.

Geo-referencing soil samples will facilitate better monitoring of soil fertility over time. It will allow soil sampling in the same location each time and overcome problems that arise with changes to block numbers or block configuration.



Figure 10: Use of EC mapping to determine appropriate sampling positions in a field

Samples should be sent to a reputable, experienced laboratory immediately after collection, as changes in available nutrient status can occur with time. If an undue delay occurs, store the sample in a refrigerator or sample the area again.

**CAUTION:** Cleanliness is essential throughout the sampling procedure. Sources of contamination include other soil or fertiliser or chemicals in buckets or sample bags or sampling gear, and ash from cigarettes. If testing for zinc, contamination of the sample can occur from sunscreen and galvanised implements such as augers, spades and wire handles on buckets. Even oxidation from galvanised iron implements on hands will contaminate a soil sample if it is handled.

Figure 11 illustrates the importance of collecting many soil subsamples to comprise a truly representative overall sample from the area being tested. A soil test in the laboratory is carried out on a sample weighing just 10 g that is obtained from the approximately 500 g of soil submitted

to the laboratory. Usually, this 500 g sample is a sub-sample of the 10–15 kg of soil sampled from the block of sugarcane (an average 2 ha area) which contains about 6,000 tonnes of soil in the plough layer. That tiny 10 g sample must be representative of the whole area for an accurate chemical assessment of the soil in that area to be made.

The standard process to sample soil for analysis is outlined in a fact sheet on the SRA website in the Nutrition section under “For Growers and Millers”.

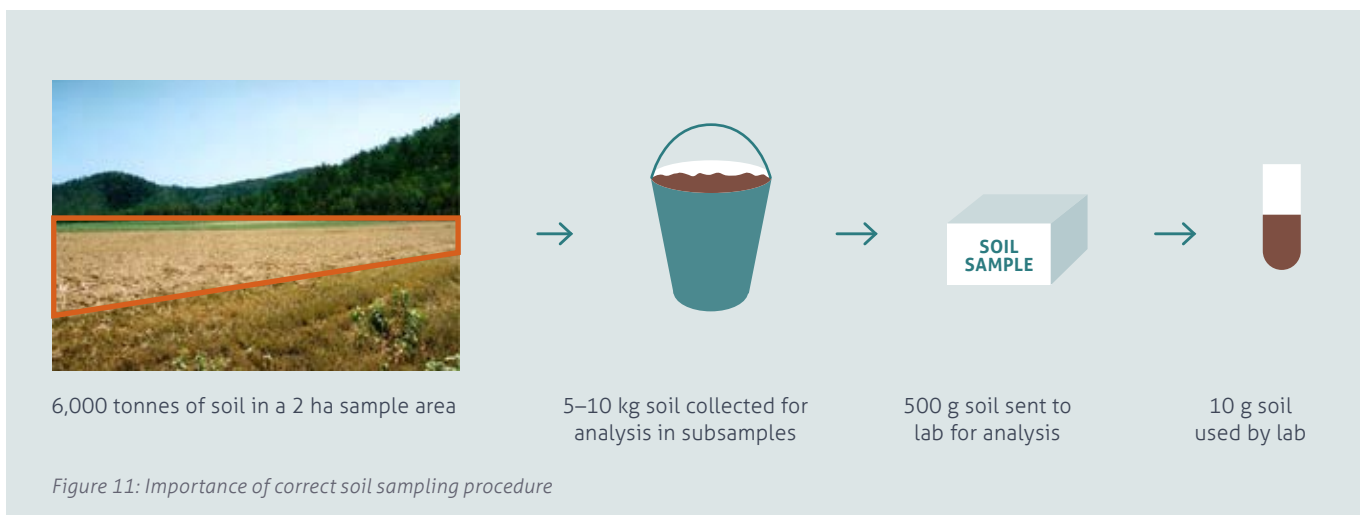
### SOIL SAMPLE ANALYSIS AND INTERPRETATION OF THE RESULTS

Samples for analysis should be sent to a reputable laboratory that, very importantly, conducts tests that are compatible with the SIX EASY STEPS Guidelines as legislated under Government regulations and have a Certificate of Proficiency issued by the Australasian Soil and Plant Analysis Council (ASPAC).

Growers should ensure they are receiving sound interpretation of the results and appropriate fertiliser recommendations by having an understanding of the basic process of determining nutrient requirements. The best way to gain this understanding is to attend a suitable nutrient management workshop. Advice should be obtained only from capable advisors or extension officers. If in doubt about the advice provided, always seek a second opinion.

### FERTILISER APPLICATION AND RECORD KEEPING

A soil test result will contain information for the full crop cycle (plant crop and four ratoon crops). Based on the results of the soil test, apply the appropriate fertiliser products at the correct rates. Records of all nutrient inputs, including from ameliorants such as mill by-products or liming products, should be kept for personal farm management purposes and to comply with any Government regulations.



## UNDERSTANDING SOIL TESTS

The person interpreting soil test results and making recommendations must be well trained and, preferably, experienced in sugarcane nutritional requirements.

The nutrient recommendations in this manual are based on SRA Limited critical values. Advice on interpreting soil test results should be sought from an experienced advisor who is familiar with sugar industry recommendations i.e. the SIX EASY STEPS Guidelines.

Recommendations on the amount of nutrient to apply are available on the SRA website.

Terms such as buffer pH, conductivity, sodium % cations, phosphorus bicarbonate, and aluminium saturation % may also appear in the results of a soil analysis.

### Relationship between mg/kg, ppm, meq%, me/100 g and cmol/kg

Soil tests from various laboratories may express soil assay results in different terms.

Milligrams of nutrient per kilogram of soil (mg/kg) is the same as parts per million (ppm).

Milliequivalents percent (meq%) is the same as milliequivalents per 100 grams of soil (me/100 g) and centimoles per kilogram of soil (cmol/kg).

Some assays – potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and aluminium (Al) – may be expressed as either mg/kg or meq% on a soil test result.

**TABLE 10 SOIL ASSAY AND CORRESPONDING APPLICATIONS**

ANALYTE/ASSAY	APPLICATION
Soil pH (1:5 water)	Used for acid soils. A measure of acidity and alkalinity. Soil pH can affect nutrient uptake.
Soil pH (1:5 CaCl <sub>2</sub> )	Used for alkaline soils (mostly in the Burdekin). A measure of acidity and alkalinity. Soil pH can affect nutrient uptake.
Electrical conductivity	An indirect measure of salinity.
Organic carbon	Used to assess the organic matter level of a soil.
Phosphorus (BSES)	Combined with PBI, used to assess the phosphorus requirement of a crop.
Phosphorus (Colwell)	Combined with PBI, may be able to be used in the future to assess the phosphorus requirement of a crop for high pH soils.
Phosphorus buffering index (PBI)	A measure of the soil's ability to tie up or "hold onto" phosphorus.
Potassium (ammonium-acetate)	A measure of the soil's available potassium.
Potassium (nitric K)	A measure of the soil's reserve potassium.
Sulfate sulfur	A measure of the sulfur availability in soils.
Cation Exchange Capacity (CEC)	An indication of the soil's nutrient-holding ability.
Calcium	A measure of the soil's available calcium.
Magnesium	A measure of the soil's available magnesium.
Sodium	A measure of water soluble and exchangeable sodium. Along with chloride, contributes to conductivity.
Chloride	One of the anions that contributes to the total soluble salt content of the soil. Along with sodium, chloride contributes to conductivity.
Zinc (HCl)	A measure of plant-available zinc (acid soils).
Zinc (DTPA)	A measure of plant-available zinc (alkaline soils).
Copper (DTPA)	A measure of plant-available copper. An unreliable test.
Silicon (BSES)	A measure of the soil's reserve silicon.
Silicon (CaCl <sub>2</sub> )	A measure of the soil's available silicon.

**TABLE 11 CONVERSION FACTORS FOR meq% TO/FROM mg/kg**

NUTRIENT	meq% (me/100 g) to mg/kg (ppm)	mg/kg (ppm) to meq% (me/100 g)
Potassium (K)	Multiply by 390	Divide by 390
Calcium (Ca)	Multiply by 200	Divide by 200
Magnesium (Mg)	Multiply by 120	Divide by 120
Sodium (Na)	Multiply by 230	Divide by 230
Aluminium (Al)	Multiply by 90	Divide by 90

**Examples**

**Q:** The soil exchangeable potassium reading is K (amm-acet) 0.15 me/100 g. How many parts per million (ppm) is that?

**A:**  $0.15 \times 390 = 58.5 \text{ ppm}$

**Q:** The soil calcium parts per million (ppm) reading is 175. What milliequivalents per 100 grams of soil (me/100 g) level is that?

**A:**  $170 \div 200 = 0.85$





## CHAPTER 5

# LEAF ANALYSIS

Soil testing and leaf analysis are complementary but different. Soil tests predict nutrient availability and how much fertiliser needs to be applied. Leaf analysis reveals the level of nutrient uptake by the crop by measuring the nutrient content of the plant tissue. It offers an excellent method of checking on the adequacy of fertiliser recommendations and nutrients applied.

Leaf analysis is a useful supplement to soil testing. It can be used to evaluate the fertility status of the crop and the effectiveness of the fertiliser program.

**CAUTION:** Although a leaf test is a useful tool to identify nutritional problems, caution is needed when interpreting the results since many factors, apart from nutrient availability, can influence nutrient levels in a plant. These factors include the age of the plant, the variety of cane, the environment and interactions between nutrients. In addition, leaf tests are not reliable if leaves are collected from plants showing insect damage, disease stress or moisture stress (either too much or too little water).

### REASONS TO LEAF TEST

Regular leaf testing over a number of seasons will enable the creation of a suitable databank that can be used to identify nutrient trends on a farm. Collectively, these data will enable people to monitor nutrient trends at district, regional and industry levels.

In summary, leaf tests will:

- identify whether a poor growth area could be associated with a nutritional problem
- confirm a visual diagnosis
- detect "hidden hunger" (yield reduction due to insufficient nutrient uptake that is not visually apparent)
- validate a fertiliser recommendation that was based on a soil analysis
- assess whether any soil nutrient imbalances are being translated into similar effects in the crop
- identify nutrient trends over time.

### HOW TO LEAF SAMPLE

Only the 200 mm (approximately) mid-section from the third leaf, with the midrib removed, is suitable for laboratory analysis. (The first partially unrolled leaf at the top of the stalk is counted as the first leaf). Ideally, samples should be collected during February or March when moisture stress (either excess or deficit) is usually not



Leaf analysis samples comprise the third unfurled or partially unfurled leaf (left). The middle 200 mm section of 20–30 leaves is selected (centre), the midrib is removed (right), and the leaf blades are dried and sent to the laboratory.

a problem and the sugarcane is actively growing. However, collection from December to April is generally suitable. A total of at least 20 leaves should be collected for each sample. Samples are best kept in a clean paper bag and stored in a styrene cooler or refrigerator prior to laboratory drying at 70°C.

As with collecting soil samples, cleanliness is essential. Ensure that samples do not become contaminated by soil, sunscreen, fertiliser, dust, agricultural chemicals or galvanised coatings.

For more information on the correct sampling of leaves for analysis, a fact sheet is available on the SRA website.

### UNDERSTANDING LEAF TESTS

Leaf analysis results are interpreted according to the third leaf critical values shown in Table 12.

An example of a leaf analysis report is shown below. The bar graph representation of the analytical data provides an easy to understand interpretation of the results. Statements below the bar graph add to this interpretation and indicate how the actual test values relate to the established third leaf critical values.

**TABLE 12 SRA CRITICAL LEVELS FOR THIRD LEAF ASSAYS**

THIRD LEAF ASSAY	UNIT	CRITICAL LEVEL OF ASSAY
Nitrogen (N)	%	<ul style="list-style-type: none"> <li>• November to mid-January: 1.9</li> <li>• Mid-January to February: 1.8</li> <li>• March to May: 1.7</li> </ul>
Phosphorus (P)	%	0.19
Potassium (K)	%	1.1
Calcium (Ca)	%	0.20
Magnesium (Mg)	%	0.08
Sulfur (S)	%	0.13
Copper (Cu)	mg/kg	2
Zinc (Zn)	mg/kg	15
Manganese (Mn)	mg/kg	15
Boron (B)	mg/kg	1
Molybdenum (Mo)	mg/kg	0.08
Silicon (Si)	%	0.55

In the example (Figure 12), the leaf analysis results can be interpreted as follows:

- The third leaf nitrogen value is high and reflects the high nitrogen application rate.
- The third leaf phosphorus value is also high. Mr Bloggs has probably been applying phosphorus fertiliser or other phosphorus source such as mill mud regularly over the years. He should reduce the phosphorus inputs.

- The third leaf potassium value is low. The problem is being exacerbated by the relatively high calcium and magnesium values. High calcium and/or magnesium may affect the uptake of potassium.
- The third leaf sulfur value is low. DAP (di-ammonium phosphate) which is often applied at planting, does not contain sulfur. Superphosphate, the usual provider of phosphorus in the past, also contains a substantial amount of sulfur. Mr Bloggs should apply a fertiliser mixture that contains sulfur.
- The third leaf zinc value is low. Had the sugarcane been younger at the time of sampling, Mr Bloggs could possibly have considered a foliar application of a 1% zinc sulfate solution (300 L/ha). Next season, Mr Bloggs should consider either applying zinc fertiliser to the soil or a foliar application of zinc sulfate when the sugarcane is about three months old.
- Although the third leaf iron and silicon values are given, they are not included in the bar graph. It is difficult to interpret leaf iron values. The third leaf silicon values should be regarded with some caution until specific guidelines are in place to ensure meaningful interpretation of the data.

**LEAF ANALYSIS REPORT**

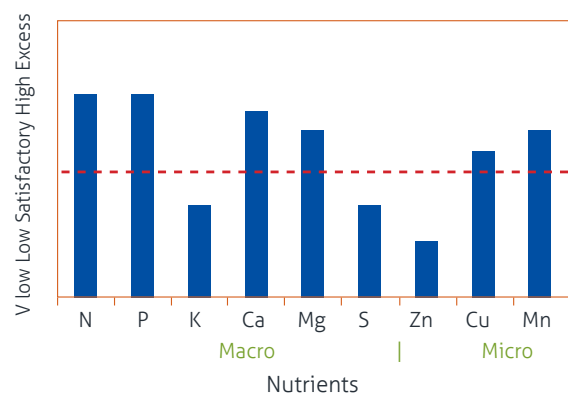
Sample No. 6862  
 Name Joe Bloggs  
 Address 123 Never Never Road  
 Mill Isis  
 Farm No. ISSB-02218  
 Block 13A  
 Age (months) 5  
 Sampling date 20/02/2013  
 Crop 1R  
 Variety Q232<sup>h</sup>

Leaf data		Critical:
Nitrogen (N)	2.25%	1.8%*
Phosphorus (P)	0.28%	0.19%
Potassium (K)	0.90%	1.1%
Calcium (Ca)	0.42%	0.2%
Magnesium (Mg)	0.23%	0.08%
Sulfur (S)	0.09%	0.13%
Zinc (Zn)	9.00 mg/kg	15 mg/kg
Copper (Cu)	5.00 mg/kg	2 mg/kg
Manganese (Mn)	72.00 mg/kg	15 mg/kg
Iron (Fe)	103.00 mg/kg	-
Silicon (Si)	0.88%	0.7%

Nutrients applied  
 CK 140 @ 500 kg/ha

Figure 12: Example of a leaf analysis report

**LEAF NUTRIENT STATUS**



Remarks:

- \* Leaf N critical value depends on the date and age of cane at sampling.
- # One or more of the macro nutrients are below satisfactory levels.
- # Relatively high Ca+Mg may be affecting the update of K.
- # One or more of the micro nutrients are below satisfactory levels.
- Foliar application should be considered if the cane is less than 5 months old.

## CHAPTER 6

# NUTRIENTS EXPORTED IN THE SUGARCANE CROP

Table 13 shows the quantities of most of the essential nutrients which are exported by sugarcane crops in various parts of Queensland.

TABLE 13 QUANTITIES OF NUTRIENTS EXPORTED IN A SUGARCANE CROP (ALLOWANCES MADE FOR % GREEN CANE TRASH BLANKET (GCTB) AND BURNT CANE)								
REGION	MOSSMAN - GORDONVALE	BABINDA - TULLY	HERBERT	BURDEKIN	CENTRAL	BUNDABERG	MARYBOROUGH - ROCKY POINT	QUEENSLAND
	QUANTITY OF NUTRIENTS EXPORTED PER TONNE CANE							
	kg/t cane							
Nitrogen (N)	0.75	0.75	0.67	1.11	0.90	0.88	1.15	0.89
Phosphorus (P)	0.10	0.11	0.11	0.24	0.15	0.16	0.17	0.15
Potassium (K)	1.12	1.22	0.76	2.05	1.53	1.93	2.18	1.54
Calcium (Ca)	0.13	0.11	0.15	0.28	0.15	0.18	0.17	0.17
Magnesium (Mg)	0.13	0.10	0.19	0.29	0.21	0.28	0.26	0.21
Sulfur (S)	0.21	0.16	0.15	0.35	0.21	0.35	0.36	0.26
g/t cane								
Manganese (Mn)	30	23	28	10	18	13	19	20
Iron (Fe)	30	36	35	34	33	44	165	54
Zinc (Zn)	3	3	3	3	2	5	4	3
Copper (Cu)	1	0	1	1	1	1	1	1
GCTB (%)	90	88	95	9	83	68	41	68
Burnt (%)	10	12	5	91	17	32	59	32

### Assumptions:

% GCTB and burnt per region as shown.

All nutrients in tops and trash returned with GCTB.

15% of N and S in tops and trash returned with burning.

50% of P, K, Ca, Mg and trace elements in tops and trash returned with burning.

15% plough-out, 30% of which would have had the residue burnt.

Note: Some regions have GCTB figures in the table that are lower, and burnt cane figures that are higher, than is currently the situation.

No simple relationship exists between soil fertility, fertiliser application, and nutrient removal by the crop.



Sugarcane stalks sent to the sugar mill contain nutrients taken from the soil. Regular soil testing will indicate the nutrient status of the soil and define the fertiliser program to ensure nutrient deficiencies do not occur.



CHAPTER 7

# NUTRIENT DEFICIENCY SYMPTOMS

Table 14 (*overleaf*) summarises leaf and stalk deficiency symptoms for each essential nutrient. Leaf deficiency symptoms:

- are not always well defined
- might not be obvious even when crop yields are impacted by nutrient deficiency
- could be masked by other factors
- can vary between varieties, locations, environmental conditions and other factors
- do not always appear as classic text book descriptions.

Figure 13 is a schematic representation of which leaves – young or old or both – exhibit deficiency symptoms for each of the essential nutrients.

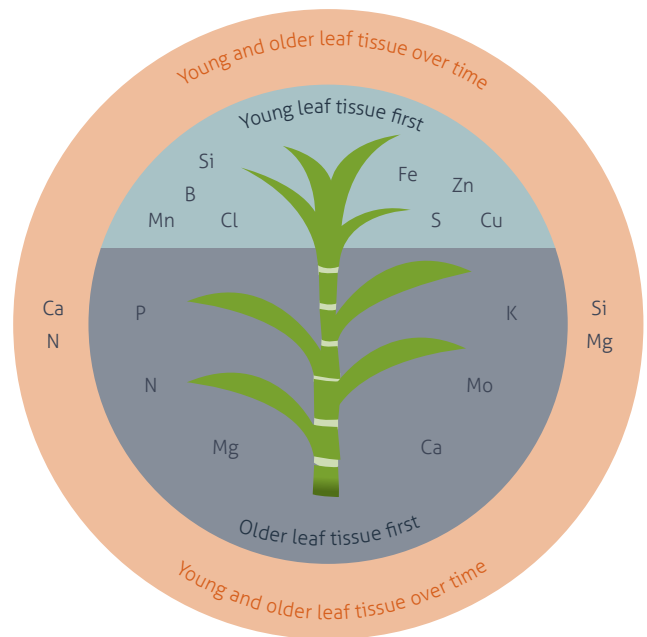


Figure 13: Type of leaf tissue displaying symptoms of deficiency of essential nutrients

**TABLE 14 LEAF AND STALK NUTRIENT DEFICIENCY SYMPTOMS**

NUTRIENT	OLD OR YOUNG LEAVES	LEAF COLOUR	LEAF TISSUE DEATH	OTHER LEAF FEATURES	STALK ABNORMALITIES
Nitrogen (N)	Old first	Pale green-yellow	On tips, margins	Overall pale appearance	Thin, stunted stalks; short internodes; reduced stooling
Phosphorus (P)	Old first	Blades dark green; tips, margins purple-red	On tips and margins after first yellowing	Abnormally erect; thin, narrow and short	
Potassium (K)	Old first	Yellow/brown/dark red stripes between leaf veins	Dead areas on margins, tips ("fired"/"salt burn")	Midribs reddish	Thin, stunted stalks; spindle has fan appearance
Calcium (Ca)	Old first	Older leaves often pale green/yellow mottling/rusty	Older leaves die prematurely	Young leaves necrotic with curled, hooked or serrated edges; spindle dies at tip and edges	Stalks thin and taper towards growing point; apical meristems die; poor top growth; soft rind; primary shoot dies
Magnesium (Mg)	Old first	Young leaves green; older leaves paler with yellow mottling or interveinal chlorosis	No	Chlorotic spots on older leaves turn orange and dark brown. Spots join giving rusted look ("orange freckle")	Stooling weak; sugarcane growth retarded
Sulfur (S)	Young first	Young leaves light green/yellowish often with purplish margin	Leaf edges	Chlorosis on most of the leaves	Stalks and leaves very thin; stalks more flexible at tip than normal
Copper (Cu)	Young first	Small, dark green patches appear as inter-veinal chlorosis	No	"Droopy top"; leaves bleached and chlorotic	Rubbery stalks; reduced tillering and vigour; reduced internode length
Zinc (Zn)	Initially on third and older	Chlorosis of leaf veins causing yellowish striping along leaf length (only nutrient exhibiting veinal chlorosis); midrib and margins stay green	No	Red fungal lesions may develop on leaf blades	Stunted stools; thin, elastic stalks
Boron (B)	Young first	Varying degrees of chlorosis; leaf tips severely burned and may split	No	Distorted; tend to be brittle; translucent lesions or "water sacks" between veins	Growing points distorted or dead; young plants bunched; excessive tillering
Manganese (Mn)	Young first	Longitudinal pale stripes between leaf veins from middle of leaf to tip	No	Leaf blades may split; entire leaf may become chlorotic	
Molybdenum (Mo)	Old first	Short, longitudinal chlorotic streaks on apical one-third of the leaf	Older leaves dry prematurely from middle towards tip	Similar to pokkah boeng disease	Stalks short and slender; growth slowed
Iron (Fe)	Young first	Longitudinal pale stripes between leaf veins from base to tip	Only in prolonged, severe cases	Entire leaf and plant bleached or chlorotic	Young stubble shoots have no new root development
Chlorine (Cl)	Young first	Leaves chlorotic	No		Leaves wilt during day and recover at night
Silicon (Si)	Young first	Light-coloured spots on surface exposed to sunlight progress to bronze freckling	Premature senescence		Rubbery stalks; tops shortened, compact and spiky (fan-like)

Note: The symptoms are general descriptions and may occur in the worst cases of nutrient deficiency. Not all leaf symptoms display the same classic characteristics. Not all symptoms occur in all cases of nutrient deficiency.

## CHAPTER 8

## NITROGEN (N)

One of the six major essential plant nutrients, nitrogen drives photosynthesis and sugar production by the plant. However, nature alone cannot supply enough nitrogen for highly productive commercial crops such as sugarcane. Together with phosphorus, nitrogen is an environmentally-sensitive nutrient that can have a significant impact on water quality when it moves off-site into waterways.

**THE ROLE OF NITROGEN IN SUGARCANE**

- One of the main building blocks of proteins.
- Necessary component in cell structure and cell functions.
- Responsible for growth, expansion of green leaves, and tiller and sucker production.
- Essential for chlorophyll synthesis, photosynthesis and sugar production.

**NITROGEN DEFICIENCY SYMPTOMS**

- Symptoms first appear in the lower (older) leaves.
- Slow growth; growth of entire plant is affected.
- Thin, stunted stalks with short internodes.
- Light green to yellow leaves from the base of the plant upwards, often with necrosis (death of tissue) on the tips and edges of older leaves.
- Reduced stalk population and low yield.
- Reduced root mass.

Nitrogen is a mobile nutrient in the plant. When nitrogen is deficient, it is readily transferred from the older cells of the plant to the young, actively growing sections of the plant (growing points, root tips). Hence, the first and most obvious symptoms of deficiency appear on the older (lower) leaves.



*The pale-coloured rows of sugarcane have received no nitrogenous fertiliser.*



*Leaves of nitrogen-deficient sugarcane stools are pale green to yellow.*



*Leaves from healthy sugarcane (left) and nitrogen-deficient sugarcane (right).*



## CONSEQUENCE OF NITROGEN EXCESS

- Prolonged growing period; delayed maturity.
- Reduced sucrose level.
- Reduced juice purity.
- Increased probability of crop lodging and suckering.
- Can lead to increased amounts of the reducing sugars (glucose and fructose) in juice particularly in the early part of season. They may react with any excess nitrogen stored in stalks as amino acids such as asparagine to produce phenolic compounds during the milling process. These compounds contribute to increased juice colour which adversely affects sugar quality.

## THE NITROGEN CYCLE

The nitrogen cycle (Figure 14) describes all the processes by which nitrogen circulates between the atmosphere, the soil, plants and animals.

Nitrogen can be provided for growth from a range of sources:

- the atmosphere
  - » biological fixation (legumes)
  - » atmospheric fixation (lightning)
  - » rainfall
- industrial fixation (manufactured solid and liquid fertilisers)
- soil organic matter
- mill mud and mud-ash mixtures
- crop residues
- composts
- animal manures.

## SOURCES OF NITROGEN

### Atmospheric nitrogen

Seventy-eight percent of the air is nitrogen. Each hectare of land has approximately 78,000 tonnes of nitrogen in the air column above it. However, plants cannot use this inert form of nitrogen until it is converted into forms called ammonium ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ). This conversion is done for plants in industrial factories where large amounts of natural gas are used to make urea, ammonium sulfate or anhydrous ammonia.

Nitrogen oxides are formed when the extreme heat of a lightning flash causes nitrogen to combine with oxygen in the air. The oxides mix with moisture in the air. The fixed nitrogen is carried by rain to the earth, where, in the form of nitrates, it is used by plants.

The other form of nitrogen received by the soil in rainwater is ammonia, an atmospheric gas that dissolves in rainwater.

An estimated two to 20 kg/ha of nitrogen falls each year in rainfall, far less than is required for profitable and sustainable sugarcane production.

### Soil nitrogen

The soil contains a large proportion of nitrogen in amino acids released from organic matter. Nitrogen is also present as nitrogen gas ( $\text{N}_2$ ), nitrite ( $\text{NO}_2^-$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), nitric oxide ( $\text{NO}$ ), ammonia ( $\text{NH}_3$ ), ammonium ( $\text{NH}_4^+$ ), and nitrate ( $\text{NO}_3^-$ ). Only the last two forms of nitrogen can be used by plants. Nitrogen in any other form must be converted to one of these forms to be available to sugarcane.

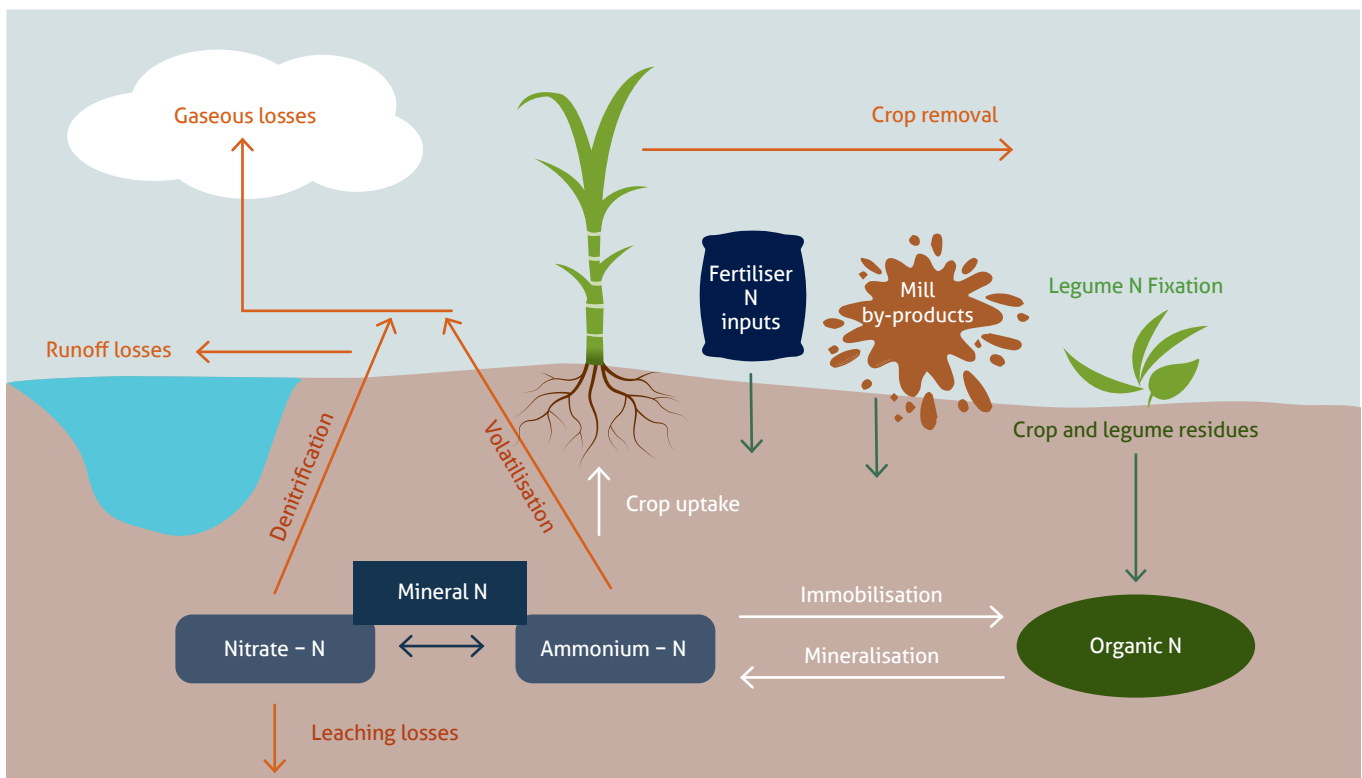


Figure 14: Nitrogen cycling in sugarcane crops

The total amount of nitrogen in soil ranges from seven to nine tonnes/hectare (equivalent to 15 to 20 tonnes/hectare of urea). Only a very small proportion of this nitrogen becomes available to the crop each year via mineralisation.

### Irrigation water nitrogen

Some groundwater and irrigation tailwater, most notably in parts of the Burdekin region, can supply significant quantities of nitrogen for crop use. The nitrogen levels can vary widely from year to year. An annual water test is recommended to determine the extent of nitrogen fertiliser reductions that can be made following irrigation.

### Legume nitrogen

Leguminous plants, such as peanuts, cowpeas and beans, can grow in soils which lack nitrogen providing the soil contains a certain type of bacteria called *Rhizobium*. About a week after the rhizobia bacteria infect the legume root and multiply within its cortex cells, small nodules appear. The rhizobia in the nodules collect nitrogen from the air. The bacterial activity converts this nitrogen into a form that can be used by the legume. This process is called nitrogen fixation.

Internally, young nodules that are not yet fixing nitrogen are usually white or grey. As nodules mature, they turn a pink to reddish colour indicating nitrogen fixation has commenced. The pink or red colour is caused by leghemoglobin (similar to blood haemoglobin) that controls oxygen.

As seeds form in the pods, nitrogen fixation ceases. Any stresses that impact on the plant will reduce nitrogen fixation. If nodules are not pink to reddish in colour, little nitrogen fixation is occurring. The reasons could be the *Rhizobium* strain is not suited to the particular legume species, pod filling has commenced, or the plant is suffering stress from any number of factors including poor nutrition or inadequate soil moisture levels.

The proportion of nitrogen fixed by a legume also depends on the amount of mineral nitrogen in the soil. If there is adequate mineral nitrogen in the soil, the legume will have no need to fix nitrogen from the atmosphere.

Careful management is the key to the production of a healthy, beneficial legume crop. The block to be planted to legumes should be levelled, if required, to avoid waterlogging. Weeds must be kept under control. If the soil nematode population is high, legumes might not be a viable option. The soil pH should be about 5.8 or higher for a legume crop to thrive. Legume variety may be important particularly if the seed is to be harvested. Treatment of the seeds with the correct inoculant prior to planting is necessary for nitrogen fixation by the crop to occur.

How the legume biomass is managed will determine the efficacy of the legume crop in supplying nitrogen to the subsequent sugarcane crop. The general recommendation is that the cover crop be sprayed out with a suitable herbicide,



*A well-managed legume crop can provide many benefits to sugarcane production.*

or slashed, and the stubble left on the soil surface. However, that option might not always be practical.

