NUTRITION OF THE PLANT

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PLANT metabolism is fuelled by a process called photosynthesis which involves chlorophyll, the green pigment in leaves. During photosynthesis, water from the soil and carbon dioxide from the atmosphere are converted by the energy of sunlight into sugars, other organic molecules for use by the plant, and oxygen. Sugar is manufactured in the leaves and stored in the stalk. The purpose of leaves is to harvest light and make sugar.

Plants require 17 elements (nutrients) to grow and function (Figure 1). Carbon, hydrogen and oxygen come from water and air. These elements account for more than 90% of a plant's dry weight. The other 14 elements are minerals that are provided by the soil and added fertilisers. Silicon is regarded as a beneficial, rather than an essential element.

Macro-elements, or the major elements, are those elements used in the greatest quantity by the crop.

Micro-elements, or the trace elements, are required in much smaller quantities than the major elements, but are just as essential as nitrogen, phosphorus and potassium for plant growth and photosynthesis; without them the plant will die.

Cane and sugar yields will be reduced if any one of the 17 essential and beneficial nutrients is in short supply, even though there may be ample quantities of all the others.

WATER AND NUTRIENT UPTAKE

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. Excess water is transpired from the leaves as water vapour, and this cools the plant and helps pull more water up from the roots. Water carries nutrients

throughout the plant in the form of tiny charged particles called ions.

Nutrients are leached from rock particles and organic matter in soil to the soil solution. Cortical cells throughout the root system transfer the water and nutrients deeper into the roots via interconnecting cell walls and protoplasm. The endodermal cells surrounding the root veins regulate the flow of minerals and water. Upon demand by the plant, the water and minerals are absorbed into the root xylem, where they are transported upward into the plant.

Nutrient availability for many plants is strongly influenced by soil pH. Under extremely acid conditions, the major nutrients are largely unavailable, or 'locked up' in the soil, while some of the minor nutrients are readily available (Figure 2). The ideal pH range for the availability of all essential nutrients is 5.5 to 7.0.

BALANCED NUTRITION

While each nutrient is required in a different quantity, all nutrients must be provided at their optimum levels to achieve maximum crop potential. This concept of balanced nutrition is illustrated by using 'the staves of a barrel' analogy (Figure 3). Each stave represents one of the essential nutrients. The total volume of the barrel indicates the maximum crop potential possible. To achieve this volume (i.e. maximum cane yield or sugar yield or profitability), all the staves (nutrients) need to be present at their full height (i.e. fully available for plant use). If one stave is shorter than the rest (i.e. there is a deficiency of that nutrient), the barrel can be filled only to the level of the short stave—the maximum potential of the crop will not be reached. The greater the deficiency, the shorter the stave and the greater the reduction of crop potential. If one stave is longer than the rest (i.e. over application of that nutrient), the crop potential will not increase. It just means there is an excess of that nutrient. In cases of gross excess of a nutrient, damage to the crop or environment might occur.
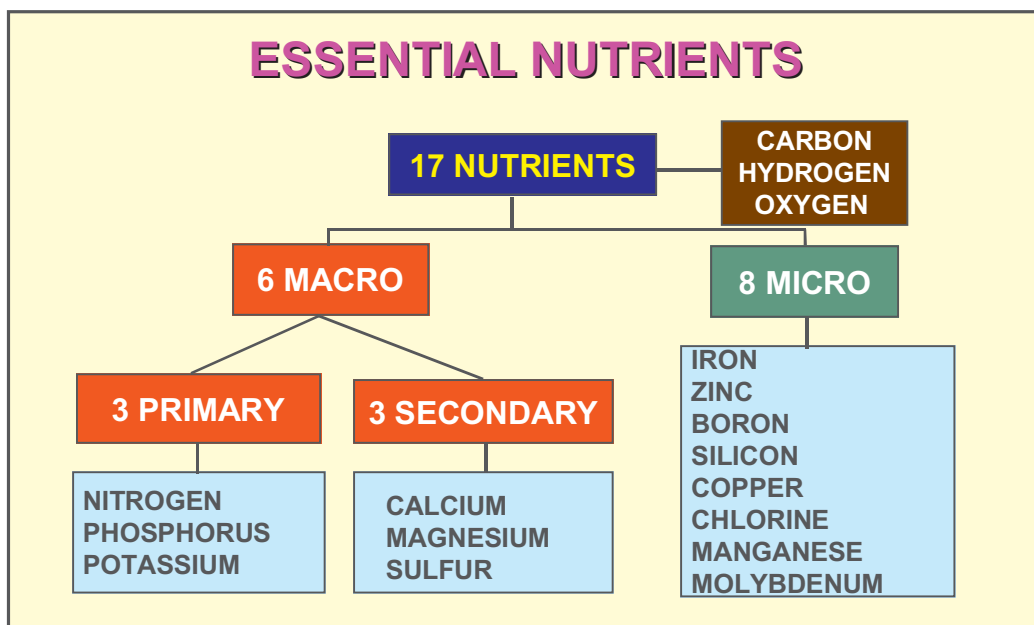

Figure 1. *The essential plant nutrients. (Silicon is thought to be beneficial at this stage.)*
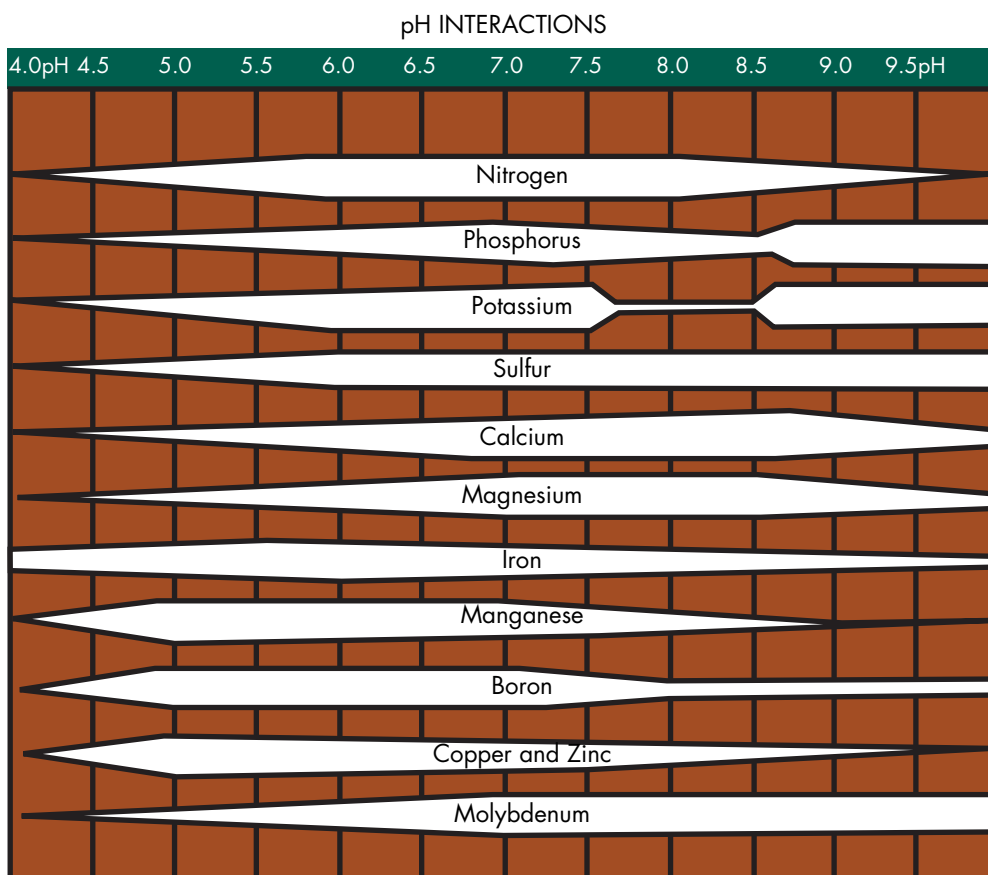
pH INTERACTIONS

Figure 2. *The influence of pH on nutrient availability.*

SOIL ANALYSIS

The basis of profitable and sustainable fertiliser programs and correction of nutritional deficiencies is the soil test. Soil tests are correlated with the results of field trials for accurate interpretation.

Procedure for soil sampling

An auger, soil tube or spade can be used to take soil samples. Samples should be taken to a depth of about 250 mm. However, if salinity and/or sodicity is suspected, samples should be taken in 250 mm intervals to a depth of at least 750 mm.

Soil samples must be representative of the area to be tested. This can be achieved by avoiding unusual areas such as old drainage lines, windbreaks, near trees, regularly used tracks etc, avoiding sampling in the position of old fertiliser bands, and avoiding areas differing in crop growth, soil type, drainage or past management practices (liming, fertilising, mill mud application etc). Sample these areas separately if they constitute a significant proportion of the block or if the purpose of sampling is to diagnose potential nutritional problems in these areas. Sample the area on a grid or zig-zag pattern to obtain about 10 sub-samples. (The most common mistake is taking too few sub-samples to adequately represent the area being tested). The sub-samples should be mixed well in a clean plastic bucket, the soil sample bag filled, and the remaining soil discarded. Samples should be

Figure 3. *Balanced nutrition. Left: all staves (nutrients) are at their full height and the maximum volume (crop potential) can be attained. Centre: the copper and potassium staves are short (deficient) and crop potential cannot be attained. Right: the phosphorus stave is long (excess phosphorus) and makes no difference to crop potential. Stave height represents 100% of each nutrient requirement. It does not represent equal amounts of all the nutrients.*

sent to the laboratory immediately after collection, as changes in available nutrient status can occur over time. If undue delay occurs, the sample should be stored in a refrigerator or sample the area again.

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

Reliability of soil tests

BSES researchers have placed soil tests into five groups according to their reliability for interpreting the nutrient status of soils (Table 1).

Soil test critical values

Critical values for soil analysis are based on BSES field experiments. Therefore, the soil critical values given in Table 2 are based on current BSES laboratory values. The main laboratories that service the sugar industry, including the BSES laboratory, all have slightly different critical values for each of the various nutrients, due to different laboratory methodologies, but the differences generally are minor. Regular exchanges of samples between the laboratories are conducted to ensure the relativity of analyses to the BSES laboratory is always known.

Terms such as buffer pH, conductivity, sodium % cations, phosphorus bicarbonate (not used widely in the sugar industry), and aluminium saturation % (not critical for sugarcane and directly related to calcium values) may also appear in the results of a soil analysis when analysed by a commercial laboratory.

Table 1. Reliability of soil analyses for sugarcane nutrition.

Soil assay	Reliability
Calcium	A
Magnesium	A
Phosphorus	A
Potassium (after harvest)	A
Zinc	A
pH (water)	Ap
Aluminium	Ap
Sodium	Ap
Conductivity (SEC)	Ap
Potassium (after fallow)	B
Potassium (nitric)	B
Cation exchange capacity (pH 7)	B
Sulfate-Sulfur	B
Copper	B
Iron	C
Manganese	C
Boron	C
Organic carbon	C
Nitrate-Nitrogen	C
Chlorine	D
Exchange acidity	D
Aluminium saturation	D
Silicon	D

Group A (most reliable). The amounts of fertiliser to be applied can be recommended from the results of these tests.

Group Ap. These tests help identify problem areas.

Group B (average reliability). When the result is very high or very low, the test indicates the need for fertiliser. If the test result is in the intermediate range, it is of limited value for predicting whether or not fertiliser applications are required for sugarcane.

Group C (unreliable). These tests are of value for other crops but are of limited value for sugarcane. They indicate only low or high values but are not reliable indicators of deficiency.

Group D (experimental). At this stage, these soil tests are regarded as experimental for sugarcane.

LEAF ANALYSIS

Leaf analysis measures the nutrient content of the plant tissue and has been correlated with yield response to provide the relevant value for balanced nutrition. Leaf analysis is a useful supplement to soil testing for evaluation of the fertility status of the crop and assessing the adequacy of fertiliser recommendations.

