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SOIL REFERENCE BOOKLET FOR NSW SUGARCANE DISTRICTS

Soil-specific Nutrient Management Guidelines for Sugarcane Production in New South Wales

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SOIL-SPECIFIC NUTRIENT MANAGEMENT GUIDELINES FOR SUGARCANE PRODUCTION IN NEW SOUTH WALES

By

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Dr Bernard Schroeder is the Leader of the Improved Cropping Systems Program and a Principal Scientist with BSES Limited based at Indooroopilly. He has been involved in R,D&E activities associated with various aspects of soil fertility and crop nutrition for about 30 years. This experience has been gained largely within the Australian and South African sugar industries. A major part of his work has been aimed at fine-tuning the nutrient requirements for the Australian sugar industry and the development of the SIX EASY STEPS nutrient management package for sugarcane. This work has often been in collaboration with other agricultural scientists, particularly within BSES and SRDC funded projects. He is the author/co-author of a large number of publications, both technical and more industry focused.

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Dr Bob Aitken is a former Senior Extension Officer with BSES Limited based at Harwood, NSW. For the past 13 years, he provided reactive and structured technology transfer to individual growers and organised grower groups as well as conducting a range of research programs involving field trials throughout the NSW sugar industry. Prior to joining BSES Limited, Bob was a Principal Soil Scientist for 13 years with the Qld DPI/DNR undertaking research into aspects of soil fertility and plant nutrition. This included work on soil acidification, soil acidity and liming in relation to maize, barley, soybean, macadamia and sugarcane production, nitrogen and phosphorus requirements of maize, soil test development and calibration, and soil chemistry.

Rick Beattie is Agricultural Services Manager with the NSW Sugar Milling Co-operative Ltd based at Broadwater Mill, NSW. In this position he manages a team of agricultural staff that provide a range of extension and technical pest and disease control services for the NSW sugar industry. Prior to coming to NSW at the end of 1999, Rick worked for CSR in cane supply and for BSES as an Extension Officer in the Bundaberg, Innisfail and Ingham districts. Rick has managed a wide range of projects including work on farming systems, water quality improvement and whole crop harvesting.

Dr Andrew Wood is a former Productivity/Farms Operation Manager, Sucrogen Cane Products in the Herbert River district. Andrew has more than 30 years of experience in the industry. In addition to a good general knowledge of sugarcane production, he has been largely responsible for mapping soils in the Herbert sugarcane district at a scale of 1:5000. This is unparalleled in any other sugarcane-growing region in Australia. Andrew has been the project leader of a number of projects covering aspects of sugarcane production, which were funded by various organisations (SRDC, CRC Sugar, Envirofund, etc). He is the author or co-author of a large number of scientific papers, books and reports.

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GLOSSARY OF TECHNICAL TERMS

It is inevitable that specialist and technical words have to be used in this publication. To assist those not familiar with some of these words, we have included a list of technical terms. This can be used as a reference source whilst reading the book.

Acidic cations: Positively charged ions of aluminium and hydrogen that give the soil CEC an acid reaction. Aluminium and hydrogen are always present in large quantities in the soil but they are only present on the CEC and in the soil solution if the soil pH is below 5.5.

Acid saturation: The proportion of the soil CEC occupied by the acidic cations aluminium and hydrogen. It appears on soil tests as aluminium saturation. Low acid saturation is desirable so that more of the CEC is available for storing basic cations.

Acid sulphate soils: Extremely acid soils with high levels of sulphur caused by oxidation of iron compounds in the subsoil. These soils become problematic when they are exposed to air by construction of drains or other earthwork operations. Under such conditions, the sulphide components of the iron compounds are converted to sulphuric acid.

Actual acid sulphate soils: Is the common name given to soils and sediments containing iron sulphides, the most common being pyrite. When exposed to air due to drainage or disturbance, these soils produce sulphuric acid.

Alluvial: Soils derived from recent stream deposits. These soils dominate floodplains.

Ameliorant: A substance added to soil that slowly improves its nutrient status and physical properties, usually beyond a single crop cycle. Examples are gypsum, lime and mill by-products.

Amino nitrogen: A form of nitrogen found in sugarcane juice that can increase colour in sugar. It is caused by excessive amounts of nitrogen available from the soil or from fertiliser.

Anions: Negatively charged ions such as nitrate, phosphate and sulphate.

Back plain: An elevated area often found between a riverbank crest and the back swamp.

Back swamp: A low-lying area some distance from current river or streams. These areas tend to be the lowest part of the landscape.

Basalt: A dark igneous rock composed of fine-grained alkaline material.

Base saturation: The proportion of the soil CEC occupied by the basic cations calcium, magnesium, potassium and sodium. In some soils the base saturation is quite high with possible effects on certain relative cation (e.g. K^+) availability.

Cations: Positively charged ions that are held on the negatively charged sites on the soil CEC. The major cations are calcium, potassium, magnesium and sodium.

CEC (Cation Exchange Capacity): A measure of a soil's capacity to store and exchange cations. The value of the CEC is dependent on the amount and type of clay and on the amount of humus. CEC is expressed as milli-equivalents per 100 grams of soil (me%).

Clay minerals: The basic building blocks of clay. They are made from the weathered minerals in rocks and include aluminium and silicate layers as well as oxides and hydroxides. (A mineral is a naturally occurring substance that has a definite chemical composition and an ordered structure).

Claystone: A sedimentary rock consisting mainly of clay material that is present in a consolidated form.

Colour: Soil colour refers to the colour of the soil when it is moist. A simple system using everyday terms is used in this booklet. Soil scientists use a more complicated system in which the colour is matched to a series of standard colours (Munsell Soil Colour Chart).

Compaction: A reduction in pore space in soil (meaning less air space and poorer infiltration rates) caused by machinery traffic and inappropriate tillage.

Conglomerate: A rock composed of rounded water worn pebbles cemented into a matrix of sand, silt, clay and mixtures of other materials.

Critical level: The value for a nutrient in either a soil or leaf test above which a yield response is unlikely to occur when that nutrient is applied.

Decomposition: The breakdown of a complex substance to something simpler. The process can be caused by weathering, chemical change (increased acidification) or biological action.

Deficiency: A nutrient level below the critical level. In extreme cases, a deficiency is reflected by plant symptoms such as leaf colour.

Denitrification: The conversion of nitrate to various nitrogen gases. It occurs under waterlogged conditions in the presence of organic matter and suitable bacteria.

Dispersive soil: A dispersive soil usually has a high ESP, which causes the soil particles to separate from each other with a resulting breakdown of soil structure.

Districts yield potential: This is determined from the best possible yield averaged over all soil types within a district. It is defined as the estimated highest average annual district yield (tonnes cane/hectare) multiplied by a factor of 1.2. This enables recognition of differences amongst districts in their ability to produce cane.

DTPA: Chemical used in soil analysis to extract micronutrients from the soil.

Duplex soils: A soil with a relatively permeable topsoil abruptly overlying a very slowly permeable subsoil.

ESP (Exchangeable sodium percentage): The percentage of the CEC occupied by sodium. ESP in the topsoil of more than 5% is undesirable and it causes soil structure to break down.

Exchangeable nutrients: Nutrients (calcium, potassium, magnesium and sodium) present as cations associated with the soil CEC. They have the ability to exchange easily.

Flocculation: The grouping of clay particles, which is an essential pre-requisite for the formation of good soil structure.

Gabbro: A dark coloured alkaline igneous rock formed from molten rock that has cooled and solidified deep below the surface.

Granite: A coarse grained light coloured rock, essentially consisting of quartz.

Horizon: A layer of soil roughly parallel to the land surface, which is distinct from the layers above and/or below it. Differences are based on colour, texture, structure or some other property. Surface horizons are often not apparent in agricultural soils because of tillage operations.

Humus: Stabilised soil organic matter as distinct from decomposing trash.

Jarosite: A pale yellow potassium iron sulphate mineral (main weathering product of pyrite oxidation).

Leaching: The downward movement of water through the soil and the accompanied movement of soluble nutrients and suspended clay particles.

Massive structure: A soil with no apparent structure. Such soils are very lumpy, difficult to cultivate and set hard when dry.

Micronutrient: An essential nutrient that is required in very small quantities, <10 kg/ha/year, such as copper and zinc.

Mineralisation: The breakdown of humus (stabilised organic matter) and release of nutrients especially nitrogen, sulphur and phosphorus.

Mottles: Patches of lighter or darker colour in soils often indicating the effects of poor drainage.

New land: Land in its first crop cycle of sugarcane.

Nitric K: Potassium extracted with the use of strong nitric acid. It is a crude measure of the potassium reserve in the clay minerals.

Organic matter: Carbon in the soil derived from plant matter. It is composed of carbon, hydrogen and oxygen, but also contains nitrogen, phosphorus and sulphur. In this booklet, organic matter is measured as organic carbon (org C) using the Walkley-Black procedure.

Parent material: The material (rock or alluvium) from which soils have formed.

Peat: A dark soil consisting of partially decomposed organic matter.

Peds: Aggregates of soil particles, usually only found in undisturbed soil.

Permeability: The ability of soil to drain water through the profile. It is dependent on pore space, which is reduced by compaction.

pH: The scale that is used to measure acidity and alkalinity. A pH of 7 is neutral, less than 7 is acidic, greater than 7 is alkaline. In this booklet, soil pH is the pH in a 1:5 soil: water suspension.

Plant Available Water Capacity (PAWC): The amount of water in the soil profile within the rooting zone between field capacity (full) and permanent wilting point (dry).

Plastic limit: The lowest soil moisture content at which a soil is capable of being moulded or deformed permanently by pressure.

Potential acid sulphate soils: Acid sulphate soils that have the potential to be exposed to air as a result of disturbance.

P-sorption: The process by which phosphorus is held tightly onto soil particle surfaces and rendered relatively unavailable to plant uptake.

Pyrite: An iron sulphide mineral often found in tidal swamps and brackish sediments. If submerged, these minerals are relatively harmless. However, when exposed through falling water levels, the pyrite will oxidise to jarosite, which forms highly acidifying acid sulphate soil.

Readily Available Water (RAW): The amount of soil water within the rooting zone that can be easily accessed for plant growth. Irrigation management should aim to maintain soil moisture levels in the “readily available” range.

Sand lenses: Sand deposited by river or wind action and present in layers of varying depths.

Sandstone: A sedimentary rock consisting mainly of grains of quartz that are present in a consolidated form.

Shale: Fine-grained sedimentary rock formed in layers by the consolidation of sand, silt and mud.

Siltstone: Fine grained consolidated rock composed of silt-sized particles.

Sodic soil: Soils having high exchangeable sodium levels (see ESP). Such soils have a poor structure, disperse easily and are prone to erosion.

Soil profile: A vertical section through the soil showing the arrangement of soil horizons.

Soil structure: The arrangement of soil particles into aggregates (peds) and the pore spaces between them.

Soil texture: A property that depends on the relative proportions of coarse sand (2 – 0.2 mm), fine sand (0.2 – 0.02 mm), silt (0.02 - 0.002 mm) and clay (< 0.002 mm) but may be modified by organic matter or the type of clay minerals.

Subsoil: Soil below the cultivated zone commonly sampled at 40 – 60 cm depth.

Topography: The shape of the landscape including height of hills, general slope and position of drainage lines.

Topsoil: The cultivated zone of soil commonly sampled at 0-20 cm depth.

Toxicity: A high level of nutrient or element that causes plant injury and/or reduction in growth or yield.

Two-year crop: Some crops in New South Wales are grown over periods longer than 12 months. At harvest, the crop age can range from 18 months to 2 years.

Volatilisation: The loss of ammonia gas from soil, mainly associated with urea applied to the soil or trash surface.

Water holding capacity: The amount of water a soil can hold after drainage.

Waterlogging: The saturation of soil with water so that all air is excluded (anaerobic). Under these conditions denitrification can occur.

Weathering: The decomposition of minerals into different sized particles caused by carbon dioxide, water and biological processes.

INTRODUCTION

Soil Specific Management Guidelines for Sugarcane Production have been produced for several sugarcane districts in Queensland. These booklets describe the basic principles of soil management and present nutrient guidelines for a range of soils based on the SIX EASY STEPS program. This booklet is aimed at soil-specific nutrient management for the New South Wales (NSW) sugarcane industry. These guidelines are based on a methodology developed within two SRDC-funded projects integrated with knowledge from local extension staff and growers.

Our philosophy is that on-farm nutrient management should be based on a sound understanding of soils. Not only does soil type influence decisions on which variety to plant and how much fertiliser to apply, but it also has an impact on the choice of tillage practices, planting techniques, drainage and irrigation requirements, and harvest scheduling. A major objective of this publication is to help growers improve and utilise their knowledge of different soils on their farms. This includes the appearance of soils, their occurrence in the landscape, their properties and how they should be managed. Soil-specific guidelines as presented in this booklet represent a much more precise way of managing fertiliser inputs than the traditional "one size fits all" approach. It provides a benchmark against which soils and soil analyses can be compared. However, it is not intended as a substitute for on-farm soil testing, local knowledge gained from demonstration strip-trials and regular checks on the adequacy of the nutrient management program. Ideally, each block on the farm should be sampled every crop cycle for both soil and leaf analyses. A system of record keeping is essential to document and review nutrient inputs, changes in soil fertility, and crop productivity and profitability.

This philosophy is particularly appropriate for the current circumstances in the Australian sugar industry. The escalating costs of fertiliser, the need to reduce production costs and mounting environmental pressures demand responsible soil and nutrient management. The guidelines in this booklet are aimed at providing best-practice soil and nutrient management for growers. Use of these will not only maintain or improve crop yields and soil fertility, but will also provide opportunities for cost reductions whilst enhancing sustainability and delivering positive environmental outcomes by minimising possible off-site nutrient movement.

CHAPTER 1

Introduction to New South Wales sugarcane soils and their properties

Sugarcane in NSW is mainly grown on the alluvial floodplains of the lower Tweed, Brunswick, Richmond, Wilson and Clarence Rivers. Although the majority of the soils supporting sugarcane are alluvial, there is a wide variation in soil properties across the different river systems caused by factors such as climate, types of parent rock in the catchments, topography and drainage. The rock types that have been weathered and eroded to produce the alluvium have had significant influences on the soil mineralogy and nutrient status of the soils in the different river valleys of coastal northern NSW. For example, the presence of basalt and gabbro in the Tweed and Richmond catchments has resulted in cracking clay soils with generally higher nutrient status than soils in the Clarence, which has less basalt in its catchment.