The nitrogen fixed by the legume crop is added to the soil following decomposition of the crop. An extremely well-grown legume crop is capable of supplying the full nitrogen requirement of the following plant cane crop provided the legume crop is very well managed. Realistically, however, most legume crops would currently supply only up to half the nitrogen requirement of the following sugarcane crop.

### Crop residue nitrogen

A sugarcane crop produces a 10–15 t/ha green trash blanket and approximately 3 t/ha of roots each year but 80% of this is lost by decomposition each year. The nitrogen in the green trash blanket and decomposing stubble is recycled as it breaks down in the soil.

### Mud/ash nitrogen

Mill mud and mud-ash mixtures can supply large quantities of nitrogen. The percentage of nitrogen in those products will vary between regions and over years. A large proportion of the nitrogen is not available for short-term crop use.

### Compost and animal manure nitrogen

These products may contain significant quantities of nitrogen and can be useful sources of crop nitrogen. However, the quantities of nitrogen vary widely and, being organic products, may release nitrogen (and other nutrients) slowly over a period of years, depending on the rate of mineralisation.

## FORMS OF NITROGEN

The various forms of nitrogen are shown in Table 15. Sugarcane has a preference for ammonium-N over nitrate-N but nitrate-N is the largest pool of available nitrogen.

### Nitrification

Soil nitrogen sources are subject to microbial activity during the process of nitrification. The naturally-occurring bacteria *Nitrosomonas* convert ammonium (which plants can use) to nitrite (which plants cannot use). Then, *Nitrobacter* bacteria convert nitrite to nitrate (which plants can use). Nitrite concentrations are normally low in soils because the conversion to nitrate occurs rapidly.



Nitrification is an important step in the nitrogen cycle in soil. Nitrogen from all sources including applied fertiliser undergoes this process.

If nitrogen is applied as urea, the enzyme called urease will convert it to ammonium, which is then subject to the above nitrification process.

### CONVERSION OF NITROGEN FERTILISER TO AMMONIUM AND NITRATE IN THE SOIL

Being a biological process involving soil bacteria, the conversion from ammonium to nitrate occurs more slowly in cooler temperatures and dry soils.

Table 16 shows the period of time required to convert dissolved urea into the ammonium form and then into nitrate-N at various soil temperatures.

Products that delay the conversion of ammonium-N to nitrate-N have the potential to reduce nitrogen losses from denitrification and leaching. These nitrification inhibitors are discussed under the section titled "Enhanced efficiency fertilisers" on page 38.

**TABLE 16 INDICATIVE DURATION OF CONVERSION OF UREA INTO AMMONIUM AND NITRATE IN THE SOIL**

UREA	→ (UREASE)	AMMONIUM	→ (SOIL BACTERIA)	NITRATE
SOIL TEMPERATURE (°C)		CONVERSION TIME OF NITROGEN FERTILISER INTO AMMONIUM		CONVERSION TIME OF 50% OF AMMONIUM INTO NITRATE
2		4 days		6 weeks
10		2 days		4 weeks
20		1 day		2 weeks
			20	1 week

(Source: Incitec Pivot Limited)

Nitrate nitrogen is usually the more common form of nitrogen available to the crop. However, the energy required by the sugarcane plant for ammonium uptake is less, so when it is available, plants can rapidly take it up.

### LOSS OF NITROGEN FROM THE SOIL

The sugarcane crop removes some nitrogen from the soil (Table 13). Nitrogen can also be lost through volatilisation, denitrification, leaching and runoff before the crop can utilise it.

### Volatilisation

Volatilisation is the loss process for nitrogen from surface-applied urea or urea-based mixtures. A biochemical reaction involving the naturally-occurring enzyme, urease, occurs when urea dissolves. Ammonia gas is formed and is lost to the atmosphere. Urease is produced by many soil micro-organisms and plants and is present in virtually all soils.

**TABLE 15 FORMS OF NITROGEN**

FORM OF NITROGEN	FORMULA	AVAILABILITY FOR PLANT UPTAKE
Nitrogen	N <sub>2</sub>	Comprises 78% of the atmosphere. Inert form of nitrogen that must be transformed to one of two forms that make nitrogen available for plant uptake.
Ammonia	NH <sub>3</sub>	A gas. Basic component of commercial nitrogen fertilisers. Can escape from the surface of the soil under volatilisation conditions.
Ammonium	NH <sub>4</sub> <sup>+</sup>	Available for plant uptake. Ammonium is held onto soil particles.
Nitrite	NO <sub>2</sub> <sup>-</sup>	An intermediate product in the conversion of ammonium to nitrate (nitrification). Present in low quantities. Toxic to plants. Cannot be taken up by plants.
Nitrate	NO <sub>3</sub> <sup>-</sup>	Available for plant uptake. Nitrate is highly mobile as it is not retained by soil particles. Easily leached from soil.
Organic nitrogen	Various compounds	Must be converted to ammonium before it can be used by plants in a process called mineralisation. Recent research suggests organic forms of nitrogen can be taken up by plants, but this requires further validation.



The process of volatilisation can be summarised as follows:



which is represented by the equation:



This reaction is the reverse of the manufacture of urea.

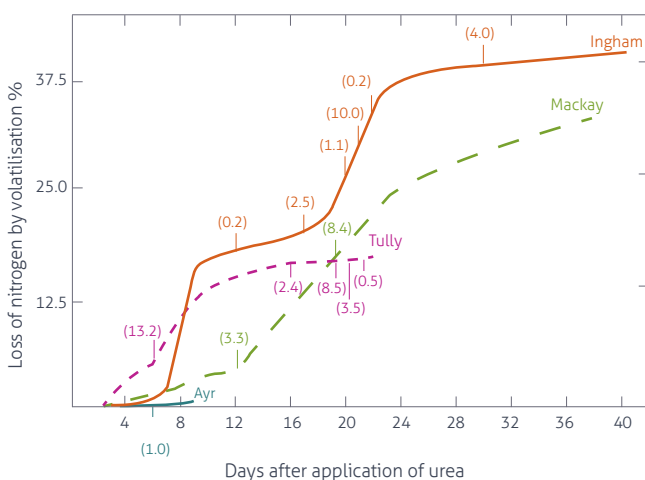
Ammonia (NH<sub>3</sub>), unlike the ammonium ion (NH<sub>4</sub><sup>+</sup>), is a gas and does not attach to the soil.

Nitrogen loss from urea or urea-based mixtures applied on the surface of bare soil or trash blankets can be very high. Volatilisation losses are highest when light rainfall (less than approximately 5 mm) or heavy overnight dew is sufficient to cause the urea to dissolve and form ammonia gas, but insufficient to wash the urea from the trash layer into the soil. Hot, windy days with no crop canopy cover will exacerbate the level of volatilisation. The potential for volatilisation increases with higher pH in the reaction zone.

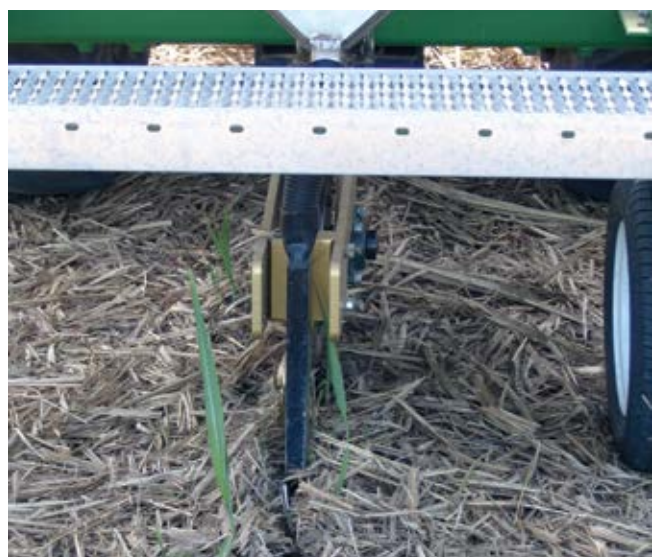
The graph below (Figure 15) illustrates the ammonia losses from urea in trials conducted at four sugarcane growing centres in Queensland. The losses ranged from almost zero after nine days at Ayr, to 39% after 41 days at Ingham. Small amounts of rainfall or dew caused an upsurge in nitrogen loss. Single or cumulative rainfall events greater than about 15 mm, while causing an initial increase in ammonia loss, were sufficient to finally wash the urea into the soil.

Volatilisation losses will be lower on a dry soil that is getting wet than on a wet soil that is drying out.

Volatilisation of sulfate of ammonia is negligible. However, the cost of sulfate of ammonia may preclude its use as an alternative to urea as a source of nitrogen unless sulfur is also required.



(Source: Denmead et al., 1990)  
 Numbers in ( ) represent daily rainfall recordings in millimetres.  
 Figure 15: Ammonia losses from applied urea, and rainfall amounts (mm) at experimental sites.



Subsurface application of urea-based fertiliser in both green harvested or burnt cane situations is normally the main recommendation to prevent volatilisation of nitrogen in the fertiliser. The fertiliser slot needs to be closed with appropriate finger or press wheels to prevent ammonia gas from escaping.

## STRATEGIES TO MANAGE VOLATILISATION

1. Subsurface-apply urea into the soil. Volatilisation will not occur if urea is buried. This option is recommended in almost every fertilising situation.
2. Surface application of urea or urea-based mixtures to ratoon cane is an option under the following management strategies:
  - **Apply urea applications to coincide with rainfall of 20 mm** or more (but not to the point where runoff occurs) in the days after surface application. Fertiliser will be washed into the soil and not subject to volatilisation. The obvious risk is less rainfall will result in conditions conducive to volatilisation.
  - **Irrigate with 20 mm** or more of water in the days after surface application. Fertiliser will be washed into the soil and not subject to volatilisation.
  - **Delay urea applications** until the sugarcane canopy is approximately 50 cm tall, when practical. When ratoons are at that height, sufficient time has elapsed for the new root system to replace the old roots that die off after harvest. The new root system will be better able to access the fertiliser. The canopy also partially protects the surface-applied urea from factors such as wind movement and sunlight which aid volatilisation.
  - **Apply urea on the row area.** This placement method applies to all fertilising situations, not only surface applications. Most of the roots are in the row, not the compacted interspace, and will have a greater ability to access the fertiliser.
  - **Use sources of nitrogen other than urea** (e.g. sulfate of ammonia). However, urea is the cheapest form of nitrogen fertiliser and is usually recommended unless sulfur is also required. Huge volatilisation losses would have to occur for one of the alternatives to urea to be economically competitive. Specific management techniques (for example, subsurface application) should be used to take advantage of urea's cost advantage. If sulfate of ammonia is surface-applied where lime is also present, the production of unstable ammonium carbonate can occur.
  - **Urease inhibitor products** delay the conversion of urea into ammonia that may be lost to the atmosphere. These products are more expensive than urea.

## Denitrification

Denitrification is the conversion of nitrate-N that plants can use to nitrogenous gases that escape to the atmosphere. Three factors are required for denitrification to occur – dissolved carbon, nitrogen in the nitrate form, and anaerobic conditions.



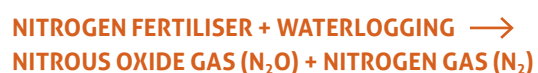
*Waterlogged conditions may cause the denitrification of nitrogen fertilisers resulting in a loss of nitrogen to the atmosphere.*

Certain soil bacteria thrive when oxygen is lacking, such as in waterlogged fields. Most denitrification bacteria and most carbon are found in the top one centimetre of soil. Under such anaerobic conditions, nitrate nitrogen may be converted by the bacteria to gases which escape to the atmosphere. This process, denitrification, is increased in the presence of trash residues and warm temperatures. The key driver of denitrification is water-filled soil pore space. The first rainfall event in the wet season is particularly important in the management of the denitrification process as this is when nitrate concentrations are usually highest.

Denitrification can occur one to three days after a significant rainfall event. Losses can amount to a substantial proportion of the applied nitrogen fertiliser. Denitrification frequently occurs in sugarcane harvested late in the season when early summer storms saturate sugarcane fields before the crop has had time to take up the nitrogen in the applied fertiliser.

Denitrification can occur with all subsurface-applied (buried) nitrogenous fertilisers, not just urea.

The process of denitrification can be summarised as follows:



Under very low oxygen conditions, soil microbes can use nitrate as an oxygen source resulting in nitrous oxide release. For agriculture and the sugarcane industry in particular, nitrous oxide (laughing gas) is a major greenhouse gas. Nitrous oxide has approximately 310 times the global warming potential of carbon dioxide. Nitrous oxide molecules stay in the atmosphere for an average of 114 years before being removed or destroyed through



chemical reactions. With continuing anaerobic conditions, nitrous oxide may be converted to N<sub>2</sub> gas that does not contribute to the greenhouse gas effect.

Denitrification losses will be higher for fertiliser buried in the middle of the interspace (the area most heavily waterlogged and never recommended as a placement method) than for fertiliser buried on the side of, or into the top of, the row.

### STRATEGIES TO MANAGE DENITRIFICATION

1. **Effective surface drainage** of blocks will prevent pooling after rainfall or irrigation. Land levelling eliminates depressions on the soil surface that provide conditions suitable for waterlogging and denitrification.
2. **Mounded rows** will raise the drill profile, putting the plants and fertiliser band above the area most likely to be waterlogged.
3. **Avoid excessive nitrogen** application by following the SIX EASY STEPS recommendations.
4. **Use water-efficient irrigation techniques** to prevent waterlogging after irrigation.
5. **Practise minimum tillage and controlled traffic**, components of best farm management strategy.
6. **Maintain a healthy and robust crop** to ensure effective use of soil mineral nitrogen and water.
7. **Stool splitting** allows fertiliser to be applied in the highest part of the row profile, reducing the chances of waterlogging.
8. **Consider splitting nitrogen fertiliser application** on early-harvested blocks where waterlogging occurs regularly. The application of the crop's full nitrogen requirement over two or more times, rather than in one pass, will improve the timing of crop demand with nitrogen availability. After harvest, a crop's initial demand for nitrogen is low. Demand is greatest approximately two to three months after harvest. This strategy aims to improve the timing of nitrogen application to better match crop nitrogen demand. The increased cost of this strategy needs to be carefully considered.
9. **Consider climate forecasting.** Then, on blocks harvested mid- to late-season, consider splitting nitrogen application if waterlogging is likely. The accuracy of climate forecasts is improving but it is important to monitor climate forecasts as the season progresses and modify plans if necessary.
10. **Consider a product with an ammonium stabiliser/nitrification inhibitor** that reduces the activity of nitrifying bacteria, retaining nitrogen in the ammonium form for a longer period.

11. **Controlled release products** might be an option but if nitrogen is released in the wet season, nitrogen losses could actually be higher.

### Leaching

Leaching refers to the loss of soil nitrates (one of the two forms of nitrogen that can be taken up by the plant) which are moved below the root zone by rainfall or irrigation. Leaching is an important method of nitrogen loss in light-textured soils and in high rainfall areas.

### STRATEGIES TO MANAGE LEACHING

1. **Apply fertiliser when the crop is best able to access nutrients** to limit the time that nitrogen is subject to leaching.
2. **Use the plant as a storage of nitrogen.** A well-grown, healthy crop is the best way to quickly capture and retain nutrients. Once the nitrogen is in the plant, it cannot be lost to leaching.
3. **Consider a product with an ammonium stabiliser/nitrification inhibitor** that reduces the activity of nitrifying bacteria, retaining nitrogen in the ammonium form attached to the soil for a longer period.
4. **Controlled release products** slow down nitrogen release and may reduce leaching.
5. **Management of irrigation water**, particularly on light-textured soils, can reduce deep leaching of nitrogen below the root zone.
6. **Avoid application of fertiliser prior to expected heavy rainfall events.**



Rows that are mounded higher than normal, or planting into pre-formed raised beds, will help keep fertiliser above the waterlogged area, reducing or eliminating denitrification. (Photo: Reghenzani, Roth, 2006)



7. **Consider splitting nitrogen fertiliser application** on very sandy soils. This strategy aims to improve the timing of nitrogen application to better match crop nitrogen demand. The increased cost of this strategy needs to be carefully considered.
8. Similar to point seven, **fertigation** will allow the crop to access and utilise smaller individual nitrogen applications over a longer period of time. This practice will reduce the potential for leaching of a single, full application of fertiliser.

### Runoff

Runoff water and soil that leaves a sugarcane block may carry nutrients, including nitrogen, dissolved in the water or attached to soil particles that are suspended in the water. Runoff can contribute to water quality decline and reduce farm profitability.

#### STRATEGIES TO MANAGE RUN-OFF

1. **Green cane trash blanketing** provides excellent soil protection and significantly reduces or eliminates soil erosion.
2. **Tailwater recycling** dams are a feasible option for furrow-irrigated blocks where the tailwater and nutrients can be reapplied to the block.

3. **Grassed headlands and drains** have the ability to intercept some of the soil and attached nutrients moving out of sugarcane blocks.
4. **Spray-out fallow** and retaining the dead final ratoon in the crop cycle which is left standing over the wet season will protect the soil from erosion.
5. **Contouring** of the land reduces water flow and the potential for soil erosion down slopes.

### Enhanced efficiency fertilisers (EEFs)

EEFs are fertiliser products that may reduce nutrient losses while increasing nutrient availability for the crop. They can either slow the release of nutrients to better match crop uptake, or delay the conversion of nutrients to other forms that may be more susceptible to losses. EEFs include slow release fertilisers, controlled release fertilisers, ammonium stabilisers/nitrification inhibitors and urease inhibitors.

The effectiveness of EEFs may be influenced by factors such as temperature (ambient and soil), soil pH, soil moisture and micro-organisms.

The use of EEFs by growers may be affected by their perceived suitability, their perceived reliability, availability and cost.



Water from sugarcane fields flowing into drains can take unprotected fertiliser and soil with it (above left). Green cane trash blanketing (above right) protects sugarcane fields from soil erosion as illustrated in this simple demonstration (below).

**SLOW RELEASE FERTILISER**

These products release nutrients gradually into the soil thus modifying nutrient availability for plant uptake. Multiple factors affect the release of nutrient/s (e.g. soil moisture, soil temperate, pH, activity of soil organisms). Most commonly, fertiliser granules or prills are coated with a semi-permeable polymer to control the water solubility and release of the fertiliser.

**CONTROLLED RELEASE FERTILISER**

(e.g. Agrocote®; Osmocote®)

Controlled release products release nutrients slower than conventional inorganic fertilisers and at a fairly specific rate. Nutrient release from controlled release (CR) fertilisers is usually more predictable than from slow release fertilisers. However, the labels "slow release" and "controlled release" are often used interchangeably.

Mode of action of CR fertilisers: CR fertiliser granules are covered with an elastic polymer. Soil water slowly seeps through the coating and dissolves the enclosed nutrients. The nutrients in solution then exit the prill through the coating and become available for plant uptake. The coating ensures a controlled release of the nutrients. Release is more rapid at higher temperatures.

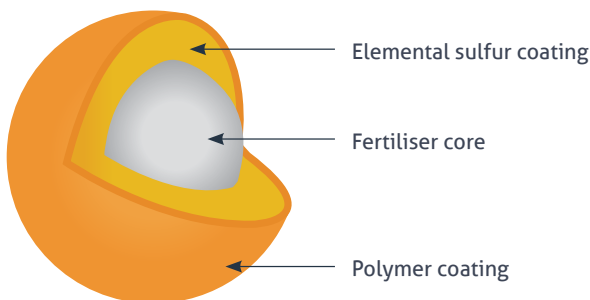


Figure 16: Example of controlled release fertiliser prill structure

**AMMONIUM-STABILISED/NITRIFICATION**

**Inhibitor Fertiliser (E.g. Entec®; eNtrench™)**

Nitrification is the process whereby ammonium-N is converted to nitrite-N and then nitrate-N.

An ammonium-stabilised or nitrification inhibitor fertiliser is stabilised in the ammonium form for a period of weeks after application. It disables the nitrifying bacteria, Nitrosomonas, and slows down nitrification by delaying the conversion of ammonium nitrogen to nitrate nitrogen (Figure 17). While stabilised in the ammonium form, potential nitrogen losses from denitrification and leaching are mitigated.

During this period, the crop still has access to nitrate nitrogen in the existing soil reserves and any that may be in the applied fertiliser as well as the ammonium nitrogen from the applied fertiliser.

**UREASE INHIBITOR FERTILISER**

(e.g. Green Urea Nv™)

Certain compounds added to urea or fertilisers containing urea may, if circumstances are suitable, result in less urea nitrogen lost to the atmosphere by ammonia volatilisation or by leaching of nitrate. The efficiency of urea and urea-containing fertilisers increases while adverse environmental impacts of nitrogen loss are reduced.

The inhibitor binds to the urease and temporarily stops the conversion to ammonia. Many compounds can inhibit urease but only a few are suitable for mixing with, or coated onto, urea-containing fertilisers. NBPT (N-(n-butyl) thiophosphoric triamide) is the most common urease inhibitor. It can be used with any nitrogen fertiliser.

The reduction in ammonia loss is variable as several factors including soil properties and climatic conditions influence the performance of urease inhibitors.

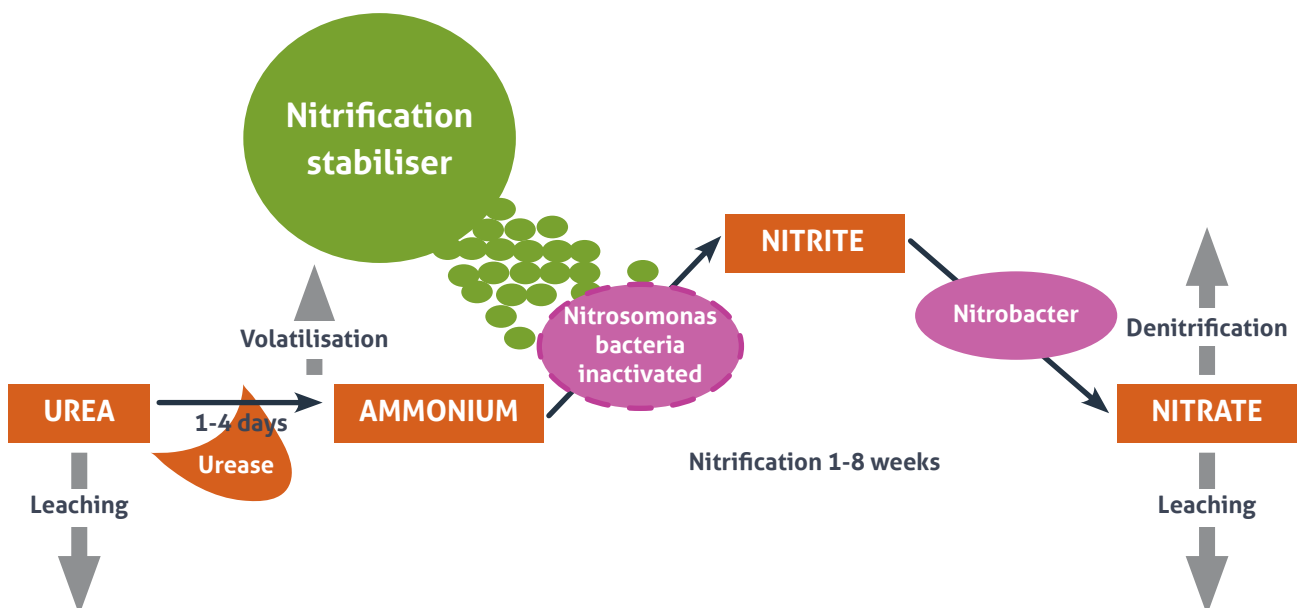


Figure 17: Mode of action of nitrification inhibitor fertilisers (Adapted from Incitec Pivot)

## NITROGEN REMOVAL BY THE SUGARCANE CROP

Table 13 shows the amount of nitrogen removed by a crop of cane each year in the various canegrowing regions. This nitrogen is supplied in the annual fertiliser application and by the mineralisation of organic nitrogen reserves.

## RESPONSE TO NITROGEN

An example of the response to applied nitrogen is shown in Figure 18. The arrow indicates the nitrogen application rate which provides the most economic return. The different letters on the curve indicate a significant yield difference at the respective nitrogen application rates. For example, there was no significant yield difference between the 160 and 240 kg N/ha rates (same letter), but both those rates produced significantly higher yield than the zero and 80 kg N/ha rates (different letters).

The optimum fertiliser rate for the most economic return depends on a number of factors including soil type, crop class, and whether a legume has been grown or mill by-products have been applied. All of these factors have been built into the SIX EASY STEPS Guidelines for each region of the industry.

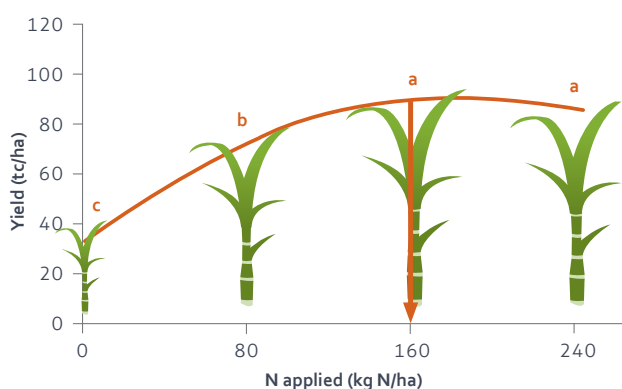


Figure 18: Example of sugarcane yield response to increasing nitrogen applications

## SOIL TYPE/MINERALISATION

Within districts, there are variations in yield responses to nitrogen fertiliser between soil types. Recommended nutrient rates account for the differences in nitrogen mineralisation between soil types using the soil's organic carbon content as a surrogate for the level of mineralisation.

## SUGARCANE VARIETY

Vigorous varieties grown on higher fertility soils will lodge at normal to high nitrogen rates resulting in lower CCS. For this reason, there may actually be a decline in sugar yield at the recommended nitrogen rates. Once sugar yields begin to fall, there will obviously be a loss from any investment in additional nitrogen fertiliser. Growers should ensure they plant only varieties recommended for a particular soil type, or obtain sound advice before reducing nitrogen below the recommended rates.

## CROP CLASS

In all districts, lower nitrogen application rates are required for plant cane than for ratoon and replant cane. The lower level is due to mineralisation of nitrogen in the soil during the fallow period which is available for growth of the plant crop. As only a short fallow period precedes a replant cane crop, the replant crop should be fertilised at the same rate as ratoon cane.

## LEGUME

Nitrogen rates for plant cane can be reduced by as much as the full nitrogen requirement following a heavy legume crop. This amount is dependent on the quantity of legume biomass and its nitrogen content and management of legume residue.

## MILL MUD AND MUD-ASH MIXTURE

These mill by-products contain significant quantities of many essential elements including all the major nutrients. Recommended rates are adjusted to reflect that contribution to the sugarcane crop.

## NITROGEN USE EFFICIENCY (NUE)

Only about one third of the nitrogen applied as fertiliser to a crop of sugarcane is used by the crop in the year of application. Most of the remaining nitrogen goes into the soil reserves while some may be lost by volatilisation, denitrification, leaching or runoff.

Nitrogen use efficiency can be described in several ways. This manual defines NUE as a measure of crop yield production (t/ha) per unit of nitrogen fertiliser input (kg N/ha).

$$\text{NUE} = \text{CANE YIELD (t/ha)} \div \text{NITROGEN APPLIED (kg/ha)}$$

For example, a 100 t/ha crop on which 140 kg/ha of nitrogen was applied has a NUE of 0.71.

Improved NUE can be achieved by producing the same yield with less fertiliser, a greater yield with less fertiliser or a higher yield with the same amount of fertiliser.

Fertiliser guidelines in the SIX EASY STEPS program aim to improve NUE, providing productivity and profitability are not compromised. Consequently, the aim is not to maximise NUE. NUE can be illustrated in the same way as nitrogen response curves (e.g. Figure 18). Each additional increment in applied nitrogen results in a smaller gain. Simple reductions of applied nitrogen to increase the NUE would mean reducing nitrogen inputs below sustainable levels. The sustainability objective is to best match crop yields to nitrogen uptake while minimising nitrogen losses.

NUE may be improved by implementing sound farm management strategies that address nitrogen rate, timing of application, crop uptake, product selection and fertiliser placement including:

- minimising nitrogen losses by not exceeding the SIX EASY STEPS recommended rates for nitrogen



- better matching nitrogen inputs with nitrogen uptake by the crop
- applying fertiliser outside the high loss risk periods of the cropping cycle
- producing a well-grown crop to maximise the uptake of nitrogen when it is applied
- possible use of enhanced efficiency fertilisers to reduce the prospects of nitrogen loss
- appropriate placement of fertiliser to minimise losses.

## NITROGEN FERTILISERS

Many commercial sources of nitrogen are available. Table 17 lists some nitrogen fertiliser sources and their nitrogen content.

The most commonly used source of nitrogen is urea. Urea is manufactured by reacting natural gas, atmospheric nitrogen and water together at high temperature and pressure to produce ammonia (NH<sub>3</sub>) and carbon dioxide (CO<sub>2</sub>). These gases are then reacted at high temperature and pressure to produce urea [CO(NH<sub>2</sub>)<sub>2</sub>.]



This reaction is the reverse of volatilisation.

Urea may contain a compound called biuret which is toxic to plants if applied to foliage. Because urea is applied to soil, biuret does not cause any problems in sugarcane production.

## ACIDIFICATION OF THE SOIL BY NITROGEN FERTILISERS

The use of most nitrogenous fertilisers tends to acidify soils. Due mainly to its sulfur content, sulfate of ammonia has about three times the acidifying effect of urea and about double that of DAP.

Nitrogen fertilisers undergo the following transition:



Only the ammonium and nitrate forms can be taken up by plants. The degree of soil acidification by nitrogenous fertilisers depends on whether the nitrate is leached or is taken up by plants. When nitrate is taken up, the net acidification per molecule of ammonium is halved compared to when nitrate is leached.

When urea is applied to the soil, it hydrolyses (reacts with water) and is converted to ammonium carbamate (NH<sub>2</sub>COONH<sub>4</sub>) which is unstable, and then to ammonia, ammonium ion and eventually nitrate ion. The reaction is faster in the presence of the naturally-occurring enzyme urease. The ammonium ion produced as a result of this reaction means that urea is acid in its ultimate reaction with the soil.

However, during the hydrolysis reaction, the pH actually rises and can become quite alkaline resulting in the production of ammonia and carbon dioxide gases which can volatilise. The pH eventually drops and becomes acidic in the soil. This is not a long-term pH change; it is a short-term localised reaction around the urea prill.

The main soil acidifiers are the ammonium-based products. Nitrate-based fertilisers have no acidification potential.

### NON-ACIDIFYING (ALKALINE)

Potassium nitrate (13% N); calcium nitrate/CAN (15.5% N); composted poultry manure (approximately 3% N).

On a kilogram of nitrogen basis, these fertilisers are all relatively expensive.

TABLE 17 NITROGEN SOURCES

NITROGEN FERTILISER	COMMON TERM	NITROGEN CONTENT (%)
Urea	Urea	46
Di-ammonium phosphate	DAP	18–19
Mono-ammonium phosphate	MAP	12.6
Calcium ammonium nitrate	Cal-Am, CAN	27
Ammonium sulfate	Sulfate of ammonia	20.2
Sulfur-fortified urea	Urea-S	40
High analysis mixtures	Various	Various
Blood and bone*	Blood and bone	5–10
Fish meal*	Fish meal	10
WASTE MATERIALS AND BY-PRODUCTS*		
Mill mud	Mill mud	1.5 (range 0.8 - 2.2)
Mill ash	Ash	0.15 (range 0.1 - 0.5)
Mill mud-ash mixtures	Mud/ash	0.6 (range 0.4 - 0.8)
Sewage sludge	Sewage sludge	3.1 (range 0.5 - 6.6)

\*Contain organic nitrogen. Only part of the organic nitrogen will be available in the year of application. Refer to Chapter 23.

### SLIGHTLY ACIDIFYING

Urea (46% N); ammonium nitrate/nitram (34% N) now rarely used in agriculture due to its classification as a dangerous good.

### MODERATELY ACIDIFYING

Diammonium phosphate/DAP (18% N).

### SEVERELY ACIDIFYING

Sulfate of ammonia (21% N); monoammonium phosphate/MAP (11.3% N).

## NITROGEN RATE RECOMMENDATIONS

Specific nitrogen recommendations for each region of the Australian sugar industry can be found on the SRA website under "For Growers and Millers".

The following information in this section explains how those recommendations have been developed over many years of research.

The SIX EASY STEPS nitrogen guidelines are based on a combination of district discriminator (referred to as the district yield potential (DYP) and soil nitrogen mineralisation index.

### District yield potential (DYP)

The district yield potential term aims to recognise productivity differences between sugarcane growing regions. It is determined from the best possible yield over all soil types within a district. It is defined as the estimated highest average annual district sugarcane yield (tonnes cane/ha) multiplied by a factor of 1.2. For example, the highest average yield for the Bundaberg district is 100 tonnes cane/ha. This figure multiplied by 1.2 gives a district yield potential of 120 tonnes of cane /ha for the Bundaberg district.