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 (e.g. water stress), and interactions between nutrients.

Procedure for leaf sampling

The crop to be analysed should be actively growing and be 3–5 months old at the time of sampling in Queensland and 4–7 months old in New South Wales. Samples should be collected between November and April in Queensland and December and March in New South Wales when moisture stress is usually not a problem. At least six weeks should have passed since any fertiliser application. Stalks of average height should be selected and only the 200 mm mid-section from the third leaf, with the mid-rib removed, is suitable for foliar analysis. (The first leaf that is more than half unrolled is counted as the first leaf). A total of at least 20 leaves should be collected for each sample. Samples should be kept in a clean paper bag and stored in a polystyrene cooler prior to laboratory drying at 70°C. Once the sample is dry, include relevant information about the sample and send it to the laboratory for analysis.

As with the collection of soil samples, cleanliness is essential. Ensure that samples do not become contaminated by soil, fertiliser, dust, agricultural chemicals or galvanised coatings. The cane must not be affected by some other factor such as disease, insect damage or abnormal climatic factors like waterlogging or drought.

Leaf analysis critical levels are shown in Table 3.

CANE ANALYSIS

Current research is focussed on determining the levels of nutrients in sugarcane at harvest, using near infra-red spectroscopy. The main

Table 2. Soil assay critical values.

Soil assay	Unit	Deficient	Marginal
Calcium	cmol(+)/kg	less than 0.65	0.65–1.50
Magnesium	cmol(+)/kg	less than 0.10	0.10–0.30
Phosphorus	mg/kg	less than 10	10–20
Potassium (after harvest)	cmol(+)/kg	less than 0.2	—
Potassium (after fallow)	cmol(+)/kg	less than 0.25	—
Potassium (nitric)	cmol(+)/kg	less than 0.2	0.2–0.60
Sulfate-Sulfur	mg/kg	less than 3	3–7

Soil assay	Unit	Low
Copper	mg/kg	less than 0.30
Zinc (HCl)	mg/kg	less than 0.60
Nitrate-nitrogen	mg/kg	less than 5.00
Iron	mg/kg	less than 5.00
Manganese	mg/kg	less than 5.90
Boron	mg/kg	less than 0.15
Silicon	mg/kg	less than 100 (BSES-P extract)
Silicon	mg/kg	less than 10.00 (calcium chloride)

Table 3. BSES critical levels for third leaf assays.

Third leaf assay		Critical level of assay
Nitrogen	%	1.80
Phosphorus	%	0.19
Potassium	%	1.11
Calcium	%	0.20 at crop age of 12-16 weeks
Magnesium	%	0.08
Sulfur	%	0.10 at crop age of 8 months, or 0.13 at 3 months + nitrogen % /sulfur % ratio > 17
Copper	mg/kg	2
Zinc	mg/kg	10
Iron	mg/kg	50
Manganese	mg/kg	15
Boron	mg/kg	1
Molybdenum	mg/kg	0.08
Silicon	%	0.7 (provisional)

focus is on monitoring nitrogenous compounds (amino acids) that are sensitive indicators of crop nitrogen supply. This information can be linked to the block from which the cane was supplied and used as a basis for adjusting nitrogen management in subsequent seasons. Potentially, the nitrogen (and possibly other nutrients) content of all rakes of cane supplied to a mill will be able to be determined.

NUTRIENT REMOVAL BY THE CANE CROP

Table 4 shows the quantities of most of the essential nutrients which are removed by

average cane crops in various parts of Queensland. Wide variations in nutrient removal figures will occur depending on soil type, weather conditions and fertiliser practices.

Generally, the crops in the highest producing regions remove most nutrients per hectare. No simple relationship exists between soil fertility, fertiliser application, and nutrient removal by the crop and the widespread practice of green-cane harvesting and preservation of the trash blanket in the field is influencing nutrient removal figures (see next section). However, the Bundaberg region has the highest removal of potassium, calcium, magnesium and sulfur per tonne of cane produced, while the Babinda-Tully region has the lowest removal of calcium, magnesium and sulfur per tonne of cane. The Herbert region has the highest nitrogen removal per tonne of cane, while the Burdekin has the lowest.

Sugarcane recovers only 20–40% of the nitrogen applied as fertiliser. However, cane will luxury feed on nitrogen and some other nutrients, including potassium and silicon, taking up far greater quantities of the nutrients than are necessary for sound growth, for no extra benefit to the plant.

For many years, phosphorus application rates have generally exceeded crop removal rates in all areas except the Burdekin Delta,

where natural soil fertility generally precludes the need for phosphorus fertilisers. Over-use of phosphorus fertiliser has resulted in an average annual gain of about 8 kg/ha of phosphorus in sugar-producing soils. However, there has been a slow depletion of soil reserves of potassium, calcium, magnesium and sulfur, because crop removal figures have exceeded inputs. The potassium imbalance is complicated by the capacity of sugarcane to acquire luxury levels of potassium from soil and fertiliser sources. The long-term situation is likely to be ameliorated by return of potassium in crop residues after green-cane harvest, and application of reserve potassium from products such as boiler ash. Calcium and magnesium reserves can be managed with calcitic and magnesic limestone and sulfur with sulfur fertilisers or gypsum.

NUTRIENT AND CARBON CYCLING IN GREEN-CANE TRASH-BLANKETS

Burning the crop before harvest and raking and burning the residues after harvest results in losses of 90–95% of carbon, nitrogen and sulfur as gases to the atmosphere. Eighty to 90% of phosphorus, potassium, calcium and magnesium can also be lost as air-borne ash from the site being burnt. Nutrient returns by incoming ash have not been quantified.

A typical green-cane trash-blanket (GCTB) contains the equivalent of 7–15 t/ha of dry

Table 4. Average amounts of nutrients removed by cane crop (cane, tops, trash) (kg/ha).

Nutrient	Mossman to Cairns	Babinda to Tully	Herbert	Burdekin	Mackay	Bundaberg	Maryborough to Rocky Point
Nitrogen (N)	143	122	128	154	123	150	134
Phosphorus (P)	18	17	15	37	18	23	20
Potassium (K)	217	208	139	276	203	260	234
Calcium (Ca)	39	27	30	55	41	51	31
Magnesium (Mg)	26	18	29	57	35	52	36
Sulfur (S)	35	25	25	47	25	48	34
Copper (Cu)	0.09	0.07	0.09	0.11	0.09	0.09	0.12
Zinc (Zn)	0.68	0.46	0.43	0.59	0.38	0.37	0.39
Iron (Fe)	6.42	7.32	7.49	5.65	6.93	8.61	6.56
Manganese (Mn)	6.79	3.91	4.89	1.90	3.64	2.66	2.89
Cane yield (t/ha)	100	93	74	119	84	92	85

matter. This residue layer contains 3000 to 6500 kg/ha of carbon as well as 50–100 kg/ha nitrogen, 5–10 kg/ha of phosphorus, 30–90 kg/ha of potassium, 30–50 kg/ha of calcium, 15–25 kg/ha of magnesium, and 8–11 kg/ha of sulfur.

Smaller amounts of the trace elements are also contained in the green trash-blanket. Improved conservation of soil moisture by the GCTB system, compared to the burnt system, also provides higher soil moisture levels which results in enhanced nutrient utilisation.

For most of the major nutrients, the quantities contained in the green trash represent about a quarter to a half of the total annual crop uptake (Table 4). However, this is not available immediately.

Most of the green trash-blanket decomposes within 12 months after harvest. The rate of decomposition is slightly higher in the tropics than in the southern areas of the industry (approximately 98% at Tully, and 82–91% at Mackay and Harwood). As the trash blanket decomposes, some of the organic matter is released as carbon dioxide gas and is lost from the system. The rest of the carbon and nutrients become part of the soil reserves, or total soil pool of nutrients. These reserves must be decomposed further to release nutrients in an available form that the crop can take up and use for growth. As the period of trash blanketing increases, total soil carbon gradually increases and microbial growth and activity is stimulated. Cane fires result in carbon that is in the form of charcoal (inert), so the quality of carbon from GCTB (more biologically active) is higher.

Soil nutrient levels take some time to increase as a result of green-cane trash-blanketing. Experiments have shown that 1–2 years of GCTB has no effect on soil carbon and nitrogen levels. As a rule of thumb, a crop cycle (approximately 5 years) of green trash-blanketing is needed for significant increases in soil nutrient levels to occur as a result of the practice. These changes occur only in the upper 20–50 mm of soil. Hence, no reduction in fertiliser application rates should be made in the first crop cycle of GCTB. A small reduction of about 10–15% (of current recommendations) in fertiliser inputs may be possible in the second crop cycle, rising to 25% of current recommendations in later crop cycles.

Eventually, equilibrium under GCTB is reached. The time to reach that equilibrium ranges between about 6 and 35 years, with the likelihood that the majority of blocks will take 10-15 years. When equilibrium is reached, maximum mineralisation of nitrogen in trash has been reached and equals the amount of nitrogen being returned annually in the trash (about 50–100 kg/ha/year). This is the maximum amount by which recommended nitrogen fertiliser rates could be reduced. It is possible that fertiliser applications may not ever be able to be reduced to this extent if, for example, fertiliser nitrogen loss is greater in GCTB than in burnt systems and/or nitrogen availability to the crop is reduced under GCTB due to increased microbial immobilisation of nitrogen. It has been suggested that leaching and denitrification may be promoted under GCTB due to the increased carbon and water contents. However, indications are that GCTB could result in soil total nitrogen increasing by 1.3–21% and soil organic carbon increasing by 1.4–14%.

NITROGEN (N)

Nitrogen is one of the main building blocks of proteins. Nitrogen is responsible for growth and expansion of green leaves and is essential for photosynthesis and sugar production.

When nitrogen is deficient, the growth of the entire plant is affected. Stalks will be thin and stunted and leaves turn light green to yellow, often with necrosis (death of tissue) on the tips and edges of older leaves (Figure 4). Both stooling and the root mass will be reduced.

Nitrogen is a mobile nutrient in the plant. When nitrogen is deficient, it is readily

Figure 4. *Leaves from nitrogen deficient cane (left) and from healthy cane (right).*

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.

Nitrogen not needed for immediate growth processes is stored in the stalk as amino acids, which can be subsequently mobilised for growth. Excessive applications of nitrogen will result in high levels of amino acids, primarily asparagine, in the stalk, prolonged growing conditions, lower CCS and reduced juice purity. Amino acids react with reducing sugars (glucose and fructose) during milling to produce high molecular weight colourants that colour sugar crystals and reduce sugar quality. The probability of crop lodging will be increased with high rates of nitrogen. Recent research points to stimulation of suckering with increased availability of nitrogen in the autumn and winter months.

The nitrogen cycle

The nitrogen cycle (Figure 5) describes all the processes by which nitrogen circulates between the atmosphere, the soil, and plants and animals.