Soil formation and distribution

Tweed and Brunswick River

In the Condong mill area, there is a predominance of riverbank alluvial, clay, sand and peat soils. The underlying bedrock of the Tweed and Brunswick river valleys comprises thick-bedded conglomerate and sandstone. More recently, volcanic activity produced a massive cone-shaped formation of fine-grained basalt over the bedrock conglomerate and sandstone. Erosion processes and the physical environment in the Tweed estuary led to the deposition of fine-grained alluvial and tidal clays in the lower catchment. Alluvial deposits resulting from flood events were deposited over the acid sulphate clays. The alluvial deposits form levee banks close to the river and become thinner away from the river. Low-lying vegetative back-swamps are found further away from the main river channels. These areas contain mainly peaty loam soils and constitute a significant portion of the cane-growing area in the Tweed. Sandy soils have formed close to the coast on remnants of old beach lines and wind-blown coastal sands.

Richmond and Wilson River

The Richmond River alluvial plain has formed from deposition of alluvial and estuarine sediments. As with the Tweed floodplain, part of the Richmond/Wilson catchment drains areas with basaltic soils. The floodplain has extensive areas of fine-grained sediments with black and brown cracking clays. Areas of poor drainage are common, with deep peat soils, which are often saturated for at least 2-3 months. In isolated areas close to the coast, sandy soils have formed from low beach ridges.

Clarence River

The Clarence River catchment geology is predominantly granite, sandstone, siltstone, and shale. Unlike the Tweed and Richmond river systems, there is relatively little basalt in the Clarence catchment. The fertility status of the alluvium deposited on the floodplain is generally lower than in the Broadwater and Condong mill areas.

Landforms in the Clarence include alluvial and tidal plains and former river channels and swamps. Existing river channels in the Clarence river ‘delta’ have created islands such as Chatsworth and Palmers Islands. Downstream of Maclean, wind-blown and marine sands are mixed with alluvium.

A typical landscape consists of a narrow riverbank levee, which slopes down into a backplain or backswamp. Different soil types have developed on each of these landforms. Sandy soils occur on low ridges of coarser alluvium parallel to the present river channels. These are probably former riverbank levees.

Smaller areas of cane are grown on the hills surrounding the Clarence floodplain. Here, the soils have developed on sandstone, siltstone, claystone or conglomerate.

Acid sulphate soils

Unlike other cane-producing districts in Australia, northern NSW has significant areas of either actual or potential acid sulphate soils. In the Tweed this material may be close to the soil surface (0.3m). Where present in the Broadwater and Harwood areas, it tends to be deeper in the profile (0.8m or more). The NSW cane industry has specifically addressed the management of these soils with individual acid hazard and management plans for each farm. Where these soils are well-managed, the acid sulphate properties do not have a major impact on cane productivity or fertiliser management practices. This booklet, whilst drawing attention to environmental risk management issues for these soils, does not prescribe separate fertiliser management practices for actual or potential acid sulphate soil.

Soil field properties

Recognition of basic soil field properties such as colour, texture, structure, depth and position in the landscape enables the separation of soils into different categories. Soil type used in combination with soil chemical properties (from soil tests) will enable growers and their advisers to make informed decisions about appropriate nutrient management strategies on-farm.

Colour

The colour of soil is determined by the amount of organic matter present, iron oxide levels and the degree of aeration/moisture content. Dark coloured soils have more organic matter than lighter-coloured soils, consequently topsoils are generally darker than subsoils. Well-drained soils have red or brown colours whereas poorer drainage is indicated by paler colours ranging from yellow, grading through to grey, light grey and even blue in very poorly drained soils. Bleached horizons (containing little organic matter or iron) with mottles are indicative of seasonal saturation and intense leaching. The mottles form around larger soil pores and root channels where there is some oxygen. The colours referred to in this booklet relate to soils that are moist.

Soil texture

This is an important soil property as it affects soil structure (see below), the capacity of soil to hold air and water, the amount and availability of nutrients, and many chemical properties. Management issues such as workability, trafficability, erodibility and root development are also associated with soil texture.

Soil texture is a measure of the relative proportions of the various sized soil particles present. While the largest particles include gravel and sand, the smallest particles are referred to as clay. Silt particles are moderate in size. Soils are classified as sand, loam or clay depending on the proportions of these basic components. Clay particles, with their large surface area and negative charge, are the most reactive constituents of the soil. They give soils the ability to store positively charged nutrients such as potassium, sodium, calcium and magnesium. The fine pores between the clay particles also allow them to store large volumes of water. Actual texture (particle size distribution) can be determined in the laboratory. Alternatively, soil texture can be estimated in the field using the guidelines provided in Appendix 1.

Structure

Structure is the natural aggregation of the soil particles (sand, silt and clay) and organic matter into units called peds (aggregates). These peds can differ markedly in terms of size, shape and level of stability. Their presence in soil affects the way soils behave, the growth of plants and the manner in which we manage the soil. For instance, while some structure is essential to enable soil stability and good water-holding characteristics, large and strong structural units in the soil can prevent root penetration and negatively affect tillage operations.

Soil horizons

Soils develop different horizons or layers in their vertical sections. Horizon development varies with the type of soil parent material, organic matter, and the influence of water through leaching/ flooding. Each horizon has characteristics, which relate to soil colour, texture and structure that distinguish it from the horizons above and below it. Farming activities mix together the surface horizons, which we refer to as topsoil. Material below this is referred to as subsoil. In the cane producing soils of New South Wales, the top 20 cm is generally considered mixed topsoil and the 40-60 cm depth increment is usually well within the subsoil.

Chemical Properties

Clay particles and soil organic matter are largely responsible for the chemical properties of soils due to their reactivity and their small particle size, which results in a large surface area.

Cation Exchange Capacity

Cation Exchange Capacity (CEC) refers to the amount of negative charge on clay and organic matter particles that attract positively charged chemicals called cations. The most common cations in soil are calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and aluminium (Al). As these cations are held electrostatically, they are not easily leached but can be exchanged for other cations enabling plants to have access to them. Soils in the wetter tropical areas generally have lower CECs than soils in cooler or drier areas as they are more highly weathered. NSW soils generally have high CEC due to prevailing cooler temperatures. The CEC of soils in this booklet is defined as the Effective Cation Exchange Capacity (ECEC), which is the sum of the exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, Na^+, Al^{3+} and H^+) as measured in the laboratory. In NSW, the ECEC is classified as very low (less than 4 me%), low (4 - 8 me%), medium (8 –16 me%) or high (more than 16 me%).

Organic matter

Soil organic matter is derived from the breakdown of plant and animal matter. It also has the ability to attract nutrients and has a greater cation exchange capacity than a similar mass of clay. Dark colour and good structure are indicators of high organic matter. Soils in NSW have organic C contents that range from low to in excess of 10%. Organic matter, measured as organic carbon %, improves soil structure and is a source of nitrogen (N), phosphorus (P), sulphur (S) and trace elements. There is no optimum level of organic matter, but it is best to maintain it at the highest possible level. The organic matter content of a soil is determined by the balance between inputs of organic matter-forming material and the breakdown (mineralisation) of the existing stabilised soil organic matter (humus). Green harvested sugarcane inputs about 10-15 t/ha in trash and 3 t/ha in roots per year, but 80% of this is lost by decomposition in the first year. However, trials conducted in NSW showed that ratooning was adversely affected by green cane trash blanketing particularly early in the season due to cool soil temperatures (Kingston and others, 1998). Later in the season the effect was not so apparent. If green cane trash blanketing is to be practised, these considerations need to be taken into account.

In soils with low clay content, organic matter is the chief store for exchangeable cations. Organic matter is a major source of N, which is released by mineralisation (the process in which organic matter is broken down into its mineral components). The potential amount of N released from specific soils can be estimated using an N mineralisation index. This index is used to guide N fertiliser recommendations.

Whilst increasing organic matter levels is difficult in tropical soils due to rapid decomposition rates, NSW soils have comparatively high levels of organic C. Breakdown of organic matter is enhanced by cultivation. Trash conservation following green cane harvesting and the use of fallow green manure crops are the major ways organic matter can be added to soil in sugarcane farming systems. Other methods of maintaining soil organic matter include reducing tillage operations, preventing soil erosion and use of imported organic matter sources such as mill mud, mud / ash and bagasse.

Acidity and soil pH

Acidity in soils is caused by excessive hydrogen (H^+) and aluminium (Al^{3+}) ions on the cation exchange sites. Acidity is expressed in terms of pH: pH values less than 7 are acidic whilst those more than 7 are alkaline. Soil tests commonly include two measures of acidity: pH in water (pH_{water}) and pH in calcium chloride solution (pH_{CaCl_2}). In this booklet, we only consider pH in water. Soil pH values greater than 5.5 are generally desirable for plant growth. Under acidic conditions, Al^{3+} is present in its soluble form and is toxic to most plants. Fortunately, Australian sugarcane varieties are fairly tolerant of high levels of Al. However, this does not apply to legume crops, which may be grown as fallow crops. Consequently, maintaining soil pH values above at least 5 is essential particularly if legume crops are going to be part of a farming system on acid soils. Increased acidity (lower pH) is associated with reduced availability of N, P and S, while micro-nutrients such as copper (Cu) and zinc (Zn) will become more available.

Low pH may reduce the CEC of some soils and causes the soil CEC to be dominated by the acidic cations H^+ and Al^{3+}. This reduces the storage capacity for nutrients such as Ca, Mg and K and can be critical particularly on sandy soils with low CEC. Soil acidification is a natural process, which is accelerated by the leaching of nitrate from nitrogen fertilisers and the removal of cane to the mill. Regular use of liming materials will reduce soil acidity, neutralise applied acidity arising from nitrogen fertiliser use and replace Ca and Mg (if using Mag lime or dolomite) withdrawn in the harvested crop.

Flocculation

Clay particles can remain suspended in water or they can flocculate and settle. Soils with their CEC dominated by calcium, magnesium and aluminium ions flocculate well and do not disperse easily in water. However, sodium dominated soils with an exchangeable sodium percentage (ESP) greater than 5% are unstable when wet and disperse. Clays that disperse readily fill the pore spaces and reduce permeability to both air and water.

Sodicity and salinity

Sodic subsoils restrict rooting depth, reduce soil water availability to roots and may increase susceptibility to surface erosion. Salinity is an issue for sugarcane grown on coastal and marine plains, and inland areas where water tables are above 0.5 m causing salt accumulation in mid and lower landscape positions.

Plant nutrition

Plants require 16 elements for optimum growth. Carbon (C), hydrogen (H) and oxygen (O) are supplied from air and water. The other mineral elements can be divided into three groups: macronutrients (nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulphur (S) and magnesium (Mg)) which are required in relatively large amounts (20 – 200 kg/ha), micronutrients (iron (Fe), copper (Cu), zinc (Zn), molybdenum (Mo), manganese (Mn), boron (B), and for some crops sodium (Na)) which are required in small amounts (less than 10 kg/ha/crop). Beneficial nutrients include silicon (Si), which may be applied in fairly large quantities. All of these nutrients are naturally available in soils. Some soils are able to supply more of a particular nutrient than other soils. Fertilisers and soil ameliorants are used to supplement these supplies of nutrients and prevent the mining of nutrients stored in our soils.

Nitrogen (N)

Past research suggests that a crop of sugarcane requires about 1.4 kg N/tonne cane up to 100 tonnes cane per hectare and 1.0 kg N/tonne of cane thereafter. In order to achieve sustainable crop production, maximum use must be made of all the available N sources within the N cycle (Figure 1.1). To do this it is important to have an understanding of the transformations of N from one form to another.

Mineralisation of organic matter to ammonium and nitrate is on-going. The amount released depends on the quantity of organic matter and microbial activity. Adverse soil conditions such as waterlogging and low pH can restrict the number and effectiveness of micro-organisms mineralising N. The rate of mineralisation is also dependent on temperature and moisture and will therefore vary through the year according to climatic conditions. Irrespective of the actual rate of mineralisation, this N is available for plant uptake and should be taken into account when N requirements are calculated. Nitrate levels fluctuate considerably in the soil. They rise substantially after cultivation in some soils (those high in organic matter) and after fertilisation. They are reduced by crop removal and after heavy rainfall (by leaching and runoff) and waterlogging (denitrification). Ammonium-N is subject to volatilisation, a loss often associated with surface applied urea fertilisers. More detail is provided on these processes in Figure 1.1.

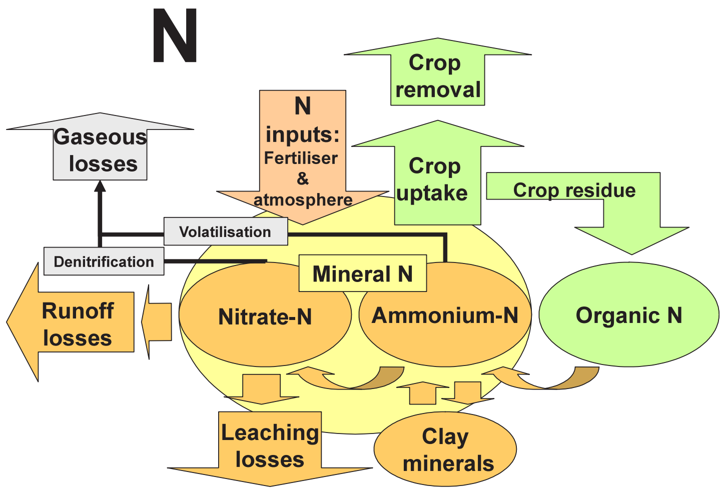


Figure 1.1 Schematic diagram of the nitrogen cycle

As it is important to minimise nitrogen losses, the following strategies are suggested:

- Apply nitrogen according to the specific requirements of different soils based on their N mineralisation index (as shown in Chapter 2).

- Reduce nitrogen losses from leaching, runoff and denitrification by splitting applications of nitrogen and avoiding applications just before the wet season.

- Reduce the potential for denitrification by improving drainage and placing fertiliser sub-surface in mounded rows where waterlogging is less likely.

- Reduce the potential for ammonia volatilisation when urea is applied to the surface of a trash blanket by delaying application until a cane canopy has developed. Applying the urea below the soil surface removes the possibility of losses by volatilisation but could increase the risk of loss by denitrification if waterlogging occurs.

Phosphorus (P)

Phosphorus cycles between the various forms in soil (Figure 1.2), with some forms being more readily available than others. In some soils with high clay and/or organic matter content, P is held tightly onto soil particle surfaces by a process called P sorption. More P fertiliser needs to be applied when P is strongly 'sorbed' as this P is relatively unavailable to plants. The Phosphorus Buffer Index (PBI) is a measure of how strongly different soils sorb added P.