### DYP AND DETERMINATION OF THE NITROGEN REQUIREMENT FOR SUGARCANE

DYP is used to establish the district baseline nitrogen application rate according to the following estimate:

*1.4 kg N per tonne of sugarcane is required up to a sugarcane yield of 100 tonnes/ha*

*plus*

*1 kg N per tonne cane/ha thereafter (as previously determined by CSIRO scientists).*

So, a DYP of 120 t/ha has a base nitrogen application rate of  $(100 \times 1.4) + (20 \times 1) = 160$  kg N/ha.

### DISTRICT YIELD POTENTIALS AND DISTRICT BASELINE NITROGEN APPLICATION RATES FOR THE VARIOUS DISTRICTS IN THE AUSTRALIAN INDUSTRY

District yield potentials and baseline nitrogen application rates for sugarcane growing districts are shown in Table 18.

These district yield potentials recognise the differences in the ability of districts to produce cane. For example, the

**TABLE 18 DISTRICT YIELD POTENTIAL AND BASELINE NITROGEN APPLICATION RATES FOR DISTRICTS**

DISTRICT	DISTRICT YIELD POTENTIAL (1.2 TIMES THE HIGHEST AVERAGE YIELD) (t cane/ha)	BASELINE NITROGEN APPLICATION RATE (FOR REPLANT AND RATOON CANE) (kg N/ha)
Wet Tropics	120	160
Mareeba-Dimbulah	150	190
Herbert	120	160
Burdekin	150 - 180	190 - 220
Proserpine	130	170
Mackay	130	170
Plane Creek	120	160
Bundaberg	120	160
Isis	120	160
Maryborough	120	160
NSW (1 and 2 year cane)	140 - 180 - 220	180 - 220 - 260

Burdekin region with its higher temperatures and solar radiation, and access to water, has a higher yield potential than the other districts.

### CAN OTHER YIELD POTENTIAL AND BASELINE NITROGEN APPLICATION RATE VALUES BE USED WITHIN SPECIFIC DISTRICTS?

The district yield potentials and baseline nitrogen application rates are those currently recommended for general use in the specified districts within the SIX EASY STEPS program.

### SOIL N MINERALISATION INDEX ADJUSTMENTS TO BASELINE NITROGEN APPLICATION RATE WITHIN DISTRICTS

The N mineralisation index is then used to make adjustments to the district baseline nitrogen application rate. This enables differences in soil type to be taken into account when determining appropriate nitrogen application rates. The N mineralisation index is based on the organic carbon content. It provides a conservative estimation of the amount of nitrogen mineralised from soil organic matter. Appropriate nitrogen application rates for replant and ratoon cane based on district yield potentials and the N mineralisation index are shown in Table 19.

### Legume fallow crop adjustments to baseline nitrogen application rate within districts

The amount of nitrogen available to a succeeding sugarcane crop will be dependent on the type of legume grown, the biomass produced (total dry mass/ha) and whether the grain was harvested. A summary of the calculated values for a range of legume species is shown in Table 20. Other factors

**TABLE 19 NITROGEN APPLICATION RATES FOR REPLANT AND RATOON CANE BASED ON DISTRICT YIELD POTENTIAL AND THE N MINERALISATION INDEX**

N MINERALISATION INDEX	ORGANIC CARBON (%)	DISTRICT YIELD POTENTIAL (t cane/ha)					
		120 <sup>1</sup>	130 <sup>2</sup>	140 <sup>3</sup>	150 <sup>4</sup>	180 <sup>5</sup>	220 <sup>6</sup>
		N APPLICATION RATE FOR REPLANT AND RATOON CANE (kg N/ha)					
VL	<0.40	160	170	180	190	220	260
L	0.41 – 0.80	150	160	170	180	210	250
ML	0.81 – 1.20	140	150	160	170	200	240
M	1.21 – 1.60	130	140	150	160	190	230
MH	1.61 – 2.00	120	130	140	150	180	220
H	2.01 – 2.40	110	120	130	140	170	210
VH	>2.4	100	110	120	130	160	200

VL very low; L low; ML medium low; M medium; MH medium high; H high; VH very high

<sup>1</sup>Wet Tropics (Mossman to Tully), Herbert, Plane Creek, Bundaberg, Isis, Maryborough <sup>2</sup>Mackay, Proserpine <sup>3</sup>New South Wales <sup>4</sup>Burdekin, Mareeba-Dimbulah <sup>5</sup>Burdekin, New South Wales <sup>6</sup>New South Wales

Note: New South Wales has a set of nitrogen rate recommendations specifically for acid peat soils. Please refer to the "SIX EASY STEPS Guidelines for NSW", available from the SRA website.

**TABLE 20 CALCULATION OF NITROGEN CONTRIBUTION FROM A FALLOW LEGUME**

LEGUME CROP	FALLOW CROP DRY MASS (t/ha)	N (%)	TOTAL N CONTRIBUTION (kg N/ha)	N CONTRIBUTION IF GRAIN HARVESTED (kg/ha)
Soybean	8	3.5	360	120
	6		270	90
	4		180	60
	2		90	30
Peanut	8	3	n/a	125
	6		n/a	100
	4		n/a	65
	2		n/a	25
Cowpea	8	2.8	290	100
	6		220	75
	4		145	50
	2		70	25
Lablab	8	2.3	240	80
	6		180	60
	4		120	40
	2		60	20

(Source: Sugarcane Yield Decline Joint Venture).

should also be considered, including the extent and timing of legume residue incorporation, and whether significant rainfall has been received following legume residue incorporation. These factors influence the likelihood of legume nitrogen being available to the following sugarcane crop. Nitrate strip tests can also be used immediately prior to top dressing to assess legume nitrogen availability.



Legume crops including soybean can have multiple benefits including supplying nitrogen, protecting the soil surface from erosion, improving soil health and providing additional income from seed production.



**TABLE 21 NITROGEN RATE RECOMMENDATIONS**

**WET TROPICS, HERBERT, PLANE CREEK, BUNDABERG, ISIS, MARYBOROUGH**  
(DISTRICT YIELD POTENTIAL 120 t cane/ha)

CROP	ORGANIC C (%)						
	<0.40	0.40–0.80	0.81–1.20	1.21–1.60	1.61–2.00	2.01–2.40	>2.40
	N MINERALISATION INDEX						
	VL	L	ML	M	MH	H	VH
N APPLICATION RATE (kg/ha)							
Replant cane and ratoon after replant	160	150	140	130	120	110	100
Plant cane after a grass/bare fallow	140	130	120	110	100	90	80
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus 70 kg N/ha)	90	80	70	60	50	40	30
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus 270 kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus 90 kg N/ha)	70	60	50	40	30	20	10
First ratoon after a good legume crop <sup>#</sup>	160	150	140	130	120	110	100
Second ratoon after a good soybean/cowpea crop	160	150	140	130	120	110	100

**MACKAY, PROSERPINE**  
(DISTRICT YIELD POTENTIAL 130 t cane/ha)

Replant cane and ratoon after replant	170	160	150	140	130	120	110
Plant cane after a grass/bare fallow	150	140	130	120	110	100	90
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus 70 kg N/ha)	100	90	80	70	60	50	40
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus 270 kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus 90 kg N/ha)	80	70	60	50	40	30	20
First ratoon after a good legume crop <sup>#</sup>	170	160	150	140	130	120	110
Second ratoon after a good soybean/cowpea crop	170	160	150	140	130	120	110

Table 21: Nitrogen rate recommendations

VL very low; L low; ML medium low; M medium; MH medium high; H high; VH very high

<sup>#</sup>Data from the Sugar Yield Decline Joint Venture and BSES trials suggest that nitrogen applied to the first ratoon sugarcane crop following a good legume crop in the fallow can possibly be reduced below the levels in these tables. The reduction in nitrogen applied will depend on several factors including legume residue management, soil type, climate and tillage practices.

**TABLE 21 NITROGEN RATE RECOMMENDATIONS**

NSW (DISTRICT YIELD POTENTIAL 140 t cane/ha)							
CROP	ORGANIC C (%)						
	<0.40	0.40–0.80	0.81–1.20	1.21–1.60	1.61–2.00	2.01–2.40	>2.40
	N MINERALISATION INDEX						
	VL	L	ML	M	MH	H	VH
N APPLICATION RATE (kg/ha)							
Replant cane and ratoon after replant	180	170	160	150	140	130	120
Plant cane after a grass/bare fallow	160	150	140	130	120	110	100
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus 70 kg N/ha)	110	100	90	80	70	60	50
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus 270 kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus 90 kg N/ha)	90	80	70	60	50	40	30
First ratoon after a good legume crop <sup>#</sup>	180	170	160	150	140	130	120
Second ratoon after a good soybean/ cowpea crop	180	170	1600	150	140	130	120
BURDEKIN, MAREEBA-DIMBULAH (DISTRICT YIELD POTENTIAL 150 t cane/ha)							
Replant cane and ratoon after replant	190	180	170	160	150	140	130
Plant cane after a grass/bare fallow <sup>*</sup>	150	140	130	120	110	100	90
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus 70 kg N/ha)	120	110	100	90	80	70	60
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus 270 kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus 90 kg N/ha)	100	90	80	70	60	50	40
First ratoon after a good legume crop <sup>#</sup>	190	180	170	160	150	140	130
Second ratoon after a good soybean/ cowpea crop	190	180	170	160	150	140	130

<sup>\*</sup>Research shows higher mineralisation rate in these regions due to increased soil temperatures

**TABLE 21 NITROGEN RATE RECOMMENDATIONS (CONTINUED)**

<b>BURDEKIN, NSW (2-YEAR CROP)</b> (DISTRICT YIELD POTENTIAL 180 t cane/ha)							
<b>CROP</b>	<b>ORGANIC C (%)</b>						
	<b>&lt;0.40</b>	<b>0.40–0.80</b>	<b>0.81–1.20</b>	<b>1.21–1.60</b>	<b>1.61–2.00</b>	<b>2.01–2.40</b>	<b>&gt;2.40</b>
	<b>N MINERALISATION INDEX</b>						
	<b>VL</b>	<b>L</b>	<b>ML</b>	<b>M</b>	<b>MH</b>	<b>H</b>	<b>VH</b>
<b>N APPLICATION RATE (kg/ha)</b>							
Replant cane and ratoon after replant	220	210	200	190	180	170	160
Plant cane after a grass/bare fallow	180	170	160	150	140	130	120
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus 70 kg N/ha)	150	140	130	120	110	100	90
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus 270 kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus 90 kg N/ha)	130	120	110	100	90	80	70
First ratoon after a good legume crop <sup>#</sup>	220	210	200	190	180	170	160
Second ratoon after a good soybean/ cowpea crop	220	210	200	190	180	170	160
<b>NSW (2-YEAR CROP)</b> (DISTRICT YIELD POTENTIAL 220 t cane/ha)							
Replant cane and ratoon after replant	260	250	240	230	220	210	200
Plant cane after a grass/bare fallow	240	230	220	210	200	190	180
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus 70 kg N/ha)	190	180	170	160	150	140	130
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus 270 kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus 90 kg N/ha)	170	160	150	140	130	120	110
First ratoon after a good legume crop <sup>#</sup>	260	250	240	230	220	210	200
Second ratoon after a good soybean/ cowpea crop	260	250	240	230	220	210	200

Table 21: Nitrogen rate recommendations

VL very low; L low; ML medium low; M medium; MH medium high; H high; VH very high

<sup>#</sup>Data from the Sugar Yield Decline Joint Venture and BSES trials suggest that nitrogen applied to the first ratoon sugarcane crop following a good legume crop in the fallow can possibly be reduced below the levels in these tables. The reduction in nitrogen applied will depend on several factors including legume residue management, soil type, climate and tillage practices.



### District nitrogen recommendation tables

Table 21 on pages 44 to 46 show the nitrogen recommendations for all districts taking into account the contribution from the mineralisation of organic matter and a legume crop or bare fallow.

### Nitrogen contribution to the sugarcane crop from mill mud, mill ash or mud-ash mixtures

Substantial amounts of nitrogen (and other nutrients) are added to a block of sugarcane through the application of mill by-products. However, the amount of nitrogen (and other nutrients) added is affected by:

- A. the particular mill by-product applied (both mill mud and mud-ash mixtures contain nitrogen; mill ash contains little available nitrogen)
- B. variability of the nutrient content of the mill by-products (because soil types differ between and within districts, and other regional factors)
- C. application rate of the by-products used. Application rates vary from district to district but usually range from 50 to 150 wet tonnes per hectare
- D. ratio of the components of the mud-ash mixtures (although this can differ from load to load; average nutrient contents are used for convenience).

Not all the nutrients in applied mill by-products are available for plant uptake as they are in organic forms. Some of the total amounts of nutrients applied become available with time and, therefore, the benefit is carried over several crops. Table 22 shows the estimated amounts of nitrogen available to successive crops from mill by-products applied prior to, or at, planting at 150 t/ha.

These amounts of nitrogen should be discounted from the overall nitrogen fertiliser requirement for those blocks that have received mill by-product applications.

In some regions, banded application of mill by-products on the sugarcane row at a reduced rate per hectare is the preferred application method. Table 23 shows the estimated amounts of nitrogen available to successive crops from mill by-products applied prior to, or at, planting at 50 t/ha.

TABLE 22 ESTIMATED CROP-AVAILABLE NITROGEN AVAILABLE TO SUCCESSIVE CROPS AFTER THE APPLICATION OF MILL BY-PRODUCTS AT 150 WET t/ha		
CROP AFTER APPLICATION	MILL MUD	MUD-ASH MIXTURE
	APPROXIMATE AVAILABLE N (kg/ha)	
1st crop	80	50
2nd crop	40	20
3rd crop	20	10

TABLE 23 ESTIMATED CROP-AVAILABLE NITROGEN AVAILABLE TO SUCCESSIVE CROPS AFTER THE BANDED APPLICATION OF MILL BY-PRODUCTS AT 50 WET t/ha

CROP AFTER APPLICATION	MILL MUD	MUD-ASH MIXTURE
	APPROXIMATE AVAILABLE N (kg/ha)	
1st crop	25	15
2nd crop	15	<10
3rd crop	<10	0

Information contained in Tables 22 and 23 is based on estimates only and should, therefore, be used only as a guideline.

### Standover cane fertiliser strategy

Experience has shown that there is little or no benefit in applying fertiliser to standover cane. Extra nitrogen might initially make the crop look greener but is unlikely to have a yield benefit.

Because the CCS of standover cane will likely be below mill average, aim to harvest standover blocks early in the season, the time when CCS is likely to be closest to mill average. Mixing standover with normal one-year cane might be a strategy to improve the CCS level and send a higher quality product to the mill. Burning prior to harvest might also be an option to eliminate heavy loads of dead sugarcane stalks and reduce extraneous matter levels.

### PLACEMENT OF NITROGEN IN THE CROP

All fertiliser, including nitrogen, should be placed in or on the drill (row) area, never in the interspace and never broadcast over the block.

### Plant and replant cane

An initial small proportion of the recommended rate of nitrogen is placed near, but never on, the sugarcane setts at planting. The remaining nitrogen is usually applied in the drill during the first pass of the filling-in/hilling-up phase (top-dressing) when soil is pulled into the furrow. To mitigate the impact of possible waterlogged conditions, growers in high rainfall areas sometimes plant into pre-formed raised beds (mound planting). In these systems, top-dressing is conducted using stool-splitting or side-banding options.

### Ratoon cane

The following recommendations apply to both solid and liquid fertiliser products.

- Subsurface application on the side of, or into, the stool to a depth of 7–10 cm. Both stool-splitting and side-banding options are equally acceptable. Ensure the tyne mark through the trash blanket and/or soil is sealed to prevent volatilisation after the operation.

- Surface application on the row under some circumstances, such as:
  - » when ratoons are approximately 50 cm high
  - » on some steeper slopes where the risk of erosion from the subsurface applicator tyne mark running vertically on the sloped land is high
  - » when rain or irrigation of at least 20 mm is applied within a few days of application.

Refer to "Strategies to manage volatilisation" above for more information.

### Foliar uptake of nitrogen

Absorption of nitrogen by the plant through leaf stomata and pores in the leaf cuticle is rapid. However, nitrogen should be foliar-applied as a last resort and only as a top-up to reach the required recommended rate. The crop canopy can take up only a small proportion of the crop requirements because the full amount of nitrogen would need to be applied at a concentration that will burn the leaves. The alternative is to apply small quantities on many occasions which would be uneconomical.

### TIMING OF NITROGEN APPLICATION TO THE CROP

Recommendations for timing of nitrogen application need to be flexible to account for the practical issues that impact on farm management practices. However, certain principles relating to timing should be followed.

Appropriate timing of fertiliser application is an important tool in reducing the risk of fertiliser losses due to leaching, runoff and/or denitrification. The best period for fertiliser applications is after the ratoon crop has emerged and is actively growing. This allows the crop to take up nutrients efficiently and act as a nutrient store. The risk of nutrient losses increases if the fertiliser is applied too early (before the onset of rain or irrigation) or too late (when heavy late spring or summer rains have commenced).

### Uptake of nitrogen

Approximately 20 to 25% of applied nitrogen is taken up in the 100 days after planting (Figure 19).

Roughly 20% of applied nitrogen is taken up in the 50 days after ratooning.

Most nitrogen uptake occurs during stalk elongation.

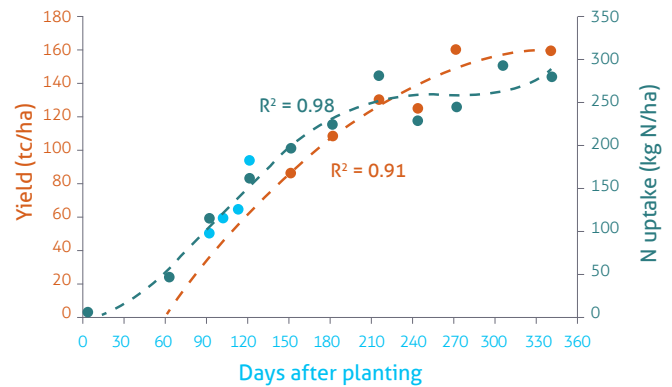
### Timing of nitrogen application

#### PLANT CANE

Conventional application to plant cane (a small proportion at planting plus the remainder at top-dressing) fits the nitrogen uptake pattern.

#### RATOON CANE

If conditions allow the application of fertiliser to be delayed, in some cases it is recommended to do so. One



(After Thompson, 1986). Four additional data points (light blue): Schroeder, 2000 (unpublished)

Figure 19: Nitrogen uptake and yield (N is non-limiting) for plant cane

exception would be on sugarcane harvested late in the year when the onset of the wet season could prevent timely fertiliser application.

- Nitrogen subsurface-applied: Apply after harvest. May be delayed for up to six weeks after harvest if practical and providing adverse weather conditions do not impact on the crop.
- Nitrogen surface-applied: Apply 6+ weeks after harvest (weather and other factors permitting; not for late-cut cane).
- Late-cut cane: Apply straight after harvest.

Do not apply fertiliser in the wet season unless absolutely necessary and following sound advice.

Do not apply fertiliser before a heavy rainfall event.

### Fate of the sugarcane stool and nitrogen uptake after harvest

Following harvest, the old root system supplies sufficient water and nutrients for stubble maintenance for approximately six weeks. During this period, the root system gradually dies, to be replaced by a developing root system of the new ratoon crop. Then, crop uptake of nitrogen rises rapidly. In effect, the old and new root systems work in tandem during this transitional phase.

## KEY POINTS: NITROGEN (N)

- Essential for photosynthesis, sugar production and plant growth.
  - Older leaves exhibit nitrogen deficiency symptoms before young leaves.
  - Nitrogen deficiency symptoms: light green to yellow leaves often with necrosis; thin and stunted stalks; short internodes; reduced stooling; low yield; reduced root mass.
  - Excess nitrogen will cause a loss of profitability and reduce sugar quality.
  - Organic matter contains a high level of nitrogen, but supplies only part of the crop requirement through mineralisation.
  - A well-grown legume crop can supply much of the nitrogen requirement of the following plant crop.
  - Mill mud and mud-ash mixtures contain significant quantities of crop-available nitrogen.
  - Significant nitrogen losses can occur via volatilisation, denitrification, leaching and run-off.
  - Volatilisation losses of nitrogen occur when surface-applied urea or urea-based mixtures are converted to ammonia which is lost to the atmosphere.
  - Denitrification losses of nitrogen occur in anaerobic conditions (e.g. poorly aerated, waterlogged soils) when any buried nitrogen source is converted to nitrous oxide gas and nitrogen gas which are lost to the atmosphere.
  - Leaching losses occur when irrigation or rainfall washes soil nitrates below the root zone.
  - Nitrification is the conversion of nitrogen fertiliser to ammonium-N and then nitrate-N, both of which can be taken up by the crop. However, nitrate is susceptible to losses by leaching and denitrification.
  - Enhanced efficiency fertilisers are products that can reduce nutrient losses while increasing nutrient availability for the crop.
  - Because of its price advantage, urea is the preferred source of nitrogen.
  - Nitrogenous fertilisers have an acidifying effect on the soil.
  - Only about one third of the nitrogen applied to a crop is used by the crop in that season.
  - Approximately 120 to 150 kg/ha of nitrogen is removed annually by an average crop.
  - Ratoon and replant cane require more fertiliser nitrogen than plant cane due to nitrogen mineralisation during the fallow period.
  - Total baseline nitrogen application rate (based on yield potential):
    - » **North Qld coastal:** 140 kg/ha (plant); 160 kg/ha (replant and ratoon)
    - » **Mareeba-Dimbulah:** 150 kg/ha (plant); 190 kg/ha (replant and ratoon)
    - » **Burdekin:** 150 or 190 kg/ha (plant); 190 or 220 kg/ha (replant and ratoon)
    - » **Proserpine & Mackay:** 150 kg/ha (plant); 170 kg/ha (replant and ratoon)
    - » **Plane Creek:** 140 kg/ha (plant); 160 kg/ha (replant and ratoon)
    - » **South Qld:** 140 kg/ha (plant); 160 kg/ha (replant and ratoon)
    - » **NSW:** 160 or 200 or 240 kg/ha (plant); 180 or 220 or 260 kg/ha (replant and ratoon).
- Reductions to these rates are made based on soil type/ mineralisation capacity, and the use of legumes, mill by-products or other source of nitrogen.
- Subsurface placement of fertiliser is the usual recommended practice.
  - In ratoon blocks, nitrogen fertiliser should be buried in a band on each side, or on top, of the row. Surface application of nitrogen is acceptable under certain circumstances e.g. once the sugarcane canopy is approximately 50 cm high; if irrigation or rainfall greater than 20 mm is received soon after surface application; a non-volatilising form of nitrogen fertiliser is used.
  - For flood irrigated blocks, nitrogen should always be subsurface-applied.



## CHAPTER 9

# PHOSPHORUS (P)

Phosphorus is one of the six major essential plant nutrients. Being very old and weathered, Australian soils usually have a low phosphorus content in their natural state. Together with nitrogen, phosphorus is an environmentally-sensitive nutrient that can have a significant impact on water quality when it moves off-site into waterways, usually when attached to eroded soil particles. On a weight basis, phosphorus is the most expensive of the major essential elements.

### THE ROLE OF PHOSPHORUS IN SUGARCANE

- Important in spindle development and tillering.
- Promotes early root formation and growth; essential for the formation of a strong and vigorous root system.
- Required for cell division and protein formation.
- Plays a role in photosynthesis, respiration and many other processes.
- Essential for crop maturation.

### PHOSPHORUS DEFICIENCY SYMPTOMS

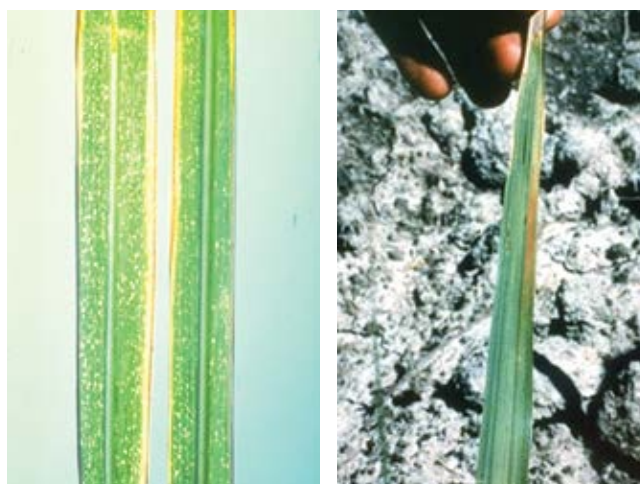
- Older leaves exhibit deficiency symptoms before young leaves.
- Thin, short stalks with short internodes.
- Poor tillering: young shoots may die before reaching the surface of the soil.
- Leaf blades are dark green to blue-green, often with red, bronzed or purple tips and margins.
- Leaves are thinner, narrower and shorter than normal.
- Older leaves turn yellow and die back from the tips and along the margins.
- Leaves may stand abnormally upright.



Phosphorus-deficient leaves are thinner, narrower and shorter than normal. Leaf reddening may occur.



Growth of this young plant cane is affected by phosphorus deficiency. Tillering is poor and the older leaves are yellow. Deficiency symptoms are not evenly spread throughout this block.



When plants are phosphorus deficient, older leaves die back from the tips and along the leaf margins.



Leaves on phosphorus-deficient sugarcane may be dark green with reddish tips and margins. (Photos: Graham Kingston)

### CONSEQUENCE OF PHOSPHORUS EXCESS

Excess phosphorus may cause other nutrients such as copper, zinc and iron to become less available for plant growth. This situation has been observed particularly in new land where copper deficiency symptoms have developed following application of recommended rates of superphosphate.

### THE PHOSPHORUS CYCLE

The phosphorus cycle (Figure 20) describes all the processes by which phosphorus circulates between the soil and plants. Phosphorus does not have a gaseous phase and does not enter the atmosphere, remaining mostly in rock and soil minerals.

### PHOSPHORUS IN THE SOIL

In their natural state, nearly all Australian soils have low phosphorus levels. The exception is relatively small areas of soil based on igneous or metamorphic rocks and alluvial soils (e.g. the Burdekin Delta).

Natural soil phosphorus is largely derived from the weathering of a mineral called apatite. Other sources of phosphorus include humus, micro-organisms, decaying animal and plant material, organic matter, and fertiliser. Phosphorus “locked up” in organic matter becomes available very slowly as it converts (mineralises) to the inorganic form which can be used by the crop. Organic matter supplies only a very small proportion of the phosphorus required by the crop.

Some Australian sugarcane growing soils now have moderate to high levels of available phosphorus. This

means that phosphorus can usually be omitted from at least one ratoon crop with no effect on yield. A soil test will assist with this decision.

### PHOSPHATE FIXATION

Some of the phosphorus applied to soils in all phosphatic fertilisers is taken up by the sugarcane crop, while some reacts with soil minerals to form insoluble compounds in a reaction called phosphorus sorption, or P-sorption. The phosphorus is precipitated or “fixed” in these insoluble compounds and is not available to the cane, or is available only very slowly over time.

Some soils (such as red volcanics/ferrosols) have large phosphorus-fixing capacities because of the high iron and aluminium content of their clays. Soils high in organic carbon such as peats also have a very high P-sorption level. With the addition of more and more phosphorus to the soil, the phosphorus-fixing capacity of the soil will eventually be satisfied and the “bank” of available phosphorus which the sugarcane can use will increase.

Phosphate does not move easily in soil and should, therefore, be applied in the root zone ready for uptake by the crop.

### Phosphorus buffering capacity (PBC) and phosphorus buffering index (PBI)

Soil phosphorus buffering capacity (PBC) is a soil property that influences the amount of phosphorus fertiliser available for plant uptake. The soil’s phosphorus buffering index (PBI) is a measure of its PBC or ability to “sorb” or “fix” phosphorus. Table 25 (page 54) outlines the various P-sorption classes.

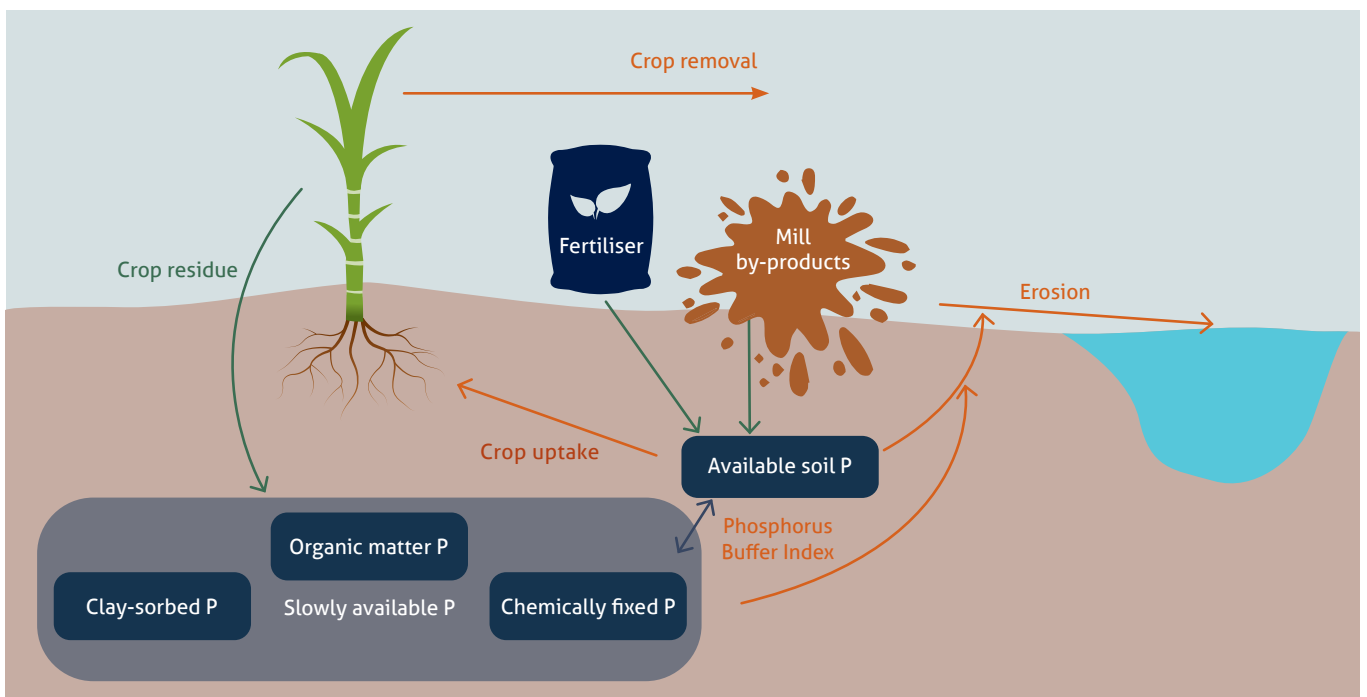


Figure 20: Phosphorus cycling in sugarcane crops





The phosphorus buffering capacity of a soil ranges from very low (sand, left) to medium (loam, centre) and very high (ferrosol, right).

## LOSS OF PHOSPHORUS FROM THE SOIL

Phosphorus in the soil is relatively immobile and is subject to very little leaching. Only very light-textured, sandy soils in high rainfall areas may be prone to some phosphorus leaching. However, phosphorus can be lost through erosion or land levelling operations which remove the topsoil.

### Minimisation of phosphorus loss

Minimisation of phosphorus loss can be achieved essentially by managing soil erosion.

### GREEN CANE TRASH BLANKET (GCTB)

The main strategy to minimise phosphorus loss from sugarcane land is to maintain a green trash blanket. In most situations, a heavy trash blanket will dramatically reduce erosion of soil and attached phosphorus that could otherwise have occurred without that protection. The efficacy of the system is enhanced because the soil has not been disturbed with tillage.

### SPRAY-OUT FALLOW

At the end of the crop cycle, maintaining the trash blanket, and killing and retaining the stubble over the wet season, will provide ground cover to minimise soil and phosphorus loss.

### LEGUME FALLOW

A heavy legume crop will protect the soil and reduce erosion over the wet season. However, many legume crops fail under very wet conditions and a spray-out fallow might be a more reliable option to minimise soil and phosphorus loss especially in areas prone to water inundation.

### GRASSED HEADLANDS AND DRAINS

On-farm waterways and headlands will be protected from erosion if an adequately managed grass cover can be maintained. In addition, the vegetation will intercept some eroded soil from non-protected areas and stop it from running off-farm.

### CONTOURED SUGARCANE BLOCKS

Contouring to reduce runoff intensity and soil erosion is an option but growers might find one of the previous strategies to be more practical and effective.



Green cane trash blanketing is a viable option in most, but not all, areas of the Australian sugar industry. GCTB significantly reduces soil erosion.



The chemical destruction and retention of the regrowth from the final crop over the wet season protects the soil from erosion.



A well-managed legume crop will reduce soil erosion.



Grassed headlands and drains will trap some of the soil that may be washed off sugarcane blocks.