Nitrogen in the air and soil

Seventy-eight per cent of the air is nitrogen. Each hectare of land has approximately 78 000 tonnes of nitrogen in the air above it. However, plants generally can not use this form of nitrogen until it is converted into a form called ammonium (NH_4^+) or nitrate (NO_3^-). This conversion is usually done for plants in industrial factories, where large amounts of natural gas are used to make urea, ammonium nitrate, ammonium sulfate or anhydrous ammonia fertilisers.
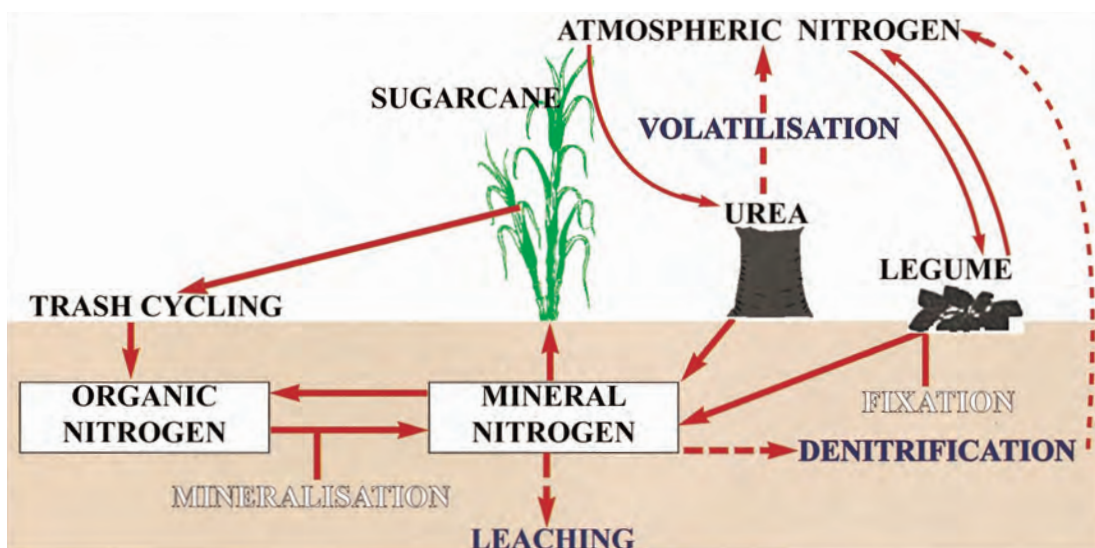

Figure 5. *Nitrogen cycling in sugarcane crops.*

The soil contains a large proportion of nitrogen in organic matter. Nitrogen is also present as nitrogen gas (N_2), nitrite (NO_2^-), nitrous oxide (N_2O), nitric oxide (NO), ammonia (NH_3), ammonium (NH_4^+), and nitrate (NO_3^-). Only the last two forms of nitrogen can be used by the plants. Nitrogen in any other form must be converted to one of these forms to be available to sugarcane.

The total amount of nitrogen in the surface metre of soil is 7–9 t/ha (equivalent to 15–20 t/ha of urea). Only a very small proportion of this nitrogen becomes available to the crop each year via a process called mineralisation.

Leguminous plants, such as cowpeas, soybeans, peanuts and beans, can grow in soils which lack nitrogen providing the soil contains a certain type of bacterium called *Rhizobium*. Legume roots form nodules in which rhizobia convert nitrogen from the air into a form that can be used by the legume. This process is called nitrogen fixation. The nitrogen fixed by the legume crop is then added to the soil following decomposition of the legume crop. A well-grown crop of cowpeas is capable of supplying about half the nitrogen requirement of the following plant-cane crop, whereas a well-grown crop of soybeans can supply the total nitrogen requirement. Leguminous residues decompose rapidly, especially when incorporated into the soil. Therefore, there is major opportunity for the nitrogen to be leached below the root zone before crop uptake. More gradual release of the nitrogen may be effected by direct planting of cane into slashed leguminous residues.
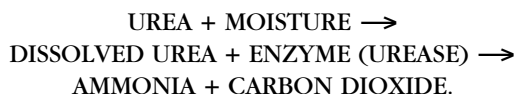
There is mounting evidence that stems, roots and leaves of a number of tropical grasses, including sugarcane, are colonised by several species of bacteria (*Acetobacter, Herbaspirillium, Burkholderia* spp.) with nitrogenase capacity (ability to convert atmospheric nitrogen to amino nitrogen) for direct use by cane. This capacity has been documented to 180 kg N/ha/yr but is thought to contribute around 60 kg N/ha/yr in some commercial Brazilian cultivars. While the bacteria recently have been isolated from a range of Australian cultivars, nitrogen-fixing capacity is still being evaluated.

Loss of nitrogen from the soil

The sugarcane crop removes some nitrogen from the soil. Nitrogen is also lost through volatilisation, denitrification and leaching.

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 the urea dissolves. Ammonia gas is formed and is lost to the atmosphere. The process of volatilisation can be summarised as follows:

$$\text{UREA + MOISTURE} \longrightarrow$$
$$\text{DISSOLVED UREA + ENZYME (UREASE)} \longrightarrow$$
$$\text{AMMONIA + CARBON DIOXIDE.}$$

Nitrogen loss from urea or urea-based mixtures applied on the surface of green-cane trash-blankets can be very high (up to 60 kg N/ha have been measured in 28 days). Volatilisation losses are highest when light rainfall (less than 10 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. Volatilisation of sulfate of ammonia is negligible. However, the cost of sulfate of ammonia usually precludes its use as an alternative to urea as a source of nitrogen.

Certain soil bacteria thrive in oxygen-deficient or anaerobic conditions such as in waterlogged fields. Under anaerobic conditions, nitrate nitrogen may be converted by the bacteria to nitrogenous gases which escape to the atmosphere. The denitrification process is enhanced in the presence of decomposing trash residues. The process of denitrification can be summarised as follows:

$$\text{NITROGEN FERTILISER + WATERLOGGING}$$
$$\longrightarrow \text{NITROUS OXIDE GAS + NITROGEN GAS.}$$
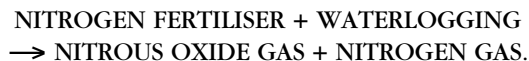
Denitrification can occur with all subsurface-applied (buried) nitrogenous fertilisers, once the nitrogen has been

converted to the nitrate form. Denitrification frequently occurs in cane harvested late in the season when early summer storms saturate blocks before the crop has had time to take up the applied nitrogen fertiliser. Denitrification losses can be higher for fertiliser buried in the middle of the interspace (the area most heavily waterlogged) than for fertiliser buried beside, or in, the row. Denitrification losses can be significant over short periods, with losses of 2–12 kg N/ha/week being measured from heavy clay soils. Losses of less than 1 kg N/ha/week were measured on well-drained soils of lighter texture.

Leaching refers to the loss of soil nitrates (one of the two forms of nitrogen that can be taken up by the plant) that 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. Loss of 50 kg N/ha from the root zone of sugarcane, within a month of application to a red earth (red kandosol) soil in southern Queensland, was attributed mostly to leaching.

Nitrogen losses can be high when urea is surface-applied to ratoons with no canopy, followed by very light rainfall or heavy dew, with hot, windy days (volatilisation), and when urea is buried in the interspace, followed by heavy, prolonged rainfall leading to waterlogging of the interspace, especially in the presence of cane-trash residues (denitrification and/or leaching). Urea is by far the cheapest source of nitrogen. Very large volatilisation losses would have to occur for one of the alternatives to urea to be economically competitive. Specific management techniques (for example, subsurface application or delayed surface application) should be used to capitalise on urea's cost advantage.

Nitrogen removal by the cane crop

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. The rest of the nitrogen goes into the soil reserves or is lost by volatilisation, denitrification, or leaching. Table 4 shows that an average of about 140 kg/ha/year of nitrogen is removed by a crop of cane. This nitrogen is supplied in the annual fertiliser application and by the mineralisation of organic nitrogen reserves, including the nitrogen in crop residues.

Response to nitrogen applications

Trial data indicate the same nitrogen rate recommendation for northern, central and southern regions of Queensland can be made, but higher application rates of nitrogen fertiliser are justified in the Burdekin and Mareeba districts because of higher yield potential. The optimum fertiliser rate for the most economic return depends on a number of factors including the climate, crop class, whether a legume has been grown, soil type, rainfall, length of time green-cane trash-blanketing has been practised, and irrigation. Extension staff and agribusiness advisers now have access to computer software to assist in determining crop nitrogen requirements based on these factors. Most recent assessments of the nitrogen requirement of sugarcane in Australia were distilled into the following rule of thumb:

N requirement from all sources =
1.4 kg N/tonne of expected cane yield to
100 t/ha then + 1 kg N/t of expected
cane yield thereafter

In all districts, trial data clearly indicate lower nitrogen requirements for plant cane than for ratoon and replant cane. This is due to mineralisation of nitrogen in the soil during the fallow period. This nitrogen is available for growth of the plant crop. Since only a short fallow period precedes a replant cane crop, the replant crop should be fertilised at the same rate as ratoon cane.

Nitrogen rates for plant cane can be reduced by at least 50–60 kg/ha following a heavy legume crop. Recent results in north Queensland show up to 200 kg N/ha can be mineralised from soybean residues within 70 days of incorporation. However, half of

this nitrogen was leached in the first 2 months of crop growth. Nitrogen fertiliser inputs should be reduced by at least 100 kg N/ha after incorporation of a heavy soybean crop.

Within districts, there are variations in yield responses to nitrogen fertiliser between soil types. The most important of these is the so-called 'rich land' effect in north Queensland and in some areas of south Queensland. Recent alluvial and peaty soils in these districts have lower nitrogen requirements because these soils mineralise more nitrogen than other soil types. This feature is likely to be represented in future fertiliser advice as a potential nitrogen mineralising capacity value, by which fertiliser inputs may be reduced when values are moderate to high.

Vigorous varieties grown on 'rich land' 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 high nitrogen rates. Once sugar yields begin to fall, there will obviously be a loss from any investment in additional nitrogen fertiliser.

In dry districts, where irrigation is either not available or available only in limited quantities, there is generally insufficient moisture available for the crop to use high application rates of nitrogen. In these cases, there is no increase in crop yield with increasing rates of nitrogen. Once the yield reaches this plateau, there will be an economic loss from further investment in fertiliser. Thus, impact of effective rainfall and radiation environments on nitrogen recommendations are recognised in the expected yield factor.

Nitrogen application rates may be reduced for blocks which have been in the green-cane trash-blanket system for about 10 years. Refer to the section titled 'Nutrient and carbon cycling in green-cane trash-blankets'.

Higher rates of nitrogen are justified where irrigation is used and the expected yield factor again comes into play.

Nitrogen fertilisers

Many commercial sources of nitrogen are available. The most common forms are summarised in Table 5.

The use of most nitrogenous fertilisers tends to acidify soils, particularly if nitrogen is leached once is has converted to the nitrate form. Ammonium fertilisers acidify soils because of hydrogen released during the nitrification process. Urea and nitram do not have an acidifying effect unless nitrogen is leached. Sulfate of ammonia has approximately three times the acidifying effect of urea and nitram, and about 1.5 times

Table 5. Common forms of mitrogen fertiliser.

Nitrogen fertiliser	Common term	% nitrogen
Urea	Urea	46
Di-ammonium phosphate	DAP	18–19
Mono-ammonium phosphate	MAP	12.6
Ammonium nitrate	Nitram	34
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
Waste materials[1]		
Filter mud	Mill mud	1.5 (0.8–2.2)
Filter mud/ash mixtures	Mud/ash	0.6 (0.4–0.8)
Mill ash	Ash	0.15 (0.1–0.5)
Sewage sludge	Sewage sludge	3.1 (0.5–6.6)

[1]Waste materials contain organic nitrogen. Only part of this nitrogen will be available in the year of application.

that of DAP. Ammonium fertilisers have a greater acidifying effect than urea because of the combined effects of nitrification and leaching.

Nitrogen rate recommendations

Recommended nitrogen rates are given in Table 6. These are broad recommendations based on regional yield calibration experiments. Variations to the broad recommendations (discussed above) should take into account yield expectation, soil properties and processes, the history of green-cane trash-blanketing, the use of legumes, vigorous sugarcane varieties, irrigation, prior use of soil ameliorants such as mill mud and dunder, and new canegrowing land. Nitrogen rates may also be reduced in blocks where GCTB is practised. Refer to the section titled 'Nutrient and carbon cycling in green-cane trash-blankets'.

Table 6. Recommended nitrogen rate (kg/ha).

		Burdekin	All other districts
All soil types (except dryland and/ or richland)*	Fallow plant	135–150	120–150
	Replant & ratoons	210–250	160–200
		All districts	
Dryland and/ or richland*	Fallow plant	80	
	Replant & ratoons	120	

*Dryland—areas receiving less than 1200 mm of annual rainfall and no irrigation. Richland—usually recent alluvial or peaty soils. The sugar yield response is cut off sharply at higher nitrogen application rates because lodging and deterioration may cause a decline in CCS and cane yield.

Nitrogen placement in ratoons

The following advice applies to urea or urea-based fertiliser mixtures, the recommended sources of nitrogen.