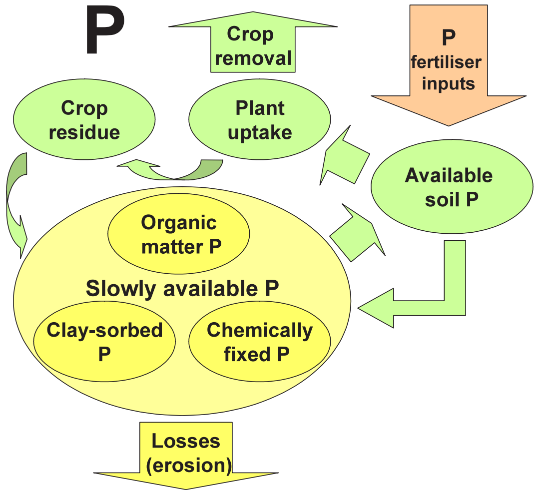


Figure 1.2 Soil phosphorus cycle

Potassium (K)

Sugarcane needs potassium in large quantities mainly for the maintenance of water balance. On average, 150 kg K/ha is removed each year in the cane harvested and sent to the mill. Plants luxury feed on K where surplus is available. Potassium is present in a number of distinct forms within soils. A schematic diagram of the K cycle is shown in Figure 1.3.

Lattice K is part of the clay structure and in some soils can represent a major part of the total K in the soil and provide a source of plant available K. Slowly available non-exchangeable K exists in some K minerals and this can also act as a source of exchangeable and solution K (plant available forms). Potassium losses are possible with leaching of exchangeable and soil solution K, particularly from sandy soils and soils with a low CEC, and by erosion, which results in losses of lattice and non-exchangeable K reserves.

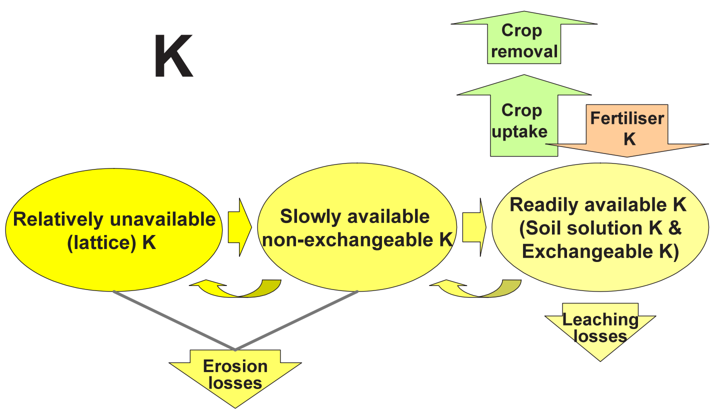


Figure 1.3 Soil potassium cycle

Calcium (Ca)
Calcium is essential for cane growth and for cell wall development. It is taken up as a positively charged cation from the soil solution. Soil reserves of Ca, which are held on the CEC, are supplemented by additions of liming materials, gypsum and mill mud. A cane crop removes about 30 kg Ca/ha/year but when applying lime, considerably more Ca than this is applied because of the need to control soil acidity.

Magnesium (Mg)
Magnesium is essential for plant photosynthesis, as it is the main mineral constituent of chlorophyll. Like Ca, it is taken up from the soil solution and from the CEC, and total uptake is similar to calcium.

Sodium (Na)
Sodium is required in very small amounts for the maintenance of plant water balance. It is stored on the CEC and can be taken up from the soil solution by plants. Sodium is readily supplied from rainfall, particularly in coastal areas. Sugarcane is susceptible to high levels of sodium. It can have a detrimental effect on soil structure even at low levels (ESP of around 5%) and at higher levels (ESP above 15%) can restrict plant growth and root development.

Sulphur (S)
Sugarcane requires S in relatively large amounts of about 25 kg S/ha/year, which is used for plant structure and growth. Plants take up S as sulphate, which is more mobile in soils than phosphate and is therefore subject to leaching. Consequently fertilising may need to supply more than that harvested in the crop. The main store of S in soils is organic matter. However, in acid sulphate soil, large quantities of S are released from the oxidation of pyrite. Irrespective of the source, soil S levels should be allowed for when developing fertiliser recommendations. Other natural sources of S are rainfall and irrigation.

Micronutrients
Micronutrients are taken up by cane in much smaller quantities than the nutrients already mentioned. Generally they are regulators of plant growth. Both copper (Cu) and zinc (Zn) have been shown to be deficient in some soils, particularly low organic matter sandy soils, whereas iron (Fe) and manganese (Mn) are usually well supplied. Little is known about the status of molybdenum (Mo) and boron (B) in NSW soils.

Silicon
Although deficiencies of silicon (Si) have been detected in sandy soils in some cane-growing districts, Si is well supplied in the majority of sugarcane soils of NSW.

CHAPTER 2

Principles for determining nutrient management guidelines

When developing nutrient management guidelines for the different soil types the following factors were taken into account:

- Crop yield potential
- Two-year versus one-year crops
- Nutrients removed in the harvested crop
- Nutrients returned to the soil in fallow crops and mill by-products
- Nutrients released by the mineralisation of soil organic matter
- Impact of cooler soil temperatures and soil acidity on mineralisation rates
- Nutrients released by the weathering of soil minerals
- Nutrients fixed (held tightly) on soil particle surfaces
- Soil acidity
- Critical levels of nutrients as determined by soil analysis
- The balance and interactions of different nutrients, particularly those on the soil CEC
- The risk of nutrient loss processes occurring.

A wide range of soil physical and chemical properties was considered during this process. Data were obtained from the analysis of samples taken from the soil reference sites and from a local database containing results of grower soil tests. They were used to produce the bar graphs for each soil type in Chapter 3 and include:

- Soil particle size distribution, particularly clay % (soil texture)
- Soil organic carbon % (a measure of organic matter)
- Nitrogen mineralisation index (a measure of the amount of N released from the breakdown of soil organic matter)
- Soil pH (a measure of soil acidity)
- Cation exchange capacity (CEC)
- Exchangeable K, Ca, Mg and Na (cations held on the soil CEC)
- Nitric K (an estimate of K reserves)
- Exchangeable sodium percentage - ESP (the % of the CEC occupied by sodium)
- Exchange acidity (a measure of acidic cations held on the CEC)
- Acid saturation (% of the CEC occupied by acidic cations)
- BSES P (index of available phosphorus)
- Phosphorus Buffer Index – PBI (a measure of the degree to which added P is held tightly onto soil particle surfaces and is unavailable for plant uptake)
- Sulphur, copper and zinc.

Nitrogen (N) (see Wood and others, 2003; Schroeder and others, 2006)
Nitrogen guidelines are now based on a combination of **district yield potential and soil N mineralisation index**. The district yield potential is determined from the best possible yield averaged over all soil types within a district and is defined as the estimated highest average annual district cane yield (tonnes cane/ha) multiplied by a factor of 1.2. As the NSW sugarcane industry produces both one- and two-year crops, three district yield potential values are used in NSW: 140, 180 and 220 tonnes cane/ha. Usually, the lower district yield potential refers to one-year crops and the 180 and 220 tonnes/ha are relevant to two-year crops. This concept of district yield potential recognises differences in the ability of districts and regions to produce cane. It is important to note that the district yield potential of 220 tonnes cane/ha is relevant to those farms/blocks that consistently achieve yields of this magnitude. In most cases the district yield potential of 180 tonnes cane/ha would be appropriate.

The district yield potential is used to establish the base N application rate according to an estimate, previously developed by CSIRO. Accordingly, 1.4 kg N per tonne of cane is required up to a cane yield of 100 tonnes/ha and 1 kg N per tonne of cane/ha thereafter. With the new approach however, inputs are adjusted according to the N mineralisation index, which is based on soil organic carbon (C) percentage and is related to soil colour. Generally, the darker the soil, the more organic matter is present. In the Queensland industry seven N mineralisation index categories are recognised based on corresponding soil organic C classes. In NSW a larger range of organic C values occur in two broad soil groups that are defined by soil pH and organic C values. One group consists of organic C values similar to those found in Queensland (0 - 2.4% C) with corresponding comparable N mineralisation values. These soils usually have organic C values less than 3% and pH values above 5. The other group contains the acid peat soils (predominantly acid sulphate or potentially acid sulphate soils) with much higher soil organic C values up to about 10% (Figure 2.1). Nitrogen mineralisation in this group of soils appears to be inhibited by low pH values and the amounts of N mineralised are lower than expected for the levels of organic matter.

The use of N mineralised from the soil organic matter (according to the N mineralisation index) results in a set of guidelines for N fertiliser inputs as shown in Tables 2.1 and 2.2. Whilst Table 2.1 refers to all soils except the "acid peat soils", Table 2.2 is relevant to the acid peat soils.

In each case if a farm **consistently** produces higher yields than the district yield potential, the baseline N application rate should be adjusted upwards by 1 kg N per tonne of cane above the district yield potential. For example, if the average yield on a farm, calculated over a number of crop cycles is 200 tonnes cane/hectare, then the baseline N application rate should be set at 240 kg N/ha ((100 x 1.4) + 100)). Conversely, if a farm consistently produces lower yields than the district yield potential, the baseline N application rate should be decreased using the same approach.

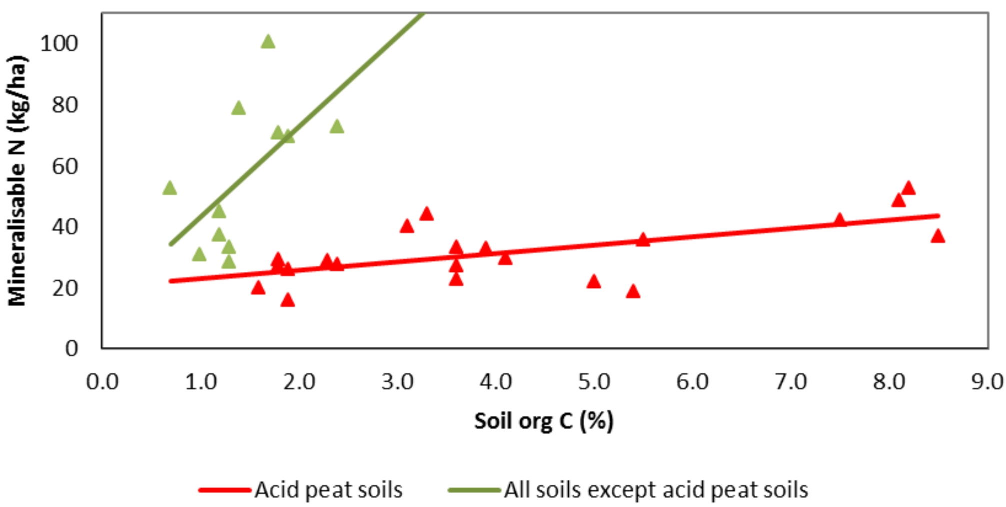


Figure 2.1 – Mineralised N plotted against soil organic C for acid peat soils (shown in red) and all other soils (shown in green) in the NSW sugarcane industry

Table 2.1 - N mineralisation index and nitrogen rates for replant and ratoon crops, and plant cane following a bare or grass fallow on all soils except acid peat soils

N mineralisation index	Organic carbon (%)	Crop	N rate kg/ha for:		
			DYP* = 140 tc/ha	DYP* = 180 tc/ha	DYP* = 220 tc/ha
VL	<0.4	Plough-out replant/ratoons	180	220	260
		Plant cane following a bare or grass fallow	160	200	240
L	0.4 - 0.8	Plough-out replant/ratoons	170	210	250
		Plant cane following a bare or grass fallow	150	190	230
ML	0.8 - 1.2	Plough-out replant/ratoons	160	200	240
		Plant cane following a bare or grass fallow	140	180	220
M	1.2 - 1.6	Plough-out replant/ratoons	150	190	230
		Plant cane following a bare or grass fallow	130	170	210
MH	1.6 - 2.0	Plough-out replant/ratoons	140	180	220
		Plant cane following a bare or grass fallow	120	160	200
H	2.0 - 2.4	Plough-out replant/ratoons	130	170	210
		Plant cane following a bare or grass fallow	110	150	190
VH	>2.4	Plough-out replant/ratoons	120	160	200
		Plant cane following a bare or grass fallow	100	140	180

*District yield potential

Table 2.2 - N mineralisation index and nitrogen rates for replant and ratoon crops, and plant cane following a bare or grass fallows on acid peat soils

N mineralisation index	Organic carbon (%)	Crop	N rate kg/ha for:		
			DYP* = 140 tc/ha	DYP* = 180 tc/ha	DYP* = 220 tc/ha
L	<3.0	Plough-out replant/ratoons	180	220	260
		Plant cane following a bare or grass fallow	160	200	240
M	3.0 - 6.0	Plough-out replant/ratoons	170	210	250
		Plant cane following a bare or grass fallow	150	190	230
H	> 6.0	Plough-out replant/ratoons	160	200	240
		Plant cane following a bare or grass fallow	140	180	220

*District yield potential

After determining the appropriate N application rate in this way, further discounting is required to recognise the contributions of other sources of N. These sources include N from legume crops and applications of mill by-products.

Determining N application rates for sugarcane following legume fallows

Unlike N held in soil organic matter, legume N is readily available for plant uptake and should be treated the same way as fertiliser N for the purposes of calculating N requirement. Information published by scientists working in the Sugar Yield Decline Joint Venture has provided details on how to estimate the amount of legume N being returned to the soil from a legume crop.

The amount of N available to the succeeding sugarcane crop will be dependent on the type of legume, how well it was grown and whether the grain was harvested. The R&D team associated with a project entitled *Improving soybean and nitrogen management in sub-tropical NSW cane systems* have developed a comprehensive method to estimate the amount of N that can be discounted for a sugarcane crop following a well-nodulated, well-grown soybean crop (Table 2.3). The values shown in the last two columns in Table 2.3 should be subtracted from the N requirements shown in Tables 2.1 and 2.2, depending on whether the soybean 'grain' was harvested or not.

Table 2.3 – Nitrogen (N) rate discounts following a well-nodulated, well-grown soybean crop (SRDC Grower Group Innovation Project 050)

Estimated soybean 'grain' yield (t/ha)	When 'grain' is harvested (kg N/ha)	When 'grain' is not harvested (kg N/ha)
1	45	70
2	60	115
3	70	155
4	85	200
5	100	240

Modifying N application rates for sugarcane where mill by-products have been used

The amount of N applied needs to be discounted for up to three years after application of mill by-products. The amount of N to be subtracted from N application rates following the use of mud and mud/ash mixture (Table 2.4).