## RESPONSE TO PHOSPHORUS

### New land

Broadcast application of phosphorus is recommended as a development option for previously uncropped land where P-sorption is very high. Responses to pre-planting broadcast phosphorus on other soils, even those with very low phosphorus levels, have not occurred.

### Old land

On sugarcane growing soils with a long history of phosphorus fertiliser application, yield responses to phosphorus fertiliser usually do not occur or are very small. These soils have reserves of available phosphorus that the sugarcane crop can use. Depending on the PBI reading on these soils, phosphorus rates may be reduced or eliminated from one or more ratoons while the crop makes use of the reserves.

Soil testing is essential to determine the phosphorus status and PBI index of the soil and to assist with the decision on whether to reduce or eliminate phosphorus applications.

## PHOSPHORUS FERTILISERS

Phosphorus in fertilisers occurs in three main forms: water-soluble, citrate-soluble, and insoluble. Fertiliser labels list these three forms of phosphorus. The available phosphorus is the sum of the water-soluble and citrate-soluble components of the fertiliser. The insoluble component becomes available to the plant only over a very long period of time. Table 24 lists some phosphorus fertiliser sources and their phosphorus content.

### Superphosphate

Superphosphate is made from rock phosphate and sulfuric acid. It also contains sulfur (11%) and calcium (20%). Superphosphate is sometimes called single super.

### Triple superphosphate

Triple superphosphate is more concentrated than superphosphate. It is made from rock phosphate and phosphoric acid, and contains little sulfur (1.3%) but a significant level of calcium (15.0–18.5%).

### DAP and MAP

DAP and MAP are concentrated sources of phosphorus. They are made from anhydrous ammonia and phosphoric acid. MAP or DAP is made by controlling the amount of ammonia added to the process. They contain significant amounts of nitrogen (13–19%) and are used in making the high analysis fertiliser mixtures.

### Rock phosphate [ $\text{Ca}_3(\text{PO}_4)_2$ ]

Rock phosphate is the basic material used in almost all phosphorus fertiliser production. Known world reserves of rock phosphate are about 100 billion tonnes. The phosphorus in rock phosphate is practically all in the insoluble form and is only very slowly available to plants. Rock phosphate must be finely ground to be of use as a source of phosphorus.

### Blood and bone

Blood and bone and other organic fertilisers are too expensive for use in sugarcane production. They are a very slowly available form of phosphorus, nitrogen and other nutrients.

### High analysis mixtures

The two most common compounds used in making high analysis mixtures are DAP and MAP. The high analysis NPK mixtures are made by adding potassic fertiliser which provides the potassium component of the mixture.

TABLE 24 PHOSPHORUS SOURCES

FERTILISER	CITRATE-SOLUBLE PHOSPHORUS (%)	WATER-SOLUBLE PHOSPHORUS (%)	AVAILABLE PHOSPHORUS (%)	TOTAL PHOSPHORUS (%)
DAP (diammonium phosphate)	0.5	19.5	20.0	20.2
MAP (monoammonium phosphate)	0.1	21.8	21.9	22.0
Superphosphate	1.5	7.0	8.5	9.1
Triple superphosphate	3.5	14.0	17.5	19.2
Rock phosphate	1.1	0.0	1.1	16.0
Blood and bone	4.4	0.7	5.1	6.0
High analysis mixtures	Various	Various	Various	Various
Mill mud, mill ash, mud-ash mixtures*	Various	Various	Various	Various

\*Refer to Chapter 23

## PHOSPHORUS RATE RECOMMENDATIONS

To determine a phosphorus recommendation, the amount of phosphorus in the soil ( $P_{BSES}$ ) and the soil's ability to "fix" phosphorus (P-sorption, as measured by the Phosphorus Buffering Index or PBI) need to be known.

The P-sorption class of each soil is based on the PBI which is measured in the laboratory (Table 25). It can also be estimated from the clay content (%) and organic matter content (%) of a particular soil (Table 26). However, care needs to be exercised in using this approach in some areas in the tropics (e.g. the Johnstone catchment) due to the occurrence of deep, dark red basalt soils with high PBIs which may not be characterised as having high PBIs using the guidelines in Table 26.

Currently, some of the older sugarcane areas do not require any phosphorus fertiliser due to their long history of phosphorus fertilisation. New land, on the other hand, is often deficient in available phosphorus and requires phosphorus fertiliser.

**TABLE 25 PHOSPHORUS SORPTION CLASSES BASED ON PBI**

PBI	P-SORPTION CLASS
< 140	Low
140–280	Medium
281–420	High
> 420	Very high

**TABLE 26 PHOSPHORUS SORPTION CLASSES BASED ON ORGANIC CARBON (%) AND TEXTURE CLASS**

ORGANIC CARBON (%)	SAND (<24% CLAY)	LOAM (24–36% CLAY)	CLAY (>36% CLAY)
<0.6 %	Low	Low	Moderate
0.6–1.2 %	Low	Moderate	Moderate
1.2–1.8 %	Moderate	Moderate	High
>1.8%	Moderate	High	High

(Wood and others, 2003)

**Table 27 PHOSPHORUS RATE RECOMMENDATIONS**

BSES P (mg/kg)	P-SORPTION CLASS	P APPLICATION (kg/ha)	
		PLANT	RATOON
>120	Low, Moderate, High, Very high	Nil	Nil
60–120	Low		Nil
	Moderate		Nil
	High	30	Nil
	Very high		20
50–60	Low		Nil
	Moderate		Nil
	High	30	Nil
	Very high		20
40–50	Low	20	0
	Moderate	20	5
	High	20	10
	Very high	30	20
30–40	Low	20	10
	Moderate	20	15
	High	20	20
	Very high	30	20
20–30	Low	20	10
	Moderate	20	20
	High, Very high	30	25
10–20	Low	30	15
	Moderate	30	20
	High, Very high	40	30
5–10	Low	30	20
	Moderate	40	30
	High, Very high	50	40
<5	Low	40	20
	Moderate	60	30
	High, Very high	80	40

All areas except Burdekin and NSW. Modifications to phosphorus application rates where mill by-products have been applied:

- Mill mud applied at 100–150 wet t/ha: Apply nil P for at least two crop cycles.
- Mud/ash mixture applied at 100–150 wet t/ha: Apply nil P for at least two crop cycles.
- Ash only applied at 100–150 wet t/ha: No modification.

Burdekin. Modifications to phosphorus application rates where mill by-products have been applied:

- Mill ash 200 wet t/ha: Apply nil P for plant and one ratoon.
- Mill mud 200 wet t/ha: Apply nil P for at least two crop cycles.
- Mud/ash mixture 200 wet tonnes/ha: Apply nil P for at least two crop cycles.

NSW. Modifications to phosphorus application rates where mill by-products have been applied:

- Mill ash 150 wet t/ha: Apply nil P for plant and one ratoon.
- Mill mud 150 wet t/ha: Apply nil P for at least two crop cycles.
- Mud/ash mixture 150 wet tonnes/ha: Apply nil P for at least two crop cycles.

**TABLE 28 ESTIMATED CROP-AVAILABLE PHOSPHORUS AVAILABLE TO SUCCESSIVE CROPS AFTER THE BANDED APPLICATION OF MILL BY-PRODUCTS AT 50 WET t/ha**

CROP AFTER APPLICATION	MILL MUD	MUD-ASH MIXTURE
	AVAILABLE P (kg/ha)	
1st crop	Sufficient	Sufficient
2nd crop	Sufficient	Sufficient
3rd crop	Sufficient	Sufficient

*Sufficient = enough for crop requirements*

In some regions, banded application of mill by-products on the sugarcane row is the preferred application method. Table 28 shows the estimated amounts of phosphorus available to successive crops from mill by-products band-applied at 50 t/ha.

Information contained in Table 28 is based on estimates only and should, therefore, be used only as a guideline. Further research is required to refine these recommendations.

High P-sorption soils include humic gleys, some yellow earths, peats, some volcanic soils/ferrosols and some old alluvials.

Soils should be sampled before each five-year crop cycle to determine phosphorus fertiliser requirements.

Because the soil can store phosphorus, it is acceptable to apply all phosphorus for the crop cycle prior to, or at, planting if this is the most economic practice. The same practice could be adopted for replant cane. However, best management practice guidelines and current regulations may differ from that strategy and should be followed.

The use of rock phosphate is satisfactory for the maintenance of phosphorus levels in soils which have had adequate phosphorus applications in the past. This strategy works better on acid soils than alkaline soils because solubilisation of phosphorus from the rock phosphate will be faster at lower pH.

The recommended rates of phosphorus should not be exceeded. On a kilogram basis, phosphorus is by far the most expensive nutrient. Excess phosphorus applications build up soil reserves but do not produce greater yields in the crops that have been fertilised (refer to Figure 9).

Phosphorus does not usually move far from the point of application. When establishing a new plant crop, there is much more mixing of the soil than in a ratoon cane situation. This causes a dilution effect and the phosphorus is spread throughout the block. Hence, the recommended phosphorus rate is higher for plant cane than ratoon cane.

**TABLE 29 EFFECT OF PHOSPHORUS APPLICATION ON GERMINATION ON HIGH PHOSPHORUS SOILS**

SOIL TYPE [P(BSES) mg /kg : PBI : P-SORPTION CLASS]	GERMINATION RATE (%)	
	0 kg P/ha AT PLANTING	50 kg P/ha AT PLANTING
Thorpe (203 : 87 : Low)	96	94
Banyan (68 : 334 : High)	98	98
Hewitt (82 : 687 : Very High)	98	97

*No significant differences in germination rates; no response to applications of P*

### Phosphorus and germination

Germination and early sugarcane crop growth are not enhanced by phosphorus applied to soils where soil phosphorus levels are greater than 50 mg P/ha, irrespective of the PBI value (Table 29).

## PHOSPHORUS PLACEMENT

### New land

When applied as a pre-plant application on new land, phosphorus fertiliser should be broadcast and incorporated into the soil.

### Plant cane, replant cane and cultivated ratoon cane

Phosphorus should be buried in a band on each side of the row or as a split-stool application.

### Trash blanket/minimum tillage cultivation

In minimum tillage ratoon situations, the phosphorus fertiliser can be applied on top of the soil or trash. However, subsurface application is preferable, particularly if the soil is low in phosphorus, to allow the roots ready access to the fertiliser. Phosphorus is relatively immobile in the soil and moves only about 10 mm from its point of application.



## KEY POINTS: PHOSPHORUS (P)

- Very important in early root formation and growth, tillering, spindle development, photosynthesis and crop maturation.
- Older leaves exhibit phosphorus deficiency symptoms before young leaves.
- Phosphorus deficiency symptoms: thin, short stalks with short internodes; poor tillering; dark green to blue-green leaf blades with dark-coloured tips and margins; thin leaves that may stand abnormally upright; older leaves turn yellow and die back from the tips and along the margins.
- Most uncultivated Australian soils are very low in phosphorus.
- Phosphorus is relatively immobile in the soil and is not readily leached.
- Organic matter supplies only a very small proportion of the phosphorus needed by the crop.
- Some phosphorus is “fixed” in the soil in insoluble compounds and is not available for crop growth.
- Adequately limed soils assist with phosphorus availability to the crop by reducing phosphorus fixation.
- Phosphorus levels build up in the soil with repeated fertiliser applications.
- Once the fixing capacity of the soil is satisfied, a reserve of available phosphorus can build up.
- Two numbers are required from a soil test to determine a phosphorus application rate: soil phosphorus level and the soil PBI.
- Approximately 20 kg/ha of phosphorus is removed annually by an average crop.
- The main sources of phosphorus are superphosphate, DAP, MAP and high analysis mixtures.
- Mill mud and mud-ash mixtures contain significant quantities of phosphorus when applied at usual rates.
- Rock phosphate is the raw material for the production of most phosphate fertiliser.
- Rock phosphate is mostly in the insoluble form and is only very slowly available to the crop.
- Soil testing should occur every crop cycle (plant crop plus four ratoon crops) to determine the nutrient status of the soil.
- Phosphorus does not volatilise.
- Maintenance dressings of phosphorus can be safely applied to the soil surface or trash surface in minimum tillage situations, providing runoff from excessive rainfall or irrigation does not occur.
- Phosphorus should be buried in minimum tillage situations when the soil phosphorus level is marginal or low.

## CHAPTER 10

# POTASSIUM (K)

Potassium is one of the six major essential plant nutrients. Sugarcane crops remove relatively high quantities of potassium when the crop is exported from the farm to the sugar mill. Potassium can be readily leached from the soil particularly light-textured soils.

### THE ROLE OF POTASSIUM IN SUGARCANE

- Essential for plant growth and photosynthesis.
- Regulates respiration in leaves.
- Helps the plant use other nutrients and water more efficiently.
- Controls the movement of sugars in the plant.
- Controls starch formation.
- Promotes root development.
- Prevents premature cell death in plant tissues.

### POTASSIUM DEFICIENCY SYMPTOMS

- Older leaves exhibit deficiency symptoms before young leaves.
- Thin stalks and stunted growth.
- Young leaves usually stay dark green.
- Spindle may have fan appearance.
- On older leaves, dead areas or yellow/brown/dark red stripes may occur between leaf veins and along leaf edges and tips, giving a "fired" or scorched appearance.
- Midribs may have a red appearance.
- Poor root system.
- Slow plant growth.
- Resistance to diseases is reduced.
- Symptoms resemble "salt burn".

### CONSEQUENCE OF POTASSIUM EXCESS

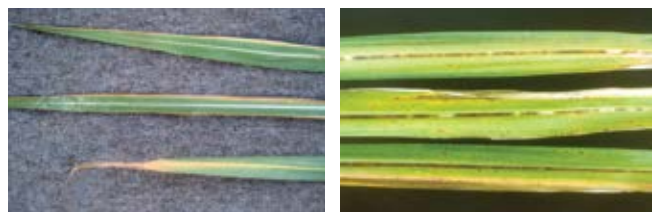
- Increases the ash content of sugarcane juice and reduces the recovery of raw and refined sugar
- May cause insufficient uptake of some trace elements
- Magnesium deficiency ("orange freckle") can also be induced where potassium is applied at high rates
- No increase in sugarcane yield or CCS.



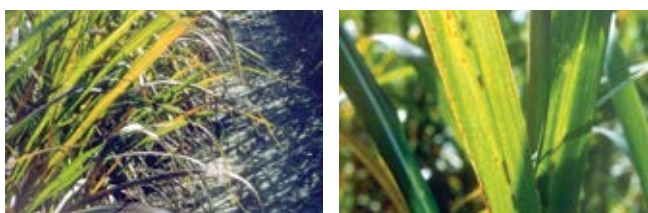
Poor growth in a sugarcane row in a potassium-deficient block that was not fertilised. (Photo: Graham Kingston)



Potassium deficiency in a crop grown on a very low CEC soil in the Burdekin. (Photos: Evan Shannon, Farmacist)



On older leaves, necrotic areas or dark stripes may occur between leaf veins and on edges giving a "fired" appearance. (Left photo: Graham Kingston)



Potassium-deficient leaves may show orange-yellow chlorosis.



Older leaves are most affected by potassium deficiency.

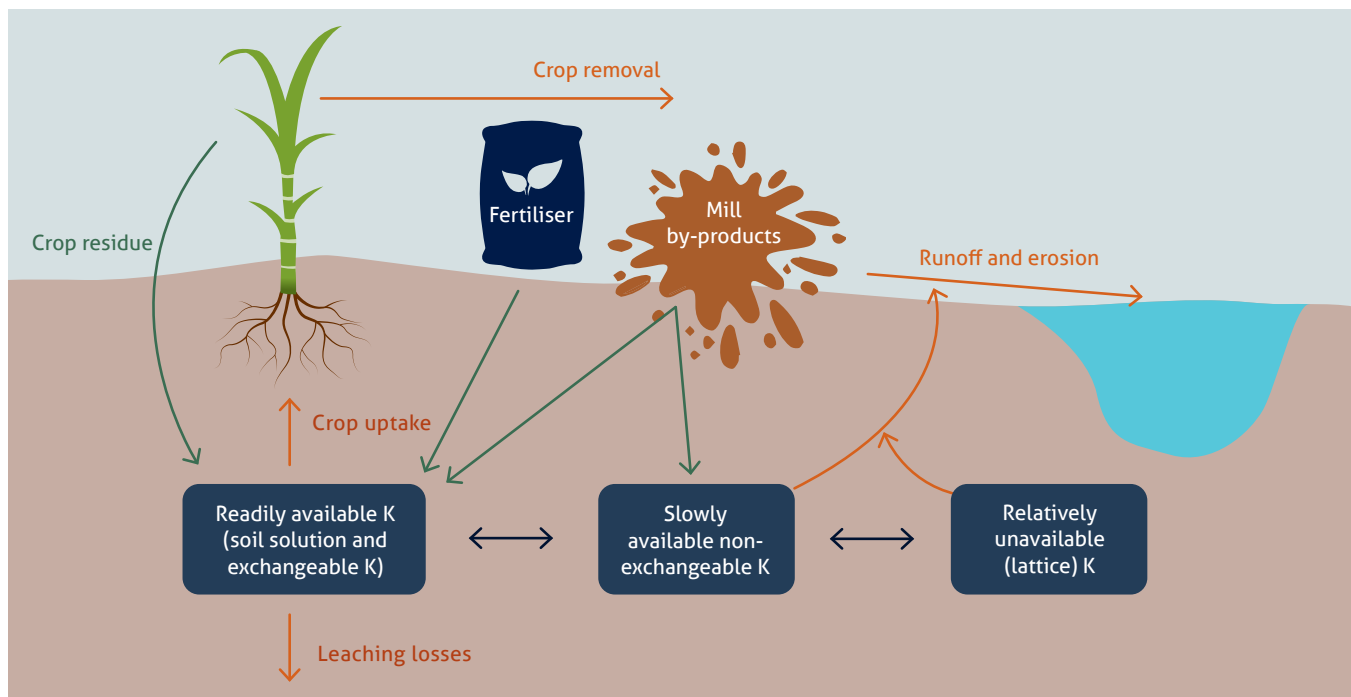


Figure 21: Potassium cycling in sugarcane crops

## THE POTASSIUM CYCLE

The potassium cycle (Figure 21) describes all the processes by which potassium circulates between the soil and plants.

## POTASSIUM IN THE SOIL

Most soils contain large amounts of potassium. In the top 15 cm of soil, up to several tonnes/hectare of potassium may exist. However, only a small percentage of this amount is available to plants.

Generally, soils rich in clay have high levels of potassium. However, some clay soils (such as volcanic soils/ferrosols) are lower in potassium because of the type of clay associated with those soils. Sandy soils generally have very low levels of potassium.

### Forms of potassium

Soil potassium exists in three forms: unavailable, slowly available and available.

**UNAVAILABLE POTASSIUM** (90–98% of total soil K). Unavailable potassium is found in minerals (rocks). The potassium is released as soil minerals are weathered. However, it is released too slowly to be available for plant growth in the short term.

**SLOWLY AVAILABLE POTASSIUM** (up to 10% of total soil potassium). Slowly available potassium is “fixed” or trapped between layers of certain soil clays. Potassium is unavailable or is only slowly released for plant growth.

**AVAILABLE (EXCHANGEABLE) POTASSIUM.** Available potassium is made up of two components: the potassium

found in the soil solution (water-soluble potassium), and the potassium held in exchangeable form by organic matter and clays (exchangeable potassium).

### Potassium soil tests

Two tests are often conducted on soil samples to assess the potassium status of the soil.

**EXCHANGEABLE POTASSIUM** test (K exchangeable) is a measure of the available potassium that is readily accessible by the crop. The test indicates the probability of a significant response to potassium fertiliser.

**NITRIC POTASSIUM** test (K nitric) is a measure of the slowly available potassium which indicates soil potassium reserves. The test is a measure of a soil’s potential to supply potassium.

### Potassium application to soil

Potassium applied as a fertiliser (usually in the form of muriate of potash) does not react in soils to form unavailable compounds as in the case of phosphorus. In other words, all potassium applied in fertiliser is available for plant use.

Potassium, like nitrogen, but unlike phosphorus, is mobile in the soil solution, and is prone to leaching. Leaching, however, is not a serious problem except on sandy soils (low cation exchange capacity) subject to high rainfall or irrigation.

### Soil factors affecting potassium uptake

Potassium uptake by plants can be affected by the soil’s cation exchange capacity (CEC), soil moisture, and soil aeration.



Like other cationic nutrients, the higher the soil's CEC, the greater the retention of nutrients on the clay surfaces of the soil. High CEC soils have a far greater ability to retain potassium than, say, a sandy soil.

Potassium must be in solution for the plant to be able to take it up. During dry spells, potassium uptake will be reduced. Excessive moisture will also compromise the plant's ability to access potassium.

Potassium uptake is affected by poor soil aeration. Soil compaction resulting in poor soil aeration and root growth should be avoided.

Low soil temperature and high potassium-fixing soils can impact on potassium uptake. However, in the Australian sugar industry, these factors do not significantly affect potassium nutrition.

### POTASSIUM IN IRRIGATION WATER

In the Burdekin region, irrigation water can supply at least 2 to 5 kg of potassium per megalitre (Table 30). A water test is recommended to determine the extent of potassium fertiliser reductions that can be made following irrigation.

**TABLE 30 POTASSIUM LEVELS IN BURDEKIN IRRIGATION WATER**

ELECTRICAL CONDUCTIVITY (dS/m)	AVERAGE POTASSIUM CONTENT (kg/ML)	MINIMUM CONTAINED IN 80% OF WATERS (kg/ML)
0 - 0.4	3.1	1.7
0.41 - 1.2	5.2	2.3
1.21 - 1.6	7.2	3.0
1.61 - 2.0	9.8	3.7
2.01 - 2.3	11.5	4.3
>2.3	14.3	5.3

### RESPONSE TO POTASSIUM

Ratoon and replant cane give a greater response to potassium fertilisers than plant cane because potassium reserves are converted to available forms of potassium during the fallow. This decreases the reliance of the plant crop on fertiliser potassium. Ratoon and replant cane require more potassium fertiliser than plant cane.

### POTASSIUM FERTILISERS

Potassium fertilisers can be produced in chemical reactions, but are usually mined from natural deposits that occur as beds of solid salts beneath the Earth's surface, or as brines in inland lakes and seas that have evaporated.

Muriate of potash (potassium chloride – KCl) is made by refining the natural potash salts.

**TABLE 31 POTASSIUM SOURCES**

SOURCE	POTASSIUM CONTENT (%)
Potassium chloride (muriate of potash)	50.0
Potassium sulfate (sulfate of potash)	41.0
Potassium nitrate	38.3
Potassium magnesium sulfate	18.0
BY-PRODUCTS*	
Mill mud, mill ash and mud/ash mixtures	Various
Dunder and dunder-based products	Various
Molasses	Various
Manures and composted bio-solids (municipal wastes)	Various

\*Refer to Chapter 23

#### Potassium chloride (KCl)

Also called muriate of potash, it is water soluble and is the cheapest and most commonly used form of potassium.

#### Potassium sulfate ( $K_2SO_4$ )

It contains 16.5% sulfur, in addition to potassium.

#### Potassium nitrate ( $KNO_3$ )

It contains 13% nitrogen, in addition to potassium.

#### Potassium magnesium sulfate ( $K_2SO_4 \cdot 2MgSO_4$ )

Also called sulfate of potash-magnesia, it contains 11% magnesium and 22% sulfur, in addition to potassium.

#### Liquid dunder and biounder

A by-product of ethanol production, dunder, and commercial fertiliser products derived from dunder, are rich sources of potassium. Commercial fortified-dunder products containing added nitrogen, phosphorus and/or sulfur are commonly used in some regions of the Australian sugar industry. They belong to the group of products referred to as liquid one-shot (LOS) fertilisers. If surface-applied, LOS fertilisers are generally at risk of nitrogen volatilisation losses. However, dunder-based LOS products containing dissolved urea have low pH which reduces the potential for volatilisation losses. Management practices such as irrigating after application also reduce this risk.

## POTASSIUM RATE RECOMMENDATIONS

Recommended rates of potassium are given in Table 32. See the SRA Nutrition section of the SRA website for the SIX EASY STEPS nutrient guidelines for individual regions.

The recommendations are based on soils using ammonium acetate as the extractant.

The recommended rate should not be exceeded. The sugarcane crop will “luxury feed” on any excess potassium, which will not improve CCS or yield, but will cause manufacturing problems in the raw sugar mill and refinery due to the increased ash content of the juice.

In some regions, banded application of mill by-products on the sugarcane row is the preferred application method. Table 34 shows the estimated amounts of potassium available to successive crops from mill by-products band-applied at 50 t/ha.

Information contained in Table 34 is based on estimates only and should, therefore, be used only as a guideline. Further research is required to refine these recommendations.

TABLE 32 POTASSIUM RATE RECOMMENDATIONS – ALL REGIONS EXCEPT BURDEKIN							
PLANT (kg/ha K)							
NITRIC K (meq/100 g)	EXCHANGEABLE K (amm-acet) - meq/100 g						
	<0.20	0.20–0.25	0.26–0.30	0.31–0.35	0.36–0.40	0.41–0.45	>0.45
< 0.70	100 (sand)	80 (sand)	50 (sand)	50 (sand)	0 (sand)	0 (sand)	0 (sand)
	120 (loam)	100 (loam)	80 (loam)	50 (loam)	0 (loam)	0 (loam)	0 (loam)
	120 (clay)	120 (clay)	100 (clay)	80 (clay)	50 (clay)	0 (clay)	0 (clay)
> 0.70	80 (sand)	50 (sand)	0 (sand)	0 (sand)	0 (sand)	0 (sand)	0 (sand)
	100 (loam)	80 (loam)	50 (loam)	0 (loam)	0 (loam)	0 (loam)	0 (loam)
	100 (clay)	100 (clay)	80 (clay)	50 (clay)	0 (clay)	0 (clay)	0 (clay)
REPLANT AND RATOON (kg/ha K)							
NITRIC K (meq/100 g)	EXCHANGEABLE K (amm-acet) - meq/100 g						
	<0.20	0.20–0.25	0.26–0.30	0.31–0.35	0.36–0.40	0.41–0.45	>0.45
< 0.70	120 (sand)	120 (sand)	100 (sand)	80 (sand)	50 (sand)	0 (sand)	0 (sand)
	120 (loam)	120 (loam)	100 (loam)	100 (loam)	80 (loam)	50 (loam)	0 (loam)
	120 (clay)	120 (clay)	100 (clay)	100 (clay)	100 (clay)	80 (clay)	0 (clay)
> 0.70	100 (sand)	100 (sand)	80 (sand)	50 (sand)	0 (sand)	0 (sand)	0 (sand)
	100 (loam)	100 (loam)	100 (loam)	80 (loam)	50 (loam)	0 (loam)	0 (loam)
	100 (clay)	100 (clay)	100 (clay)	100 (clay)	80 (clay)	50 (clay)	0 (clay)

Modifications to potassium application rates where mill by-products have been used:

- Mill mud applied at 100–150 wet t/ha: Subtract 40 kg K/ha on first crop after application.
- Mill mud applied at 200 wet t/ha: Subtract 50 kg K/ha on first crop after application.
- Mud/ash mixture applied at 100–150 wet t/ha: Apply nil K on the first crop after application. (For NSW, apply nil K for two crops.)
- Mud/ash mixture applied at 200 wet t/ha: Apply nil K on the two crops after application.
- Ash only applied at 100–150 wet t/ha: Apply nil K for the two crops after application.
- Ash only applied at 200 wet t/ha: Apply nil K for the three crops after application.

**Table 33 POTASSIUM RATE RECOMMENDATIONS – BURDEKIN**

PLANT, REPLANT AND RATOON (kg/ha K)						
NITRIC K (meq/100 g)	EXCHANGEABLE K (amm-acet) - meq/100 g					
	<0.20	0.20–0.25	0.26–0.30	0.31–0.35	0.36–0.40	> 0.40
< 0.70	100 (sand)	80 (sand)	50 (sand)	50 (sand)	Nil (sand)	Nil
	120 (loam)	100 (loam)	80 (loam)	50 (loam)	Nil (loam)	
	120 (clay)	120 (clay)	100 (clay)	80 (clay)	50 (clay)	
> 0.70	80 (sand)	50 (sand)	Nil (sand)	Nil (sand)	Nil	Nil
	100 (loam)	80 (loam)	50 (loam)	Nil (loam)		
	100 (clay)	100 (clay)	80 (clay)	50 (clay)		

Modifications to potassium application rates where mill by-products have been used:

- Mill mud applied at 200 wet t/ha: Subtract 50 kg K/ha on the first crop after application.
- Mud/ash mixture applied at 200 wet t/ha: Apply nil K on the two crops after application.
- Ash only applied at 200 wet t/ha: Apply nil K for the three crops after application.

Modifications to K rate are recommended where blocks of sugarcane are irrigated with ground water which may contain substantial amounts of potassium. The K application needs to be reduced to take this source of K into account.

## POTASSIUM PLACEMENT

When added to the soil, potassium becomes lightly attached to the clay, and therefore, is not as easily leached from the soil like nitrogen. However, it is not firmly attached like phosphates, and does migrate slowly in the soil under the influence of water.

Losses from volatilisation do not occur as with surface-applied urea. Surface-applied potash, like nitrogen, will eventually find its way into the root zone of ratoons.

### Plant cane, replant cane and cultivated ratoon cane

Potassium fertiliser should be buried into, or in a band on each side of, the ratoon row.

Care should be taken when applying the planting mixture or straight potash at planting to ensure that “potash burn” does not occur. If the potash is in contact with, or very close to, the sugarcane setts, fertiliser burn can result in delayed, or even prevention of, germination of some of the eyes of the plants. Root stubbing may also occur.

### Trash blanket/minimum tillage cultivation

In zero or minimum tillage ratoon situations (such as on blocks with a trash blanket), the potassium fertiliser can be applied on top of the soil or trash.

**TABLE 34 ESTIMATED CROP-AVAILABLE POTASSIUM AVAILABLE TO SUCCESSIVE CROPS AFTER THE BANDED APPLICATION OF MILL BY-PRODUCTS AT 50 WET t/ha**

CROP AFTER APPLICATION	MILL MUD	MUD-ASH MIXTURE
	APPROXIMATE AVAILABLE K (kg/ha)	
1st crop	15	40
2nd crop	0	0
3rd crop	0	0



## KEY POINTS: POTASSIUM (K)

- Essential for root development, plant growth and photosynthesis; controls movement of sugars in the plant; helps sugarcane to use other nutrients and water more efficiently; regulates respiration in leaves.
- Older leaves exhibit potassium deficiency symptoms before young leaves.
- Potassium deficiency symptoms: thin stalks and stunted growth; fan-like spindle; “fired” or scorched appearance on older leaves; poor root system; red midribs. Young leaves usually stay dark green.
- Excessive potassium applications cause problems with the manufacture of raw sugar.
- Potassium applications above the recommended rates do not increase sugarcane yield or CCS.
- Most soils contain large amounts of potassium but only a small proportion is available to the plant.
- Soil potassium exists in three forms: available, slowly available, and unavailable to the crop.
- Two soil tests are used for potassium: exchangeable K (a measure of soil potassium that is available to the crop), and nitric K (a measure of soil potassium reserve that is slowly available to the crop).
- Potassium fertilisers do not react in soils to form unavailable compounds.
- Significant quantities of potassium are removed by the crop with much of the uptake coming from the soil reserves.
- Ratoon and replant cane require more applied potassium fertiliser than plant cane.
- Potassium fertilisers are usually obtained from natural deposits.
- Dunder, a by-product of ethanol production, and dunder-based commercial liquid fertilisers are rich sources of potassium.
- Muriate of potash (also called potash or potassium chloride) is made by refining the natural potash salts.
- Muriate of potash is the potassium fertiliser normally used in sugarcane production, and is the cheapest form of potassium.
- Muriate of potash is water soluble and may be leached.
- Muriate of potash does not volatilise; it can be safely applied to the soil surface or trash surface in zero or minimum tillage situations, providing surface runoff from rainfall or irrigation does not occur.
- Recommended potassium application rates must take account of applications of mill by-products or where high-potassium content irrigation water is used.
- Sugarcane “luxury feeds” on potassium.
- At planting, fertiliser burn will occur if potassium fertiliser is placed on, or very close to, the sugarcane setts.

## CHAPTER 11

# CALCIUM (Ca)

Calcium is the fifth most abundant element in the Earth's crust, occurring commonly as natural lime deposits. Calcium is an important plant food. Calcium deficiency in old sugarcane growing soils is common, often associated with soil acidification, and can be severely limiting to crop productivity. Calcium and magnesium deficiency symptoms often occur together. Both deficiencies can be rectified at the same time with the application of a calcium-magnesium blended product.

### THE ROLE OF CALCIUM IN SUGARCANE

- Essential for the growth and development of the spindle, leaves and roots.
- Comprises part of the cell walls, thus strengthening the plant.
- Plays an important role in nitrogen metabolism.

Calcium is required for nodulation and nitrogen fixation in legumes used as break crops in sugarcane production.