In cultivated ratoons, fertiliser should be applied subsurface (buried) in the soil in a band on each side of the cane row in blocks that are mechanically cultivated after burnt harvest. Burying fertiliser directly into the row (split stool application) is a satisfactory alternative to banding the fertiliser on each side of the row.

In green-cane trash-blanketed (GCTB) ratoons, there are three ways of applying N fertiliser. In Method A, fertiliser can be applied safely on the surface of cane rows soon after harvest if rainfall or overhead irrigation greater than 15–20 mm is applied soon after fertiliser application. Otherwise, one of the following options should be used.

In Method B, urea is buried in a band on each side of the cane row, and this overcomes volatilisation losses. Denitrification losses may be reduced since the band of fertiliser is higher in the soil profile than the middle of the interspace that is most prone to waterlogging. The nitrogen is close to the stool and is readily accessed by the cane roots.

However, equipment to bury fertiliser through a trash blanket and into the soil is expensive, but employment of a contractor may be an economical alternative. Subsurface application is also much slower and is more difficult than surface application.

Research shows split-stool application often produces similar yields to those achieved by burying fertiliser on each side of the row. No permanent stool damage appears to result when the fertiliser is applied behind a coulter and tine to a depth of 70–100 mm.

In Method C, urea is applied in a surface band along the row when the cane canopy is approximately 0.5 m high (delayed surface application).

This option is not recommended for flood-irrigated blocks. Method B is safest for flood irrigated blocks.

Surface application is very quick and inexpensive. The canopy reduces volatilisation losses by lowering the trash and soil surface temperature, by reducing wind flow across the surface, and by protecting the fertiliser from overnight dew. The new ratoon roots have developed and are ready to use the

fertiliser. (Ratoons do not effectively use applied fertiliser until several weeks after harvest).

In most experiments, delayed surface application of urea has produced similar yields to subsurface application on green trash-blanketed blocks. This was particularly the case if rainfall or overhead irrigation of 15 mm or more occurred soon after application of the urea.

However, volatilisation losses may still be significant, and delaying surface fertiliser application until the cane canopy is 0.5 m high on cane harvested late in the season can be risky. If summer rains set in, fertiliser application may not be possible for an unacceptably long time.

In burnt-cane trash-blanketed (BCTB) ratoons, urea should be buried in a band on each side of the cane row or be applied in a surface band along the row when the cane canopy is approximately 0.5 m high, providing rainfall or overhead irrigation greater than 15 mm is applied soon after fertiliser application.

PHOSPHORUS (P)

Phosphorus is absorbed by plants as phosphate (PO_4^{3-}) ions. Phosphorus is important in spindle development and in the promotion of early root formation and growth. Phosphorus is essential for the formation of a strong and vigorous root system and plays a role in photosynthesis and many other biochemical processes such as cell division and cell growth. Phosphorus also contributes to disease resistance in most plants.

The older leaves exhibit phosphorus deficiency symptoms before young leaves. Stalks will be thin and short with short internodes. Tillering will be poor and young shoots may die before reaching the surface of the soil. The leaf blades are dark-green to blue-green, often with red or purple tips and margins (Figure 6). Leaves are thinner, narrower and shorter than normal. The older leaves turn yellow and die back from the tips

Figure 6. *Phosporus deficiency.*

and along the margins. The leaves may stand abnormally upright.

Excessive levels of soil phosphorus may cause other nutrients such as copper, zinc, manganese and iron to become less available for plant growth. This interaction has been observed particularly in new land where relief of phosphorus deficiency with recommended rates of superphosphate induced symptoms of copper deficiency. The latter example probably includes the former effects of nutrient availability, and sequential expression of nutrient limitations to growth as various deficiencies are corrected. It has been suggested that excess phosphorus in the soil is associated with zinc deficiency. However, recent field and glasshouse studies have not shown a link between high levels of phosphorus in soil and sub-optimal zinc nutrition of sugarcane in Queensland.

Phosphorus in the soil

Most Australian soils have low phosphorus levels in their natural state. 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 to the inorganic form that can be used by the crop. Organic matter supplies only a very small proportion of the phosphorus required by the crop.

Phosphorus in the soil is relatively immobile (see Fixation below) and is subject to very little leaching. The major loss process for phosphorus is erosion or land levelling operations that remove the top soil.

Most Australian canegrowing soils now have moderate to high levels of available phosphorus because of long-term use of rates above crop and soil requirements prior to 1983. After that time, application rates declined in response to modified recommendations and low sugar prices. Phosphorus can usually be omitted from at least one ratoon crop with no effect on yield. A soil test will assist with this decision.

Fixation

The cane crop takes up some of the phosphorus applied to soils in phosphatic fertilisers, and some reacts with soil minerals to form insoluble compounds. The phosphorus is fixed in these insoluble compounds (iron and aluminium phosphates) and is not readily available to the cane crop. Some soils (for example, red volcanics or krasnozems) have large phosphorus-fixing abilities because of the high iron and aluminium content of their clays. 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 that the cane can use will increase. This effect is reproduced by banding phosphorus fertilisers close to the stool. Thus, the phosphorus-fixing capacity of a soil is not likely to impact on the nutrition of sugarcane where soil phosphorus levels are moderate to high and phosphorus fertiliser is banded rather than broadcast.

Response to phosphorus

Broadcast phosphorus is recommended as a 'new' land development option only for phosphorus deficient soils with a very high P-sorption. Responses to pre-planting broadcast phosphorus on other soils, even those with very low phosphorus levels, have not occurred.

On canegrowing 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 cane crop can use. On these soils, phosphorus rates can 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 of the soil and to assist with the decision to reduce or eliminate phosphorus applications. Plant and replant cane give a greater response to phosphorus than ratoon cane.

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. Phosphorus fertilisers include superphosphate, triple superphosphate, DAP (diammonium phosphate), MAP (monoammonium phosphate), rock phosphate, and high-analysis fertiliser mixtures.

Superphosphate (9.1% total P) is made from rock phosphate and sulfuric acid. It also contains sulfur (11%) and calcium (20%). Superphosphate is sometimes called single super.

Triple superphosphate (19.2% total P) 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 (diammonium phosphate—20.2% total P) and MAP (monoammonium phosphate—22.0% total P) are concentrated sources of phosphorus made from anhydrous ammonia and phosphoric acid. MAP or DAP is made by controlling the amount of ammonia added to the process. Both products contain significant amounts of nitrogen (13–19%) and are used in making the high analysis fertiliser mixtures.

Rock phosphate (about 22% total P) 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, therefore, must be finely ground to be of use as a direct source of phosphorus in agriculture. High-analysis NPK mixtures are made by adding potassic fertiliser to DAP or MAP. Urea is also added to produce high-analysis 'one shot' mixtures where the total NPK requirement of the crop is applied in single application of mixed fertiliser.

Phosphorus rate recommendations

Recommended rates of phosphorus are given in Table 7. Soils should be sampled before each crop cycle to determine fertiliser requirements.

Since 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 economical practice. The same practice could be adopted for replant cane.

Rock phosphate is satisfactory for the maintenance of phosphorus levels in soils that have had adequate phosphorus applications in the past.

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.

Phosphorus placement

When applied as a pre-plant application on new land, phosphorus fertiliser should be broadcast and incorporated into the soil. In plant cane, replant cane and cultivated ratoon cane, phosphorus should be buried in a band on each side of the row. In zero- or minimum-tillage ratoon situations, the phosphorus fertiliser can be applied on top of the soil or trash. Losses from volatilisation do not occur, and reserves of soil phosphorus will increase. However, if the soil is low in phosphorus, subsurface application is preferable to allow

Table 7. Recommended phosphorus rates.

Soil phosphorus level (P mg/kg)	High yield (more than 120 t/ha)		Lower yield (less than 120 t/ha)	
	Plant & Replant	Ratoon	Plant & Replant	Ratoon
	Recommended rate of phosphorus (kg/ha)			
Lower than 6*	80	40	80	25
6–10*	60	40	40	25
11–20*	40	40	25	25
21–40	20	20	20	20
More than 40	20	Nil	20	Nil

*Economic yield responses could be expected from initial broadcasting of 1.25 t/ha of superphosphate on soils with high P sorption (more than 500 mg/kg phosphorus); row application should be restricted to 40 kg/ha phosphorus in these instances. High P-sorption soils include humic gleys, some yellow earths, some krasnozems and some old alluvials.

the roots ready access to the fertiliser. Phosphorus is immobile in the soil and moves only about 10 mm from its point of application.

POTASSIUM (K)

Potassium is taken up by the plant in the form of potassium ions (K^+). Potassium is essential for plant growth and photosynthesis by being involved in chlorophyll development in the leaves. Potassium helps the plant use other nutrients and water more efficiently and controls the movement of sugars in the plant. It regulates stomatal opening and closing. Potassium promotes root development and allows plants to take up water (and nutrients) by osmosis. It helps prevent premature cell death and controls starch formation.

The older cane leaves exhibit deficiency symptoms before young leaves. Stalks will be thin and stools will be stunted. The young leaves usually stay dark green. The spindle may have a fan appearance. On the older leaves, dead areas or dark-red stripes may occur between the leaf veins and along leaf edges and tips, giving a 'fired' appearance (Figure 7). In young crops, lower leaves often turn deep yellow, with 'fired' margins and tips, before the whole leaf undergoes premature senescence. Potassium deficiency symptoms resemble those of salinity stress, but in the latter case young leaves are also affected. The root system will be poor and plant growth will be slow. The plant's resistance to diseases is reduced.

Sugarcane can acquire luxury levels of potassium from fertile soils or applied fertiliser. Excessive potassium increases the ash content of sugarcane juice and reduces the recovery of raw and refined sugar. Applications of potassium above BSES recommended rates will not result in increased cane yield or CCS. Too much potassium can induce calcium or magnesium deficiency where the latter nutrients are at marginal levels in soil.

Potassium in the soil

Most soils contain large amounts of potassium. In the top 150 mm of soil, up to several tonnes per hectare of potassium may exist. However, only a small percentage of this amount is available to plants. Soils rich in clay or minerals derived from granite generally have high levels of potassium. However, some clay soils [for example, the red volcanics (krasnozems or red ferrosols)] are lower in potassium because of the type of clay associated with those soils. Sandy soils generally have very low levels of potassium.

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

Unavailable potassium (90–98% of total soil K) is found usually as feldspar minerals from 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 K) is fixed or trapped between layers of certain soil clays (illites and montmorillonites). Potassium is unavailable or is only slowly released for plant growth.

Available potassium is made up of two components: the potassium found in the soil

Figure 7. *Potassium deficiency.*

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

Two tests are often conducted on soil samples to assess the potassium status of the soil. The 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. The nitric potassium test (K nitric) measures the slowly available potassium and indicates soil potassium reserves. The test is a measure of a soil's potential to supply potassium.

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. Some clay soils have the potential to absorb potassium between clay platelets. These soils usually have high potassium reserves. The implications of this potential to fix potassium are yet to be evaluated for caneland soils. However, in most soils all potassium applied in fertiliser is available for plant use.

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

Response to potassium

Ratoon and replant cane is more responsive to potassium fertilisers than plant cane because soil 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, therefore, require more potassium fertiliser than does plant cane.

Potassium fertilisers

Potassium fertilisers may 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—50.0% K) is made by refining the natural potash salts. Other potassium sources include potassium sulfate (sulfate of potash—41.0% K), potassium nitrate (38.3% K), and potassium magnesium sulfate (18.0% K).

Dunder, a by-product of ethanol production, and molasses are also rich sources of potassium.

Potassium chloride is water soluble. It is the cheapest and most commonly used form of potassium. Potassium sulfate contains 16.5% sulfur, in addition to potassium. Potassium nitrate contains 13% nitrogen, in addition to potassium. Potassium magnesium sulfate contains 11% magnesium and 22% sulfur, in addition to potassium.