Table 2.4 – N contribution from mill by-products

Product	Application rate (wet t/ha)	To be subtracted from the appropriate N application rate		
		Year 1 (kg N/ha)	Year 2 (kg N/ha)	Year 3 (kg N/ha)
Mill ash	150	Nil	nil	nil
Mill mud	150	80	40	20
Mud/ash	150	50	20	10

Phosphorus (P)

Two techniques are used to decide how much P fertiliser is required. Firstly, a BSES soil test is used to determine the quantity of P fertiliser required. This is then modified by the soil's ability to fix added P (P sorption), which determines how much of the fertiliser P will be available to the crop. The P sorption class of each soil is based on the Phosphorus Buffer Index (PBI), which is measured in the laboratory (Table 2.5).

Table 2.5 - P sorption classes based on PBI (see Burkitt and others, 2000)

P sorption class	PBI
Low	< 140
Moderate	140 - 280
High	281 - 420
Very high	> 420

Currently, some older sugarcane areas do not require any P fertiliser due to their long history of P fertilisation. New land, on the other hand, is often deficient in available P with BSES P values less than 5 and requires substantial amounts of P fertiliser in the first crop cycle (Table 2.6). The guidelines in Table 2.6 are based on a combination and subsequent re-interpretation of information supplied by Calcino (1994), Bramley and Wood (2000) and Burkitt and others (2000).

Table 2.6 - Phosphorus guidelines for old and new land (see Schroeder and others, 2006)

BSES P in soil test (mg/kg)	P sorption class	Phosphorus application (kg/ha)	
		Plant	Ratoon
>120	All	0	0
60 - 120	Low	0	0
	Moderate	0	0
	High	0	0
	Very high	30	20
50 - 60	Low	0	0
	Moderate	0	0
	High	0	0
	Very high	30	20
40 - 50	Low	20	0
	Moderate	20	5
	High	20	10
	Very high	30	20
30 - 40	Low	20	10
	Moderate	20	15
	High	20	20
	Very high	30	20
20 - 30	Low	20	10
	Moderate	20	20
	High and Very high	30	25
10 - 20	Low	30	15
	Moderate	30	20
	High and Very high	40	30
5 -10	Low	30	20
	Moderate	40	30
	High and Very high	50	40
<5	Low	40	20
	Moderate	60	30
	High and Very high	80	40

Discounts should be made where mill by-products have been used because they are a source of P (Table 2.7).

Table 2.7 - P contribution from mill by-products

Product	Application rate (wet t/ha)	P contribution
Mill ash	150	Sufficient P for plant crop and one ratoon
Mill mud	150	Sufficient P for two crop cycles
Mud/ash	150	Sufficient P for two crop cycles

Potassium (K)

Potassium fertiliser guidelines are based on two measures of soil potassium: readily available or exchangeable K (potassium in the soil solution and on the CEC) and reserve or nitric K (slowly available, non-exchangeable potassium).

The maximum recommended K rate for New South Wales is 120 kg K/ha that is slightly less than the amount of K removed in the harvested sugarcane crop. This is aimed at sustaining soil reserves of K. However, economic K rates may be slightly lower. If this strategy is adopted, then growers should closely monitor their soil and leaf K levels (Kingston and others, 2009). The maximum recommended K rate is aimed at avoiding luxury consumption of K by the crop (resulting in reduced juice quality) and leaching losses from low CEC soils.

Soil critical levels for exchangeable K are dependent on clay content. Soils are assigned into one of three textural classes: sand (<24% clay); loam (24 - 36% clay); and clay (>36% clay). Potassium fertiliser recommendations can then be derived from Table 2.8.

Table 2.8 - Potassium fertiliser guidelines for sustainable sugarcane production (Wood and Schroeder, 2004)

<table>
<tr><th colspan="7">Plant (kg/ha K)</th></tr>
<tr><td rowspan="2">Nitric K (me%)</td><td colspan="6">Exchangeable K (me%)</td></tr>
<tr><td>< 0.20</td><td>0.20 - 0.25</td><td>0.26 - 0.30</td><td>0.31 - 0.35</td><td>0.36 - 0.40</td><td>> 0.40</td></tr>
<tr><td rowspan="3">< 0.70</td><td>100 (sand)</td><td>80 (sand)</td><td>50 (sand)</td><td>50 (sand)</td><td>0 (sand)</td><td rowspan="6">0</td></tr>
<tr><td>120 (loam)</td><td>100 (loam)</td><td>80 (loam)</td><td>50 (loam)</td><td>0 (loam)</td></tr>
<tr><td>120 (clay)</td><td>120 (clay)</td><td>100 (clay)</td><td>80 (clay)</td><td>50 (clay)</td></tr>
<tr><td rowspan="3">> 0.70</td><td>80 (sand)</td><td>50 (sand)</td><td>0 (sand)</td><td>0 (sand)</td><td>0 (sand)</td></tr>
<tr><td>100 (loam)</td><td>80 (loam)</td><td>50 (loam)</td><td>0 (loam)</td><td>0 (loam)</td></tr>
<tr><td>100 (clay)</td><td>100 (clay)</td><td>80 (clay)</td><td>50 (clay)</td><td>0 (clay)</td></tr>
<tr><th colspan="7">Replant and Ratoon (kg/ha K)</th></tr>
<tr><td rowspan="2">Nitric K (me%)</td><td colspan="6">Exchangeable K (me%)</td></tr>
<tr><td>< 0.26</td><td>0.26 - 0.30</td><td>0.31 - 0.35</td><td>0.36 - 0.40</td><td>0.41 - 0.45</td><td>> 0.45</td></tr>
<tr><td rowspan="3">< 0.70</td><td>120 (sand)</td><td>100 (sand)</td><td>80 (sand)</td><td>50 (sand)</td><td>0 (sand)</td><td rowspan="6">0</td></tr>
<tr><td>120 (loam)</td><td>100 (loam)</td><td>100 (loam)</td><td>80 (loam)</td><td>50 (loam)</td></tr>
<tr><td>120 (clay)</td><td>100 (clay)</td><td>100 (clay)</td><td>100 (clay)</td><td>80 (clay)</td></tr>
<tr><td rowspan="3">> 0.70</td><td>100 (sand)</td><td>80 (sand)</td><td>50 (sand)</td><td>0 (sand)</td><td>0 (sand)</td></tr>
<tr><td>100 (loam)</td><td>100 (loam)</td><td>80 (loam)</td><td>50 (loam)</td><td>0 (loam)</td></tr>
<tr><td>100 (clay)</td><td>100 (clay)</td><td>100 (clay)</td><td>80 (clay)</td><td>50 (clay)</td></tr>
</table>

Discounts should be made where mill by-products have been used as they represent a source of K (Table 2.9).

Table 2.9 - K contribution from mill by-products

Product	Application rate	To be subtracted from the appropriate K application rate		
		Plant crop	First ratoon	Second ratoon
Mill ash	150 wet t/ha	120 kg K/ha	120 kg K/ha	0
Mill mud	150 wet t/ha	40 kg K/ha	0	0
Mud/ash	150 wet t/ha	120 kg K/ha	120 kg K/ha	0

Sulphur (S)

As the mineralisation of soil organic matter is a source of sulphur, S fertilising guidelines are in part based on the N mineralisation index. For all soils except acid peat soils, S guidelines are based solely on extractable sulphate S (Table 2.10). For acid peat soils, soils are placed in one of three N mineralisation classes. Soil sulphate S critical levels are then used to calculate sulphur fertiliser rates (Table 2.10). Discounts should be made where mill by-products have been used, because they supply S (Table 2.11).

Table 2.10 - Sulphur fertiliser guidelines

For all soils except acid peat soils		Acid peat soils		
Sulphate S (mg/kg)	S application rate (kg/ha)	S application rate based on N mineralisation categories (kg/ha)		
		L	M	H
< 5	25	25	20	15
5 - 10	15	15	10	5
11 - 15	10	10	5	0
> 15	0	0	0	0

Table 2.11 - S contribution from mill by-products

Product	Application rate	To be subtracted from the appropriate S application rate		
		Plant crop	First ratoon	Second ratoon
Mill ash	150 wet t/ha	0	0	0
Mill mud	150 wet t/ha	10 kg S/ha	10 kg S/ha	10 kg S/ha
Mud/ash	150 wet t/ha	10 kg S/ha	10 kg S/ha	0

Lime (See Aitken, 2000; Nelson and others, 2000; Wood and others, 2003)

Lime is used to neutralise soil acidity and to supply calcium. Soils are constantly being acidified through the use of N fertiliser, removal of nutrients in the harvested crop and by leaching of nitrate. Maintenance applications of about 2 tonnes lime/ha each crop cycle are needed to neutralise this effect. The more N fertiliser is used, the greater is the lime requirement. In addition, some forms of N fertiliser acidify more than others (ammonium sulphate acidifies more than urea which acidifies more than calcium ammonium nitrate). Some soil tests include liming estimates to a target pH of 5.5, 6.0 and 6.5. Generally, the liming estimate aimed at a soil pH of 5.5 should be used when available. Local NSW extension knowledge suggests that liming to a soil pH of 5 is however sufficient, with a higher soil pH target not being economically justified. With this in mind, growers are strongly recommended to follow liming estimates for sugarcane to at least a pH of 5 (based on soil tests). When soybean is part of the cropping system liming to a pH of 5.5 may be more appropriate. In the absence of laboratory generated lime requirements, Table 2.12 provides estimates of the amount of lime needed when soil pH is below 5. Lime is also required when exchangeable Ca is below the critical value of 1.5 me% (Table 2.13). Discounts are necessary where mill by-products have been used (Table 2.14).

Table 2.12 - Lime guidelines for acid soils (when pH_{water} <5.0)

CEC (meq/100g)	Lime application (tonnes/ha)
< 4.0	1.25
4.0 - 8.0	2.5
8.0 - 16.0	4
> 16.0	5

Table 2.13 - Ag lime guidelines based on exchangeable Ca (adapted from Calcino and others, 2000)

Ca (me%)	Suggested lime application (tonnes/ha)
< 0.2	3
0.2 - 0.4	2.5
0.4 - 0.6	2
0.6 - 0.8	1.5
0.8 - 1.1	1
1.1 - 1.5	0.5
> 1.5	0

Table 2.14 - Ameliorant contribution from mill by-products

Product	Application rate (wet t/ha)	Reduction in next Ag lime* application (t/ha)
Mill ash	150	2
Mill mud	150	2
Mud/ash	150	2

*Ag lime application can adjust soil pH and supply Ca

Magnesium (Mg)

Magnesium guidelines are based on soil critical levels for exchangeable Mg (Table 2.15). Whilst a Mg level of 10-20% of CEC is desirable, levels of over 50% of CEC can occur on some soils. This may affect soil physical properties, making the soils prone to hard-setting and possibly causing germination difficulties. However, subsequent growth does not appear to be affected, provided all nutrients are above their critical levels and soil pH is above 5.5. Discounts are appropriate where mill by-products have been used (Table 2.16).

Table 2.15 - Magnesium guidelines for plant crops (adapted from Calcino, 1994)

Soil test (me% Mg)	<0.05	0.06-0.10	0.11-0.15	0.16-0.20	0.21-0.25	>0.25
Mg rate (kg/ha)	150	125	100	75	50	0

Table 2.16 - Mg contribution from mill by-products

Product	Application rate (wet t/ha)	Mg contribution
Mill ash	150	Sufficient Mg for one crop cycle
Mill mud	150	Sufficient Mg for one crop cycle
Mud/ash	150	Sufficient Mg for one crop cycle

Sodium (Na)

Sodium does not need to be applied to sugarcane but needs to be reduced when the exchangeable sodium percentage (ESP) is above 6% of the CEC in the topsoil. Where this occurs, it is suggested that subsoil samples be taken to determine ESP in the soil profile and specialist advice be sought on possible remedial activities. Gypsum is the normal ameliorant for sodic soils because it is relatively soluble. However, lime is an alternative on acidic soils. Rates of application are dependent on exchangeable sodium percentage (ESP). Guidelines are provided in Table 2.17.

Table 2.17 - Gypsum requirement for sodic soils (see Nelson, 2000)

ESP (%)	**Gypsum rate** (tonnes/ha)
< 6	0
6 - 10	2
10 -15	4
> 15	6

Micronutrients

Copper and zinc guidelines are based on previously determined soil critical values. The BSES zinc and DTPA copper tests are used in NSW (Table 2.18). Copper and zinc are most often required on low CEC and very sandy soils. Leaf analysis is also a suitable method of diagnosing whether micro-nutrient applications are required. Heavy applications of Ag lime may induce deficiencies, particularly of zinc, when micronutrient levels are marginal.

Table 2.18 - Copper and zinc guidelines (Calcino and others, 2000)

Micronutrient	**Soil test value**	**Suggested application rate**
DTPA soil test		
Copper	<0.2 mg Cu/kg	10 kg Cu/ha once per crop cycle
BSES zinc test		
Zinc	<0.6 mg Zn/kg	10 kg Zn/ha once per crop cycle

Silicon (Si)

Two soil tests are appropriate for assessing silicon deficiencies. These are based on calcium chloride extractable Si and dilute sulphuric acid extractable Si. The latter is sometimes referred to as BSES-Si. Ameliorants are only required if both of the Si test values are low (Table 2.19). Leaf analysis is appropriate for assessing whether crops have been able to take up adequate amounts of Si.

Table 2.19 - Silicon guidelines for plant cane (Calcino and others, 2000; Berthelsen and others, 1999)

	Sulphuric acid (0.005M)		**Calcium chloride (0.01M)**	**Rating**	**Suggested application rate**
Si (mg/kg)	<70	and	<10	Low	Calcium silicate @ 4 t/ha **or** Cement @ 3t/ha **or** Mill mud/ash @ 150 wet t/ha

Description of NSW sugarcane soils and guidelines for their management

This chapter presents information on the location, appearance, properties and management requirements of the main cane-producing soils in NSW. The soils of the three mill areas are presented separately. The soil maps were produced from information collected in 2008 and is based on input from individual cane growers and agricultural staff in each mill area. Much of the soil mapping was done by growers at a farm scale. Perceptions of what constitutes a particular soil type, for example, a good riverbank alluvial soil, may differ between growers. The soil types are listed in Table 3.1 together with the proportion of the cane-producing area occupied by each soil type.