### CALCIUM DEFICIENCY SYMPTOMS

- Older leaves exhibit deficiency symptoms before young leaves.
- Older leaves are often pale green with yellow mottling or a rusty appearance and may die prematurely.
- Young leaves may be distorted (curled) and necrotic.
- Stalks are thin and taper towards the growing point.
- Apical meristems may die.
- Top growth is poor.
- Rind may be soft.
- Often poor root growth (root growth is affected before top growth).
- In severe cases, the young leaves become hooked and the spindle dies off at the tip and edges.
- Leaf margins may be serrated.
- Primary shoot may die.

Calcium deficiency symptoms are reasonably common. The crop removes calcium each year but sugarcane land no longer receives regular applications of calcium from superphosphate which was once used in low analysis mixtures. Today's high analysis mixtures are based on DAP or MAP which contain no calcium, so calcium ameliorants may need to be applied if a soil test identifies the requirement.

Calcium deficiency usually occurs in acid soils, but acid soils are not necessarily calcium deficient.



Calcium-deficient plant cane in light-textured soils. The older leaves have yellow mottling.



Pale green leaves with yellow mottling are common symptoms of calcium-deficient sugarcane.



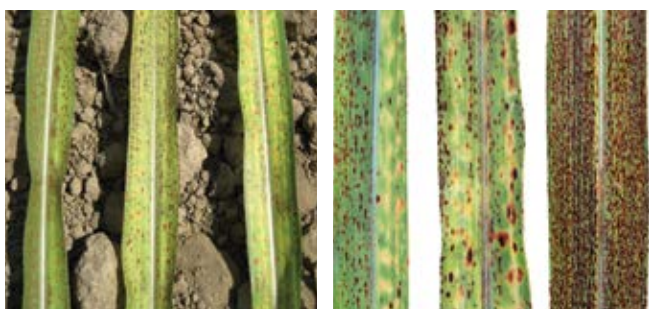
The older leaves may have a rusty appearance along with pale mottling. The leaves may die prematurely. (Right photo: Graham Kingston)



Stalks are thin and taper towards the growing point. Top growth is poor with a spiky appearance. When calcium is severely deficient, the primary shoot may die. (Centre and right photos: Graham Kingston)



Severe calcium deficiency in young plant cane.



Calcium deficiency and magnesium deficiency often occur together. Affected leaves may express symptoms of both nutrient deficiencies.

## CONSEQUENCE OF CALCIUM EXCESS

Excessive soil calcium levels are uncommon in sugarcane growing soils but can occur in small areas where loads of lime have been dumped prior to spreading on a block. Soil pH will be raised to high values which restricts nutrient uptake, causing deficiency of some other nutrients such as magnesium. Nutritional disorders such as zinc and copper deficiency can also result. Refer to Figure 6.

## CALCIUM SOURCES

A wide range of products can be used to supply calcium to the soil. These products vary in price, nutrient availability and nutrient content. Only some of these products are registered under the Agricultural Standards Act. This legislation gives the producer an assurance of the quality of the product being applied.

The purchase of unregistered cheaper products involves risk as far as nutrient content and product quality are concerned.

TABLE 35 CALCIUM SOURCES	
SOURCE	CALCIUM CONTENT (%)
Calcium/magnesium blends	Usually 29–33
Agricultural lime/earth lime (calcium carbonate)	30–40
Burnt lime/quicklime /unslaked lime (calcium oxide)	68
Hydrated lime/slaked lime/builders lime (calcium hydroxide)	51
Gypsum (calcium sulfate) products	12.5–19.0 (23 in pure product)
Dolomite (calcium magnesium carbonate)	14–18
Cement	46
Agricultural calcium silicate	35 (approx.)
Superphosphate	20
Triple superphosphate	15.0–18.5
Mill mud, mill ash and mud-ash mixtures*	Various

\*Refer to Chapter 23



Three aspects on the label of registered liming products are of prime importance to canegrowers:

1. **The fineness of the product** determines the speed at which it reacts with the soil. The higher the fine percent, the faster it reacts and releases calcium to the crop.
2. **The content (percent) of calcium contained in the product.** The content, combined with the price per tonne spread, allows calculation of the cost per kilogram of calcium applied. To be competitive, a product with a lower calcium content should have a reduced cost in proportion to the reduced calcium content.
3. **The form in which the calcium is present** e.g. calcium oxide/burnt lime is more soluble and reacts with the soil much faster than the cheaper and less caustic carbonate form, agricultural lime. Depending on the origin of the product, gypsum is often more soluble than burnt lime but is subject to leaching. Liming products would, therefore, be preferred in most situations.

The label may also contain the term neutralising value (NV) which is the ability of a calcium product to neutralise or counteract acidity. The neutralising value is expressed as a percentage. Pure limestone (calcium carbonate) has a NV of 100%. Pure hydrated lime and burnt lime have NVs of 135% and 178% respectively.

Lime should be used on acid soils that are low in calcium. Lime also corrects acidity by raising the soil pH.

### Calcium-magnesium blends (mostly 29–33% calcium)

A range of blended products provide an economical source of both calcium and magnesium. The blends are usually a mixture of agricultural lime and magnesium oxide, magnesium carbonate or dolomite. The blends provide about 29–33% calcium and 3–5% magnesium.

### Agricultural lime/earth lime ( $\text{CaCO}_3$ ; 30–40% calcium)

Calcium carbonate. Crushed limestone is the usual form of lime used in agriculture to correct calcium deficiency. It is normally the most economical source of calcium. Agricultural lime is relatively slow acting in the soil. It should be applied and incorporated into the soil a minimum of one month before planting.

Relatively fine liming material should be used. The minimum standard should be 60% fine material and 40% coarse material.

### Burnt lime ( $\text{CaO}$ ; 68% calcium)

Calcium oxide. Burnt lime is produced by burning limestone. It is not stable. It reacts with water to form hydrated lime, which then reacts with carbon dioxide to

produce finely divided lime. It is fast acting and can be applied just prior to planting. Burnt lime is very caustic and may burn the eyes and skin. It is rarely used in the sugarcane industry as a source of calcium for depleted soils.

### Hydrated lime ( $\text{Ca(OH)}_2$ ; 51% calcium)

Calcium hydroxide. Hydrated lime is made by reacting burnt lime with water. Hydrated lime is fast acting and can be used at a lower rate than agricultural lime because of its high calcium content. However, compared to agricultural lime, it is not an economical source of calcium.

### Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ; 18–22% calcium)

The gypsum available to the sugar industry is a by-product of superphosphate manufacture and mined from naturally-occurring deposits. Gypsum provides a soluble source of calcium. It is more soluble than lime and is readily leached from sandy soils.

Because of its very low bulk density and resulting high freight costs, gypsum is not an economical source of calcium. Gypsum is, however, useful as a soil additive in certain problem soils such as soda patches and hard-setting soils to improve the physical condition of the soil. Gypsum also contains 12–18% sulfur.

Because gypsum has no carbonate ion, it will not neutralise acidity. It is much more soluble than most lime products so it is a good source for quick-acting, soluble calcium (and sulfur). In other words, applying gypsum to the soil will raise the calcium and sulfur levels but it will not raise the pH.

### Dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ; 14–18% calcium)

Dolomite is a mixture of calcium and magnesium carbonates and is used mainly to correct magnesium deficiency. Because it contains a relatively low percentage of calcium (14%–18%) and a high percentage of magnesium (8%–10%), dolomite is not used to correct calcium deficiencies as far too much magnesium would be applied.

### Cement (46% calcium)

Cement is fast acting in the soil and is a readily available source of calcium and magnesium (1.3%) plus some trace elements. Cement is usually too expensive to be used as a source of calcium.

### Calcium silicate ( $\text{Ca}_2\text{SiO}_4$ ); 35% calcium approx.)

Calcium silicate also contains about 13% silicon and is used to correct silicon deficiency.

### Superphosphate and triple superphosphate (15–20% calcium)

These products provide a soluble form of calcium.

## CALCIUM RATE RECOMMENDATIONS

Soils are constantly being acidified through the use of nitrogenous fertilisers and through the removal of nutrients in the harvested crop. The more nitrogen fertiliser used, the greater is the lime requirement. In addition, some forms of nitrogen fertiliser are more acidifying than others. (See page 41.)

Lime is used to neutralise soil acidity and to supply calcium. A maintenance application of about 2 tonnes lime/ha each five-year crop cycle is needed to neutralise this effect.

Calcium rate recommendations are derived from calcium response curves (Figure 22). The soil test critical value for calcium is 0.65 meq%. Below this value, a response to calcium is almost certain. The marginal value is 2.0 meq%. Between these two figures, a maintenance calcium application is recommended to ensure yields are not being limited.

In the Mossman to Tully region, soil calcium levels were found to be a reliable indicator of potential crop yield response to lime application. This was adopted as the standard because soil pH/soil acidity was not a good indicator of potential crop response to lime application in that region. In all other areas, both soil pH and soil calcium levels need to be considered. This is due to soils in other regions having much higher calcium levels in the subsoil.

Crop management should focus on lower rates of a calcium-based product being applied more frequently than a single application each crop cycle.

Recommended rates of calcium are given in the following tables.

The recommendations are based on the soil tests that use ammonium acetate as the extractant.



The application of a liming product will rectify soil calcium deficiency. When soil magnesium is also required, a calcium-magnesium blend is usually the best option. These products should normally be applied during the fallow period.

SOIL Ca (meq/100 g)	LIME APPLICATION (tonnes/ha)
< 0.20	4.0
0.21–0.40	3.5
0.41–0.60	3.0
0.61–0.80	2.5
0.81–1.20	2.0
1.21–1.60	1.5
1.61–2.00	1.0
>2.00	0

Modifications to calcium application rates where mill by-products have been used:

After an application of mill mud, mill ash or mud-ash mixture, reduce the lime application by 2 t/ha (for 150 t/ha rate) or 2.5 t/ha (for 200 t/ha rate).

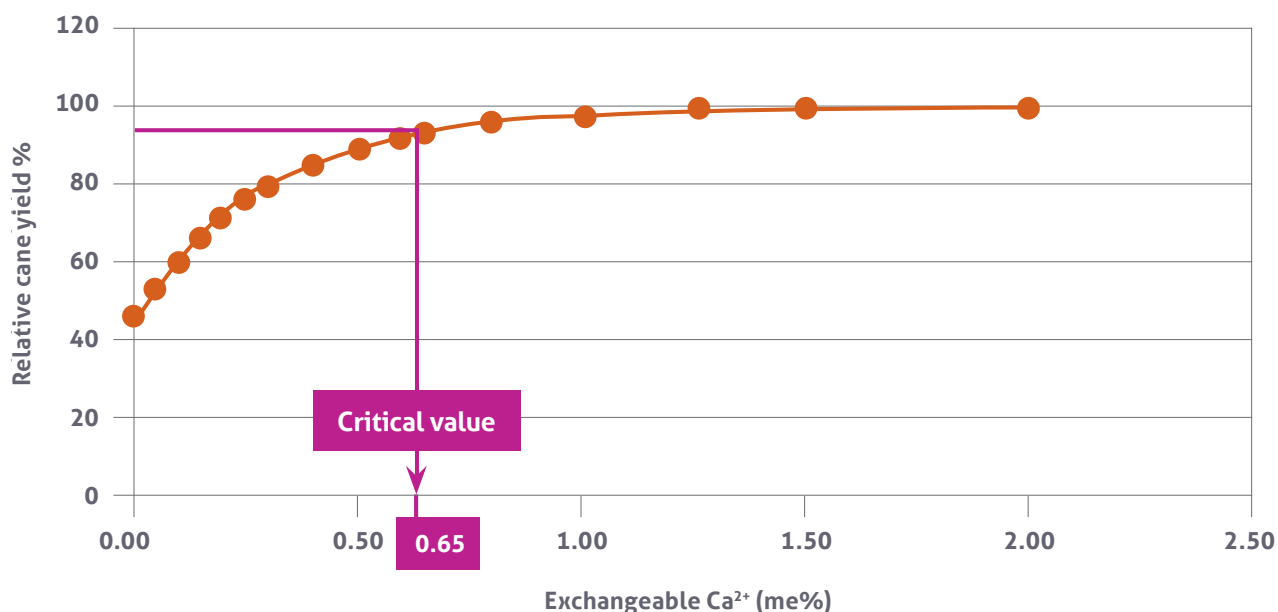


Figure 22: Yield response v soil calcium level

### How often should lime be applied?

A regular program of soil testing is most important in determining the calcium level of the soil, the rate of application of the liming material, and when to reapply calcium. In most instances, a lime application will last approximately five to six years. Rather than applying the full quantity of a liming product at the end of the crop cycle, smaller but more frequent liming product applications will reduce marked changes in the soil calcium values and may help with on-farm cash flow. A soil test at the end of the crop cycle will assist with this decision.

Calcium leached into the subsoil that is accessible to sugarcane roots should be taken into account when making retreatment decisions. The additional calcium in the subsoil can reduce an anticipated response to applied calcium if the rate is based only on a surface soil analysis.

### CALCIUM APPLICATION AND ZINC AND COPPER DEFICIENCY

Liming may induce zinc and copper deficiency symptoms. This situation would mean that soil zinc and/or copper levels were low to start with, and the liming has reduced the availability of these elements by increasing soil pH. In these cases, the zinc and copper problem should be rectified. It does not mean that the liming should not have been carried out. A calcium product is always necessary if soil calcium levels are low.

### CALCIUM PLACEMENT

The two most commonly used sources of calcium, agricultural lime and calcium-magnesium blends, should be broadcast-applied to the fallow block at least one month, but preferably three to six months, prior to planting. For sugarcane growing on permanent beds in wide rows (1.8 m or wider), the product should be broadcast on the row area. After application, the product should be incorporated into the soil. This practice will allow the slow-acting product time to react with the soil, making some calcium available to the young plant cane.

If the calcium-depleted block is not fallowed, the lime or the blend can be applied prior to replant. However, the following crop may gain limited benefit from the calcium as it is only slowly available for crop growth.

Calcium or calcium-magnesium products can be applied to plant or ratoon cane as band treatments through conventional fertiliser boxes at reduced rates.

Calcium is subject to leaching, particularly in sandy soils in high rainfall areas.

**TABLE 37 LIME REQUIREMENTS FOR ACID SOILS WHEN pH<sub>water</sub> <5.5 (HERBERT)**

CEC (meq/100 g)	LIME APPLICATION (tonnes/ha)
<3.0	2.25
3.0 – 6.0	4.0
>6.0	5.0

*Modifications to calcium application rates where mill by-products have been used:*

*After an application of mill mud, mill ash or mud-ash mixture, reduce the lime application by 2 t/ha (for 150 t/ha rate) or 2.5 t/ha (for 200 t/ha rate).*

**TABLE 38 LIME REQUIREMENTS FOR ACID SOILS WHEN pH<sub>water</sub> <5.5 (TABLELAND, PROSERPINE, MACKAY, PLANE CREEK, SOUTH QUEENSLAND)**

CEC (meq/100 g)	LIME APPLICATION (tonnes/ha)
<2.0	1.25
2.0–4.0	2.5
4.1–8.0	4.0
>8.0	5.0

*Modifications to calcium application rates where mill by-products have been used:*

*After an application of mill mud, mill ash or mud-ash mixture, reduce the lime application by 2 t/ha (for 150 t/ha rate) or 2.5 t/ha (for 200 t/ha rate).*

**TABLE 39 LIME REQUIREMENTS FOR ACID SOILS WHEN pH<sub>water</sub> <5.0 (NSW)**

CEC (meq/100 g)	LIME APPLICATION (tonnes/ha)
<4.0	1.25
4.0–8.0	2.5
8.1–16.0	4.0
>16.0	5.0

*Table 39 Lime requirements for acid soils when pH<sub>water</sub> <5.5 (NSW)*

*Modifications to calcium application rates where mill by-products have been used:*

*After an application of mill mud, mill ash or mud-ash mixture, reduce the lime application by 2 t/ha (for 150 t/ha rate) or 2.5 t/ha (for 200 t/ha rate).*

## KEY POINTS: CALCIUM (Ca)

- Occurs commonly as natural lime deposits.
- Stimulates root growth and is essential for normal leaf and spindle development.
- Calcium and all other plant nutrients are vital for maximum crop production: if calcium is deficient, it must be rectified.
- Calcium deficiency is common in many regions.
- Calcium and magnesium deficiency symptoms often occur together and can both be treated with an application of a calcium-magnesium blend.
- Older leaves exhibit calcium deficiency symptoms before young leaves but both older and younger leaves are affected.
- Calcium deficiency symptoms: older leaves are often pale green with yellow mottling or a rusty appearance and may die prematurely; curled and necrotic young leaves; thin stalks that taper towards the growing point; the apical meristems may die; poor top growth; poor root growth; young leaves may become hooked and the spindle may die off at the tip and edges; leaf margins may be serrated; primary shoot may die.
- A maintenance dressing of lime alone supplies about 900 kg/ha of calcium which lasts about one crop cycle.
- High analysis fertiliser mixtures contain no calcium.
- Three items on the label of registered liming products are important: the calcium content (%), the fineness of the product, and the form in which the calcium is present.
- The neutralising value of a calcium product may also be on the label. It measures the ability of the product to counteract soil acidity.
- Agricultural lime is slow acting. It should be applied during the fallow and incorporated into the soil.
- Gypsum is very useful on hard-setting soils and soil affected by sodium. It is relatively expensive as a source of calcium. It does not alter soil pH.
- Agricultural lime (limestone) is the product commonly used to rectify calcium deficiency. It will raise soil pH.
- Dolomite supplies calcium and magnesium, but required rates of both nutrients are obtained more economically from commercial blends of lime and magnesium products.
- Cement is a source of readily available calcium but is very expensive.
- Liming may induce zinc or copper deficiency which should also be corrected.



CHAPTER 12

# MAGNESIUM (Mg)

Magnesium is present in large amounts in the clay minerals of most Australian soils. Sandy, acid soils in high rainfall zones where magnesium, calcium and other cations have been leached from the root zone are those most likely to be deficient in exchangeable (plant-available) magnesium. Magnesium and calcium deficiencies often occur together and are usually associated with acid soils. Soils with very high magnesium levels are likely to be poorly structured and difficult to cultivate.

Magnesium is a key component of chlorophyll, the green colouring material of plants. Magnesium is mobile in the plant and can be quickly relocated to the young plant tissue.

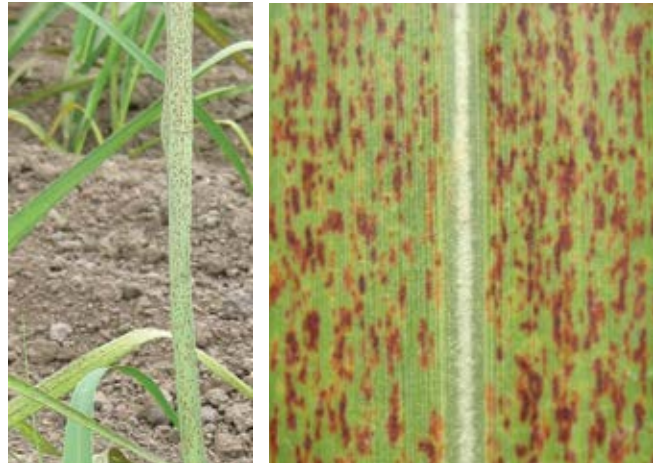
### THE ROLE OF MAGNESIUM IN SUGARCANE

- Essential for photosynthesis and sugar production
- Needed for movement of phosphorus in the plant
- Involved in plant respiration
- Involved in nitrogen metabolism and nitrogen assimilation.

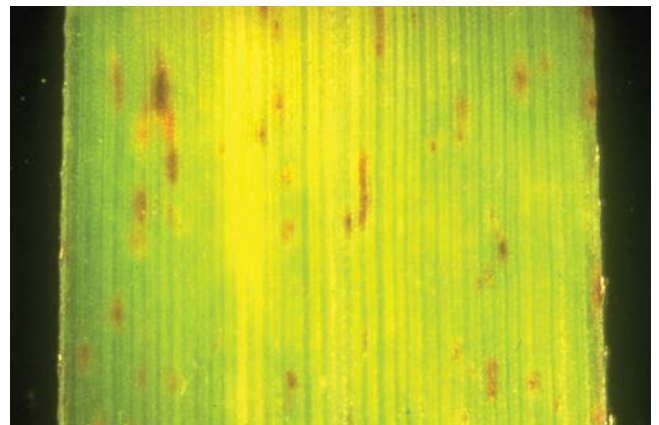
### MAGNESIUM DEFICIENCY SYMPTOMS

- Older leaves exhibit deficiency symptoms before young leaves
- Young leaves are green, while older leaves are paler with yellow mottling or interveinal chlorosis
- Older leaves develop chlorotic spots which turn orange, and later dark brown. These spots may join, giving the leaf a rusted appearance. This condition is called "orange freckle".
- Stooling is weak and sugarcane growth is retarded.

Mild symptoms of magnesium deficiency are often present only in young sugarcane and disappear as the crop develops. Magnesium deficiency has become more common in recent years, especially in the northern sugarcane growing regions. Calcium and magnesium deficiency often occur together.



*In magnesium-deficient cane, the older leaves are often paler with dark spots. The leaves may have a mottled appearance.*



*A close view of a sugarcane leaf exhibiting early magnesium deficiency symptoms. Interveinal chlorosis, pale leaf colouring and mottling are evident.*



*Magnesium deficiency and calcium deficiency often occur together. Affected leaves may express symptoms of both nutrient deficiencies. (Also refer to the calcium and magnesium photos in Chapter 11).*



A spectacular example of "orange freckle" where chlorotic spots coalesce giving the leaf a rusted appearance.

## CONSEQUENCE OF MAGNESIUM EXCESS

Excessive soil magnesium levels may interfere with the uptake of potassium and calcium. The soil may become hard, crusty and difficult to till. Water infiltration will be reduced and drainage will be compromised.

## MAGNESIUM SOURCES

### Calcium-magnesium blends (mostly 3–5% magnesium)

A range of blended products provide the most economical source of both calcium and magnesium. The blends are usually a mixture of agricultural lime and magnesium oxide, magnesium carbonate or dolomite. The blends provide about 29–33% calcium and 3–5% magnesium.

### Magnesium oxide products (54–55.5% magnesium)

Magnesium oxide is a relatively insoluble material but provides a reliable, long term source of magnesium. Product names include Granomag and Magfeed.

### Epsom salts ( $MgSO_4$ ; 9.6% magnesium)

Because it is soluble, Epsom salts (magnesium sulfate) is a quickly available source of magnesium. It does not need to be applied early in the fallow, but can be incorporated just before or after planting. As it leaches relatively easily, Epsom salts is not a long term source of magnesium, unlike dolomite and magnesium oxide products.

### Cement (1.3% magnesium)

Cement is usually too expensive to use as a source of magnesium on sugarcane fields.

### Magnesite ( $MgCO_3$ ; 28% magnesium)

Magnesite is a relatively insoluble material which provides a reliable, long term source of magnesium.

### Potassium magnesium sulfate ( $K_2SO_4 \cdot 2MgSO_4$ ; 10.5% magnesium)

Because the magnesium is in the soluble sulfate form, it can be used where a quick response to magnesium is required.

### Dolomite [ $CaMg(CO_3)_2$ ; 8–10% magnesium]

Dolomite, or dolomitic limestone, is a naturally-occurring material which also provides calcium. It is crushed to provide a slow-acting product which should be incorporated into the soil early in the fallow period.

TABLE 40 MAGNESIUM SOURCES

SOURCE	MAGNESIUM CONTENT (%)
Calcium-magnesium blends	Usually 3–5
Magnesium oxide products	54.0–55.5
Epsom salts (magnesium sulfate)	9.6
Cement	1.3
Magnesite (magnesium carbonate)	28.0
Potassium magnesium sulfate	10.5
Dolomite (calcium magnesium carbonate)	8.0–10.0
Mill mud, mill ash and mud-ash mixtures*	Various

\*Refer to Chapter 23

## MAGNESIUM RATE RECOMMENDATIONS

Magnesium rate recommendations are derived from magnesium response curves (Figure 23). The soil test critical value for magnesium is 0.10 meq%. Below this value, a response to magnesium is almost certain. The marginal value is 0.25 meq%. Between these two figures, a maintenance magnesium application is warranted to ensure yields are not being limited.

Recommended rates of magnesium to rectify soil deficiency are given in Table 41.

The recommendations are based on the soil test using ammonium acetate as the extractant.

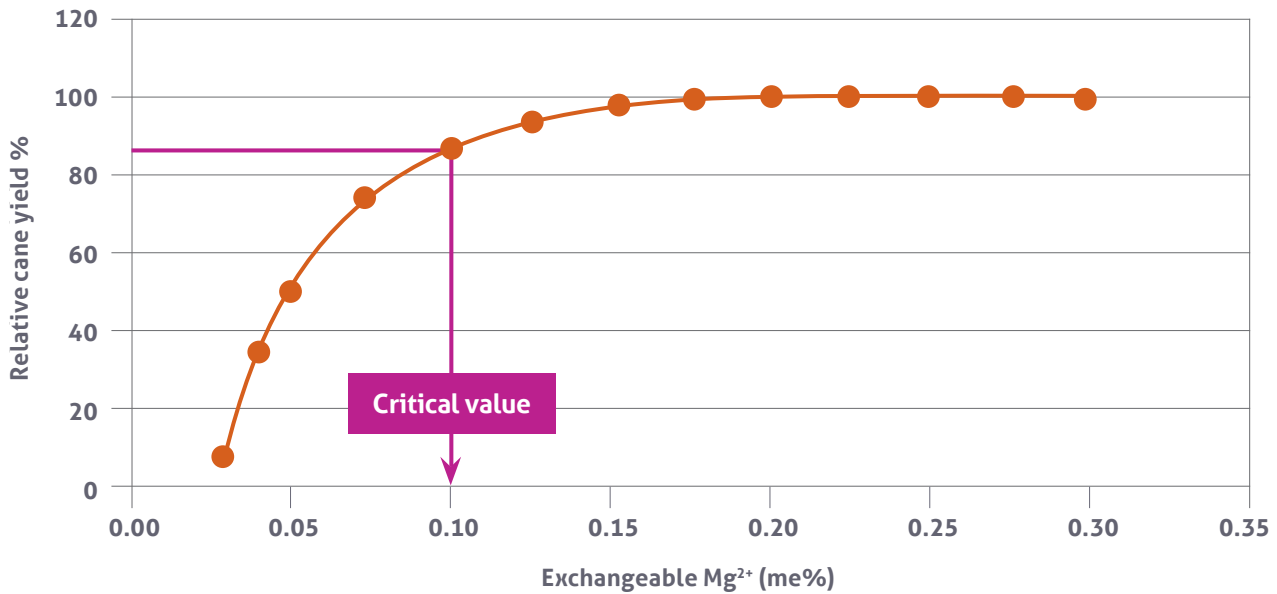


Figure 23: Yield response v soil magnesium level

**Determining the amount of a product to apply**

**RATE OF PRODUCT = [100 ÷ MAGNESIUM CONTENT OF PRODUCT (%)] X RATE OF MAGNESIUM REQUIRED (kg/ha)**

**Example**

**Q:** A calcium-magnesium blended product contains 3% magnesium. How much of that product should I apply if my soil test for magnesium is 0.12 meq/100 g?

**A:** Rate of product = (100 ÷ 3) x 100 kg Mg/ha (from Table 41) = 3,333 kg/ha = 3.5 t/ha (approximately).

**How often should magnesium be applied?**

A regular program of soil testing is most important in determining the magnesium level of the soil, the rate of application of the magnesium product, and when to reapply magnesium.

An application of magnesium will usually last one crop cycle (five years). A maintenance dressing of magnesium (for example, magnesium oxide at 150 kg/ha or a calcium-magnesium blend when calcium is also required) at the end of each crop cycle is then often required to maintain an adequate magnesium level in the soil.

Rather than applying the full quantity of a magnesium product at the end of the crop cycle, smaller but more frequent applications will reduce marked changes in the soil magnesium values and may help with on-farm cash flow. A soil test at the end of the crop cycle will assist with this decision.

TABLE 41 MAGNESIUM RATE RECOMMENDATIONS FOR PLANT AND RATOON CROPS						
SOIL Mg (amm-acet) meq/100 g	< 0.05	0.06 - 0.10	0.11 - 0.15	0.16 - 0.20	0.21 - 0.25	> 0.25
Mg rate (kg/ha)	150	125	100	75	50	0

Modifications to magnesium application rates where mill by-products have been used: After an application of mill mud, mill ash or mud-ash mixture at any rate between 100 to 250 t/ha, eliminate additional magnesium applications for at least one crop cycle. A soil test at the end of that crop cycle will identify future magnesium requirements.

## KEY POINTS: MAGNESIUM (Mg)

- Essential for photosynthesis and sugar production.
- Magnesium deficiency on old sugarcane growing soils is common, particularly in the high rainfall areas of north Queensland.
- Older leaves exhibit magnesium deficiency symptoms before younger leaves.
- Stools deficient in magnesium often develop “orange freckle” on the older leaves; stooling is weak and sugarcane growth is retarded.
- Magnesium and calcium deficiency symptoms often occur together and should be rectified together usually with a blended product for convenience and cost.
- Recommended magnesium rates: depending on the soil test outcome, a result below 0.25 meq/100 g requires between 50 and 150 kg magnesium/ha.
- A maintenance dressing of a magnesium product supplies about 80 kg/ha of magnesium which lasts about one crop cycle (5 - 6 years).
- Magnesium oxide products, calcium-magnesium blends, and dolomite are commonly used to rectify magnesium deficiency; all are slow acting in the soil and should be incorporated into the soil during the fallow; all provide a reliable, long-term source of magnesium.
- Epsom salts can be used to treat deficiency if magnesium application was previously overlooked and a quick response is required. In these circumstances, it may be the best source of magnesium to treat deficient plants.



CHAPTER 13

# SULFUR (S)

Sulfur is continuously entering the atmosphere in the form of sulfur dioxide from volcanoes and the burning of fossil fuels, as hydrogen sulfide (rotten egg gas) from the decay of organic materials, and as sulfate from sea spray. Plants can absorb sulfur directly from these sources. Sulfur from sulfur dioxide reaches the ground as sulfuric acid in acid rain, causing damage to buildings and ecosystems in many overseas countries. Atmospheric sulfur is a major source of supply for sugarcane crops.

The vast majority of soil sulfur is located in the organic matter. Before it can become available for plant uptake, this sulfur must be mineralised to the sulfate form (SO<sub>4</sub><sup>2-</sup>) which is not bound onto clay and organic particles. Consequently, leaching losses can be significant on light-textured soils in areas of high rainfall.

Sulfur is a constituent of many flavour and odour compounds in plants such as onions and cabbages, and in urine.

### THE ROLE OF SULFUR IN SUGARCANE

- Essential for chlorophyll formation, photosynthesis and plant growth
- Required for cell metabolism
- Component of some proteins, enzymes and vitamins.

### SULFUR DEFICIENCY SYMPTOMS

- Young leaves exhibit deficiency symptoms before older leaves
- Young leaves are light green to yellowish, often with a purplish margin
- Chlorosis spreads to most of the leaves but without die-back from the tips (as with nitrogen deficiency)
- Leaf edges become necrotic
- Stalks and leaves are very thin
- Stalks are more flexible at the tip than normal.



Healthy green leaf (left); sulfur-deficient leaves (centre and right). Middle leaf is yellowing with purple edges. Right leaf has full purple discoloration.



Purple leaf tips and margins on young plant cane growing in sulfur-deficient soil. (Photos: Lawrence DiBella, HCPSL)



Severe sulfur deficiency in an extremely light-textured soil.

## CONSEQUENCE OF SULFUR EXCESS

Excessive sulfur will lower the soil pH level, increasing the acidity of the soil which may impact the uptake of some other nutrients.

## SULFUR IN THE SOIL

Inorganic soil sulfur occurs in the sulfate form which the crop can use.

Typically, the majority of soil sulfur is tied up in soil organic matter which must be mineralised and converted to the sulfate form ( $\text{SO}_4^{2-}$ ) for the crop to be able to use it. The mineralisation of sulfur is similar to the mineralisation of soil nitrogen.

Sulfur is easily leached. Subsoils often contain high levels of sulfur.

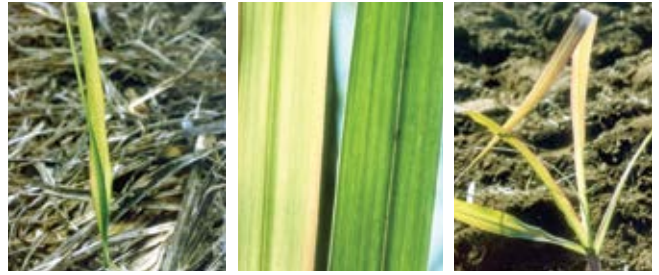
Soil sulfur is replenished primarily by atmospheric sulfur dioxide gas which is brought down by rainfall, and by irrigation water. Small amounts of sulfur occur in most fertiliser mixtures. These sources often, but not always, provide enough sulfur to prevent deficiency occurring.