Green-cane trash-blankets return a significant amount of potassium to the soil. A typical green trash-blanket contains approximately 30–90 kg/ha of potassium. This potassium is leached out of the trash very quickly. Potassium in the trash is in the inorganic form and becomes available for crop growth immediately. Most of the potassium can be leached from a trash blanket by about 20 mm of rain.

Potassium rate recommendations

Broad recommended application rates of potassium are given in Table 8. These inputs are less than the crop removal figures. However, preliminary experimental data indicate the current potassium fertiliser recommendations plus the potassium returned in green-cane trash-blankets approximately balances the amount of potassium removed by the millable crop.

The recommended rate should not be exceeded, particularly for soils with good potassium status, as the cane crop will luxury feed on any excess potassium. This 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.

Table 8. Recommended potassium rate.

Soil potassium level	Recommended rate of potassium (kg/ha)	
LOW K exchangeable less than 0.2 cmol(+)/kg & K nitric less than 0.2 cmol(+)/kg	Plant Ratoon & replant	100 120
INTERMEDIATE* K exchangeable less than 0.2 cmol(+)/kg & K nitric 0.2–0.6 cmol(+)/kg	Plant Ratoon & replant	80 100
K exchangeable less than 0.2 cmol(+)/kg & K nitric more than 0.6 cmol(+)/kg	Plant Ratoon & replant	50 70
HIGH K exchangeable more than 0.2 cmol(+)/kg & K nitric less than 0.6 cmol(+)/kg	Plant Ratoon & replant	50 50
K exchangeable more than 0.2 cmol(+)/kg and K nitric more than 0.6 cmol(+)/kg	Plant Ratoon & replant	0 0–50

*In the Burdekin, reduce potassium fertiliser by the amount applied in irrigation water (approximately 30-40 kg/ha). An analysis of irrigation water is advisable.

Potassium inputs in the GCTB system may be reduced on soils with good potassium fertility by the amount of potassium released from the trash blanket (50–100 kg K/ha) depending on cane yield and degree of luxury uptake.

Potassium inputs to GCTB crops on soils with low potassium fertility should not be reduced in the short to medium term until research establishes the impacts of previous over-extraction of low soil potassium reserves.

Potassium placement

When added to the soil, potassium becomes lightly attached to the clay and, therefore, is not readily 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 with nitrogen from surface-applied urea. Surface-applied potash, like nitrogen, will eventually find its way into the root zone of ratoons.

In plant cane, replant cane and cultivated ratoon cane, potassium fertiliser should be buried in a band on each side of the row. Care should be taken when applying the planting mixture or straight potash at planting to ensure that potash burn does not occur. This effect is caused by osmotic desiccation of plant cells and is effectively a salting injury. If the potash is in contact with, or very close to, the cane setts, fertiliser burn can result in delayed or failed germination of some of the eyes of the sett. Root stubbing may also occur.

In trash-blanket or minimum-tillage cultivation, the potassium fertiliser can be applied on top of the soil or trash.

CALCIUM (Ca)

Calcium is an abundant element in the earth's crust, occurring commonly as natural limestone deposits. Calcium is an important plant food. Calcium deficiency symptoms in old canegrowing soils have become evident since the mid-1970s. Calcium and magnesium deficiency symptoms often occur together.

Calcium is absorbed by plants as a calcium ion (Ca^{2+}). Calcium is essential for the growth and development of the spindle, leaves and roots. Calcium comprises part of the cell walls, thus strengthening the plant. The nutrient plays an important role in nitrogen metabolism.

When calcium is deficient, the older leaves are often pale green or yellow (Figure 8) and may die prematurely. The stalks are thin and

taper towards the growing point. Root growth is often poor. 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 and the primary shoot may die.

Calcium is relatively immobile in the plant. When it is deficient, calcium is not transferred in significant quantities from the older parts of the plant to the actively growing younger leaves and growing point. The first and most obvious symptoms of deficiency appear on the younger leaves.

Calcium deficiency symptoms have become more common in recent years and usually occurs in acid soils, but acid soils are not necessarily calcium deficient.

The crop removes calcium each year, but cane land no longer receives regular applications of calcium from superphosphate that was used in low-analysis mixtures prior to 1970. Today's high-analysis mixtures are based on DAP or MAP which contain no calcium.

Excessive soil calcium levels are uncommon in canegrowing soils, but can

Figure 8. *Calcium deficiency.*

occur in small areas where loads of lime have been dumped prior to spreading on a block. Soil pH is raised to high values which restricts the uptake of some other nutrients. Nutritional disorders such as zinc, copper, and magnesium deficiency can result (Figure 2).

Calcium sources

A wide range of products can be used to supply calcium to the soil. These products vary in price 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.

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

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.

The calcium content (%) in the product, 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.

The form in which the calcium is present is also important, 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. Gypsum is even more soluble than burnt lime but is subject to leaching. Lime will adjust soil pH upwards, whereas gypsum supplies only calcium and sulfur and has no effect on soil pH. Liming products would, therefore, be preferred in most situations, but the solubility of gypsum can be used to overcome calcium deficiency below the plough layer.

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 an NV of 100%. Pure hydrated lime and burnt lime have NVs of 135% and 178%, respectively.

Agricultural lime or earth lime (calcium carbonate—30–40% Ca) is crushed limestone, and is the most common form of lime used in agriculture to correct calcium deficiency. It is usually 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 or quicklime/unslaked lime (calcium oxide—68% Ca) 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 an agricultural source of calcium.

Hydrated lime or slaked lime (calcium hydroxide—51% Ca) 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 (calcium sulfate—18–22% Ca) provides a soluble source of calcium. It is more soluble than lime and is readily leached from sandy soils. Some of the gypsum available to the sugar industry is a by-product of superphosphate manufacture (phospho-gypsum). Natural gypsum from north-west Queensland is also sold into the sugar industry. Natural gypsum can contain insoluble silicate minerals that decrease the solubility of calcium. A quality-assurance analysis is required to ensure such products qualify to be sold as gypsum and will be

effective. Because of its very low bulk density and resulting high freight costs, gypsum is less economic than lime as a source of calcium. The solubility of gypsum makes it an ideal soil ameliorant for sodic and hard setting soils to improve the physical condition of the soil. Gypsum also contains 12–18% sulfur.

Dolomite (calcium magnesium carbonate —14–18% Ca) is a naturally occurring mixture of calcium and magnesium carbonates and is used mainly to correct co-occurrence of calcium and 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 alone, as far too much magnesium would be applied.

Cement (46% Ca) is very fast acting in the soil and is a readily available source of calcium, magnesium (1.3%) plus silicates and some trace elements. Cement is usually too expensive to be used as a source of calcium.

Superphosphate (20% Ca) and triple superphosphate (15–18.5% Ca) provide a soluble form of calcium.

A range of calcium-magnesium blends (usually 29–33% Ca) provides economical sources of both calcium and magnesium. The blends are usually a mixture of agricultural lime and magnesium oxide or other source of magnesium such as serpentine. The blends provide about 3–5% magnesium. Lime and dolomite can also be blended to give more appropriate levels of calcium and magnesium than found in dolomite alone.

Calcium rate recommendations

Research shows soils are severely deficient in calcium if the soil test value is less than 0.65 cmol(+)/kg. Cane will respond to applied calcium until the value in soil is approximately 1.00 cmol(+)/kg. Therefore, for sustainable cane yield, 1.5 cmol(+)/kg has been established as the safety value below which soil calcium should not be allowed to fall. The required rate of calcium to achieve

MANUAL OF CANEGROWING

this position can be determined from the Liming Calculator in Figure 9. The Liming Calculator also allows a choice of lime or lime/magnesium blends to provide the required rate of calcium.

How do you determine how much of a product to apply if the product's calcium level is different to that represented in Figure 9?

$$\text{Rate of product} = \frac{100}{\text{calcium content of product (\%)}} \times \text{rate of calcium required (kg/ha)}$$

Example: If a product contains 30% calcium, how much of that product should I apply if my soil test is less than 0.55?

Answer:

$$\text{Rate of product} = \frac{100}{30} \times 750$$
$$= 2500 \text{ kg/ha}$$
$$= 2.5 \text{ t/ha}$$

Lime products with a neutralising value less than 90 should be applied at a higher rate. The rate can be calculated by using a ratio of the two neutralising values.

Example: An earth lime has a neutralising value of 70. What rate should the earth lime be applied to be equivalent to 5 t/ha of lime with a neutralising value of 90?

Answer:

$$\text{Rate of product} = \frac{5 \text{ t/ha}}{70} \times 90$$
$$= 6.4 \text{ t/ha of earth lime (NV = 70)}$$

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 5–6 years. A maintenance dressing of lime of about 1.5 t/ha at the end of each crop cycle is generally a good policy. A soil test at the end of the crop cycle will assist with this decision.

Liming may induce zinc and copper deficiency symptoms. There are two mechanisms for this effect: relief of calcium deficiency has increased productive capacity of soil to the point where low soil levels of copper and zinc are sub-optimal for growth; or soil zinc or copper levels were very low to start with, and the liming has reduced the availability of these elements by increasing
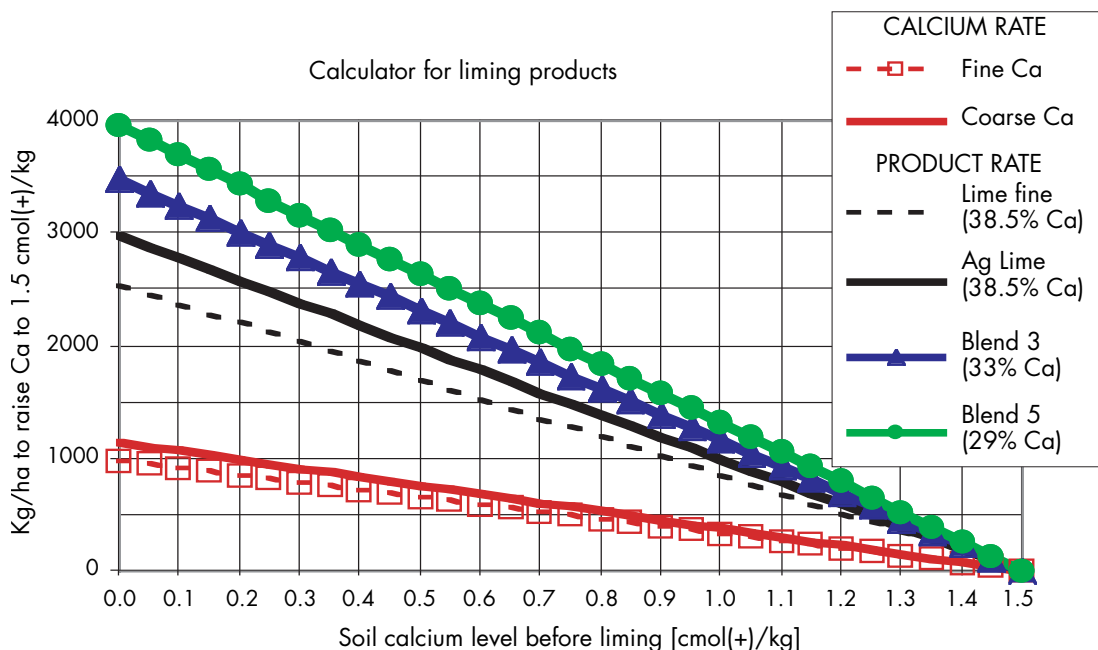

Figure 9. *Liming calculator for optimum calcium nutrition.*

174

soil pH. In both cases, the zinc and copper problem should be rectified. It does not mean that the liming should not have been carried out. Lime 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 1 month, but preferably 3–6 months, prior to planting. If suSCon® Blue is to be applied, a longer period is recommended. 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 ameliorant 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 is subject to leaching, particularly in sandy soils in high rainfall areas.

Calcium or calcium/magnesium products can be applied to plant or ratoon cane as band treatments through conventional fertiliser boxes at reduced rates. The pre-planting, broadcast method is, however, the preferred placement method.