Table 3.1 - NSW cane-producing soils

Mill area	Soil types	Soil quality	Brief description	Proportion of mill area	Australian Soil Classification	Page
Condong	Riverbank alluvials	Good	Brown clay loams to clay soils with deep topsoils	9%	Brown Dermosols; Brown Kandosols	24
	Clay soils	Good	Brown clay loams to clays	36%	Brown Dermosols	26
	Deep peat soils	Good	Grey to dark grey clay loams; high organic matter	33%	Redoxic Hydrosols	28
	Shallow peat soils	Medium	Grey to dark grey clay loams to light clays with shallow peaty topsoil	18%	Redoxic Hydrosols	30
	Sand soils	Poor	Grey to brownish grey sands	4%	Semiaquic Podosols	32
Broadwater	Clay soils	Good to medium	Brown to dark brown clays	67%	Brown and Black Dermosols	34
	Peat soils	Good	Dark brown to black; high organic matter levels	29%	Redoxic Hydrosols	36
	Sand soils	Poor	Dark grey sandy topsoil over a bleached sand subsoil	4%	Semiaquic Podosols	38
Harwood	Riverbank alluvials	Good	Brown clay loams to clays with deep topsoil	23%	Brown Dermosols; Brown Kandosols	40
	Back plain soils	Medium	Dark structured clay topsoils over mottled medium clay subsoils	50%	Brown and Black Dermosols; Black Kandosols; Redoxic Hydrosols	42

Mill area	Soil types	Soil quality	Brief description	Proportion of mill area	Australian Soil Classification	Page
Harwood	Back plain shallow topsoil	Poor	Dark structured clay topsoil (<0.25m depth)	6%	Grey and Black Kandosols; Redoxic Hydrosols	44
	Sandy (loam and sandy clay loam) ridges	Medium	Massive to weakly structured soils, probably relict levees	6%	Red and Yellow Kandosols	46
	Back swamp soils	Poor	Dark structured topsoil with elevated organic matter, often saline	3%	Redoxic Hydrosols	48
	Hill soils	Poor	Yellow and red duplex soils and sandy or shallow stony soils on hills	12%	Grey, Red and Yellow Kurosols; Semiaquic Podosols	50

Location of soils

Generally each soil type is found in a particular part of the landscape. Typical landscape sections for each mill area are shown in Figures 3.1, 3.2 and 3.3. They illustrate where soil types occur and their relationship to the system of river channels, floodplains and different topographic features.

Soil reference sites representative of the major soil types producing cane in NSW were established (Figures 3.1, 3.2 and 3.3). Profile pits were excavated for describing field appearance of each soil type. Representative topsoil (0-20cm) and subsoil (40-60cm) samples were taken from the surrounding cane area. These samples were analysed in laboratories for a range of chemical and physical properties.

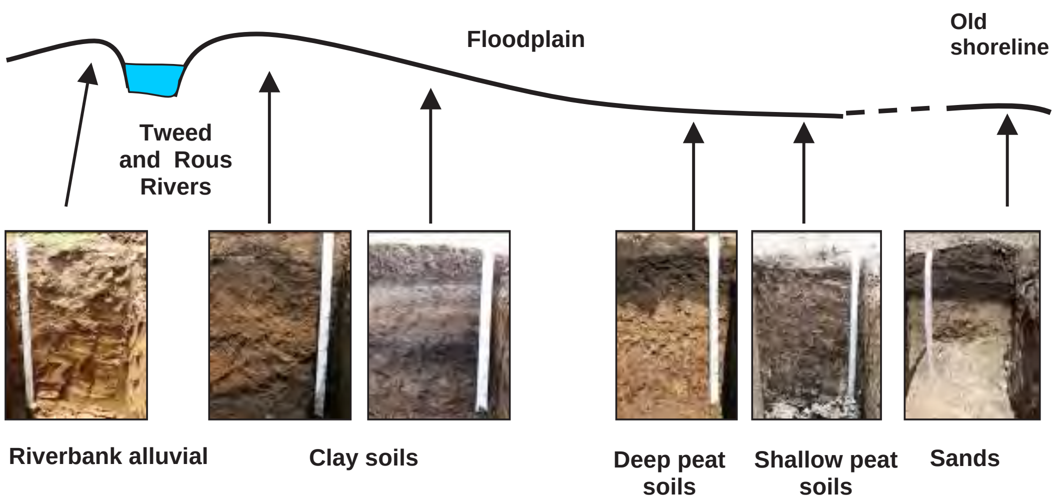


Figure 3.1 - Typical landscape in the Condong mill area

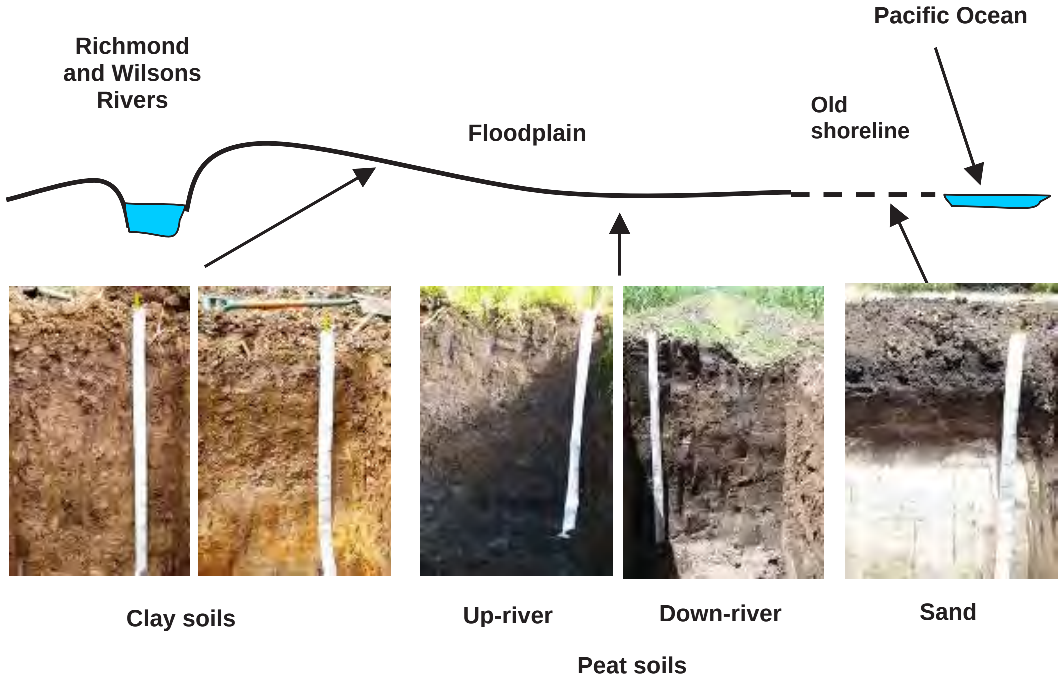


Figure 3.2 - Typical landscape in the Broadwater mill area

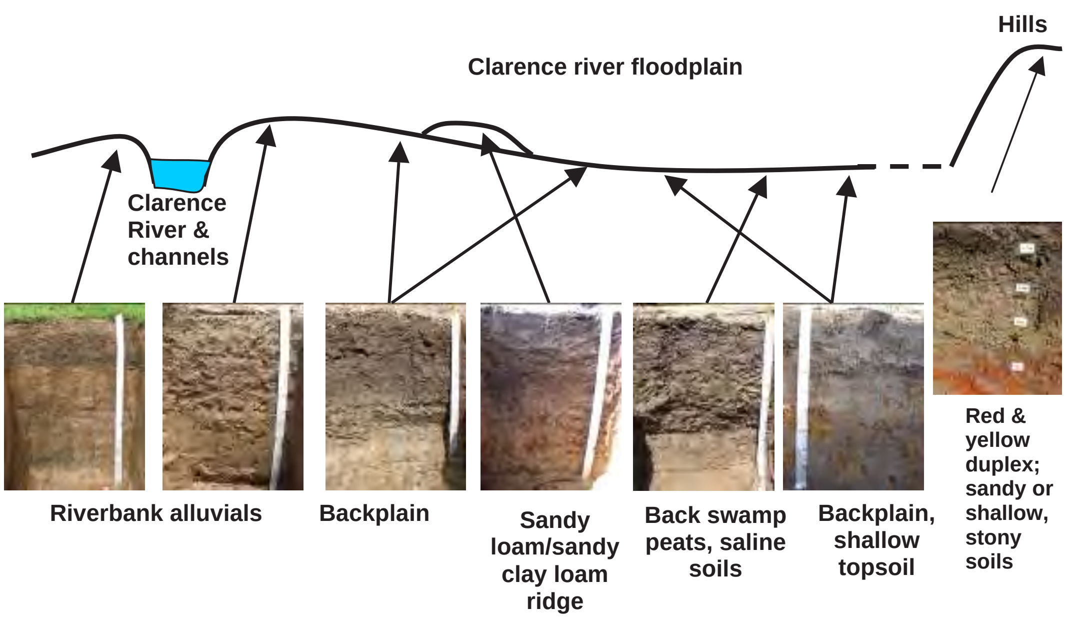


Figure 3.3 - Typical landscape in the Harwood mill area

Occurrence and properties of soil types

In the remainder of this chapter, information on the occurrence, formation, field appearance and chemical and physical properties of the soils is provided in a two-page format. Bar graphs are used to compare the properties of the soil type (blue bars) with the median properties for all soil samples for the respective district (maroon bars). Both sets of properties were collated from databases of routine soil test values collected over a number of years for each mill area. Analysis data indicated that the individual reference sites generally had properties typical of the different soil types.

Guidelines are given for the management of nutrient applications, tillage, water and environmental risks. Nutrient management guidelines are provided for different crop classes, such as fallow plant, plough-out/replant and ratoons. However, specific nutrient guidelines following the use of legume crops and mill by-products are not included and readers need to refer to the information in Chapter 2. The guidelines are intended as an indicator for determining nutrient inputs when recent soil and/or leaf tests are not available for specific blocks.