### Acid sulfate subsoil toxicity

This problem can cause spectacular yield loss. Sulfate accumulation in subsoil in the form of pyrite (iron sulfide) under anaerobic (waterlogged) conditions causes no damage. However, if this material is exposed to the atmosphere in, for example, drain spoil, there is a rapid oxidation resulting in the formation of sulfuric acid which causes a drastic reduction of soil pH and the toxic release of aluminium.

Damage will be caused if this material is spread on the block. The material has a distinctive vinegar smell and is acid to the taste. Areas affected may not grow sugarcane or grass for many years. Treatment is extremely difficult to accomplish. If only small areas are involved, the best treatment is to remove the affected material. Alternatively, farmers should improve internal drainage by the use of mole drains. Slotted agricultural pipe should not be used as it will rapidly clog with iron oxides (the rusty material frequently seen in acid sulfate areas). Ploughing should be avoided and tynes should be used with minimal turning over of soil. A few wet seasons should pass to leach the material from the surface before attempting to treat the area with lime. Incorporation of lime should be shallow.

Fortunately, the problem occurs infrequently and only in small areas. However, sub-acute symptoms could be causing yield loss on a wider area as drainage is improved and the spoil is spread over blocks growing cane.



Young sulfur-deficient leaves may be yellow (left and centre) or yellow with purple margins (right). (Middle photo: IPNI)



(Left) Sulfur-deficient sugarcane in the foreground is yellowish and less advanced than the background sugarcane that has been treated with a sulfur product. (Right) Stalks are very thin and leaves are narrower than normal in sulfur-deficient sugarcane.



Acid sulfate toxicity causes severe abnormality or death of cane.



Acid sulfate toxicity can cause complete destruction of vegetation. The spoil has been removed from this site but nothing grows there three years later.





Acid sulfate soil that was used to fill an old drain killed this cane.

## SULFUR ADDITION BY FERTILISER, RAINFALL AND IRRIGATION

Table 13 shows the amount of sulfur removed by sugarcane crops in various parts of Queensland. An average of about 25 kg/ha of sulfur per year is removed by the crop.

Most high analysis fertiliser mixtures apply approximately 1 to 3 kg/ha of sulfur which is insufficient for crop needs in areas that are marginal or deficient in sulfur. Sulfur-fortified mixtures supply about 25 kg/ha of sulfur when used at recommended rates.

Rainfall supplies about 5 to 18 kg/ha of sulfur per year. In non-irrigated districts, sulfur removal by the crop and loss by leaching exceed inputs from rainfall and the usual fertiliser programs, so the crop must obtain sulfur from reserves in the soil.

For irrigated farms, there is also an input of sulfur in irrigation water, particularly where bore water is used. The sulfur content of irrigation bore water varies between districts but is generally adequate to meet crop requirements. When used for irrigation, most river water contains insufficient sulfur for the crop. The amount of sulfur applied in irrigation water can be determined from a water analysis.

## SULFUR SOURCES

The main source of sulfur for fertiliser manufacture in Australia is brimstone. Brimstone is elemental sulfur (almost 100% pure) that is obtained from oil refineries and Canadian natural gas sources which contain significant quantities of sulfur. Australian natural gas has a low sulfur content.

Materials used as sulfur fertilisers can be grouped into two broad compounds:

- Those soluble in water
- Those insoluble in water

### SOLUBLE SULFUR SOURCES

Soluble sulfur compounds (e.g. sulfate of ammonia, bluestone, Epsom salts, superphosphate) are immediately available to the crop. They also readily leach from the topsoil, especially in sandy soils.

### INSOLUBLE SULFUR SOURCES

The most important insoluble form is elemental sulfur. It is not immediately available to the crop. Elemental sulfur needs to be converted to the sulfate form which the plant can use. The fineness of the product also influences how quickly the sulfur will become available to the crop: the finer the dust, the quicker the elemental sulfur is converted to the sulfate form. Particles coarser than about 500 microns (0.5 mm) are of little value as a sulfur source. Elemental sulfur, while slowly available, has a larger residual effect than the soluble sulfur sources, and is much more resistant to leaching.

Products which are used to rectify other nutritional deficiencies e.g. zinc sulfate heptahydrate for zinc deficiency, may contain insufficient sulfur to also rectify sulfur deficiency. If the rate of zinc sulfate heptahydrate was increased to provide enough sulfur, zinc toxicity could occur.

Elemental sulfur and other sulfur-containing materials may reduce soil pH. However, at normal application rates of these products to overcome sulfur deficiency, acidification of the soil is minor.

TABLE 42 SULFUR SOURCES

SOURCE	SULFUR CONTENT (%)
Sulfate of ammonia	24.0
DAP	2.0
MAP	3.0
Superphosphate	11.0
Triple superphosphate	1.3
Gypsum products	10.0–15.0 (18.6 in pure product)
Copper sulfate monohydrate	17.4
Sulfate of potash	16.5
Phosphogypsum	14.5
Bluestone (copper sulfate)	12.6
Elemental sulfur	90–100
Epsom salts (magnesium sulfate)	12.4
Zinc sulfate heptahydrate	11.0
Zinc sulfate monohydrate	16.8
Fertiliser mixtures	Various
Mill mud, mill ash and mud-ash mixtures*	Various

\*Refer to Chapter 23

## SULFUR RATE RECOMMENDATIONS

Recommended rates of sulfur to rectify soil deficiency are given in Tables 43 and 44. The N mineralisation index is determined from the organic carbon content of the soil as identified in a soil test. (Refer to Table 19.)

Sulfate of ammonia at 105 kg/ha will supply 25 kg/ha of sulfur. While the sulfur requirements of deficient or marginal soils will have been met with these applications, very little nitrogen will have been supplied. The extra nitrogen would normally be supplied as urea, the most economical nitrogen product.

## SULFUR PLACEMENT

The most convenient forms of sulfur fertilisers are the sulfur-fortified mixtures or sulfate of ammonia which can be applied at planting or when fertilising the ratoon crop.

Insoluble sulfur sources should be spread over the fallow block and incorporated into the soil before planting. For replant blocks, a soluble form of sulfur is recommended to allow sufficient sulfur to be immediately available to the new crop.

**TABLE 43 SULFUR RATE (kg/ha) RECOMMENDATIONS FOR PLANT AND RATOON CANE - ALL REGIONS EXCEPT NSW**

SULPHATE S (mg/kg)	N MINERALISATION VL – L	N MINERALISATION ML – M	N MINERALISATION MH – VH
< 5	25	20	15
5–10	15	10	5
11–15	10	5	0
> 15	0	0	0

VL very low; L low; ML medium low; M medium; MH medium high; VH very high

Modifications to sulfur application rates where mill by-products have been used:

- Mill ash at any rate: no reduction.
- Mill mud at 100-150 t/ha: reduce application rate by 10 kg/ha each year for 3 years.
- Mill mud at 200 t/ha: reduce application rate by 15 kg/ha each year for 3 years.
- Mud-ash mixture at 100-150 t/ha: reduce application rate by 10 kg/ha each year for 2 years.
- Mud-ash mixture at 200 t/ha: reduce application rate by 15 kg/ha each year for 2 years.

Modifications to the sulfur rate are recommended where blocks of sugarcane are irrigated with ground water which may contain substantial amounts of sulphate. The sulfur application needs to be reduced to take this source of sulfur into account.

**TABLE 44 SULFUR RATE RECOMMENDATIONS – NSW**

FOR ALL SOILS EXCEPT ACID PEAT SOILS		ACID PEAT SOILS		
SULPHATE S (mg/kg)	S APPLICATION RATE (kg/ha)	N MINERALISATION CATEGORY		
		L	M	VH
		S APPLICATION RATE (kg/ha)		
< 5	25	25	20	15
5–10	15	15	10	5
11–15	10	10	5	0
> 15	0	0	0	0

L low; M medium; VH very high

Modifications to sulfur application rate where mill by-products have been used:

- Mill ash at any rate: no reduction.
- Mill mud at 150 t/ha: reduce application rate by 10 kg/ha each year for 3 years.
- Mud-ash mixture at 150 t/ha: reduce application rate by 10 kg/ha each year for 2 years.



## KEY POINTS: SULFUR (S)

- Sulfur can be absorbed through the leaves as sulfur dioxide gas, but is usually taken up by the roots as sulfate.
- Sulfur is essential for chlorophyll formation and plant growth.
- Younger leaves exhibit sulfur deficiency symptoms before older leaves.
- When sulfur deficient, young leaves are yellow, often with a purplish margin; stalks and leaves are very thin.
- Sulfur continuously enters the atmosphere via sulfur dioxide (burning of fossil fuels, volcanoes), hydrogen sulfide (decay of organic materials), and sulfate (sea spray).
- Most soil sulfur is present in organic matter (slowly available for plant growth) and in the sulfate ( $\text{SO}_4^{2-}$ ) form (readily available for plant growth).
- Sulfate is easily leached.
- Approximately 25 kg/ha/year of sulfur is removed by the crop.
- Soil sulfur is replenished by atmospheric sulfur brought down by rainfall, irrigation water, and the small quantities of sulfur in many fertilisers.
- Rainfall supplies approximately 5 to 18 kg/ha/year of sulfur.
- Irrigation water often supplies significant amounts of sulfur.
- Most high analysis fertiliser mixtures supply 1 to 3 kg/ha of sulfur.
- Sulfur-fortified mixtures provide about 25 kg/ha of sulfur when used at recommended rates.
- Acid sulfate subsoil toxicity can cause soil to be unproductive for many years; difficult to rectify.
- Brimstone is the main source of sulfur for fertiliser manufacture in Australia.
- Sulfur fertilisers are either water soluble (e.g. sulfate of ammonia, bluestone, Epsom salts) and immediately available to the crop, or water insoluble (e.g. elemental sulfur) and slowly available for crop growth.
- Insoluble sulfur sources have a longer residual effect and are more resistant to leaching than soluble sulfur.
- Sulfur acidifies the soil.

## CHAPTER 14

# COPPER (Cu)

The first trace element disorder to be recorded and studied in sugarcane was copper deficiency. Identified first in small areas near Mackay and Nambour, copper deficiency has now been found in most areas of Queensland although it is not common and usually affects only small patches of sugarcane.

Copper is more plant-available in acid soils. As the soil becomes alkaline, copper availability declines due to stronger copper adsorption to the soil (Figure 6). Copper is very tightly held on to soil clay particles and organic matter so it is not normally subject to leaching.

### THE ROLE OF COPPER IN SUGARCANE

- Involved in chlorophyll formation and photosynthesis
- Associated with protein and carbohydrate metabolism
- Involved in chemical reactions in the plant.

### COPPER DEFICIENCY SYMPTOMS

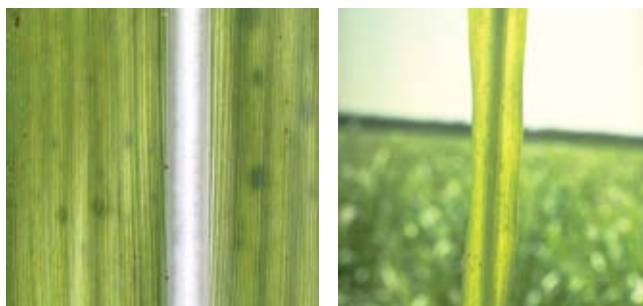
- Young leaves exhibit deficiency symptoms before older leaves
- Drooping leaves characteristic of the “droopy top” symptom
- Stalks become rubbery and flexible
- Small, dark green patches, or “islands”, may occur on leaves as inter-veinal chlorosis
- Leaves may become bleached and chlorotic
- Reduced tillering and vigour
- Internode elongation is reduced.



*The most obvious symptom of copper deficiency is droopy leaves. Stalks become rubbery and general vigour is reduced. (Above photo: IPNI)*



*Leaves may become chlorotic. Internode growth is reduced.*



*Small, dark green patches (“islands”) may occur on the leaves. (Left photo: Graham Kingston).*

## AREAS DEFICIENT IN COPPER

Organic soils such as the peats are most likely to be copper deficient. Such soils usually contain plenty of copper, but the copper is adsorbed so tightly to the organic matter that only very small amounts of copper are available to the crop.

Sandy, highly leached soils which are low in organic matter may also become copper deficient.

Calcareous soils with a relatively high pH may induce copper deficiency since copper, like zinc, is less available for plant growth when the soil is alkaline.

## COPPER TOXICITY

While copper toxicity of sugarcane has not been reported in Australia, care should be taken not to apply too much copper fertiliser when treating copper-deficient areas. Copper is a trace element which means the crop requires only very small amounts of the nutrient. It is easy to induce copper toxicity if recommended rates are exceeded. Copper toxicity can be overcome by liming the affected soil.

## COPPER IN THE SOIL

Sugarcane growing soils usually contain less than three parts per million (3 mg/kg) of copper. Factors which influence copper availability include climatic conditions, organic matter content of soil, the soil pH, and the presence of some other trace elements such as aluminium, molybdenum and iron. Most soils readily “fix” copper into organic forms that are only very slowly available for plant growth. Copper is not readily leached from the soil.

**TABLE 45 COPPER SOURCES**

SOURCE	COPPER CONTENT (%)
Bluestone (copper sulfate pentahydrate)*	25.0
Copper sulfate monohydrate	34.5
Copper oxide	80.0
Copper chelates	10.0–14.0
Copper-fortified planting mixtures*	Various
Copper-fortified superphosphate	Various

\*Commonly used to correct copper deficiency

## COPPER SOURCES

An application of copper to overcome deficiency will usually last a minimum of one crop cycle but probably much longer before re-treatment is necessary.

### Bluestone (copper sulfate)

The copper in bluestone is readily available for crop growth. It may be applied as a solution or in the solid form through a suitable applicator and lightly incorporated into the soil before planting or in the drill after planting. Copper solutions can damage some metal surfaces and may burn foliage.

### Copper-fortified fertilisers

These fertilisers provide a convenient way of rectifying copper deficiency.

## COPPER RATE RECOMMENDATIONS

Current soil tests are not reliable indicators of copper deficiency. They merely highlight a potential copper deficiency problem. Usually, a response to an application of copper will occur only when the “droopy top” deficiency symptom is visible. As a guide, if the soil sample shows a soil copper level less than 0.2 mg/kg, an application of copper may be required.

**TABLE 46 COPPER RATE RECOMMENDATION**

SOIL COPPER (DTPA) (mg/kg)	APPLICATION RATE
< 0.2	10 kg Cu/ha once per crop cycle

The recommended rate of bluestone to correct copper deficiency is 40 kg/ha which provides 10 kg/ha of copper. If a copper-fortified planting mixture is used, the recommended application rate of the mixture will provide sufficient copper for at least one crop cycle. If used as a foliar spray, the concentration of copper sulfate should not exceed 1% to avoid leaf burn or necrotic spots.



## CHAPTER 15

# ZINC (Zn)

Zinc is one of the seven micro-nutrients, or trace elements, required for the growth of all plants. Zinc, and the other trace elements, is as important to sugarcane nutrition as the major nutrients, although the sugarcane crop does not require as much of the trace elements. Like copper, zinc is more plant-available in acid soils. As the soil becomes basic, zinc availability declines due to stronger zinc adsorption to the soil.

### THE ROLE OF ZINC IN SUGARCANE

- Involved in chlorophyll formation
- Involved in the regulation of the plant's growth rate and development
- Involved in the efficient use of water by the plant.

### ZINC DEFICIENCY SYMPTOMS

- Deficiency symptoms initially become evident on the third and older leaves
- Initially, veinal chloroses which coalesce to form broad bands of yellowish striping along the whole leaf with the midrib and leaf margins remaining green. (Zinc is the only nutrient exhibiting veinal – as opposed to inter-veinal – chlorosis when it is deficient. This symptom can help differentiate it from other nutrient deficiencies in the early stages.)
- Red fungal lesions may develop on the leaves in the yellowish band between the midrib and the leaf margin
- Stunted growth of the stool
- Poor root growth
- Thin, elastic stalks
- Symptoms may vary with sugarcane variety.

Zinc deficiency symptoms can range from being very obvious to almost undetectable, depending on the sugarcane variety. A variety can suffer significant yield loss without displaying symptoms of zinc deficiency.

Some varieties are susceptible to infection by a red fungus, *Curvularia brachyspora*, when zinc deficiency is present.

Zinc deficiency in Australian sugarcane fields was first identified in the sugarcane variety Q113 in the Mossman area in the early 1980s. Since that time, zinc deficiency has been reported throughout north Queensland, from Ingham to Mossman. An estimated 15 percent of canegrowing land in northern mill areas could be zinc deficient or approaching deficiency. Responses to zinc applications have also been noted on some sandy soils in the Bundaberg district in south Queensland.



*Zinc deficiency in young ratoon cane. From the distance, the leaves appear pale green or yellowish with a green midrib.*



*Sometimes broad bands of green and yellow may appear on the leaves with longitudinal striping visible on closer inspection.*



Soils likely to be zinc deficient are:

- Beach ridges
- Soils formed from metamorphic and granite rock
- Sandy, dark alluvial soils near granitic hills
- Soils where excess lime has been applied, or soils marginal in zinc where recommended applications of lime have been made
- Areas where extensive earthworks have been carried out.

A substantial area of relatively new and expanded sugarcane areas in Queensland are on soil types identified as being potentially deficient in zinc.

## ZINC TOXICITY

Zinc toxicity is likely to occur only with over-application. Symptoms of zinc toxicity may resemble iron deficiency.

## ZINC IN THE SOIL

Most sugarcane growing soils contain less than five parts per million (5 mg/kg) of zinc. Fine-textured soils usually contain more zinc than sandy soils. Most soil zinc is associated with organic matter and, therefore, has low mobility in the soil. The factors that determine zinc availability to the crop include soil pH/liming history, soil organic matter, earthworks and high soil phosphate.

### Soil pH/liming

Zinc becomes less available for crop growth as soil pH increases. There is a greater tendency for soils to develop zinc deficiency when the pH rises above 6. The application of lime increases soil pH and makes zinc less available for uptake by the crop. However, if soil calcium levels are low, liming should be carried out. If zinc then becomes deficient, it should also be applied.

### Soil organic matter

A significant quantity of zinc may be fixed, or tied up, in the soil organic matter.

### Earthworks

Zinc is relatively immobile in the soil and tends to stay in the topsoil. It is not easily leached. If the topsoil has been removed, zinc deficiency may occur.

### High soil phosphate

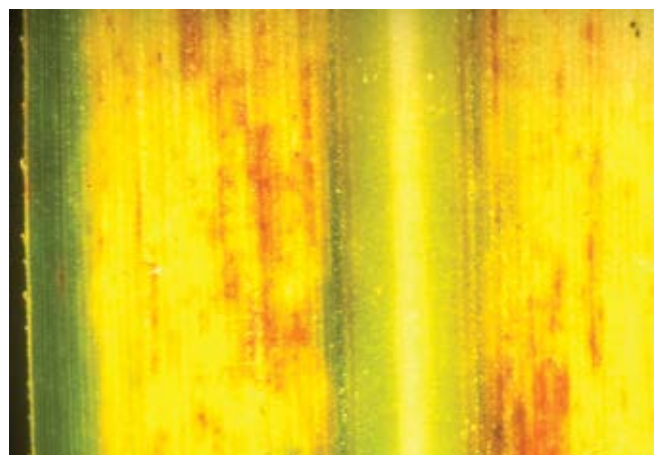
Zinc deficiency may occur on soils which have received high phosphorus applications. Zinc phosphate compounds may be formed. These compounds have low solubility and may cause zinc to become unavailable for crop growth.



The midrib and leaf blades may retain their normal colouring while broad bands of yellowing may appear in the leaf blades. When zinc deficiency is severe, the entire leaf may appear yellow.



Well-defined longitudinal veinal striping is often associated with zinc deficiency.



The fungus *Curvularia brachyspora* attacks the zinc-deficient leaf tissue of some sugarcane varieties.

## ZINC SOURCES

Zinc application to deficient soils increases root mass, cane yield and CCS.

### Zinc sulfate heptahydrate

Zinc sulfate heptahydrate can be applied prior to planting or in the drill after planting. It is a soluble, granulated product which can be applied as a solution or as the granulated solid and incorporated into the soil. Up to 40 kg of the product can be dissolved in 100 litres of water. The zinc is readily available for uptake by the crop. If the product is applied as a solution, do not use brass and galvanised iron spray tank components as they may be damaged.

Zinc sulfate heptahydrate can also be applied as a foliar spray, although soil application and incorporation is usually recommended. Foliar sprays can burn the crop if applied at concentrations greater than one percent of the product. Zinc chelate is a better option for foliar applications because of the lower risk of leaf burn.

Zinc sulfate heptahydrate is not compatible with DAP or MAP. Trace elements including zinc should not be added to herbicide sprays.

### Zinc-fortified planting mixtures

Applying zinc at planting is a convenient way to rectify zinc deficiency. Recommended fertiliser rates at planting will supply adequate zinc for at least a crop cycle.

## ZINC RATE RECOMMENDATIONS

Recommended rates of zinc to rectify soil deficiency are given in Table 48.

Zinc sulfate heptahydrate at 44 kg/ha or zinc-fortified planting mixtures at a planting rate of approximately 380 kg/ha will supply adequate zinc for one crop cycle in deficient soils.

TABLE 47 ZINC SOURCES

SOURCE	ZINC CONTENT (%)
Zinc sulfate heptahydrate*	22.7
Zinc sulfate monohydrate	35.0
Zinc oxide	50.0–80.0
Zinc chelates	9.0–14.0
Zinc chloride	30.0
Zinc-fortified planting mixtures*	2.0–3.0

\*Commonly used to correct zinc deficiency in sugarcane

TABLE 48 ZINC RATE RECOMMENDATION

SOIL ZINC (HCL) (mg/kg)	APPLICATION RATE
< 0.6	10 kg Zn/ha once per crop cycle
>0.6	Nil
SOIL ZINC (DTPA) (mg/kg)	APPLICATION RATE
< 0.3	10 kg Zn/ha once per crop cycle
>0.3	Nil

When interpreting soil test values for zinc, soil pH is used to determine the appropriate laboratory test to use:

- If soil pH < 6.5, use the zinc(HCL) guideline.
- If soil pH > 6.5, use the zinc(DTPA) guideline.

## CHAPTER 16

## BORON (B)

In Australia, boron deficiency of sugarcane has not been identified in the field. Most soil boron is found in organic matter and becomes available as it mineralises. Boron is highly mobile and leachable in the soil as it is not readily adsorbed on to soil clay particles.

**THE ROLE OF BORON IN SUGARCANE**

- Essential for the growth of new cells
- Appears to be involved in the uptake and efficient use of calcium, nitrogen and potassium in the plant
- Appears to regulate the plant's use of other essential nutrients and aids in the production of sugars and carbohydrates
- Important for the development of young roots and shoots.

**BORON DEFICIENCY SYMPTOMS**

- Young leaves exhibit deficiency symptoms before older leaves
- Symptoms are similar to Fiji leaf gall disease and pokkah boeng disease
- Growing points may be distorted, or may die
- Leaves are distorted
- Translucent lesions or "water sacks" form between veins and water droplets may exude from the lesions on the upper leaf surface
- Leaf striping may result when small, elongated spots develop parallel to the vascular bundles
- Leaves show varying degrees of chlorosis and tend to be brittle but do not wilt
- Leaf tips can be severely burned and may split
- Young plants are bunched with an excessive number of tillers.

As for some other trace elements, boron deficiency is much more likely in high pH soils than in acid soils. Apart from the Burdekin region, virtually the rest of the Australian sugar industry is located on acid soils.



*When boron is severely deficient, young plants tend to be brittle and bunched with many tillers. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)*



*Leaves may become distorted, particularly along the leaf margins of immature leaves which may not unfurl. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)*



## BORON TOXICITY

Great care should be taken when applying boron to soils which have apparently low boron levels. Boron toxicity can easily be induced and is common in grasses and other crops. In general, grasses (including sugarcane) have a lower requirement for boron than other plant types. It is difficult to remove or neutralise toxic levels of boron in the soil. Liming boron-toxic areas may help alleviate the problem.

## BORON IN THE SOIL

Small amounts of boron are found in organic matter and silicate minerals. As sea water contains high levels of boron, soils formed from marine sediments usually have a high amount of boron.

Most soil boron is relatively insoluble and only slowly released. Much of the available boron comes from soil organic matter.

Boron is quite readily leached. Dry weather can cause a temporary deficiency until soil moisture is adequate again. Excessive lime applications could induce deficiency if soil boron levels are low.

## BORON SOURCES

Borax is not recommended for foliar spray application due to its low solubility. Borax should be used for soil application. For foliar boron application, Solubor should be used.

TABLE 49 BORON SOURCES	
SOURCE	BORON CONTENT (%)
Borax (disodium tetraborate decahydrate)	11.3
Solubor (sodium octaborate pentahydrate)	20.5
Boric acid	17.5

## BORON RATE RECOMMENDATIONS

Soil tests for boron are unreliable for predicting deficiencies in sugarcane. A leaf tissue analysis will give a better indication of deficiency than the currently available soil test. The third leaf critical value of less than 1 mg/kg of boron is an indication of possible boron deficiency. In this case, a test strip of land within the area suspected to be deficient could be treated with a boron product to assess any response to boron. Care should be taken not to exceed the recommended rate which is Borax applied at 10 kg/ha. This application supplies 1.1 kg/ha of boron.



Growing points may be distorted or may die. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)



Sometimes the apical meristem remains alive while the immature leaves have varying degrees of chlorosis but do not wilt. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)



(Left) Translucent lesions called water sacks may occur along leaf margins as boron deficiency progresses. (Right) Leaf edges become chlorotic when boron is at toxic levels. (Photos: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)



## CHAPTER 17

## MANGANESE (Mn)

Manganese deficiency has never been reported in soils growing sugarcane in Australia. Manganese is relatively common in the soil. Like copper and zinc, manganese is more plant-available in acid soils.

### THE ROLE OF MANGANESE IN SUGARCANE

- Involved in photosynthesis and chlorophyll production
- Involved in respiration and nitrogen metabolism
- Accelerates germination and maturity
- Involved in the formation of organic compounds
- Associated with iron, copper and zinc as a catalyst in plant growth processes.

### MANGANESE DEFICIENCY SYMPTOMS

- Younger leaves exhibit deficiency symptoms before older leaves
- Longitudinal pale stripes between leaf veins; the stripes generally run only from the middle of the leaf to the tip
- Leaf blades may split and fray in the wind
- Entire leaf may become chlorotic under severe deficiency.

The symptoms are similar to iron deficiency symptoms. The main difference is that the interveinal striping runs from the middle of the leaves to the leaf tip when iron is deficient.

### MANGANESE TOXICITY

Manganese toxicity is only possible in extremely acid soils and exacerbated by waterlogged conditions.



*Manganese deficiency affects younger leaves. Interveinal chlorosis (striping) runs from the middle of the leaf towards the leaf tip. (Photos: (Left) Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.); (Right) Graham Kingston)*



*(Left) Under severe manganese deficiency, the entire leaf may become bleached. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.) (Right) Interveinal chlorosis is evident in these manganese-deficient leaves. (Photo: Graham Kingston)*

## MANGANESE IN THE SOIL

The main factor controlling the availability of soil manganese is pH. Acid soils, such as most Australian sugarcane growing soils, supply ample manganese for crop growth. Manganese toxicity is possible on extremely acid soils when aluminium levels would also be extreme, but liming the soil will effectively overcome this problem. Sugarcane appears to be fairly tolerant of high soil manganese levels. Any manganese deficiency is likely to occur in alkaline soils since manganese availability reduces as pH increases. Highly organic soils are also more likely to have manganese deficiency.

Manganese in soils occurs predominantly as several relatively insoluble oxides. These oxides are formed from soluble manganese by bacterial action, a process that is particularly rapid in alkaline soils. Some organic compounds dissolve manganese from these oxides making it available to plants. Waterlogging speeds up the release of manganese.

Australian sugarcane growing soils generally contain from one to several hundred parts per million of manganese.

## MANGANESE SOURCES

Manganese sulfate can be used as a foliar spray.

<b>SOURCE</b>	<b>MANGANESE CONTENT (%)</b>
Manganese sulfate	33.2
Manganese chelate	12.0

## MANGANESE RATE RECOMMENDATIONS

Current soil tests for available manganese have little value in indicating potential deficiency due to the change in availability of manganese during the season. A leaf tissue analysis is more useful than a soil test for detecting potential problem areas. A third leaf critical value of less than 15 mg/kg of manganese is used. For a foliar spray, apply 5 to 10 kg/ha of manganese sulfate in 1,000 litres of water (0.5% to 1% solution). For soil application, incorporate 20 to 30 kg/ha of manganese sulfate before planting the crop.

## CHAPTER 18

## IRON (Fe)

Almost all soils contain considerable quantities of iron as various iron oxides and iron silicates. The different yellow, orange, red and brown colours of soils reflect the different amounts and forms of iron oxides. Iron is the fourth most common element in the Earth's crust. As with copper, manganese and zinc, iron has lower availability in alkaline (above pH 7) soils than in acid soils. Iron is relatively immobile within plants; it does not easily relocate from old tissue to young tissue.

### THE ROLE OF IRON IN SUGARCANE

- Essential for the production of chlorophyll
- Role in photosynthesis
- Involved in internal chemical reactions in the plant.

### IRON DEFICIENCY SYMPTOMS

- Young leaves exhibit deficiency symptoms before older (lower) leaves
- Longitudinal pale stripes between the veins of the leaves extending from the leaf base to the tip of the leaf
- Entire leaf may become bleached or chlorotic (pale yellow to white)
- Entire plant may become bleached or chlorotic
- Young stubble shoots have no new root development.

Iron deficiency symptoms tend to be temporary and leaf colour later becomes normal. Any iron deficiency in plants is due to its inadequate availability, not the amount present in the soil. Symptoms can be patchy but eye-catching in the field: a stool exhibiting very distinctive iron deficiency symptoms can be growing next to healthy sugarcane stools. The symptoms appear to be caused by a temporary imbalance or low uptake by the plant.

The incidence of iron deficiency is often exacerbated by dry conditions particularly in coarse-textured sections of a field. It is quite often noted in old stream beds. Symptoms usually disappear with the onset of rain or irrigation.

Adding large amounts of lime to a soil can induce iron deficiency. Crops on high pH soils are more likely to have iron deficiency than crops on acid soils. Excessive phosphorus in the soil or an imbalance of metals such as copper, molybdenum or manganese may trigger iron deficiency. Because it is normally temporary, iron deficiency usually causes negligible yield loss.

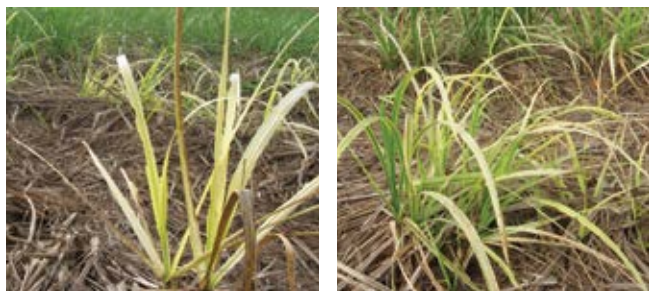


*Iron deficiency occurrences in the field are usually patchy, appearing on drier areas. Symptoms are temporary, disappearing after rainfall or irrigation.*



*From a distance, leaves may exhibit broad bands of striping. Closer inspection will also reveal narrow, longitudinal striping*





*Virtually the entire plant may become bleached.*

Waterlogging may result in iron toxicity in acid soils and iron deficiency in alkaline soils.

### IRON IN THE SOIL

Most sugarcane growing soils contain from 10 to several hundred parts per million of iron. No definite toxic effect on sugarcane has been established for soils containing very high levels of iron. As soils become more acid, the availability of iron to plants increases. Plants take up iron mainly in the chelated form in the soil solution.

### IRON RATE RECOMMENDATIONS

Treatment of iron deficiency is not recommended. Iron deficiency is temporary and usually occurs in isolated patches in a block. Yield responses to iron applications have not been reported in Queensland. However, if iron deficiency was to be corrected, an iron chelate solution foliar-applied at 0.1 - 0.5% or an iron sulfate solution foliar-applied at 0.5 - 1.0% could be used. For ground application, apply 50 kg/ha of iron chelate in solid form.

Soil tests are not a reliable indicator of potential iron deficiency.



*Striping between the leaf veins extends from the base of the leaf to the leaf tip.*

**TABLE 51 IRON SOURCES**

SOURCE	IRON CONTENT (%)
Iron chelate	13
Iron sulfate monohydrate	30
Iron sulfate heptahydrate	20
Iron oxides	60–70



## CHAPTER 19

## CHLORINE (Cl)

Chlorine is the most recent of the 16 nutrients identified as being essential for plant growth (in 1954). The Earth's crust contains an average of about 500 ppm of chlorine. Chlorine is present as chloride in sea water and is found in sea spray and in the atmosphere near the ocean. Significant quantities of chlorides (mainly sodium chloride (common salt) fall in rain. Rainfall near the coast may contain up to 7 mg/L of chlorine. In a coastal area which receives an average annual rainfall of 2,000 mm, up to 140 kg/ha/year of chlorine may fall in rain.

Chlorine is a major component of potassium chloride (KCl or potash).