MAGNESIUM (Mg)

Magnesium is present in large amounts in the clay minerals of most Australian soils. Few Australian soils in their natural state are deficient in magnesium. Sandy, acid soils are the exception.

Magnesium is used by plants in the form of a magnesium ion (Mg^{2+}). It is an essential constituent of chlorophyll where photo-synthesis takes place to underpin sugar production and other growth processes. Magnesium is needed for movement of phosphorus in the plant and is involved in plant respiration and protein synthesis.

Older leaves exhibit magnesium deficiency symptoms before young leaves. The young leaves are green, while older leaves are paler with yellow mottling or interveinal chlorosis (Figure 10). The older leaves develop chlorotic spots that turn orange, and later dark brown. These spots may join, giving the leaf a rusted appearance. The symptoms will gradually increase to cover the leaf sheaths as well. This condition is called orange freckle. Stooling is weak and cane growth is retarded.

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

Excessive levels of soil magnesium may interfere with the uptake of potassium by the plant.

Figure 10. *Magnesium deficiency.*

Magnesium sources

Dolomite (calcium magnesium carbonate—8–10% Mg) or dolomitic limestone is a naturally occurring material which also provides calcium. It is crushed to provide a slow-acting product that should be incorporated into the soil early in the fallow period.

Magnesium oxide (54–55.5% Mg) is a relatively insoluble material but provides a reliable, long-term source of magnesium. Product names include Granomag and Magfeed.

Epsom salts (magnesium sulfate—9.6% Mg), because it is soluble, is a readily available source of magnesium. It does not need to be applied early in the fallow, but can be incorporated just before planting. As it leaches relatively easily, Epsom salts is neither a long-term nor economic source of magnesium, unlike dolomite and magnesium oxide products.

Cement (1.3% Mg) is a source of rapidly available magnesium. However, it is too expensive to use for this purpose alone.

Magnesite (magnesium carbonate—28% Mg) is a relatively insoluble material which provides a reliable, long-term source of magnesium.

A range of calcium/magnesium blends (usually 3–5% Mg) is available that 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 rate recommendations

Recommended rates of magnesium to rectify soil deficiency are given in Table 9.

How do you determine the amount of a product to apply if the product's magnesium content is different to that represented in Table 9?

$$\text{Rate of product} = \frac{100}{\text{magnesium content of product (\%)}} \times \text{rate of magnesium required (kg/ha)}$$

Example: If a product contains 3% magnesium, how much of that product

Table 9. Recommended magnesium rate.

Soil magnesium level (cmol(+)/kg)	Situation	Recommended application rate of product	Approx. amount of magnesium supplied (kg/ha)
Less than 0.09 (deficient in magnesium)	Likely response to magnesium application	Magnesium oxide at 300 kg/ha or Dolomite* at 1.6 t/ha or Calcium/magnesium blend** at 3.2 t/ha	160
0.09–0.25 (marginal in magnesium)	Possible response to magnesium application	Magnesium oxide at 150 kg/h or Dolomite* at 0.8 t/ha or Calcium/magnesium blend*** at 2.6 t/ha	80
Greater than 0.25	Adequate magnesium level	No application required	

*Dolomite containing 10% magnesium. (This rate will not supply sufficient calcium to correct deficient soil calcium levels).
**Blend containing 5% magnesium.
***Blend containing 3% magnesium.

should I apply if my soil test for magnesium is less than 0.09 cmol(+)/kg?

Answer:

$$\text{Rate of product} = \frac{100}{3} \times 160 \text{ kg/ha}$$
$$= 5333 \text{ kg/ha}$$
$$= 5.3 \text{ t/ha (approximately)}$$

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.

Like lime, an application of magnesium will last at least one crop cycle. A maintenance dressing of magnesium (for example, Granomag at 150 kg/ha) at the end of each crop cycle is then often required to maintain an adequate magnesium level in the soil. A soil test at the end of the crop cycle will assist with this decision.

Magnesium placement

The three most commonly used sources of magnesium are dolomite, magnesium oxide, and calcium/magnesium blends. They should be broadcast on the block early in the fallow period and worked into the soil. This practice will allow the slow-acting product time to react with the soil, making some magnesium and calcium available to the young plant cane.

If the magnesium-depleted block is not fallowed, the magnesium product can be applied prior to the replant. However, a fast-acting magnesium source may be preferable so the replant crop can access sufficient magnesium to benefit crop growth.

Magnesium or calcium/magnesium products can be applied to plant or ratoon cane as band treatments through conventional fertiliser boxes at reduced rates. The pre-planting, broadcast method is, however, the preferred placement method.

SULFUR (S)

Sulfur is a constituent of many flavour and odour compounds in plants such as the aroma of vegetables like onions and cabbages. 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, the now familiar acid rain, causing damage to buildings and ecosystems in many overseas countries. Atmospheric sulfur is a major source of supply for cane crops.

Sulfur is a chief component of amino acids, essential for protein synthesis. Sulfur is essential for chlorophyll formation, cell metabolism and plant growth.

Sulfur is a non-mobile element. Symptoms of sulfur deficiency are similar to nitrogen deficiency, except the symptoms appear first in the upper (young) leaves. New leaves appear light green to yellowish, often with purplish margins, but do not die back from their tips as in nitrogen deficient leaves (Figure 11). Plants may be small and spindly. Growth is retarded and maturity is delayed. Stalks and leaves are very thin and stalks are more flexible at the tip than normal. Sulfur deficiency in Australian canefields has been uncommon but it is increasing, mainly in the

Figure 11. *Sulfur deficiency.*

central district of Queensland. Areas on the Atherton Tableland are also low in soil sulfur levels.

Sulfur in the soil

Inorganic soil sulfur occurs in the sulfate form which the crop can use. Considerable quantities of sulfur are also tied up in the soil organic matter, which must be mineralised and converted to the sulfate form (SO_4^{2-}) for the crop to be able to use it. The process of mineralisation of sulfur is similar to the mineralisation of soil nitrogen. As 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 usually, but not always, provide enough sulfur to prevent deficiency occurring.

Sulfate accumulation in subsoil in the form of pyrite (iron sulphide) under anaerobic (waterlogged) conditions causes no damage. However, if this material is exposed to the atmosphere as drainage 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. This is called acid-sulfate subsoil toxicity

Yield loss will occur if this material is spread on the block. The material has a distinctive sulfurous smell and is sharp or acidic if tasted. Areas affected may not grow cane or grass for many years. Treatment is extremely difficult. If only small areas are involved, the best treatment is to remove the affected material, flush the area with salty water if drainage is good enough to rapidly leach the salt, or apply high localised rates of lime. A calculator is now available for determining lime requirement to neutralise drain spoil from acid-sulfate sites. Slotted agricultural pipe should not be used as it will rapidly clog with iron oxides (the rusty material frequently seen in acid-sulfate areas). In-field drains should be shallow and above the sulfidic layer. Ploughing should be avoided and tines 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.

Sulfur removal by the cane crop and addition by fertiliser, rainfall and irrigation

Table 4 shows the amount of sulfur removed by cane crops in various parts of Queensland. An average of 34 kg/ha/year is removed by the crop, of which approximately 50% will be returned in GCTB residues and become available to the crop on time scales similar to nitrogen in trash blankets (pp 159–160).

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

Rainfall supplies about 5–18 kg/ha/year. In non-irrigated districts, sulfur removal by the crop and loss by leaching exceed inputs from rainfall and most fertiliser programs, and 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 bores are used. The sulfur content of irrigation bore water varies between districts but is generally adequate to meet crop requirements. Irrigation water from most rivers 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 low sulfur content.

Materials used as sulfur fertilisers can be grouped into two broad groups: those soluble in water and those insoluble in water

Sulfur in soluble sulfur compounds (e.g. sulfate of ammonia [24% S], bluestone [copper sulfate—12.6% S], Epsom salts [magnesium sulfate—12.4% S], superphosphate [11% S]) and gypsum [14.5% S], is immediately available to the crop. This sulfur can also readily leach from the topsoil, especially in sandy soils.

The most important insoluble form of sulfur is elemental sulfur [90–100% S]. It is not immediately available to the crop. Elemental sulfur needs to be converted to the sulfate form that 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 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 that are used to rectify other nutritional deficiencies, e.g. zinc sulfate heptahydrate [11% S] 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.

Sulfur rate recommendations

Recommended rates of sulfur to rectify soil deficiency are given in Table 10. Sulfur fertiliser recommendations provide a maintenance regime in the absence of a defined response function.

The soil test for sulfur is not as reliable for predicting deficiency as soil tests for phosphorus, potassium, magnesium, calcium and zinc (Table 1). However, sulfur applications may be justified if soil levels are low and there is no input of sulfur from irrigation water or other source. Identification of sulfur deficiency may involve a number of factors including soil test, visual symptoms, soil type, expected rainfall, irrigation, fertiliser history, green-cane trash-blanketing and, possibly, a leaf tissue analysis (sulfur deficient if N:S ratio in leaf dry matter is greater than 17).

Table 10. Recommended sulfur rate.

Soil sulfate-sulfur level (mg/kg)	Situation	Recommended application rate of sulfur
0–2	Possibly deficient in sulfur	25 kg/ha to each crop
3–7	Possibly marginal in sulfur	10 kg/ha to each crop
Greater than 7	Likely adequate sulfur level	No application required

Sulfate of ammonia at 105 kg/ha and 40 kg/ha will supply 25 kg/ha and 10 kg/ha of sulfur, respectively. 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 should 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 that 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.

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 light textured soils in most areas of Queensland.

Copper is involved in chlorophyll formation and catalyses other chemical reactions in the plant. When adequate supplies of copper are present in the soil, the plants are usually more resistant to fungal attack.

Young leaves exhibit deficiency symptoms before older leaves. Leaves become droopy and the stalks become rubbery and flexible (Figure 12). This is the distinctive droopy top symptom that is synonymous with copper deficiency. Small dark green patches, or islands, may occur on chlorotic leaves. The leaves may become generally chlorotic. Tillering and vigour are reduced.

Areas deficient in copper

Organic soils, such as the peats, are most likely to be copper deficient if there is no clay horizon close to the surface. 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 that are low in organic matter may also become copper deficient. Calcareous soils with a relatively high pH

Figure 12. *Copper deficiency.*

may induce copper deficiency since copper, like zinc, is less available for plant growth when the soil is alkaline.

Canegrowing soils usually contain less than 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.

An application of copper to overcome deficiency will usually last a minimum of one crop cycle but probably much longer before retreatment is necessary.

In bluestone (copper sulfate pentahydrate —25% Cu), the copper 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. Copper solutions can damage some metal surfaces (especially brass components in spray equipment) and may burn foliage.

Copper-fortified fertilisers also provide a convenient way of rectifying copper deficiency.

Copper rate recommendations

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 analysed by the BSES laboratory shows a soil copper level less than 0.3 mg/kg, an application of copper may be required.

The recommended rate of bluestone 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.

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. Copper toxicity is very easy to induce if recommended application rates are exceeded. Copper toxicity can be overcome by liming the soil.

ZINC (Zn)

Zinc is one of the seven micronutrients, or trace elements, required for the growth of all plants. Zinc and the other trace elements are as important to sugarcane nutrition as the major nutrients, although the cane does not require as much of the trace elements. Like sulfur, zinc deficiency has been detected in some canegrowing areas in recent years.

Zinc is involved in chlorophyll formation, the regulation of plant growth and development, and the efficient use of water. Zinc application to deficient soils increases root mass, cane yield and CCS.

Zinc deficiency symptoms become evident on the third and older leaves. Broad bands of yellowish striping may occur in the leaves, with the midrib and leaf margins remaining green.

The stool may suffer stunted growth and root growth can be poor. Stalks may be thin and elastic. Some cane varieties are susceptible to infection by a red fungus, *Curvularia brachyspora*, when zinc deficiency is present and red fungal lesions may develop on the leaves in the yellowish band between midrib and leaf margin.

Zinc deficiency symptoms can range from being very obvious to almost undetectable depending on the cane variety. A variety can suffer significant yield loss without displaying obvious symptoms of zinc deficiency. Zinc deficiency in Australian canefields was first identified in 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% 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.