CONDONG

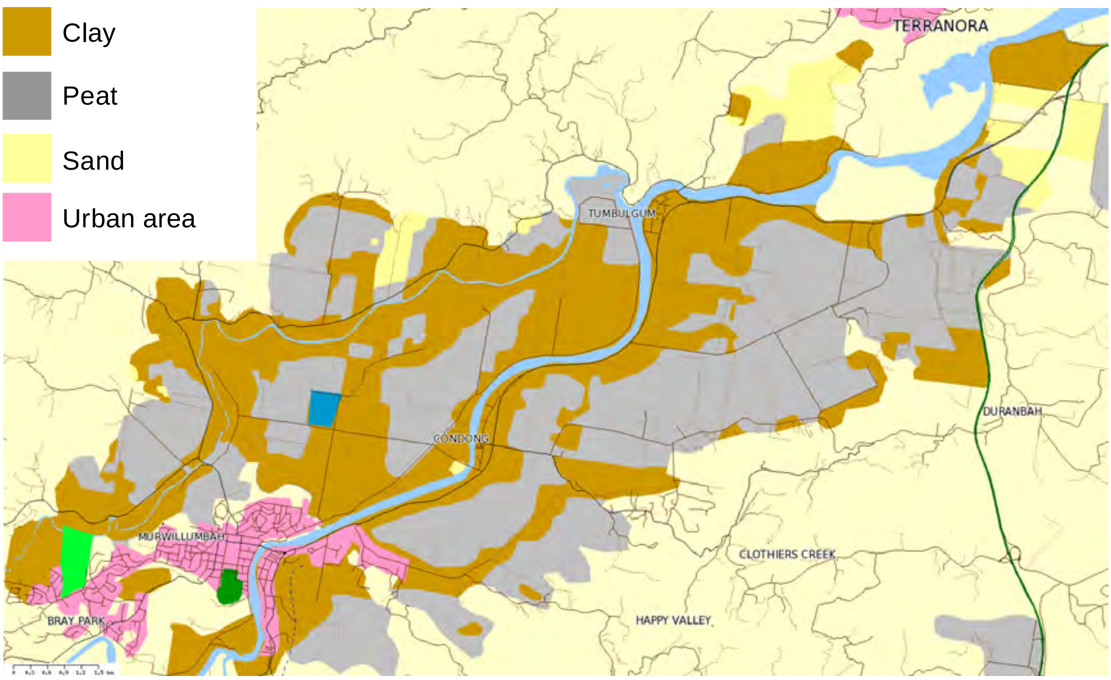


Figure 3.4 - Map of soil types in the Condong mill area

BROADWATER

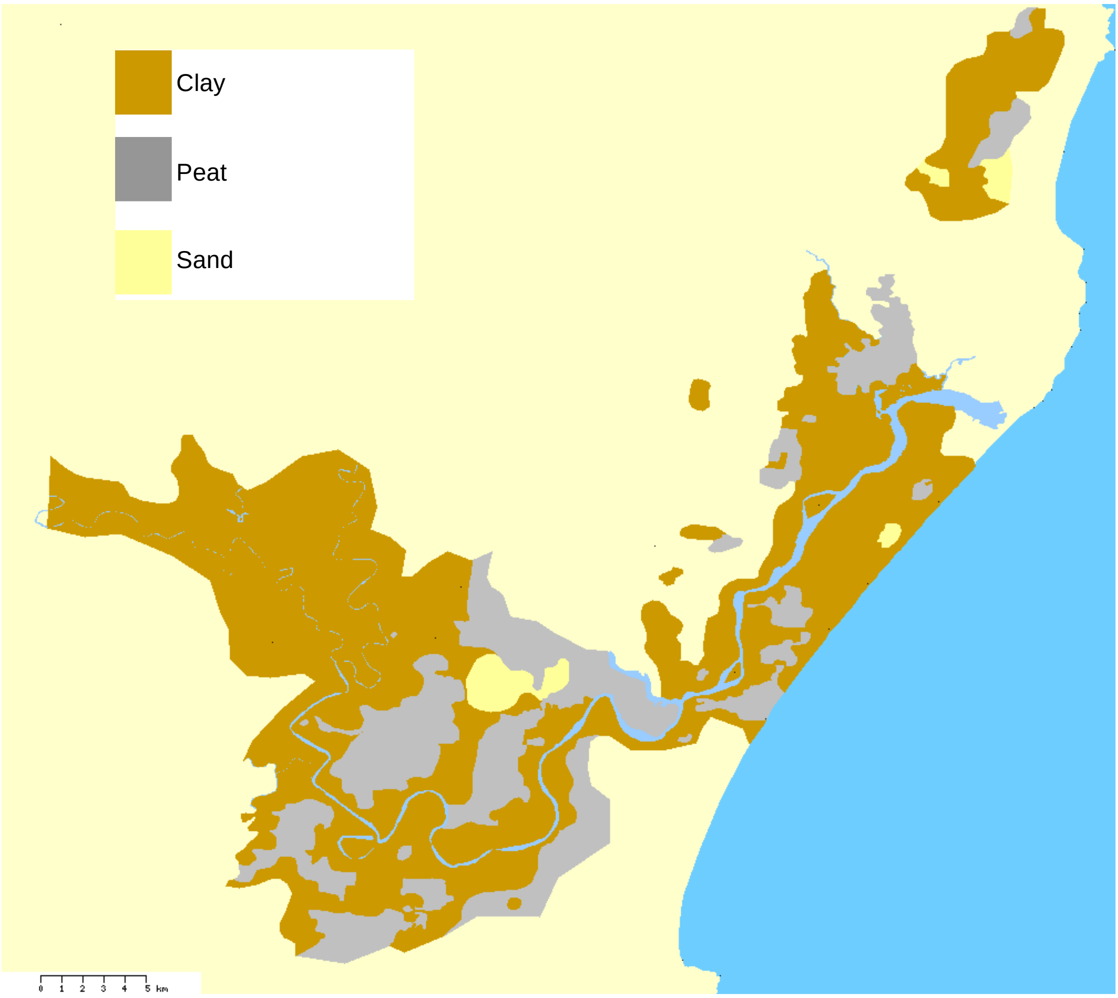


Figure 3.5 - Map of soil types in the Broadwater mill area

HARWOOD

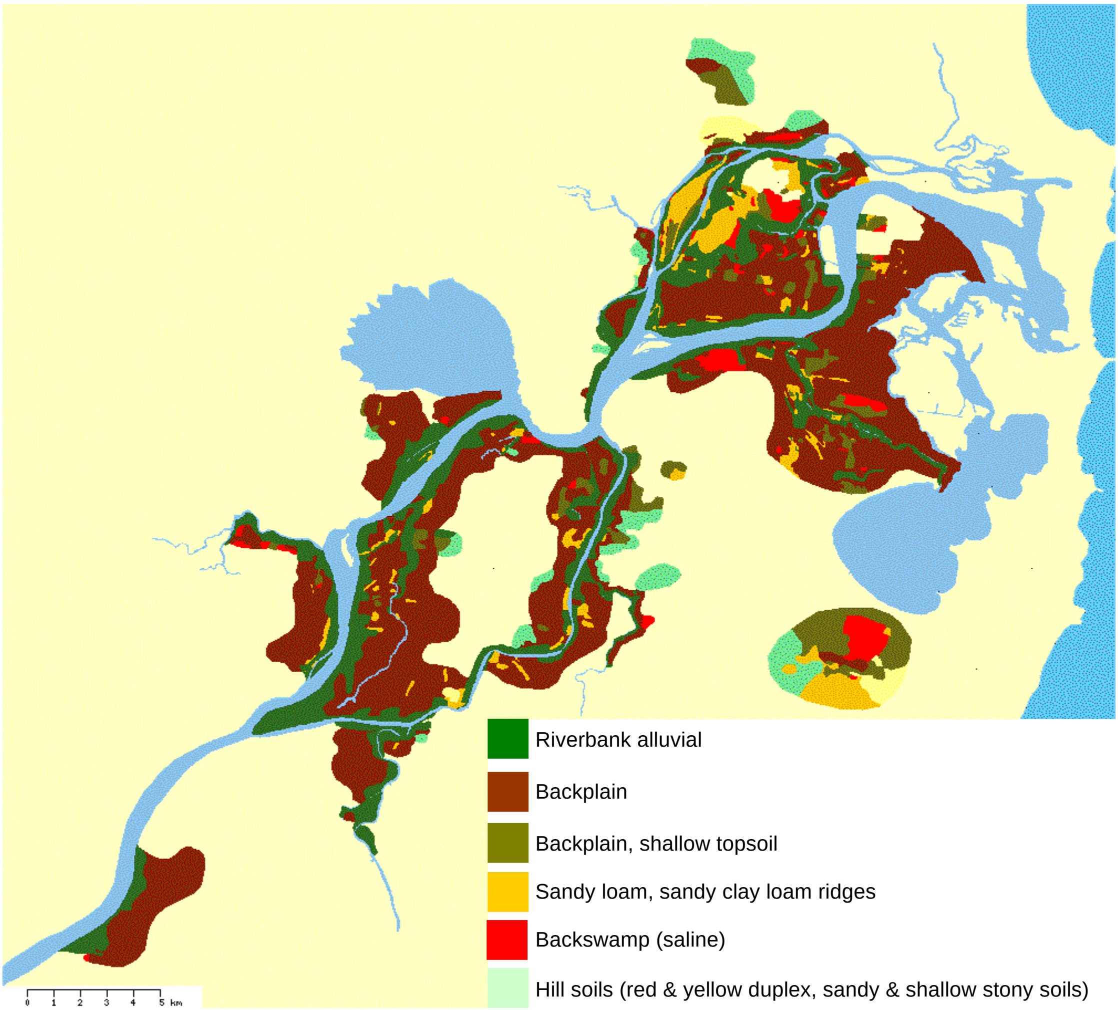


Figure 3.6 - Map of soil types in the Harwood mill area

CONDONG MILL AREA

Riverbank alluvials

Brown sandy clay loam to clay loam with topsoil depth of 0.5 - 0.7 m or more.

Soil quality: Good

Occurrence: Riverbank alluvials occur on the levees along the Tweed, Rous and Brunswick Rivers. The levee crests are often narrow with these soils grading into clay soils further from the river. These occupy less than 10% of the sugarcane soils in the Condong mill area. They have some of the longest cropping history on the floodplain.

Formation:
These soils are formed from recent fine sandy alluvium deposited immediately adjacent to river channels. They may contain sand lenses.

Riverbank alluvial soil profile (Rous levee)

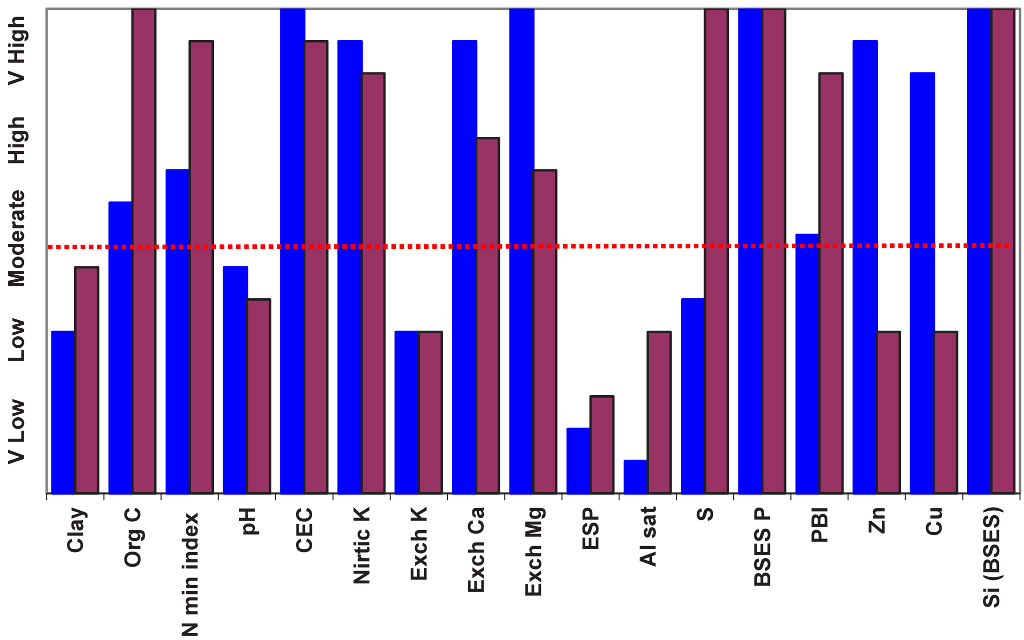
Riverbank alluvial landscape (Kynnumboon)

Field appearance:
Topsoils are weakly structured brown sandy clay loams to clay loams with a topsoil depth of 0.5 - 0.7 m or more. Subsoils exhibit a lighter dull yellowish brown colour and may have relatively clear boundaries to sand lenses.

Physical properties:
These soils are moderately permeable and generally have good surface drainage. Their elevated position on the floodplain and their depth of topsoil are beneficial because they are rarely waterlogged. Rooting depths are often in excess of 1m. The water table is generally at a significant depth below the surface.

Chemical properties:
Soil pH values typically range from 5.5 to 6.5 and cation exchange capacity is high. Organic matter levels are moderate. The phosphorus status of these soils is usually very high. PBI values indicate moderate to high P sorbing capacity. Levels of immediately available potassium may be low. Potassium reserves are high. Sulphur levels are usually low to moderate. Silicon and micronutrient levels are high and there have been no instances of micronutrient deficiencies reported.

Riverbank alluvials compared with median analysis data for all Condong cane soils



Nutrient management guidelines based on median values for Condong riverbank alluvials:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	120	0	80	10	0	0	0
	Ratoon	0	140	0	100	10	0	0	0
180 tc/ha	Plant	0	160	0	80	10	0	0	0
	Ratoon	0	180	0	100	10	0	0	0
220 tc/ha	Plant	0	200	0	80	10	0	0	0
	Ratoon	0	220	0	100	10	0	0	0

Tillage and management:
These soils have moderate to few limitations for cane cultivation and are easily tilled and produce a good seedbed. If tilled when too wet, they are prone to compaction and will produce large clods. These soils have a moderate to good water-holding capacity.

Environmental risk management:
Due to their elevation, there is a potential for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. Grassed headlands will help keep sediment out of drainage lines. As these soils are susceptible to stream bank erosion, growers should consider vegetating drain and stream banks.

CONDONG MILL AREA

Clay soils

Grey brown to brown clay loams to clays with topsoil depth of 0.6 - 0.7 m or more.

Soil quality: Good

Occurrence: These clay and clay loam soils occur down slope of the levees along the Tweed, Rous and Brunswick Rivers. These soils occupy around 40% of the sugarcane area in the Condong mill area. They have some of the longest cropping history on the floodplain.

Formation:
Grey brown to brown alluvium mainly comprising clays and silts deposited down slope of the levees. Orange and red mottles are present in the subsoil. These soils are formed on relatively recent alluvium and may contain sand lenses.

Clay soil profile (Tumbulgum)

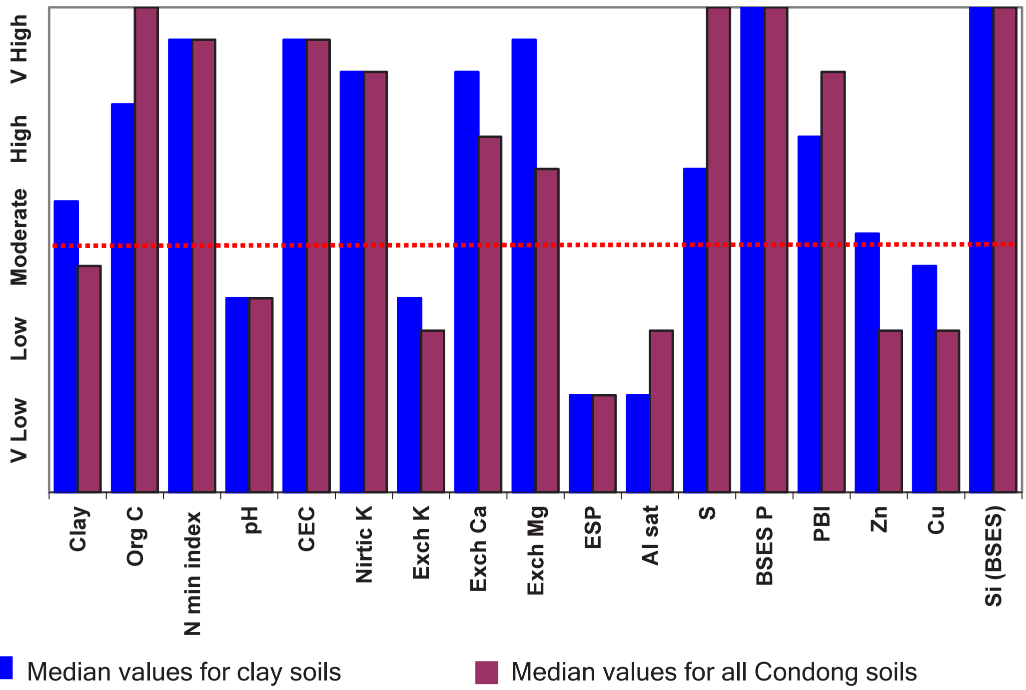
Clay soil landscape (Tumbulgum)

Field appearance:
Topsoils are moderately to strongly structured brown clay loams to clays with a topsoil depth of 0.6 - 0.7 m. Subsoils exhibit a lighter dull yellowish brown colour.

Physical properties:
These soils have poor permeability but generally have good surface drainage because of their elevated position on the floodplain. They also have a good depth of topsoil. Consequently rooting depths are often in excess of 1m. The water table is generally at a significant depth below the surface as indicated by the yellowish brown colours.

Chemical properties:
Soil pH values typically range from 5.0 to 6.0 and cation exchange capacity is high to very high. Organic matter levels are high. The phosphorus status of these soils is usually high. PBI values indicate moderate to high P sorbing capacity. Levels of immediately available potassium may be medium to low. Potassium reserves are relatively high. Sulphur levels range from low to moderate in these soils. Silicon and micronutrients levels are high and there have been no instances of micronutrient deficiencies reported in these soils.

Clay soils compared with median analysis data for all Condong cane soils



Nutrient management guidelines based on median values for Condong clay soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	100	30	80	0	0	0	0
	Ratoon	0	120	20	100	0	0	0	0
180 tc/ha	Plant	0	140	30	80	0	0	0	0
	Ratoon	0	160	20	100	0	0	0	0
220 tc/ha	Plant	0	180	30	80	0	0	0	0
	Ratoon	0	200	20	100	0	0	0	0

Tillage:

Clay soils have moderate to few limitations for cane cultivation. If tilled when the soils are too wet or too dry, they produce large clods, which are hard to break down. Ideally they should be cultivated when the soil at the bottom of the plough layer is drier than its plastic limit. This can be determined in the field by hand rolling a small quantity of soil into a rod with a diameter about 1-2 cm. If the rod has cracks, then tillage is OK, if no cracks form then the soil is too wet and compaction will result from tillage. These soils have a moderate to good water-holding capacity.

Environmental risk management:

In the interspace, most water movement occurs as surface drainage. There is a slight potential for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. Grassed headlands will help keep sediment out of drainage lines. These soils are susceptible to stream bank erosion. Vegetating stream banks (e.g. using Lomandra grass) will help stabilise the banks. Growers can reduce denitrification risk from waterlogging by planting and fertilising into mounds, or using nitrification inhibitors.