Almost all the chlorine in soil occurs naturally as the soluble chloride ion (Cl<sup>-</sup>) in the soil solution. Plants take up chlorine as the chloride ion.

The toxic form of chlorine is chlorine gas. It is a manufactured product and does not occur naturally and is not used in agriculture.

Chlorine is very easily leached from the soil.

### THE ROLE OF CHLORINE IN SUGARCANE

- Has a role in photochemical reactions during photosynthesis
- Maintains ionic balance
- Involved in the water-holding capacity of plant tissues.

### CHLORINE DEFICIENCY SYMPTOMS

- Deficiency symptoms appear on young leaves before older leaves
- Apical meristems remain alive
- Leaves wilt during the day and recover at night
- Leaves may be chlorotic
- Abnormally short roots
- Increased number of lateral roots.

Chlorine deficiency is extremely unlikely to occur since sufficient chlorine is applied by rainfall and irrigation and in potassium chloride (muriate of potash).

### CHLORINE TOXICITY

Chlorine toxicity causes short roots with very little lateral branching. Growth is reduced while the leaf tips become chlorotic and the leaf blades become necrotic.

While unlikely, chlorine toxicity may occur with excessive applications of chloride salts or from high chlorine levels in irrigation water.



*(Left) Young leaves affected by chlorine deficiency at 0 ppm (left) and chlorine toxicity at 100 ppm (right). Chlorine deficiency and toxicity are unlikely to occur in Australian sugarcane fields.*

*(Right) Chlorine deficiency and toxicity are difficult to compare and describe, especially in the field. Chlorine deficiency causes abnormally short roots and an increased number of lateral roots. Chlorine toxicity also causes abnormally short roots but with very little lateral branching. Chlorine concentration from left to right is 100 ppm, 1 ppm and 0 ppm. (Photos: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)*

## CHAPTER 20

# MOLYBDENUM (Mo)

Molybdenum deficiency has not been identified in Australian sugarcane fields. Molybdenum deficiencies in other crops are widespread throughout Australia, occurring mainly on acid soils.

### THE ROLE OF MOLYBDENUM IN SUGARCANE

- Involved in chemical reactions in the plant
- An essential cofactor in enzyme systems
- A major factor in nitrogen metabolism in the plant.

### MOLYBDENUM DEFICIENCY SYMPTOMS

- Older leaves exhibit deficiency symptoms before young leaves
- Symptoms similar to mild infections of pokkah boeng disease
- Short, longitudinal chlorotic streaks on the apical one-third of the leaf
- Older leaves dry prematurely from the middle towards the tip
- Stalks become short and slender
- Growth is slowed.

Any molybdenum deficiency is likely to be found on acid soils. Liming will overcome the problem since molybdenum becomes more available as the pH increases.

### MOLYBDENUM IN THE SOIL

Of the trace elements in soil, molybdenum is the least abundant. Much of the molybdenum is associated with iron oxides. A small amount is contained in organic matter. Very little molybdenum is present in a form that is available to the crop, but plants need only extremely small quantities of the trace element for growth.

### MOLYBDENUM RATE RECOMMENDATIONS

Soil testing for molybdenum is an unreliable guide for assessing deficiency. If molybdenum deficiency is suspected, a test strip should be established. An area of land should be treated with sufficient product to supply 100 grams per hectare of molybdenum to determine a response to molybdenum.



*Molybdenum deficiency occurs first in older leaves. Symptoms are similar to a mild infection of pokkah boeng disease. Short, longitudinal chlorotic streaks occur on the top one-third of the leaf. Older leaves dry prematurely from the middle of the leaf towards the tip. (Photo: Anderson and Bowen, 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)*

**TABLE 52 MOLYBDENUM SOURCES**

SOURCE	MOLYBDENUM CONTENT (%)
Molybdenum trioxide	60
Sodium molybdate	39
Ammonium molybdate	54
Molybdenum-fortified superphosphate	0.02

## CHAPTER 21

## SILICON (Si)

Silicon is not regarded as an essential nutrient for plant growth. However, due to its role in plant nutrition, it is now recognised as a “beneficial element”. The plant processes involving silicon are still unknown.

Although silicon is the most abundant element in the Earth’s crust after oxygen, it is mostly inert. Its low solubility means it is only slightly available to plants for growth.

Apart from potassium, sugarcane can take up more silicon than any other mineral nutrient. An average crop can remove 100 to 175 kg/ha of silicon. Very high yielding crops can contain over 250 kg/ha of silicon in the harvested biomass.

Silicon refers to the chemical element, while silica or silicon dioxide ( $\text{SiO}_2$ ) is a solid, glass-like compound containing both silicon and oxygen. Silica is the major constituent of sand. Silica is most commonly found as quartz and in various living organisms. Plant roots take up soluble silicon from the soil in the form of silicic acid [ $\text{Si}(\text{OH})_4$ ]. It is translocated through the plant until it is deposited in the intercellular spaces of the plant. Sugarcane tends to “luxury feed” on silicon.

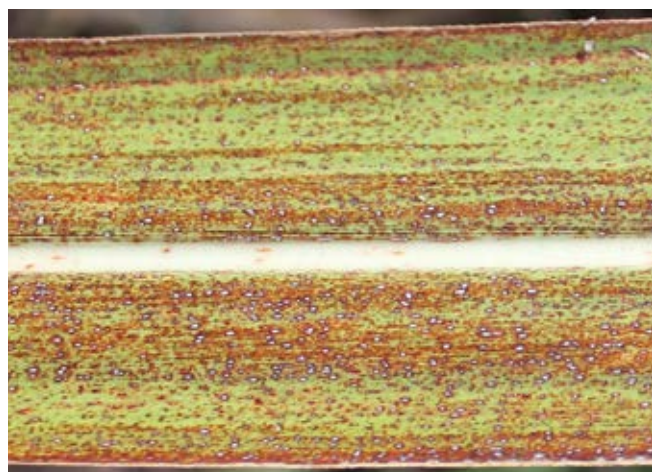
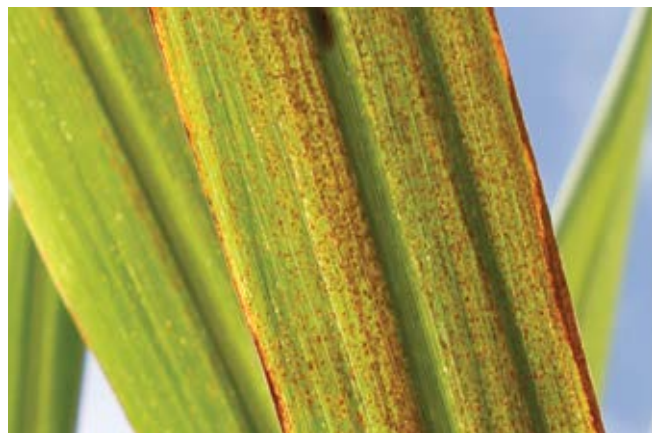
Silicon deficiencies typically occur in light-textured soils. In Australian trials, the addition of silicon to deficient soils has resulted in sugarcane yield responses of 16 to 45%.

### THE ROLE OF SILICON IN SUGARCANE

- Provides strength to cell walls; contributes to stalk strength and helps resist lodging
- Assists plants to resist biotic attack by insects (e.g. stem borers) and disease
- Alleviates environmental stresses such as drought and frost
- Beneficial in stimulating natural plant defences against fungal pathogens by activating various organic compounds and enzymes
- Provides protection from ultraviolet light thus preventing leaf freckling
- Improves photosynthesis because of the better use of sunlight
- Improves water use efficiency (rate of transpiration may increase and become excessive when silicon is deficient)
- Improves the resistance of sugarcane to toxic levels of aluminium, manganese and other elements
- Acts as an enzyme regulator in sugar synthesis, storage and retention in the sugarcane plant
- Improves crop tolerance against salinity, waterlogging, and nutrient deficiency and toxicity.



“Sunny side up” leaf freckling appears on the surface of leaves exposed to the sun.



The most obvious symptom of silicon deficiency is leaf freckling on the sunlight-exposed surface.



## SILICON DEFICIENCY SYMPTOMS

- Symptoms usually appear at five to six months of age, often in February–March when the soil supply of silicon cannot match crop demand
- Initial symptoms are white or yellowish flecks or tiny spots (leaf freckling) on the surface of young leaves that are exposed to the sun (known as “sunny-side up”)
- Over time, the spots on the sunlight-exposed surface coalesce to form a reddish-brown or bronze colouration on the older leaves, turning to dark grey brown and becoming necrotic as the leaf ages
- The spots enlarge and merge, severely reducing the area of active green leaf tissue; photosynthetic area may be significantly reduced
- Leaves may exhibit premature senescence
- Stalks can sometimes be flexible and able to be bent into a circle
- Tops can sometimes appear shortened, compact and spiky (fan-like).

No adverse effects on sugarcane have been reported when soil silicon levels are high or excessive.

## SILICON IN THE SOIL

Soils commonly contain as much as 30% silicon, almost all of which is found in minerals and rocks. A lack of silicon in soil is not common, but the concentration of soluble silicic acid can be too low to meet plant needs.

Soil texture is one of the most important factors affecting silicon concentration in the soil solution. Although sand is mostly composed of silicon dioxide, it is not soluble.



Small, rigid, upright (“fan-like”) tops can result from soil silicon deficiency.

The low water-holding capacity of sandy soils also prevents silicon accumulation. Highly weathered tropical soils tend to have a lower silicon content, as do soils containing very high organic matter, such as peats.

## SILICON SOURCES

Several products contain significant amounts of silicon. Sand is an obvious example but sand is inert meaning the silicon component of sand is unavailable for crop growth. Similarly, while about one third of diatomaceous earth is composed of silicon, its low solubility precludes it as a useful source of silicon for sugarcane production.

In regions where it is available, the most commonly applied silicon fertiliser source is calcium silicate ( $\text{Ca}_2\text{SiO}_4$ ). Calcium silicate occurs naturally as the mineral wollastonite. Calcium silicate can be used as a liming agent in low pH soils where silicon amelioration is also required. It does not have as high a neutralising value as agricultural lime but is often applied as a lime blend.

Cement contains readily available silicon and is a reliable, although expensive, source of silicon.

Mill ash contains a large proportion of silicon. While much of it is unavailable for plant growth, sufficient silicon to rectify soil deficiency makes it one of the more useful sources of silicon for sugarcane crops.

Silicon in the plant has very low solubility. Therefore, green cane trash is not a useful source of silicon.

TABLE 53 SILICON SOURCES

SOURCE	SILICON CONTENT (%)
Pure calcium silicate	24
Naturally-occurring (agricultural) calcium silicate	13 (approx.)
Mill ash	Variable but approx. 43*
Mill ash/mill mud mixture	Variable but approx. 20*
Cement	9–11
Diatomaceous earth	32^
Crushed rock	25^

\*Only a small proportion is available for plant growth

^Unsuitable due to very low solubility and low availability of silicon to the crop

### SILICON RATE RECOMMENDATIONS

Silicate guidelines are based on available soil silicon and reserve soil silicon. The Si(CaCl<sub>2</sub>) test shows the level of readily available silicon in the soil for immediate plant growth. The Si(BSES H<sub>2</sub>SO<sub>4</sub>) analysis measures reserve silicon in the soil that becomes slowly available for plant uptake as it mineralises.

Some suggested products and application rates include:

- Agricultural calcium silicate at 4 t/ha
- Mud-ash mixture at 100 to 150 wet t/ha
- Cement at 3t/ha.



*In some situations, flexible stalks can easily be bent into a circle.*

**TABLE 54 LIKELY RESPONSE TO APPLIED SILICA**

SILICON (BSES H <sub>2</sub> SO <sub>4</sub> ) (Reserve Si)	SILICON (CaCl <sub>2</sub> ) (Available Si)		
	LESS THAN 10 mg/kg Si	10 - 20 mg/kg Si	GREATER THAN 20 mg/kg Si
Less than 70 mg/kg Si	Very low silicon – response highly likely	Low silicon – response possible	Response unlikely
Greater than 70 mg/kg Si	Low available silicon – response possible at lower Si(BSES H <sub>2</sub> SO <sub>4</sub> ) values	Response unlikely	High silicon – no action required

## CHAPTER 22

# ALUMINIUM (Al)

After oxygen and silicon, aluminium is the third most abundant element present in the soil.

Although not essential or beneficial for plant growth, aluminium has an important role in sugarcane production because of its potential adverse effect on crop growth and impact on soil fertility.

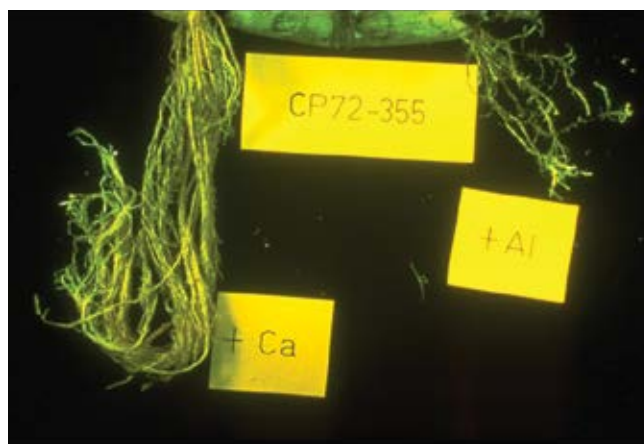
Being one of the cations, the aluminium ion ( $\text{Al}^{3+}$ ) occupies exchange sites on soil colloids. With three positive charges, aluminium ions adsorbed onto the soil take up a large amount of space to the detriment of other crop-beneficial cations. For example, the  $\text{Al}^{3+}$  ion takes up the same space as three single-charged ammonium ( $\text{NH}_4^+$ ) ions. The ammonium could be left in the soil water solution where it may be leached.

Very high soil aluminium levels have the potential to cause root stubbing and yield loss. However, sugarcane is highly tolerant of aluminium. Significant yield reductions caused by aluminium toxicity in sugarcane are uncommon.

High soil aluminium levels are associated with low soil calcium levels and acid soils. Liming is normally conducted to rectify low soil calcium levels. Liming will reduce the level of available aluminium by replacing aluminium ions attached to the clay particles with calcium ions.



*Aluminium root damage resembles nematode damage. Affected plants are highly susceptible to water stress. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)*



*Calcium added to the aluminium-toxic soil will displace aluminium ions, allowing improved root growth and crop production. Sugarcane is relatively tolerant of high soil aluminium levels. (Photo: Anderson and Bowen. 1991. Sugarcane Nutrition. Potash & Phosphate Institute, Atlanta, GA. 1990 Copyright.)*



CHAPTER 23

# ALTERNATIVE SOURCES OF NUTRIENTS

## MILL BY-PRODUCTS

The by-products of raw sugar manufacture (filter mud, ash, mud-ash mixtures and molasses) and of ethanol production (liquid dunder) are valuable fertiliser sources.

### Nutrient content of mill by-products

The total nutrient content of typical application rates of each mill by-product is given in Table 55. The figures are approximate values only and will vary between districts and from year to year.

Because of the organic nature of many of the compounds containing plant nutrients in mill mud, molasses and dunder and the fused condition of ash, precise information on the rate of release of nutrients for use by the sugarcane plant is not known. In some cases where by-products have been applied, sufficient nutrients may not be available for the succeeding sugarcane crop and additional fertiliser may be required.

## Filter mud and mud-ash mixtures

*The following information relates to an application of 150 tonnes per hectare.*

### NITROGEN

Research suggests that for sugarcane growth in the year of application, about 80 kg of nitrogen is available from applied filter mud and 50 kg of nitrogen is available from mud-ash mixture. (The remainder of the total nitrogen content becomes available slowly as the organic material is broken down.)

### PHOSPHORUS

Enough phosphorus for at least one crop cycle (plant and four ratoon crops), and possibly two crop cycles, is supplied.

### POTASSIUM

For filter mud, about 80 kg of potassium is immediately available for sugarcane growth. This is approximately 80% to 100% of the potassium fertiliser requirement of plant cane, or 65% to 80% of ratoon cane fertiliser requirement.

**Table 55 INDICATIVE AMOUNTS OF NUTRIENTS APPLIED BY TYPICAL APPLICATIONS OF BY-PRODUCTS (kg/ha)**

PLANT NUTRIENT	FILTER MUD (150 t/ha)	FILTER MUD-ASH (150 t/ha)	ASH (150 t/ha)	MOLASSES (10 t/ha)	DUNDER (3 CUBIC m/ha)
Nitrogen (N)	465	360	60	69	29
Phosphorus (P)	360	300	120	5	2
Potassium (K)	120	195	390	397	110
Calcium (Ca)	645	600	435	88	28
Magnesium (Mg)	135	165	225	47	19
Sulfur (S)	80	50	100	N/A	11
Copper (Cu)	6	4	5	N/A	N/A
Zinc (Zn)	19	17	14	N/A	N/A
Manganese (Mn)	190	180	140	N/A	N/A

*Important notes:*

- Figures are approximate.
- Additional fertiliser for several nutrients (especially nitrogen) may be required as significant amounts of some of the nutrients in by-products are "locked up" in organic forms.
- N/A – figures not available.
- 150 t/ha is the equivalent of about six 10-tonne loads per acre.

For mud-ash application, no additional potassium fertiliser is required by the crop in the year of application.

### CALCIUM

One application supplies the calcium equivalent of approximately 1.5 to 2.0 tonnes of agricultural lime per hectare.

### MAGNESIUM

The products contain significant levels of available magnesium which assist to maintain soil fertility.

### SULFUR

The sulfur applied is of benefit in marginally deficient soils, although additional fertiliser application may be required on sulfur deficient soils.

### Dunder

Dunder is primarily a source of potassium. When applied at three to four cubic metres per hectare, dunder supplies the potassium requirement for one crop. It also applies a useful amount of sulfur. Nitrogen and phosphorus are not

present in sufficient quantities to affect normal fertiliser application rates. However, commercial dunder products often have other nutrients such as nitrogen or sulfur added to them.



*Dunder or other liquid fertilisers can be subsurface-applied under pressure.*



*Mill mud produced on sugar mill rotary vacuum filters is a valuable source of fertiliser. It is often mixed with mill ash and returned to sugarcane fields. Ash has a high potassium content and lower quantities of other nutrients than mill mud.*



*Much lower application rates of mill by-products are possible with precision-application equipment.*

### LEGUMES

Legumes can provide a significant quantity of nitrogen for the following plant crop (Table 20), as well as organic matter. Nitrogen rates for plant cane can be significantly reduced following a heavy legume crop. Refer to the regional SIX EASY STEPS Guidelines on the SRA website for reductions in fertiliser nitrogen that can be made following a legume crop.



*Productive legume crops can, if well managed, produce a large proportion of the nitrogen requirement of a sugarcane crop.*

## COMPOSTS

Composted organic matter contains many nutrients that are beneficial to crop growth. The quantities of nutrients in a compost will be governed by the source material. Organic forms of nutrients in compost must be mineralised into inorganic or “plant-available” forms such as nitrate. The rate of mineralisation depends on compost composition, soil type, temperature, moisture and other factors. Organic forms of nutrient will usually continue to mineralise and become available to crops several years after the initial application of compost.

Limited research on the agricultural benefits of compost applications to sugarcane crops has been undertaken but the use of composts in sugarcane production is likely to increase. One of those sources may be community waste that has to be disposed of in an acceptable manner. As a guide, one regional Queensland council produces a compost with the following nutrient makeup: nitrogen 1 - 1.5%; phosphorus 0.3 - 0.5%; potassium 0.3 - 0.5%; calcium 3 - 5%; magnesium 0.2 - 0.3%, as well as trace elements.

## OTHER PRODUCTS

From time to time new products appear on the market. Occasionally, the products are a satisfactory source of nutrients, as claimed by the manufacturers. Often, however, the product represents a poor investment by the canegrower and the claims made by the manufacturer cannot be substantiated. Solid research data to support the claims are invariably unavailable.

If in doubt about a product, growers should contact a reliable, independent source of advice. A small experimental test strip of the product, rather than treatment of a large area, may be warranted.

In summary, treat the claims with caution. Seek independent advice. If it seems too good to be true, it most likely is.



*Trials with compost produced from municipal waste have shown promising results as a nutrient source for sugarcane.*



## CHAPTER 24

# LIQUID FERTILISERS

Liquid fertilisers include granulated urea dissolved in water, often with added phosphorus, potassium and/or sulfur. Dunder, and mixtures of dunder containing urea and/or phosphorus and/or sulfur, are also applied as a liquid fertiliser source.

### POSSIBLE BENEFITS OF LIQUID FERTILISERS COMPARED TO SOLID FERTILISERS

- Application rates are very consistent; allows a more even distribution throughout the block than granular fertilisers
- Fewer workplace health and safety risks
- Logistically easier than using bagged fertiliser
- Some companies provide an application service which is attractive to many growers.

### POSSIBLE DISADVANTAGES OF LIQUID FERTILISERS COMPARED TO SOLID FERTILISERS

Liquids are likely to cost more per kilogram of nutrient than solids. Liquid fertilisers are composed mostly of the water in which the nutrients are dissolved. There are costs to mix the products and to transport that water. Growers should calculate and compare the real cost of nutrients obtained from both the liquid and solid forms based on the amount of nutrient applied per hectare.

Even if the liquid form is more expensive, the advantages mentioned above may outweigh that extra cost.

### NITROGEN APPLICATION RATES FOR LIQUID FERTILISERS

The SIX EASY STEPS rates apply to all forms of fertiliser including liquid fertilisers.

Irrespective of whether the fertiliser is in liquid or solid form, urea still has to go through the same process in the soil to become available to the plant. The plant cannot take up nitrogen until it is converted to the ammonium ( $\text{NH}_4^+$ ) or nitrate ( $\text{NO}_3^-$ ) forms.

Liquid fertilisers are generally no more available to the crop than bagged, dry fertiliser. For example, at application rate of 400 litres/hectare, only 72 ml of liquid is applied per metre of row (1.8 metre row spacing). In dry soil, being liquid rather than a dry solid would make negligible difference to the uptake of nutrients. On moist soils, nutrient uptake would not be an issue.



*Sugarcane billet planter and liquid fertiliser applicator. Pumping fertiliser into application tank.*

### CORRECT APPLICATION FOR LIQUID FERTILISERS

- Subsurface application is safest
- Surface application (to soil or trash blanket) risks the same nitrogen volatilisation losses as for surface application of any urea-based product. However, dunder-based liquid fertilisers containing dissolved urea have low pH which reduces the potential for volatilisation losses
- Products surface-applied under pressure might be at a reduced risk of loss than if just dropped on top
- Adequate rainfall or irrigation soon after surface application will minimise volatilisation losses
- Foliar application can burn the leaves, further reducing the very limited potential uptake through the leaves
- Liquids can be applied with a high clearance spray rig when the sugarcane crop is out of hand (a useful option if spring has been too wet to fertilise).

## CHAPTER 25

# FERTILISER AND GREEN CANE TRASH BLANKET FIRES

Accidental green cane trash blanket fires are a constant hazard. Trash fires will kill the young shoots and stalks of sugarcane but usually will not destroy the stool.

If fertiliser was applied on top the trash surface prior to a fire, the following steps should be taken to ensure the new crop has the best chance to re-establish:

- As a general rule, slash the remaining stubble if the sugarcane canopy was above 0.5 metres before the fire. Stubble less than 0.5 metres does not need to be slashed as it is small enough not to cause shading of the stool which could retard new growth.
- Reapply approximately 50 to 75% of the nitrogen component of the fertiliser that had been surface-applied. The amount of nitrogen lost in the fire depends on many factors including how hot the fire was, the duration of the fire, and the period of time between application of nitrogen and the fire. While not all of the nitrogen will be lost in the trash fire, it is not possible to say what proportion was lost in any particular fire.

The reapplied nitrogen should be buried as there is no longer any protection from the trash blanket or sugarcane canopy.

If the nitrogen was buried before the trash fire, it is unlikely that any of the nitrogen will have been lost. A reapplication of nitrogen is unnecessary.

Whether surface-applied or buried, phosphorus and potassium are not lost in trash fires and do not need to be reapplied.



*Fires in green cane trash blankets cause yield reduction. If the sugarcane canopy was above 0.5 metres, the remaining crop should be slashed. If nitrogen was surface-applied, approximately half to three quarters of the nitrogen should be reapplied.*



*If the canopy was less than approximately 0.5 metres high at the time of the green cane trash blanket fire, the stubble need not be slashed. Surface-applied and buried phosphorus and potassium, and buried nitrogen, are not lost in trash fires.*

# REFERENCES AND FURTHER READING

SRA has developed a number of information sheets and publications on nutrition that are freely available on the SRA website. These publications include:

- Leaf sampling (Information sheet 13014)
- Best-practice nutrient management SIX EASY STEPS (Information sheet 13016)
- Soil sampling (Information sheet 13017)
- NutriCalc® (Information sheet 13020)
- Calibrating your fertiliser box (Information sheet 13021)
- Finding the fertiliser that best suits your needs (Information sheet 16005)
- RP20 Trial Results and Case Studies 2011-2017

You can also access online tools to assist with nutrient management, including:

- FertFinder®
- NutriCalc®
- CogCalibrator™

For final reports on nutrient-related research projects, visit the SRA elibrary via the SRA website. A list of current investments in soil health, nutrient management and sustainability, is also available from the SRA website.

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## APPENDIX 1

# DETERMINATION OF SOIL TEXTURAL GRADE FROM HAND TEXTURING

CHARACTERISTICS OF THE SOIL BOLUS AND RIBBON	LENGTH OF THE RIBBON (mm)	FIELD TEXTURAL GRADE	APPROXIMATE CLAY CONTENT (%)
Coherence nil to very slight, cannot be moulded; single sand grains adhere to fingers	Nil	Sand	<10 (often <5)
Slight coherence, sandy feel, discolouration of fingers	Approx. 5 mm	Loamy sand	5–10
Slight coherence, sticky when wet; many sand grains stick to fingers; clay stains the hands	5–15 mm	Clayey sand	5–10
Bolus just coherent but very sandy to touch; dominant sand grains are of medium size and are easily visible	15–25 mm	Sandy loam	10–20
Bolus coherent and rather spongy; smooth feel when manipulated, no obvious sandiness or silkiness; may be greasy to the touch if much organic matter is present	Approx. 25 mm	Loam	Approx. 25%
Coherent bolus; very smooth to silky when manipulated	Approx. 25 mm	Silty loam	Approx. 25% (with silt)
Strongly coherent bolus, sandy to touch; medium size sand grains visible in finer matrix	25–40 mm	Sandy clay loam	>25%
Coherent plastic bolus, smooth to manipulate	40–50 mm	Clay loam	25–30
Coherent plastic bolus; medium size sand grains visible in finer matrix	40–50 mm	Clay loam, sandy	30–35
Coherent smooth bolus; plastic and often silky to the touch	40–50 mm	Silty clay loam	30–35% (with silt)
Plastic bolus; fine to medium sand grains can be seen, felt or heard in clayey matrix	50–75 mm	Sandy clay	35–40
Plastic bolus; smooth to touch	50–75 mm (slight resistance to ribbon shear)	Light clay	35–40
Plastic bolus; smooth to touch	Approx. 75 mm (mod. resistance to ribbon shear)	Light medium clay	40–45
Smooth plastic bolus; handles like plasticine; can be moulded into rods without fracture; resistance to shearing	>75 mm (mod. resistance to ribbon shear)	Medium clay	45–55
Smooth plastic bolus; handles like stiff plasticine; can be moulded into rods without fracture; resistance to shearing	>75 mm (firm resistance to ribbon shear)	Heavy clay	>50

## APPENDIX 2

# CONVERSION OF 50 kg BAGS PER ACRE TO/FROM KILOGRAMS PER HECTARE

## CONVERSION FACTORS

50 kg bags/acre multiply by 125 = kilograms/hectare

Kilograms/hectare divided by 125 = 50 kg bags/acre

### Examples

**Q:** *How many kilograms of fertiliser per hectare are equal to 4 bags/acre?*

**A:** 4 bags/acre x 125 = 500 kg/ha

**Q:** *How many bags/acre are equal to 500 kilograms/hectare?*

**A:** 500 kg/ha ÷ 125 = 4 bags/acre



## APPENDIX 3

# CONVERSION OF FERTILISER PRODUCT TO/FROM NUTRIENTS PER HECTARE

### CONVERSION FACTORS

Kilograms of product per hectare multiplied by % of each nutrient in product  
divided by 100

= kilograms of each nutrient per hectare

Kilograms of nutrient per hectare divided by % of each nutrient in product  
multiplied by 100

= kilograms of product per hectare

#### Examples

**Q:** If you apply 250 kg urea/ha, how many kilograms of nitrogen (N) per hectare (kg N/ha) will be applied? (Urea = 46% N)

**A:**  $250 \text{ kg/ha} \times 46 \div 100 = 115 \text{ kg N/ha}$

**Q:** If you want to apply 115 kg N/ha, how many kilograms of urea/ha would be required? (Urea = 46% N)?

**A:**  $115 \text{ kg N/ha} \div 46 \times 100 = 250 \text{ kg urea/ha}$

**Q:** How much nitrogen (N), phosphorus (P) and potassium (K) is applied in 400 kg/ha of CK150/GF500/HF151? (CK150/GF500/HF151 = 25.3% N, 3.6% P, 17.0% K)

**A:**  $400 \text{ kg/ha} \times 25.3 \div 100 = 101 \text{ kg N/ha}$   
 $400 \text{ kg/ha} \times 3.6 \div 100 = 14 \text{ kg P/ha}$   
 $400 \text{ kg/ha} \times 17.0 \div 100 = 68 \text{ kg K/ha}$

**Q:** If wish to apply 20kg P/ha, how much DAP will have to be applied? How much nitrogen will this also apply? (DAP = 18.0% N, 20.0% P)

**A:**  $20 \text{ kg P/ha} \div 20.0 \times 100 = 100 \text{ kg DAP/ha}$   
 $100 \text{ kg/ha DAP} \times 18 \div 100 = 18 \text{ kg N/ha}$

# GLOSSARY

## ACID

Substance containing or releasing an excess of hydrogen ions over hydroxyl ions.

## ACID SATURATION

The proportion of the soil cation exchange capacity (CEC) occupied by the acidic cations aluminium and hydrogen. It appears on soil tests as aluminium saturation. Low acid saturation is desirable so that more of the CEC is available for storing nutrient cations.

## ACID SOIL

Soil with a pH below 7. Sugarcane is very tolerant of acid soils.

## ACID SULFATE SOILS (ASS)

Soils and sediments that contain sulfides capable of oxidising and producing sulfuric acid. These soils become problematic when they are exposed to air by construction of drains or other earthworks. Under such conditions, the sulfide components of the iron compounds oxidise to sulfuric acid and produce actual acid sulfate soils with pH <4. In the saturated or reduced state, these soils remain unaltered and have normal pHs mainly in the range of 5.5 to 7.5. These soils are referred to as potential acid sulfate soils.

## ACIDIC CATIONS

Positively-charged ions of aluminium and hydrogen that give the soil CEC an acid reaction. Aluminium and hydrogen are always present in large quantities in the soil but they are only present on the CEC and in the soil solution if the soil pH is below 5.3.

## ACIDIFICATION

The process whereby soils become acidic over time as a result of the soil parent material, the addition of nitrogen to the soil by either fertiliser or legumes, and/or the leaching of nutrients from the soil by rainfall.

## ADSORBED

Gathered on a surface. In soil, cations gather on clay surfaces due to a difference in charge between the cations and the clay surfaces.

## AEROBIC

Soil conditions in which there is plenty of oxygen; these conditions are suitable for plant roots and those soil organisms that carry out processes beneficial to plant nutrition and soil structure. Best in well-drained, well-structured soils.

## ALKALINE

Containing or releasing an excess of hydroxyl ions over hydrogen ions.

## ALKALINE SOIL

Soil with a pH above 7. Soils in the Burdekin district tend to be alkaline; in the rest of the Australian industry, soils are mostly acidic.

## ALUMINIUM (Al)

An element which has the potential to cause yield reductions when in very high levels in the soil. Sugarcane has a high tolerance to aluminium. Soil pH is the main factor that controls the amount of Al<sup>3+</sup> available for plant uptake. Aluminium becomes plant available when the soil pH drops below 6.0 but does not seriously affect crop growth until the pH drops below about 5.5. Soluble Al usually rises dramatically below pH 5.0.

## ALUMINIUM SATURATION PERCENTAGE

The percent of the cation exchange capacity occupied by the exchangeable acidic cations aluminium (Al<sup>3+</sup>). A very high reading could indicate crop production problems. See Acid saturation; Aluminium.

## ALUMINIUM TOXICITY

Damage to plant growth caused by high levels of soil aluminium, usually when the soil pH(1:5 water) is lower than about 5.3 and the calcium content is low.

## AMELIORANT

A soil improver. A substance added to soil to improve the growing conditions for plant roots. A soil ameliorant e.g. gypsum, lime or mill by-products, improves the structure and/or nutritional level of the soil.

## AMMONIA (NH<sub>3</sub>)

A gas formed under conditions of volatilisation which results in a loss of nitrogen to the atmosphere.