Soils most likely to be zinc deficient are those formed on beach ridges and from metamorphic and granitic 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. Zinc deficiency may also occur in areas where extensive earthworks have been carried out. Much of the new and increased sugarcane assignments in Queensland are on soil types identified as being potentially deficient in zinc.

Zinc in the soil

Most canegrowing soils contain less than 5 mg/kg of zinc. Fine-textured soils usually contain more zinc than sandy soils. Several factors determine zinc availability to the crop.

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 can make zinc less available for uptake by the crop through this mechanism. However, if soil calcium levels are low, liming should be carried out. If zinc then becomes deficient, it should also be applied.

A significant quantity of zinc may be fixed, or tied up, in the soil organic matter. Following 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. Zinc deficiency may also occur on soils that 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.

Zinc sources

Zinc sulfate heptahydrate (22.7% Zn) should be applied prior to 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 L of water. The zinc is readily available for uptake by the crop. If the product is applied as a solution, brass and galvanised-iron spray tank components should not be used 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 sulfate heptahydrate is not compatible with DAP or MAP. Trace elements including zinc should not be added to herbicide sprays.

Zinc fortified planting mixtures (usually 2–3% Zn) applied at planting are 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 11.

The recommendations are based on the HCl test developed by BSES and available through some commercial laboratories. One application of a zinc product (10 kg Zn/ha) will last several crop cycles.

BORON (B)

Boron deficiency of sugarcane has not been identified in the field in Australia.

Boron is important in the growth of new cells. It appears to be involved in the uptake and efficient use of calcium, nitrogen and potassium in the plant. Boron is thought to regulate the plant's use of other essential nutrients and aids in the production of sugars and carbohydrates. It is important for the development of young roots and shoots.

Young leaves exhibit boron deficiency symptoms before older leaves. Deficiency symptoms are similar to Fiji disease and the fungal disease, pokkah boeng. The 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. Young plants are bunched with an excessive number of tillers. Leaves tend to be brittle and leaf tips can be severely burned and may split.

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 of the 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.

Great care should be taken in applying boron to soils that 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

Table 11. Recommended rate of zinc fertilisers.

Soil zinc level (0.1 M HCI extract)	Zinc rate (kg/ha)	Product rate to supply 10 kg/ha zinc
0–0.6 mg/kg	10	Zinc sulfate heptahydrate at 44 kg/ha or
Greater than 0.6 mg/kg	No application required	Zinc fortified planting mixtures at normal planting rate (approximately 380 kg/ha)

toxic levels of boron in the soil. Liming boron toxic areas may help alleviate the problem.

Boron sources

Borax (disodium tetraborate decahydrate—11.3% B) is not recommended for foliar spray application due to its low solubility. Borax should be used for soil application. For foliar boron application, Solubor (sodium octa-borate pentahydrate—20.5% B) should be used.

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.

MANGANESE (Mn)

Manganese is involved in photosynthesis, chlorophyll production, and the formation of organic compounds, especially enzyme systems. It is required for oxygen production during photosynthesis. Manganese acceler-ates germination and maturity. It is associated with iron, copper and zinc as a catalyst in plant growth processes.

Manganese deficiency has never been reported in soils growing sugarcane in Australia. Younger leaves exhibit manganese deficiency symptoms before older leaves. Longitudinal pale stripes appear between the leaf veins, the stripes generally running only from the middle of the leaf to the tip. The leaf blades may split and the 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 base of the leaves to the leaf tip when iron is deficient.

Manganese in the soil

The main factor controlling the availability of soil manganese is pH. Acid soils (most Australian canegrowing soils) supply ample manganese for crop growth. Manganese toxicity is possible on extremely acid soils, 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 occurs in soils 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. Zones of manganese nodules in soils are indicative of seasonal waterlogging.

Australian canegrowing soils generally contain from one to several hundred mg/kg of manganese.

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 soil application, 20–30 kg/ha of manganese sulfate should be applied before the crop is planted. For a foliar spray, 5–10 kg/ha of manganese sulfate should be applied in 1000 L of water (0.5% to 1% solution).

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 essential for the production of chlorophyll. It is involved in internal chemical reactions in the plant such as photosynthesis and respiratory enzyme systems and is involved with oxygen transport.

Young leaves exhibit iron deficiency symptoms before older leaves. Longitudinal pale stripes appear between the veins of the leaves extending from the leaf base to the tip of the leaf. The entire leaf may become bleached (pale yellow to white) and the entire plant may become bleached. Young stubble shoots have no new root development.

Symptoms tend to be temporary and leaf colour later becomes normal. Symptoms can be patchy but eye-catching in the field; a stool exhibiting very distinctive iron deficiency symptoms can be growing next to healthy, maturing cane stools. The severe symptoms of albinism appear to be caused by a temporary imbalance of iron and manganese in the soil.

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.

Soil tests are not a reliable indicator of potential iron deficiency.

Iron in the soil

Most canegrowing soils contain from 10 to several hundred mg/kg of iron. No definite toxic effect on cane has been established for soils containing very high levels of iron. As soils become more acid, the availability of iron to plants increases.

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 been not recorded in Queensland.

CHLORINE (Cl)

Chlorine is the most recent of the nutrients identified as being essential for plant growth and appears to have a role in photosynthetic reactions involved in oxygen production. It is also thought to be involved in the water-holding capacity of plant tissues.

Chlorine deficiency symptoms have not been recorded in Australia, but appear on young leaves before older leaves. Leaves wilt during the day and recover at night. Leaves may be chlorotic, the plant may have abnormally short roots, and there may be an increased number of lateral roots.

Chlorine is very easily leached from the soil. 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 an area that receives an average annual rainfall of 2000 mm, up to 140 kg/ha/year of chlorine may fall in rain. Some irrigation waters contain high chloride levels.

Chlorine deficiency is very unlikely to occur since sufficient chlorine is applied by rainfall and irrigation and in potassium chloride (muriate of potash) fertiliser.

MOLYBDENUM (Mo)

Molybdenum is involved with the synthesis and activity of nitrate reductase enzyme and in the conversion of inorganic phosphate to organic compounds. Molybdenum deficiency has not been identified in Australian canefields. Molybdenum deficiencies in other crops are widespread throughout Australia, occurring mainly on acid soils.

Older leaves exhibit molybdenum deficiency symptoms before young leaves. Symptoms are similar to mild infections of pokkah boeng disease. Short, longitudinal chlorotic streaks form on the apical one-third

of the leaf. The older leaves dry prematurely from the middle towards the tip, stalks become short and slender, and 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.

If molybdenum deficiency is suspected, a test strip should be established. An area of land should be treated with sufficient product to supply 100 g/ha of molybdenum to determine a response to molybdenum.

Much of the molybdenum in soils is associated with iron oxides. Of the trace elements in soils, molybdenum is the least abundant. 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.

SILICON (Si)

Silicon is a relatively abundant element with silica minerals making up approximately 12% of the earth's crust. Rocks contain various silicate minerals and quartz is the most commonly occurring free silica mineral. Yield responses to silicate materials have been recorded for sugarcane in Australia.

The essentiality of silicon for plant growth has not been demonstrated, yet many beneficial roles have been reported for sugarcane and other plant species. Improved silicon status of plants confers greater resistance to certain fungal diseases, improves resistance to damage by insects such as stem borers, improves tolerance of salinity, and assists with control of transpiration.

When deficient in silicon, young leaves develop yellow flecks which eventually coalesce to form a bronze freckle on the surface of older leaves which are exposed to the sun.

This symptom is known as sunny side up freckle and can be seen most prominently along the edge of fields during late summer–winter.

Silicon in soil

All soils contain high levels of silicon, either in clay minerals or sand (silicon dioxide). However, plants can acquire silicon only from the soluble form of mono-silicic acid. This form of soluble silicon is released by the slow dissolution of iron and aluminium silicates in clay soils, or from silicate ameliorants that can dissolve in acidic soil solutions, or from soluble silicate fertilisers. Plant-available silicon can be determined by soil analysis. Critical levels are yet to be confirmed but previous research suggests yield responses will be obtained if soils have less than 100 mg Si/kg or 10 mg Si/kg in 0.005M sulfuric acid or 0.01M calcium chloride extracts, respectively (BSES laboratory analyses). These levels are most likely to be found in lighter textured soils or strongly weathered soils on volcanic or metamorphic parent material in the tropics. Up to 95% of soils in the wet tropics are considered to be marginal to deficient in silicon.

Sources of plant-available silicon

Total silicon content of potential ameliorants is not necessarily an index of utility for correction of silicon deficiency. Products must be assessed by analysis or field response for capacity to supply mono-silicic acid. Calcium silicate (wollastonite) has been used as a standard for assessing plant response to silicate materials. Calcium silicate ($CaSiO_3$) has slow solubility, similar to lime, and provides continual release of silicon to the soil solution. Rates of 3–4 t/ha of calcium silicate are indicated. Cement at 3 t/ha is also a useful source of plant-available silicon. Sugar mill ash and filter mud/ash mixtures (25–50 dry t/ha) have also provided good yield responses on silicon-deficient soils. Potassium silicate is an alkaline and soluble source of silicon of variable composition that is also being investigated as a silicon fertiliser. Silicates in crushed rocks supply very low levels of plant-available silicon.

Irrigation water from bores contains substantial quantities of soluble silicon.

Silicon in sugarcane residues may not be readily available for subsequent use by the crop, because the silicon is deposited as opalised phytoliths in plant cells. Further research is required to determine impacts of burnt cane and GCTB systems on cycling of silicon in sugarcane systems.

ALTERNATIVE FERTILISER SOURCES

Sugar mill by-products

The by-products of raw sugar manufacture (filter mud, ash, mud/ash mixtures and molasses) and of ethanol production (liquid dunder and biostil dunder) are valuable fertiliser sources.

The total nutrient content of typical application rates of each mill by-product is given in Table 12. The values are approximate only and will vary between districts and within and between years. 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 cane plant is not known. In some cases where by-products have been applied, sufficient nutrients may not be available for the succeeding cane crop and additional fertiliser may be required.

With the application of 150 wet tonnes/ha of filter mud and mud/ash mixtures, research suggests that about 100 kg of nitrogen is available for cane growth in the year of application. (The remainder of the total nitrogen content becomes available slowly as the organic material is broken down). This is about 65–80% of the nitrogen fertiliser requirement of plant cane, and 40–60% of replant and ratoon cane fertiliser requirement. (For cane on richland or dryland, the figures are even higher).

Of the other elements, enough phosphorus for at least one crop cycle of plant and four ratoons is supplied. For filter mud, about 80 kg of potassium is immediately available for cane growth. This is about 80–100% of the potassium fertiliser requirement of plant cane, or 65–80% of ratoon cane fertiliser requirement. No additional potassium fertiliser is required by the crop in the year of application of a mud/ash mixture.

One application supplies the calcium equivalent of approximately 1.5 tonnes of agricultural lime per hectare, and the products contain significant levels of available magnesium which assists in maintaining soil fertility. The sulfur applied is of benefit where sulfur levels are marginal, but additional fertiliser application may be required on sulfur deficient soils.

Table 12. 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)	Liquid dunder after re-boiling (5 cubic metres/ha)	Biostil dunder (3 cubic metres/ha)
Nitrogen	465*	360*	60*	69*	16*	24*
Phosphorus	360*	300	120	5*	1*	2*
Potassium	120	195	390	397	112	90
Calcium	645	600	435	88	17	24
Magnesium	135	165	225	47	9	18
Sulfur	80	50	N/A	N/A	13	9*

*Additional fertiliser may be required (nutrients locked up in organic forms).

N/A Figures not available.

Biostil dunder and liquid dunder are primarily sources of potassium. When applied at 3–5 cubic metres per hectare, they supply the potassium requirement for one crop.

Legumes

Legumes can provide a significant quantity of nitrogen for the following plant crop, as well as organic matter. Nitrogen rates for plant cane can be reduced by at least 50–60 kg/ha following a well-grown legume crop.