CONDONG MILL AREA

Deep peat soils

Grey to dark grey clay loams to clay soils with topsoil depth of 0.25 - 0.4 m.

Soil quality: Good

Occurrence: These light clay to clay loam soils occur on the backplains of the Tweed and Rous Rivers. Deep peat soils occupy around 33% of the sugarcane area in the Condong mill area.

Formation:
Grey to dark grey alluvium mainly comprising clays and silts deposited over organic material in back swamps. In their original state many of these soils were true peats but peat fires and oxidisation following drainage have reduced the organic matter content. In lower Crabbes Creek areas of true peat soils exist; these soils may be several metres in depth.

Deep peat soil profile (Eviron)

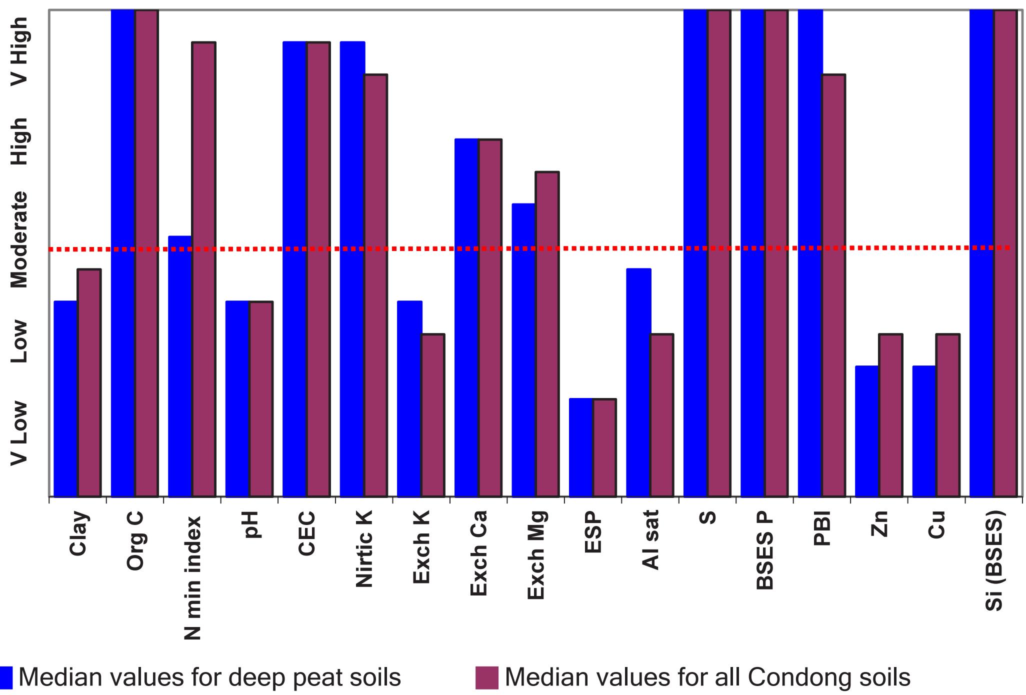
Deep peat soil landscape (Eviron)

Field appearance:
Topsoils are moderate to strongly structured brown clay loams to clays with a topsoil depth of 0.3 to 0.4 m. Some deeper peat soils do occur. Subsoils exhibit a lighter dull yellowish brown colour. Yellow Jarosite and orange/red mottles are often present.

Physical properties:
These soils have good permeability with limited surface drainage due to their low slopes. Rooting depths are mostly limited to the topsoil. The water table is generally close to the surface.

Chemical properties:
Soil pH values typically range from 4.7 to 5.7. Lime may be required to raise the pH to above 5. The cation exchange capacity is high to very high. Organic matter levels are very high. The phosphorus status of these soils is usually high, but because the PBI values indicate moderate to high P sorbing capacity, some P fertiliser may be required. Levels of immediately available potassium may be medium to low. Potassium reserves are relatively high. Sulphur levels are usually high in these soils. Silicon is high. Micronutrients (Zn and Cu) can be deficient in certain blocks.

Deep peat soils compared with median analysis data for all Condong cane soils



Nutrient management guidelines based on median values for Condong deep peat soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	150	30	50	0	0	10	10
	Ratoon	0	170	20	100	0	0	0	0
180 tc/ha	Plant	0	190	30	50	0	0	10	10
	Ratoon	0	210	20	100	0	0	0	0
220 tc/ha	Plant	0	230	30	50	0	0	10	10
	Ratoon	0	250	20	100	0	0	0	0

Tillage and management:

These soils have few limitations for cane cultivation. They have a moderate to good water-holding capacity and can be affected by a high water table. Laser grading is essential for these soils. Mole draining is advisable.

Environmental risk management:

The surface of peat soils is close to the potential acid sulfate layer so deep soil disturbance should be minimised. Construction and maintenance of drains will generally require liming to neutralise acidity caused by oxidation of the acid sulfate layer. These soils are prone to flooding. Growers can reduce denitrification risk by planting and fertilising into mounds.

In the interspace, most water movement occurs as surface drainage. There is a slight potential for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. Grassed headlands will help keep sediment out of drainage lines. These soils are susceptible to stream bank erosion. Vegetating stream banks (e.g. using Lomandra grass) will help stabilise the banks.

CONDONG MILL AREA

Shallow peat soils

Grey to dark grey clay loams to light clay soils with topsoil depth less than 0.25 m.

Soil quality: Poor to medium

Occurrence: These light clay to clay loam soils occur on the back plains of the Tweed and Rous Rivers. In their original state many of these soils were true peats but peat fires and oxidisation following drainage have reduced the organic matter content. These soils occur in the lowest part of the landscape. Shallow peat soils occupy around 18% of the sugarcane area in the Condong mill area.

Formation:
Grey to dark grey alluvium mainly comprising clays and silts deposited over organic material in back swamps. In their original state many of these soils were true peats but peat fires and oxidisation following drainage have reduced the organic matter content.

Shallow peat soil profile (Blacks Drain)
Note the yellow jarosite (actual acid sulphate) and blue/grey clay (potential acid sulphate)

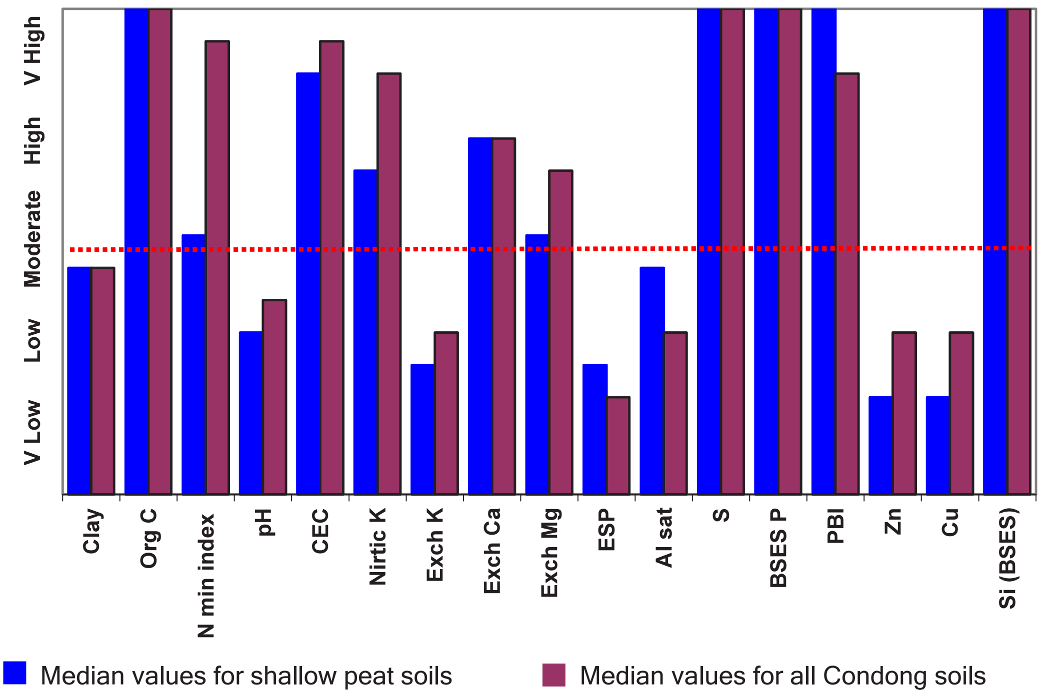
Shallow peat soil landscape (South Murwillumbah)

Field appearance:
Topsoils are moderate to strongly structured grey brown clay loams to light clays with a topsoil depth less than 0.25 m. Subsoils exhibit a lighter dull yellowish brown colour.

Physical properties:
The topsoil has good permeability but the subsoil has poor permeability. Surface drainage is generally poor. Rooting depths are shallow which predisposes cane to stool tipping. The water table is generally close to the surface. Flooding and water logging limit productivity on these soils.

Chemical properties:
Soil pH values are low typically ranging from 4.3 to 5.3. Lime may be required to raise the pH to above 5. The cation exchange capacity is mostly high. Organic matter levels are very high. The phosphorus status of these soils is usually high, but because the PBI values indicate moderate to high P sorbing capacity, some P fertiliser may be required. Levels of immediately available potassium may be low. Potassium reserves are moderate to high. Sulphur levels are usually very high in these soils. Silicon levels are high. Some micronutrients (zinc and copper) are low but there have been no instances of micronutrient deficiencies reported in these soils.

Shallow peat soils compared with median analysis data for all Condong cane soils



Nutrient management guidelines based on median values for Condong shallow peat soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	4	150	30	100	0	0	10	10
	Ratoon	0	170	20	100	0	0	0	0
180 tc/ha	Plant	4	190	30	100	0	0	10	10
	Ratoon	0	210	20	100	0	0	0	0
220 tc/ha	Plant	4	230	30	100	0	0	10	10
	Ratoon	0	250	20	100	0	0	0	0

Tillage and management:

Flood hazard, poor drainage and high water tables/shallow rooting depth are the main limitations to cropping on the shallow peats. They have a moderate to good water-holding capacity. Laser grading is essential for these soils. Mole draining is advisable to improve subsoil drainage.

Environmental risk management:

The surface of peat soils is close to the potential acid sulphate layer so deep soil disturbance should be minimised. Construction and maintenance of drains will generally require liming. These soils are prone to flooding. Growers can reduce denitrification risk by planting and fertilising into mounds.

In the interspace, most water movement occurs as surface drainage. There is a slight potential for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. Grassed headlands will help keep sediment out of drainage lines. Soils are susceptible to stream bank erosion. Vegetating stream banks (e.g. using Lomandra grass) will help stabilise the banks.

CONDONG MILL AREA

Sand soils

Light grey to brownish grey sands with topsoil depth of 0.3 to 0.4 m.

Soil quality: Medium

Occurrence: These sandy soils are remnants of ancient beach lines, which occur in the Coast, Chinderah and North Tumbulgum areas. They occur in the lowest part of the landscape and occupy around 4% of the sugarcane area in the Condong mill area.

Formation:
Grey to brown grey sands which are the remnants of beaches formed when sea levels were higher. Orange and red mottles are present in the subsoil.

Sand soil profile (North Tumbulgum)

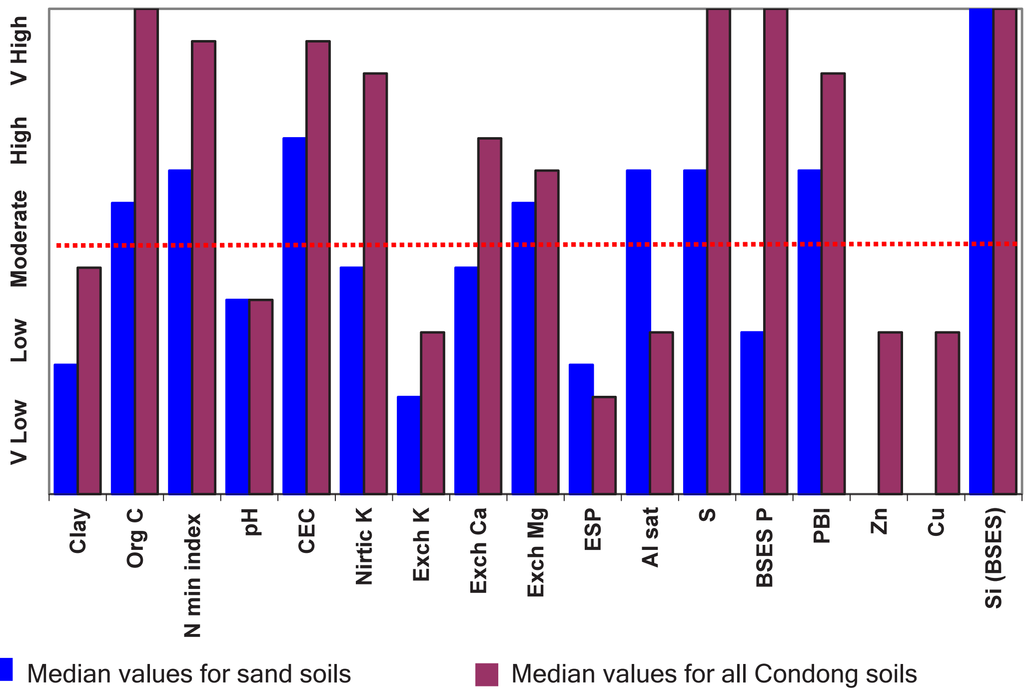
Sand soil landscape (North Tumbulgum)

Field appearance:
Topsoils are weakly structured light grey to grey brown sands with a topsoil depth of 0.3 to 0.4 m. Subsoils exhibit a lighter grey to white colour because of lower organic matter content.

Physical properties:
These soils have good permeability with low water holding capacity. Rooting depths are generally deep.

Chemical properties:
Soil pH values typically range from 4.8 to 5.8 and cation exchange capacity is moderate. Organic matter levels are moderate. The phosphorus status of these soils is usually low. PBI values indicate moderate P sorbing capacity. Levels of immediately available potassium may be low. Potassium reserves are relatively high. Sulphur levels are usually moderate in these soils. Silicon levels are high. Micronutrients levels are low but there have been no instances of micronutrient deficiencies reported in these soils.

Sand soils compared with median analysis data for all Condong cane soils



Nutrient management guidelines based on median values for Condong sandy soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	120	30	80	0	0	-	-
	Ratoon	0	140	25	100	0	0	-	-
180 tc/ha	Plant	0	160	30	80	0	0	-	-
	Ratoon	0	180	25	100	0	0	-	-
220 tc/ha	Plant	0	200	30	80	0	0	-	-
	Ratoon	0	220	25	100	0	0	-	-

Tillage and management:

Sandy soils have moderate to few limitations for cane cultivation and are easily tilled and produce a good seedbed. These soils have a low water-holding capacity.