## AMMONIUM (NH<sub>4</sub><sup>+</sup>)

One of the two forms of nitrogen which plants can use for growth, the other being nitrate (NO<sub>3</sub><sup>-</sup>).

## AMMONIUM STABILISER

See Nitrification inhibitor.

## ANAEROBIC

In the absence of free oxygen and where reducing processes predominate. This condition generally occurs in poorly-drained or waterlogged soils where water has replaced the air resulting in a bluey-grey coloured soil. Denitrification by certain soil organisms occurs under waterlogged, anaerobic conditions.

## ANION

Negatively-charged ion such as nitrate, phosphate, sulfate and chloride. See Ions.

### **AVAILABILITY OF NUTRIENTS**

A measure of how readily nutrients are able to be taken up by plants. Nutrients in organic products are generally slowly available, needing time to mineralise into forms that the plant can utilise. Inorganic, soluble fertilisers can be rapidly taken up by plants.

### **BANDED FERTILISER**

Fertiliser that is applied in bands along the sugarcane drill. Banding includes a line of fertiliser along each side of a drill or a single row along the top of the drill (called split stool fertiliser application when subsurface-applied). See Stool splitting.

### **BALANCED NUTRITION**

The supply to a crop of adequate amounts of all the essential nutrients and silicon to meet crop demand. Over supply or under supply of one or more nutrients may be detrimental to crop yields, profitability or environmental stewardship.

### **BASE SATURATION**

The percentage of the CEC occupied by the basic cations  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$  and  $\text{Na}^+$ . If all the exchangeable bases total 100%, there is no exchangeable acidity.

### **BED PLANTING**

See Mound planting.

### **BEST MANAGEMENT PRACTICE (BMP)**

Industry practices that can maximise productivity and profitability of a cropping system and deliver sustainability and positive environmental stewardship outcomes. A commitment to continuous improvement focusing on reducing the negative impacts of sugarcane production.

### **BIOMASS**

The amount of living matter in a given area or volume.

### **BIURET**

An impurity in urea caused during its manufacture which is toxic to plants, but phytotoxic damage to sugarcane occurs only if urea is foliar applied. The amount of biuret allowed in commercial urea-based fertiliser is regulated.

### **BROADCAST APPLICATION**

Application of a fertiliser (solid or liquid) over the soil or sugarcane trash blanket surface, not limited to bands in the vicinity of the plant roots. Can increase the risk of nutrient loss by volatilisation or water runoff.

### **BSES-P**

See Phosphorus BSES.

### **BUFFER pH**

Determined by a laboratory test under which the exchange acidity of the soil being analysed alters the known pH of an added buffer. The change in pH of this buffer is sometimes related to the quantity of lime required to reach

a predetermined soil pH value. More useful for horticultural crops than for sugarcane.

### **BUFFERING CAPACITY**

Indicator of the potential for a soil to become more acid as nutrients are removed in crop growth. Light-textured soils are poorly buffered and have a low capacity to resist pH changes. Heavy-textured soils have a high buffering capacity.

### **BURNT CANE TRASH BLANKET**

The layer of sugarcane residues covering the ground after blanket harvest of the crop which had previously been burnt.

### **BURNT LIME (CaO)**

See Quicklime.

### **CALCIUM CARBONATE (CaCO<sub>3</sub>)**

Agricultural lime. Most naturally-occurring limestone is principally calcium carbonate. Contains 30 – 40 % calcium.

### **CALCIUM HYDROXIDE (Ca(OH)<sub>2</sub>)**

See Slaked lime

### **CALCIUM OXIDE (CaO)**

See Unslaked lime

### **CARBON: NITROGEN RATIO (C:N)**

Ratio of the weight of organic carbon to the weight of total nitrogen in the soil or organic material. Equals organic carbon % / total nitrogen %. Influences the rate of decomposition of organic matter and the resultant release (mineralisation) or immobilisation of soil nitrogen. Influences the amount of soil nitrogen made available to plants.

### **CATION**

Positively-charged ions that are held on to the negatively-charged sites on the soil CEC. The major cations are calcium, potassium, magnesium and sodium, hydrogen and ammonium. See Anion, Exchangeable cations, Ions.

### **CATION EXCHANGE CAPACITY (CEC)**

An indication of the soil's nutrient-holding ability. The sum of total exchangeable cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Al}^{3+}$ ). A measure of the soil's capacity to hold and exchange cations. CEC measurements are often made with a buffer solution at a particular pH value. If this pH differs from the natural pH of the soil, the measurement will not reflect the true CEC under normal conditions. CEC is a major factor affecting soil structure, nutrient availability, soil pH and the soil's response to fertiliser. The value of the CEC is dependent on the amount and type of clay and on the amount of humus. The higher the clay content of the soil, the higher the CEC and the lower the leaching susceptibility of the soil. CEC is expressed as milli-equivalents per 100 grams of soil (meq%). Also see Effective CEC.

**CHELATE**

A soluble organo-metal complex that makes metal ions in soluble form more available for uptake by plants. Certain micro-nutrients are supplied as chelates. The leaching of immobile  $Al^{3+}$  and  $Fe^{3+}$  cations can be enhanced by the formation of chelates.

**CHEMICALLY-FIXED PHOSPHORUS**

Phosphorus that reacts with chemical compounds in the soil solution and precipitates as insoluble phosphates that plants cannot extract.

**CHLOROSIS**

Lack of chlorophyll in a plant resulting in a pale green to yellow colour. Caused by lack of light, nutritional deficiency or disease. The leaf/plant becomes chlorotic.

**COLLOID**

Clay and humus particles containing negative charge onto which positively-charged anions attach.

**DTPA**

Chemical used in soil analysis to extract micro-nutrients from the soil.

**DUNDER**

A liquid by-product of ethanol production and a rich source of potassium. Used as a fertiliser on sugarcane farms in some regions of the Australian sugar industry. Also known as vinasse or stillage in some countries.

**EFFECTIVE CEC (ECEC)**

The effective cation exchange capacity of a soil. The amount of cation charges that a soil can hold at the pH of the soil. Effective CEC = sum of the exchangeable cations ( $Ca^{2+}$ ,  $Mg^{2+}$ ,  $K^{+}$ ,  $Na^{+}$ ) + exchangeable acidity ( $Al^{3+}$ ). The ECEC measurement is made at the natural soil pH. See Cation exchange capacity.

**ELECTRICAL CONDUCTIVITY**

A measure of the amount of soluble salt compounds in the soil solution. Soluble salts are present in small amounts in all fertile soils, but excessive quantities are undesirable as plant growth suffers. Units are decisiemens/metre (dS/m), numerically equal to the old units millisiemens/centimetre (mS/cm) and the even older units millimho/centimetre (mmho/cm).

**ENHANCED EFFICIENCY FERTILISER (EEF)**

Fertiliser products that can reduce nutrient losses while increasing nutrient availability for the plant or the crop. Can either slow the release of nutrients for uptake or delay the conversion of nutrients to other forms that may be more susceptible to losses. EEFs include slow and controlled release fertilisers, ammonium stabilisers, urease inhibitors and phosphate management products.

**EXCHANGE COMPLEX**

All the clay and humus that contribute to a soil's exchange capacity.

**EXCHANGEABLE ACIDITY**

A measure of the amount of acid cations, aluminium ( $Al^{3+}$ ) and hydrogen ( $H^{+}$ ), occupied on the CEC.

**EXCHANGEABLE CATIONS**

Positively-charged ions including calcium, magnesium, potassium, sodium and aluminium that are held on negatively-charged soil particles.

**EXCHANGEABLE NUTRIENTS**

Essential nutrients (calcium, potassium, magnesium and sodium) present as cations associated with the soil CEC. They have the ability to exchange easily.

**EXCHANGEABLE POTASSIUM (K(amm-acet); K(exch))**

Potassium that is readily available to the growing crop. Exchangeable K is loosely held by soil organic matter and clays. Two other forms of potassium in the soil are slowly available K [K(Nitric)], and unavailable potassium, which is found in minerals and which the plant cannot use.

**EXCHANGEABLE SODIUM PERCENTAGE (ESP)**

The percent of the cation exchange capacity (CEC) occupied by exchangeable sodium. Also called sodium percent of cations. A high ESP reading indicates crop production problems: 5 – 15% indicates some breakdown of soil structure; above 15% indicates severe structural deterioration in most soils.

**FALLOW**

A piece of land that normally grows sugarcane but is left without a sugarcane crop for a season in order to let it recover its fertility. The fallow block may be left bare, with a grass/weed cover, with a legume crop, or with the retained final crop that has been killed with herbicide. See Spray-out fallow.

**FERTILISER BURN**

The damaging or death of emerging young plant cane roots that occurs when certain fertilisers are placed on or too close to the sett. Fertilisers are salts and vary in their tendency to burn roughly in accordance with their salt index. Potassium and nitrogen fertilisers are the main culprits. Fertiliser burn is most likely to occur on soils that are light textured, low in organic matter and/or have low pH. Dry weather exacerbates the problem.

**FERTILITY**

The capacity of a soil to support plant growth. It has three components: chemical, physical and biological fertility. Chemical fertility is the ability of a soil to supply adequate quantities and correct balance of nutrients. Physical fertility is the ability of a soil to supply plants with water and oxygen, to protect plant roots from temperature stress, and to allow unrestricted shoot emergence and root penetration; it is dependent largely upon soil texture and structure. Biological fertility refers to the diversity, quantity and activity of organisms in the soil.



**FIRING**

Necrotic or dead areas on leaf margins and tips giving a scorched appearance.

**FIXATION**

(1) Process by which available plant nutrients (mainly ammonium, phosphorus and potassium) react with soil components and become unavailable for plant growth.  
(2) Process whereby atmospheric nitrogen is converted to plant-available nitrogen by legumes or the manufacture of industrial nitrogen fertiliser. See Nitrogen fixation.

**FLY ASH**

Fine residue particles of ash and partly burned bagasse generated during combustion that rise ("fly") with the flue gases.

**FRECKLING**

Small, usually dark-coloured spots on the leaf blades.

**GREEN CANE TRASH BLANKET (GCTB)**

Green cane trash blanket (GCTB). The layer of sugarcane residues covering the ground after harvest of the crop which had not previously been burnt. Amounts to approximately 10 – 15 t/ha. Approximately 80% of the trash blanket is lost by decomposition per year.

**GREEN MANURE**

Plants grown for incorporation into the soil to improve soil fertility and organic matter. Legumes can also provide nitrogen to the soil by converting inert atmospheric nitrogen to plant-available nitrogen.

**GREENHOUSE GAS**

Gases including carbon dioxide, methane and nitrous oxide which absorb incident and reflected radiation from the sun and re-radiate this heat into the atmosphere thereby warming Earth's atmosphere.

**GYP SUM (CaSO<sub>4</sub>.2H<sub>2</sub>O)**

Calcium sulfate. A natural, mined substance and a by-product of fertiliser manufacture. Used to reduce soil swelling and dispersion and for improving soil structure. Useful for overcoming poor growth in problem soils such as soda patches or hard-setting soils. Gypsum does not alter the soil pH level.

**HIDDEN HUNGER**

Condition where crops lose yield before deficiency symptoms become obvious.

**HUMUS**

The stable, black organic matter in soils (distinct from decomposing trash) which is the end-product of the decomposition of animal and vegetable matter. Humus can no longer be recognised as individual components. The compounds that make up humus are able to resist further decomposition and, therefore, accumulate in the soil.

**HYDRATED LIME (Ca(OH)<sub>2</sub>)**

Calcium hydroxide. Produced by reacting burnt lime with water. Contains 51% calcium.

**IMMOBILE NUTRIENTS**

Those nutrients which are not redistributed in the plant in significant quantities under deficiency conditions. Symptoms of deficiency first appear and are most obvious on young leaves. Immobile nutrients are calcium, sulfur, iron, copper, boron, manganese, and zinc.

**IMMOBILISATION**

Also called demineralisation, the opposite of mineralisation. The conversion of inorganic compounds to organic compounds by micro-organisms or plants, by which it is prevented from being accessible to plants. Occurs when nitrate (NO<sub>3</sub><sup>-</sup>) and/or ammonium-N (NH<sub>4</sub><sup>+</sup>) in the soil is used by microbes. Can occur during the initial breakdown of crop residues. Immobilisation causes a temporary unavailability of mineral nitrogen in the soil for plants to utilise.

**INTERVEINAL**

Between the major veins of the leaf blade.

**ION**

An electrically charged atom or molecule. Cations are positive ions; anions are negative ions.

**LABILE CARBON**

Comprises a small part of the organic carbon pool but provides the major food source for soil microbes and is a measure of soil fertility. It is the fraction of soil organic carbon that breaks down the fastest.

**LEACHING**

Washing soluble nutrients and suspended clay particles downwards through the soil profile with rainwater or irrigation water and out of the root zone.

**LIME/LIMING MATERIAL**

A material with a high level of calcium which is effective in neutralising soil acidity. Usually refers to calcium carbonate (agricultural lime or earth lime) but also includes hydrated lime and burnt lime, and sometimes, dolomitic limestone. Other products may produce a "liming action" by increasing soil pH.

**LIQUID FERTILISER**

In the sugar industry, it generally refers to inorganic fertilisers such as urea and potash dissolved in water. Can also include dunder and dunder-based products that contain dissolved urea and/or other products.

**LOCKED-UP NUTRIENTS**

Nutrients that are not immediately available for plant growth but usually become available over time during mineralisation. Organic nutrient sources are largely locked up and slowly available.

### LUXURY FEEDING

The process whereby sugarcane takes up some nutrients in excess of the levels required for sound growth, for no extra benefit to the plant. It can lead to poor nutrient use efficiency and increased ash and colour in sugarcane juice. Sugarcane "luxury feeds" on nitrogen and potassium.

### MACRO-ORGANISMS

Soil fauna larger than 2 mm.

### MAINTENANCE DRESSING

The addition of sufficient nutrient to maintain an adequate level of that nutrient in the soil.

### MANGANESE (Mn)

One of the trace elements required for plant growth. Functions mainly as part of enzyme systems. Involved in photosynthesis by aiding chlorophyll synthesis. Manganese deficiency in sugarcane crops in Australia has not been confirmed.

### meq%

Milli-equivalents percent. The quantity of some nutrients in the soil is expressed in this unit. Conversion: 1 meq% K = 390 ppm; 1 meq% Ca = 200 ppm; 1 meq% Mg = 120 ppm; 1 meq% Na = 230 ppm.

### mg/kg

Milligrams per kilogram. The quantity of some nutrients in the soil is expressed in this unit. Equivalent to parts per million (ppm).

### MICRON

One millionth of a metre. 1,000 microns = 1 millimetre.

### MICRO-NUTRIENTS

Essential plant nutrients required in small or trace amounts – zinc, copper, iron, manganese, molybdenum, boron and chlorine.

### MICRO-ORGANISMS

Microscopic organisms including soil bacteria, fungi, protozoans, yeast, moulds, viruses and algae that recycle nutrients making them available for plant growth. Also includes pathogenic organisms that have an adverse effect on plant growth. Also called microbes. Are less than 0.2 mm.

### MILL MUD

The residual mud and fibre filtered from the raw juice after lime addition and juice clarification in rotary vacuum filters. Mud is comprised mainly of water, fibre, mud solids from soil and natural impurities in the sugarcane. Filter mud % sugarcane is approximately 7. Also called filter mud, filter cake or sugarcane press mud.

### MINERALISATION

The process whereby nutrients, particularly nitrogen, phosphorus and sulfur, are released from the breakdown of humus (stabilised organic matter) by soil microbes,

becoming available for plant growth in the inorganic form. For nitrogen, the ammonium form ( $\text{NH}_4^+$ ) is produced which is subsequently converted to nitrate ( $\text{NO}_3^-$ ) through the microbial process of nitrification.

### MOBILE NUTRIENTS

Under deficiency conditions, mobile nutrients are readily withdrawn from the older leaves and redistributed to the young, actively growing parts of the plant. The first and most obvious symptoms of deficiency appear on the older (lower) leaves. Includes nitrogen, potassium, phosphorus, magnesium, molybdenum, and chlorine.

### MOUND PLANTING

As a counter to wet soil conditions, growers in high rainfall areas sometimes plant into pre-formed raised drills or beds. The sett is planted above the surrounding soil level thus keeping the sett out of saturated soil. Also called bed planting.

### MULCH

Any material spread on a soil surface to protect the soil.

### MYCORRHIZAE

Fungi which grow in association with the roots of a plant in a symbiotic relationship. The fungus links the plant with soil by acting as agents of nutrient exchange. The fungus receives carbohydrates as energy from the host plant root whilst nutrients such as phosphorus and zinc are passed back into the plant roots from the soil.

### NECROSIS

Death of tissue.

### NEUTRALISING VALUE (NV)

The ability of a liming product to neutralise or counteract soil acidity. Pure lime (calcium carbonate) has a neutralising value of 100%. Commercial products may have neutralising values of 95 to 99% for pulverised limestone and 80 - 90% for earthy lime.

### NITRATE ( $\text{NO}_3^-$ )

Compound formed in one of the stages of the conversion of nitrogen fertiliser: nitrogen  $\rightarrow$  ammonium ( $\text{NH}_4^+$ )  $\rightarrow$  nitrite ( $\text{NO}_2^-$ )  $\rightarrow$  nitrate ( $\text{NO}_3^-$ ). Sugarcane uses the ammonium and nitrate forms, not nitrite.

### NITRIC POTASSIUM

Nitric K. Potassium extracted from a soil sample with the use of strong nitric acid. It is a crude measure of the slowly available, non-exchangeable (reserve) potassium in the soil. The higher the value, the greater the potassium reserve in the clay minerals.

### NITRIFICATION

The conversion of ammonium-N ( $\text{NH}_4^+$ ) in soils to nitrite-N ( $\text{NO}_2^-$ ) followed by the conversion of the nitrite to nitrate-N ( $\text{NO}_3^-$ ) by certain nitrifying bacteria such as Nitrosomonas and Nitrobacter.

### **NITRIFICATION INHIBITOR**

Also called ammonium stabiliser. Substance that inhibits the biological conversion of the ammonium ion ( $\text{NH}_4^+$ ) to nitrite ( $\text{NO}_2^-$ ) which slows the production of nitrate ( $\text{NO}_3^-$ ). It does this by controlling the population of Nitrosomonas and other bacteria. Ammonium is attached to the soil; nitrate is not attached and is prone to leaching and denitrification. These inhibitors can help reduce losses of nitrogen in soil that would otherwise be used by crops.

### **NITRITE ( $\text{NO}_2^-$ )**

Compound formed in one of the stages of the conversion of nitrogen fertiliser: nitrogen  $\rightarrow$  ammonium ( $\text{NH}_4^+$ )  $\rightarrow$  nitrite ( $\text{NO}_2^-$ )  $\rightarrow$  nitrate ( $\text{NO}_3^-$ ). Sugarcane uses the ammonium and nitrate forms, not nitrite.

### **NITROBACTER**

The second step of the nitrification process (oxidation of nitrite into nitrate) is done mainly by aerobic bacteria of the genus Nitrobacter.

### **NITROGEN (N)**

One of 16 nutrients essential for growth of plants. Present in all living cells. Present in organic matter and as nitrogen gas (N), nitrite ( $\text{NO}_2^-$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), ammonia ( $\text{NH}_3$ ), ammonium ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ). Only the last two forms can be used by plants from the soil.

### **NITROGEN CYCLE**

The continuous cycling of nitrogen and nitrogen compounds in nature between the atmosphere, the soil, and plants and animals.

### **NITROGEN FIXATION**

The process whereby atmospheric nitrogen is converted to ammonia. This process must occur before the atmospheric nitrogen can be used by plants. The most widely known example is the association between Rhizobium bacteria in the nodules on legume roots. Industrial nitrogen fixation produces manufactured nitrogen fertiliser.

### **NITROGEN STABILISER**

A substance added to a fertiliser which extends the time the nitrogen component of the fertiliser remains in the soil in the urea or ammoniacal form. The stabiliser inhibits the ability of nitrosomonas bacteria to convert ammonium-N to nitrite-N. Consequently, the production of nitrate-N, which is subject to leaching and denitrification, is also restricted.

### **NITROGEN USE EFFICIENCY (NUE)**

A measure of crop production per unit of nitrogen fertiliser input. In this manual,  $\text{NUE} = \text{cane yield (t/ha)} \div \text{nitrogen applied (kg N/ha)}$ .

### **NITROSOMONAS**

The first step of the nitrification process (oxidation of ammonium to nitrite) is done mainly by aerobic bacteria of the genus Nitrosomonas. Ammonium is the preferred energy source of Nitrosomonas.

### **NITROUS OXIDE ( $\text{N}_2\text{O}$ )**

Laughing gas. A product of denitrification resulting in nitrogen loss. Has approximately 310 times the greenhouse gas potential of carbon dioxide.

### **NON-EXCHANGEABLE POTASSIUM**

Potassium held within clay minerals which becomes available slowly.

### **OFF-SITE IMPACTS**

The consequences, usually adverse, that farming practices have on locations outside the farm boundary e.g. nutrient runoff causing degraded water quality.

### **ORANGE FRECKLE**

Symptom of magnesium deficiency. The older leaves develop small spots which become orange and then dark brown, which can give the leaf a rusted appearance.

### **ORGANIC AMENDMENT**

The addition of material high in organic matter which has the potential to improve soil condition and fertility. Examples are mill mud and mud-ash, compost, manures, sugarcane residues and fallow crop residues.

### **ORGANIC CARBON**

A measure of the organic matter content of the soil. The carbon content of organic matter is relatively constant and comprises about 60% of soil organic matter. Organic carbon pools comprise labile, resistant and inert carbon. Soils have low organic carbon if below 1%; soils greater than 4% are peaty and tend to indicate poor drainage where decomposition of the organic matter is slow. The terms total organic carbon, soil organic carbon and organic carbon are the same.

### **ORGANIC FERTILISER**

Organic material that supplies plant nutrients when added to the soil. Must be decomposed by micro-organisms to make the nutrients available for plant growth.

### **ORGANIC MATTER**

Consists of plant residues, soil organisms and animal remains. Composed of three pools: living biomass of micro-organisms; fresh and partially decomposed residues (the active fraction); the decomposed and highly stable organic material. Undecomposed surface litter is normally not included as a component of soil organic matter. Contains all the essential plant nutrients, particularly nitrogen, phosphorus and sulfur, which are slowly available for plant growth. Acts as a reservoir of plant nutrients, helps conserve moisture, improves the physical structure of the soil and provides a favourable environment for soil micro-organisms. Organic matter (%) may be estimated as  $1.72 \times \text{organic carbon (\%)}$ .

### **PERCENT COARSE/ PERCENT FINE**

Relates to liming materials. A measure of the reactivity of the product in the soil. The minimum standard should

be 60% fine material (particles finer than 250 microns or 0.25 mm) by weight. Fine liming products react faster with soil acidity thereby increasing the effectiveness of the treatment. Coarse liming material reacts with soil acidity very slowly, usually 6 to 8 months after application.

### **pH**

A measure of acidity or alkalinity (of the soil, water etc.) On a scale of 0 (extreme acidity) to 14 (extreme alkalinity). Pure water has a pH of 7. The scale is logarithmic: a change of one unit on the scale represents a 10-fold change in pH. pH is short for the Latin term "potentia hydrogenii" and means hydrogen ion concentration.

### **pH BUFFERING CAPACITY**

The ability of a soil to absorb acid or lime with little or no change to pH.

### **PHOSPHORUS BICARBONATE**

A measure of soil phosphorus which is readily available for sugarcane growth in neutral or alkaline soils.

### **PHOSPHORUS BSES**

A measure of soil phosphorus which is readily available for sugarcane growth in acid soils. Test developed by BSES.

### **PHOSPHORUS BUFFERING INDEX (PBI)**

A measure of the degree to which added phosphorus is held tightly onto soil particle surfaces and is unavailable for plant uptake.

### **PHOSPHORUS FIXATION**

The formation of insoluble phosphorus compounds in the soil. "Fixed" phosphorus is unavailable for plant growth. Fixation can be high in soils outside the pH range 5.5 to 7.0, and in soils with high iron or aluminium content in the clay. Fixation becomes less of a problem for sugarcane growth when the phosphorus-fixing capacity of the soil has been satisfied by adequate applications of phosphate fertilisers.

### **PLOUGHOUT-REPLANT**

Also called replant. The plant crop which is established very soon after the harvest of the previous crop without the benefit of an extended fallow period.

### **POTASH**

Another name for muriate of potash or potassium chloride. Contains 50% potassium and is manufactured by refining natural potash salts.

### **POTASH BURN**

Damage to young roots and eyes of germinating sugarcane setts as a result of placing potassium fertiliser on, or very close to, the sugarcane setts. Caused by the high solubility and salt effect of muriate of potash.

### **POTENTIAL ACID SULFATE SOIL**

Soil that contains sulfides that have the potential to generate sulfuric acid if disturbed (drained, excavated etc.) and exposed to air. See Acid sulfate soils.

### **PRILL**

A pellet or solid globule of a substance formed by the congealing of a liquid during an industrial process. Formed by allowing drops of the melted prill substance to congeal in mid-air after being dripped from the top of a tall prilling tower. Certain fertilisers such as urea are often supplied in prilled form.

### **P-SORPTION**

The process by which phosphorus is held tightly onto soil particle surfaces and rendered relatively unavailable for plant uptake.

### **QUICKLIME (CaO)**

Calcium oxide. Also called burnt lime or unslaked lime. Made by burning limestone. Unstable. Contains approximately 68% calcium.

### **RHIZOBIA**

Bacteria that live in nodules on the roots of legumes and carry out nitrogen fixation.

### **ROCK PHOSPHATE (Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>)**

The basic material used in almost all phosphorus fertiliser production. Only very slowly available to plants as it is largely insoluble.

### **RUNOFF**

The draining away of water and substances (e.g. soil, phosphorus attached to soil, dissolved nitrogen) carried in the water from the surface of an area of land. May cause erosion. When runoff water carries nutrients, it may contribute to water quality decline and reduce farm profitability.

### **SALINE SOIL**

A non-alkali soil containing an excessive level of salt in the soil water, restricting plant growth. The salt is soluble and may be leached out.

### **SALINE-ALKALI SOIL**

Soil containing high proportion of soluble salts with either a high degree of alkalinity or high amount of exchangeable sodium or both.

### **SALT INDEX**

An index used to compare solubilities of fertilisers. Most nitrogen and potassium compounds have high indices. Phosphorus compounds have low indices. High salt index fertilisers can cause fertiliser burn if not placed correctly. See Fertiliser burn.

### **SENESCENCE**

The process of aging in plants. The terminal phase of leaf development resulting in the death of leaves. Premature senescence occurs when factors cause leaves to die before their normal life span.



**SILT**

Soil particles which together with sand, clay and organic matter are the main constituents of soil. Derived from eroded rocks, silt is intermediate in size between sand and clay. Individual silt particles are so small they are difficult or impossible to see, in the size range 0.002 mm to 0.05 mm.

**SIX EASY STEPS**

An integrated nutrient management tool that enables the adoption of on-farm best-practice nutrient management. It is aimed at sustainable and balanced nutrition of sugarcane. It consists of (1) Knowing and understanding your soils; (2) Understanding and managing nutrient processes and losses; (3) Soil testing regularly; (4) Adopting soil-specific nutrient management guidelines; (5) Using leaf analysis as a check on the adequacy of nutrient inputs, and (6) Keeping good records and modifying nutrient inputs when necessary. The recommended SIX EASY STEPS nutrient rates are recognised by government and industry as being the most appropriate for the Australian sugar industry.

**SLAKED LIME (Ca(OH)<sub>2</sub>)**

Calcium hydroxide. Hydrated lime. Contains approximately 51% calcium. Readily available for plant growth.

**SLOW RELEASE FERTILISER**

A fertiliser that releases nutrients slower than conventional inorganic fertilisers. Multiple factors affect the release of nutrient/s (e.g. soil moisture, soil temperate, pH). Thus, nutrient release from controlled release fertilisers (only soil temperature affects nutrient release) is usually more predictable than from slow release fertilisers. See Controlled release fertiliser.

**SODIC SOIL**

Soil in which high levels of exchangeable sodium are attached to the clay particles, causing breakdown of the soil structure and poor plant growth. Soda patches are areas containing sodic soil. Such soils have a poor structure, disperse easily and are prone to erosion. Generally, a sodic soil is regarded as having an exchangeable sodium percentage 15 or greater. See Exchangeable sodium percentage (ESP).

**SODIUM (Na)**

Excessive levels cause plant nutritional and soil structural problems. Very soluble in water. Part of common or table salt (sodium chloride), it contributes to electrical conductivity along with chloride. See Electrical conductivity.

**SODIUM % CATIONS**

An approximation of exchangeable sodium percentage. See Exchangeable sodium percentage (ESP).

**SOIL COLOUR**

Generally determined by the amount and state of organic matter, the amount and state of iron oxides, and the degree of aeration of the soil.

**SOIL HEALTH**

The physical, chemical and biological components that make up a living soil, how they interact with one another and how they interact to sustain production. A healthy soil has properties that promote the health of plants, animals and humans while maintaining environmental quality.

**SOIL ORGANIC CARBON**

Same as organic carbon and total organic carbon.

**SOIL SOLUTION**

The water in the soil available for plant use, together with the dissolved plant nutrients and oxygen.

**SPECIFIC ELECTRICAL CONDUCTIVITY (SEC)**

See Electrical conductivity.

**SPINDLE**

Youngest immature leaves which have not yet unfurled.

**SPLIT APPLICATION**

Fertiliser applied to a crop two or more times during its seasonal growth.

**SPLIT STOOL APPLICATION**

See Stool splitting.

**SPRAY-OUT FALLOW**

A block on which the final sugarcane crop in a cycle is allowed to ratoon for a short period after its harvest so that it can then be killed with a herbicide. The dead crop is left standing during the wet season to protect the soil from erosion.

**STABILISED NITROGEN FERTILISER**

A fertiliser to which a nitrogen stabiliser has been added. A nitrogen stabilizer is a substance added to a fertiliser which extends the time the nitrogen component of the fertiliser remains in the soil in the urea-N or ammoniacal-N form.

**STOOL SPLITTING**

The use of a coulter to slice a thin line through sugarcane stools along the length of the row. Fertiliser is dropped into the shallow slot (about 7 cm to 10 cm deep) via a hollow tyne directly behind the coulter. A following press wheel closes the slot to prevent volatilisation loss of nitrogen.

**SUBSURFACE-APPLIED FERTILISER**

Fertiliser buried in bands in the soil. With suitable equipment, fertiliser can be subsurface-applied through a green trash blanket.

**SUCROSE (C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>)**

Pure chemical compound called white sugar. The sucrose molecule is a disaccharide combination of the monosaccharides glucose and fructose.

**SUGAR**

The generalised name for sweet, short-chain, soluble carbohydrates, many of which are used in food. They are carbohydrates, composed of carbon, hydrogen, and oxygen. There are various types of sugar derived from different sources. Simple sugars are called monosaccharides and include glucose (also known as dextrose), fructose and galactose. The table or granulated sugar most customarily used as food is sucrose, a disaccharide. (In the body, sucrose hydrolyses into fructose and glucose.) Other disaccharides include maltose and lactose. Longer chains of sugars are called oligosaccharides. Sugars are found in the tissues of most plants.

**SURFACE-APPLIED FERTILISER**

Fertiliser applied in bands or as a broadcast application either on top of the green or burnt trash blanket or on the soil surface.

**SUSTAINABLE AGRICULTURE**

The production of agricultural output using farming techniques that abide by three pillars: profit (economic); stewardship of land, water and air (environmental); quality of life for agricultural producers and communities (social).

**TILLERING**

Growth of stalks from the below-ground buds.

**UNSLAKED LIME (CaO)**

See Quicklime.

**UREA (CO(NH<sub>2</sub>)<sub>2</sub>)**

A white, crystalline solid containing 46% nitrogen that is widely used in agriculture as a fertiliser.

**UREASE**

A naturally-occurring enzyme which converts urea to ammonia.

**UREASE INHIBITOR**

A substance which inhibits hydrolytic action on urea by urease enzyme. A urease inhibitor results in less urea nitrogen lost by ammonia volatilisation or leaching of nitrate. The efficiency of urea and urea-containing fertilisers is increased while adverse environmental impacts of nitrogen loss are reduced.

**VOLATILISATION**

The loss of nitrogen to the atmosphere when surface-applied urea or products containing urea are converted to ammonia gas.

**WATERLOGGED**

A soil which is saturated with water, displacing air to the point where there is insufficient oxygen for full root activity and plant growth. See Anaerobic.

**WOLLASTONITE (CaSiO<sub>3</sub>)**

A white or greyish silica-limestone mineral comprised chemically of calcium, silicon and oxygen. A source of silicon for agricultural soils.

**YIELD POTENTIAL**

The best yield that could be expected in a field situation in a particular year. It is determined from the average best block yields occurring over a number of seasons and across all soils. District sugarcane yield potential in Queensland ranges from 120 – 180 t/ha; for NSW where some of the crop is two-year cane, the range is 140 – 220 t/ha.



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