ACKNOWLEDGEMENTS

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GLOSSARY

Acid soil. Soil with a pH below 7. Sugarcane is very tolerant of acid soils.

Agricultural lime. Crushed limestone. Most economical source of calcium.

Aluminium. An element which has the potential to cause yield reductions in most crops. Associated with acid soils. Sugarcane has a high tolerance to aluminium.

Aluminium saturation percentage. The percent of the cation exchange capacity occupied by exchangeable aluminium. A reading above 60% could indicate production problems and is also likely to be associated with low values of soil calcium. Crops such as maize experience yield reductions above 16% aluminium saturation.

Ameliorant. An improver. A soil ameliorant improves the structure and/or nutritional level of the soil.

Ammonium (NH_4^+). One of the two forms of nitrogen which plants can use for growth, the other being nitrate (NO_3^-).

Anaerobic. In the absence of oxygen. Denitrification by certain soil organisms occurs under waterlogged, anaerobic conditions.

Anion. Negatively charged ion e.g. chloride. See 'IONS'.

Ash. The inorganic matter in sugar. High levels cause sugar manufacturing difficulties. Increased by excessive potash use, growing sugarcane on saline soil, or using saline irrigation water. Also a sugar mill by-product from the burning of bagasse. Can be used as a potassium or silicate source or for amelioration of sodic soils.

BCTB. Burnt-cane trash-blanket. The layer of sugarcane residues covering the ground after harvest of the crop which had previously been burnt.

Biuret. Compound in some sources of urea. Biuret is toxic to plants and animals, but damage to sugarcane occurs only if urea is foliar applied.

Brimstone. Elemental sulfur. Pure brimstone is 100% sulfur.

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 and organic soils have a high buffering capacity.

Burnt-cane trash-blanket. See 'BCTB'.

Burnt lime (CaO). Calcium oxide. Also called quicklime or unslaked lime. Made by burning limestone. Unstable. Contains 68% calcium.

Calcium (Ca). One of the major elements required for plant growth. The main component of liming products. Increases soil pH thus reducing acidity.

Calcium carbonate ($CaCO_3$). Agricultural lime. Most naturally occurring limestone is principally calcium carbonate. Contains 30–40% calcium.

Carbon (C). Element required for plant growth. Obtained from carbon dioxide gas in the atmosphere or dissolved in water.

Cation. Positively charged ions, including calcium, magnesium, potassium, sodium, hydrogen and ammonium. See 'Ions' and 'Exchangeable cations'.

Cation exchange capacity (CEC). An indication of the soil's nutrient-holding

ability. Measure of the soil's capacity to hold and exchange cations. The higher the clay or organic content of the soil, the higher the CEC and the lower the leaching susceptibility of the soil.

Chlorine (Cl). One of the trace elements required for plant growth. Muriate of potash (potassium chloride) contains a significant level of chlorine.

Chlorophyll. The green colouring substances of leaves and plants. Involved in photosynthesis.

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.

Conductivity. See 'Electrical conductivity'.

Copper (Cu). One of the trace elements required for crop growth.

Denitrification. One of the main ways nitrogen in fertiliser is lost. The process involves conversion of the fertiliser nitrogen to nitrous oxides and nitrogen gas which are lost to the atmosphere. Occurs in anaerobic, waterlogged conditions and is caused by certain bacteria in the soil.

Dolomite. A mixture of naturally occurring calcium and magnesium carbonates. Contains about 14% calcium and 8–10% magnesium. Suitable for correction of magnesium deficiency.

Dunder. A by-product of ethanol production and a rich source of potassium. Used as a fertiliser on canefarms in the central district of Queensland and the Rocky Point mill area in south Queensland.

Effective CEC. The effective cation exchange capacity of a soil. Effective CEC = sum of the exchangeable cations + exchangeable acidity. A less accurate measure of the soil's nutrient holding capacity than CEC. 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 from osmotic stress.

Exchange acidity. Measures the amount of aluminium and hydrogen in a soil.

Exchangeable cations. Positively charged ions, including calcium, magnesium, potassium, sodium and aluminium which are available for plant uptake.

Exchangeable potassium. 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 (nitric K), and unavailable K which is found in minerals which the plant can not use.

Exchangeable sodium percentage (ESP). The percent of the cation exchange capacity occupied by exchangeable sodium. Also called sodium percent of cations. A high ESP reading indicates crop production problems associated with sodicity: 5–15% indicates some breakdown of soil structure; above 15% indicates severe structural deterioration in most soils.

GCTB. Green-cane trash-blanket. The layer of sugarcane residues on the ground after harvest of the crop which had not previously been burnt.

Green-cane trash-blanket. See 'GCTB'.

Gypsum ($CaSO_4.2H_2O$). Used for improving soil structure and overcoming poor growth in problem soils such as sodic soils or hard setting soils.

Humus. The black organic matter in soils which is a product of the decomposition of animal and vegetable matter.

Hydrated lime ($Ca(OH)_2$). Produced by reacting burnt lime with water. Contains 51% calcium.

Hydrogen (H). An element required for plant growth. Obtained from water.

Ion. An electrically charged atom or molecule. Cations are positive ions; anions are negative ions.

Iron (Fe). One of the trace elements required for plant growth.

Immobile nutrients. 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.

Leaching. Washing nutrients downwards through the soil profile with rainwater or irrigation water.

Legume. Plants such as cowpeas and beans which manufacture plant-available nitrogen from the air by the process of nitrogen fixation. Decomposition of leguminous residues supplies nitrogen to soil.

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 (magnesic limestone). Other products, such as cement and magnesium oxide, may produce a liming action by increasing soil pH.

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. Sugarcane luxury feeds on nitrogen and potassium.

Magnesium (Mg). One of the major elements required for plant growth.

Maintenance dressing. The addition of sufficient nutrient to maintain an adequate level of that nutrient in the soil.

me%. Milli-equivalents per cent or cmol(+)/kg (preferred unit). The quantity of some nutrients in the soil is expressed in this unit. Conversion: 1 cmol(+)/kg K = 390 mg/kg; 1 cmol(+)/kg Ca = 200 mg/kg; 1 cmol(+)/kg Mg = 120 ppm; 1 cmol(+)/kg Na = 230 mg/kg.

mg/kg. Milligrams per kilogram. Quantity of some nutrients in soil is expressed in this unit. Equivalent to parts per million (ppm).

Micron. One millionth of a metre. 1000 microns = 1 millimetre.

Mineralisation. The process whereby nutrients are released from organic matter, becoming available for plant growth.

Mixtures/mixed fertilisers. Fertilisers that are a mixture of two or more of the straights or single nutrient fertilisers.

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.

Necrosis. Death of tissue.

Neutralising value. 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 95–99% for pulverised limestone and 80–90% for earthy lime.

Nitrate (NO_3^-). One of two forms of nitrogen that plants can use for growth, the other being ammonium (NH_4^+).

Nitric potassium. Nitric K. A measure of the slowly available (reserve) potassium in the soil.

Nitrification. The conversion of ammonium-N (NH_4^+) in soils to nitrate-N (NO_3^-) by certain nitrifying bacteria.

Nitrogen (N). One of 16 nutrients essential for growth of plants. Present in organic matter and as nitrogen gas (N), nitrite (NO_2^-), nitrous oxide (NO_2), nitric oxide (NO), ammonia (NH_3), ammonium (NH_4^+), and nitrate (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 amino nitrogen. This process must occur

before the atmospheric nitrogen can be used by plants. The most widely known example is the association between *Rhizobium* bacteria and legume roots. Bacteria in some varieties of sugarcane also have capacity to fix atmospheric nitrogen.

One-shot fertiliser. Fertilisers which can supply all of a crop's requirements of nitrogen, potassium, and phosphorus if needed, in one application.

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 carbon. A measure of the organic matter content of the soil. The carbon content of organic matter is relatively constant. 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 conventional measure of organic carbon includes active humic carbon fractions as well as relatively inert charcoal material.

Organic matter. Consists of plant residues, soil organisms and animal remains. Contains all essential plant nutrients which are slowly available for plant growth. Acts as a reservoir of plant nutrients, helps conserve moisture, improves physical structure of the soil and provides a favourable environment for soil micro-organisms. Organic matter (%) may be estimated as $1.72 \times$ organic carbon (%).

Oxygen (O). One of the elements required for plant growth. Obtained from oxygen and carbon dioxide gases in the atmosphere, and from water.

Per cent coarse/per cent 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 6–8 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 acidity.

Phosphorus (P). One of the major nutrients required for plant growth. The main sources of phosphorus are super-phosphate, DAP, MAP and high analysis mixtures. Rock phosphate is the raw material used in the production of most phosphate fertiliser.

Phosphorus bicarbonate. A measure of soil phosphorus which is readily available for sugarcane growth in neutral or alkaline soils.

Phosphorus BSES. A measure of the soil phosphorus which is readily available for sugarcane growth in acid soils. Test developed by BSES.

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, particularly when fertiliser is applied in a narrow band.

Photosynthesis. The production of organic materials, such as sugars, from carbon dioxide and water, by green plants using light energy trapped by the green pigment (chlorophyll) to activate the process. Photosynthesis also produces oxygen.

Ploughout–replant. Also called replant. The plant crop which is established soon after 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 roots and eyes of germinating cane setts as a result of placing potassium fertiliser on, or very close to, the cane setts. Caused by the high solubility and salt effect of muriate of potash.

Potassium (K). One of the major nutrients required for plant growth. Muriate of potash (also called potash or potassium chloride) is the main source of fertiliser potassium.

P-Sorption. A measure of a soil's capacity to fix phosphorus in forms not readily available to plants.

Quicklime (CaO). Calcium oxide. Also called burnt lime or unslaked lime. Contains 68% calcium.

Replant. See 'Ploughout-replant'.

Rhizobium. Bacteria that live in nodules on the roots of legumes and carry out nitrogen fixation.

Rock phosphate. The basic material used in almost all phosphorus fertiliser production. Only very slowly available to plants as it is insoluble.

Saline soil. Soil containing excessive level of salt in the soil water, restricting plant growth. The salt is soluble and may be leached out.

Silicon. A major element in sand and clay. Plant available silicon is released by clay minerals. Silicon is beneficial to plant growth.

Slaked lime (Ca(OH)$_2$). Hydrated lime. Contains 51% calcium.

Soda patch. See 'Sodic soil'.

Sodic soil. Soil in which levels of sodium attached to the clay particles exceeds 6% of the cation exchange capacity. This sodicity causes breakdown of the soil structure and poor plant growth. Soda patches are areas containing severely sodic soil (>15% exchangeable sodium).

Sodium (Na). Excessive levels cause salinity stress to plants 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 (ESP).

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 stool application. See 'Stool splitting'.

Stool splitting. The use of a coulter to slice a thin line through cane stools along the length of the row. Fertiliser is dropped into the shallow slot (about 70–100 mm deep) via a hollow tine behind the coulter. A press wheel closes the slot to prevent volatilisation loss of nitrogen.

Straights/straight fertilisers. Fertilisers containing only one of the three major elements: nitrogen, phosphorus, potassium. e.g. urea (N), superphosphate (P), potash (K).

Subsurface-applied fertiliser. Fertiliser buried in bands in the soil. With suitable equipment, fertiliser can be subsurface-applied through a green trash blanket.

Sulfur (S). One of the major elements required for plant growth.

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.

Tillering. Growth of stalks from the below-ground buds.

Trace elements. Also called micro-nutrients. They are the seven essential elements that are required in only small quantities for plant growth (copper, zinc, boron, manganese, iron, chlorine, molybdenum).

Transpiration. The evaporation of water through the pores (stomata) of plant leaves and stem.

Unslaked lime (CaO). Burnt lime or quicklime. Contains 68% calcium.

Urease. A naturally occurring enzyme which converts urea to ammonia.

Volatilisation. The loss of nitrogen to the atmosphere when urea is converted to ammonia gas.

Zinc (Zn). One of the trace elements required for plant growth.