Environmental risk management:

These soils are prone to both leaching and waterlogging. To reduce loss of nitrogen and potassium split fertiliser applications should be considered. There is a slight potential for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. Grassed headlands will help keep sediment out of drainage lines.

As these soils are very susceptible to stream bank collapse, drain banks should be vegetated using suitable species such as Lomandra grass.

BROADWATER MILL AREA

Clay soils
Brown to dark brown clay soils.

Soil quality: Medium to good

Occurrence: Clay soils occur widely in flat or gently sloping areas adjacent to the rivers on the Richmond floodplain. Clay soils occupy around 67% of the cane land in the Broadwater mill area.

Formation:
These soils have formed from fine clay particles deposited during flood events. The alluvial material in downriver areas overlies sandy subsoils.


Upriver clay soil profile (Coraki)


Clay soil landscape


Downriver clay soil profile (Empire Vale)

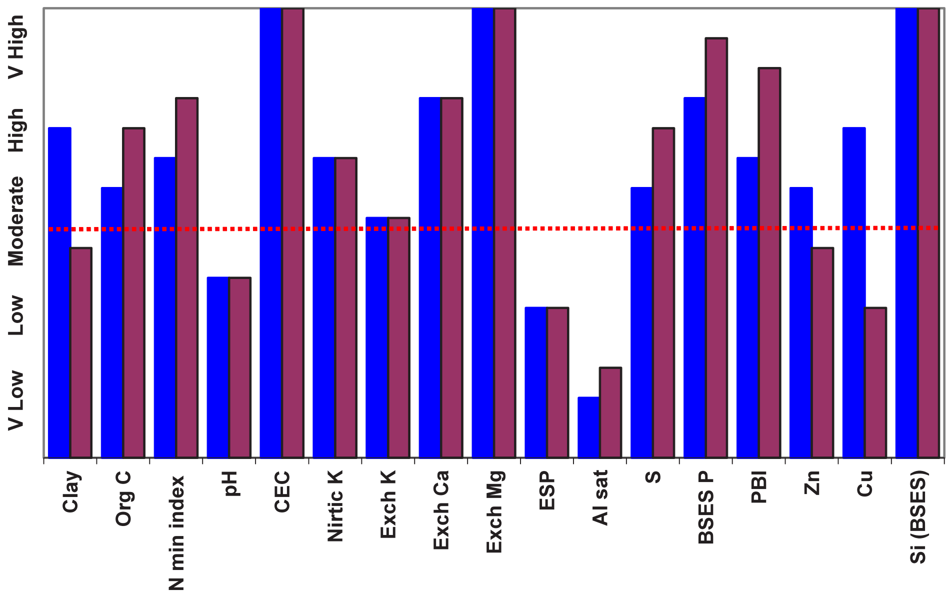
Field appearance:
These soils have clay or clay loam topsoils. In upriver areas the soil profile is generally uniform to depths of 1 metre. They crack to depth in dry weather. In downriver areas the topsoil is 0.4 - 0.6 m and overlies sandy or sandy clay subsoil.

Physical properties:
These soils have moderate internal drainage. They cultivate to a good tilth if not worked too wet. Surface drainage on the low slopes (less than 0.13%) is improved by the installation of shallow surface drains.

Chemical properties:

Soil pH values are low to moderate and cation exchange capacity is very high and consistent with the clay texture. As with most Broadwater cane soils, the exchange complex is dominated by calcium and magnesium. The organic matter and N mineralisation potentials are moderately high. Because of the long history of cultivation and fertiliser inputs the phosphorus status of these soils is usually high. The PBI values indicate relatively high P sorbing capacity. Potassium reserves are also high. Sulphur may be at levels that require application in plant and ratoon cane. Silicon and micronutrients are high.

Clay soils compared with median analysis data for all Broadwater soils



Nutrient management guidelines based on median values for Broadwater clay soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	120	0	0	0	0	0	0
	Ratoon	0	140	0	50	0	0	0	0
180 tc/ha	Plant	0	160	0	0	0	0	0	0
	Ratoon	0	180	0	50	0	0	0	0
220 tc/ha	Plant	0	200	0	0	0	0	0	0
	Ratoon	0	220	0	50	0	0	0	0

Tillage and management:

These soils have few limitations for cane cultivation and are easily tilled to produce a good seedbed. If tilled when too wet, they are prone to compaction, and will produce large clods. Only cultivate when the soil at the bottom of the plough layer is drier than its plastic limit. Determine this in the field by hand rolling a small quantity of soil into a rod with a diameter about 1-2 cm. If the rod has cracks, then tillage is OK. No cracks means that the soil is too wet and compaction will result from tillage. These soils have a high water-holding capacity.

Environmental risk management:

Most water movement occurs as surface drainage. The low slopes on the floodplain result in low risk for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events.

BROADWATER MILL AREA

Peat soils

Brown to dark brown soils with high organic matter content.

Soil quality: Good

Occurrence: Peat soils occur in low-lying depressions and former back swamps throughout the Richmond floodplain. Peat soils occupy around 29% of the cane land in the Broadwater mill area.

Formation:
These soils are formed in areas that were former back swamps where organic matter accumulated due to waterlogged conditions. Under these wet conditions organic matter breakdown was inhibited. Drainage and flood mitigation works have allowed these areas to be cultivated.

Upriver peat soil profile (East Coraki)

Peat soil landscape (East Coraki)

Downriver peat soil profile (Boundary Creek)

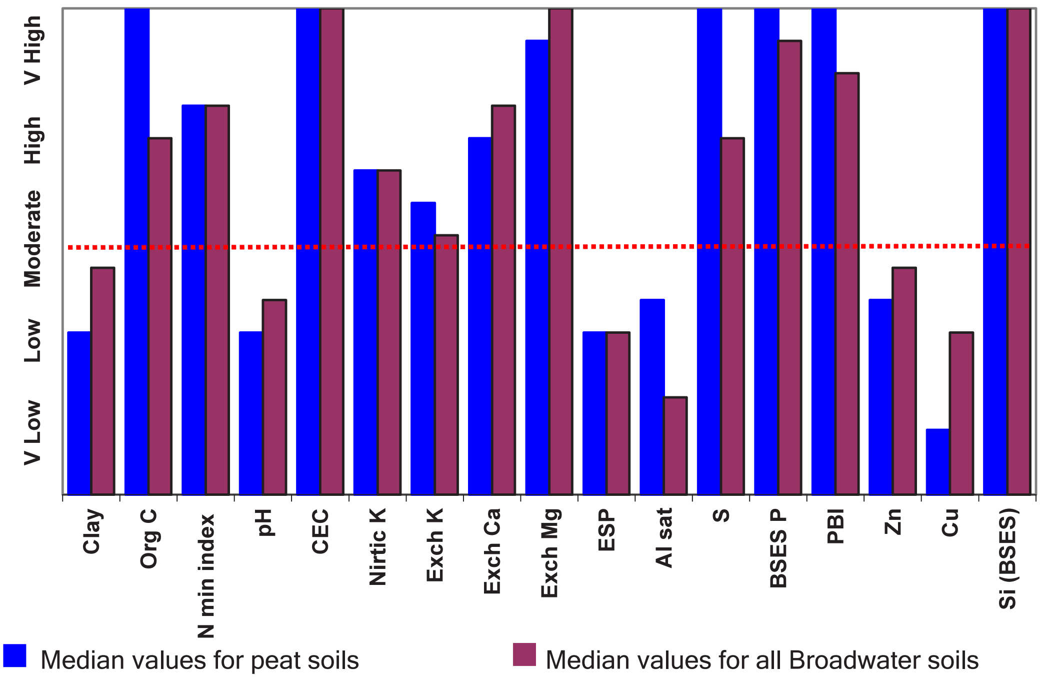
Field appearance:
In upriver areas the profile has dark clay topsoil overlying a dark organic layer to about 1 m that comprises undecomposed organic matter. In downriver areas these peat soils occur closer to the coast in depressions. The profiles are generally dark brown clay loam overlying light sandy clay at a depth of around 1 m.

Physical properties:
These soils have moderate internal drainage but are subject to periods of inundation and high water tables. These soils cultivate to a good tilth if not worked too wet. Surface drainage on the low slopes (less than 0.13%) is improved by installing shallow surface drains.

Chemical properties:

Soil pH is low and CEC is very high. As with most Broadwater cane soils the exchange complex is dominated by calcium and magnesium. The organic matter content is high resulting in moderately high N mineralisation potential. Because of the long history of cultivation and fertiliser inputs the P status of these soils is usually high. The PBI values indicate relatively high P sorbing capacity. Potassium reserves are medium. Sulphur may be at levels that require application in plant and ratoon cane. However sulphur levels may also be high due to the influence of acid sulfate soils. Silicon and micronutrients are high.

Peat soils compared with median analysis data for all Broadwater soils



Nutrient management guidelines based on median values for Broadwater peat soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	5	140	0	0	0	0	10	0
	Ratoon	0	160	0	0	0	0	0	0
180 tc/ha	Plant	5	180	0	0	0	0	10	0
	Ratoon	0	200	0	0	0	0	0	0
220 tc/ha	Plant	5	220	0	0	0	0	10	0
	Ratoon	0	240	0	0	0	0	0	0

Tillage and management:

These soils have few limitations for cane cultivation and are easily tilled to produce a good seedbed. If tilled when too wet, they are prone to compaction, and will produce large clods. These soils have a high water-holding capacity.

Environmental risk management:

Most water movement occurs as surface drainage. The low slopes on the floodplain result in low risk for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events.

BROADWATER MILL AREA

Sand soils

Sandy soils with brownish grey to brownish black topsoil grading to bleached sand subsoil.

Soil quality: Medium/poor

Occurrence: Sand soils occur in isolated areas close to the coastline throughout Broadwater. Sand soils occupy around 4% of the Broadwater mill area.

Formation:
These soils have formed from old beach ridges and sand dunes that once formed the coastline. Sediment from the river in some cases has extended the coastline beyond these features.

Sand soil profile (Patch's Beach)

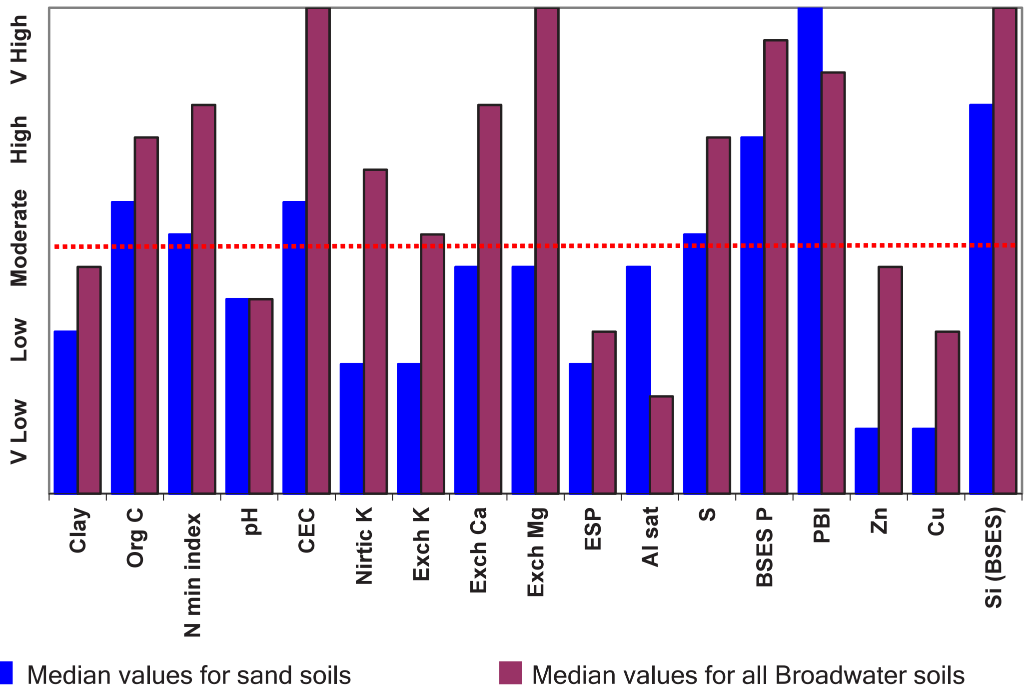
Sand soil landscape (Patch's Beach)

Field appearance:
In these soils profiles are dominated by dark loamy sand topsoil to 40 cm overlying white beach sand subsoil.

Physical properties:
These soils have good internal drainage but a poor water holding capacity. These soils are easy to cultivate at all moisture contents.

Chemical properties:
Soil pH is low. The CEC and organic matter content are below average for Broadwater soils. As with most Broadwater cane soils the exchange complex is dominated by calcium and magnesium. Because of the long history of cultivation and fertiliser inputs the P status of these soils is usually adequate. The PBI values indicate relatively high P sorbing capacity. Potassium reserves are low to medium. Sulphur may be at levels that require application in plant and ratoon cane. Silicon and micronutrients are high.

Sand soils compared with median analysis data for all Broadwater soils



Nutrient management guidelines based on median values for Broadwater sand soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	100	30	100	0	0	10	10
	Ratoon	0	120	20	120	0	0	0	0
180 tc/ha	Plant	0	140	30	100	0	0	10	10
	Ratoon	0	160	20	120	0	0	0	0
220 tc/ha	Plant	0	180	30	100	0	0	10	10
	Ratoon	0	200	20	120	0	0	0	0

Tillage and management:

These soils have few limitations for cane cultivation and are easily tilled to produce a good seedbed. These soils have a low water-holding capacity.

Environmental risk management:

These soils are prone to leaching because water movement occurs mainly as drainage. To reduce loss of nitrogen and potassium split fertiliser applications should be considered. The low slopes on the floodplain result in low risk for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. Grassed headlands will help keep sediment out of drainage lines.

HARWOOD MILL AREA

Riverbank alluvials

Brown clay loams to clay soils with topsoil depth of 0.6 - 0.8 m or more.

Soil quality: Good

Occurrence: Riverbank alluvials occur on the major and minor levees along the Clarence River and associated channels. The levee crests are often narrow (50 m) with slopes of 50 to 1000 m grading out onto a back plain. These soils occupy about 25% of the sugarcane area in the lower Clarence. They have some of the longest cropping history on the floodplain.

Formation:
These soils comprise fine sand, clay and silt deposited adjacent to river channels. They are formed on relatively recent alluvium and may contain sand lenses.

Riverbank alluvial soil profile (Woodford Is.)

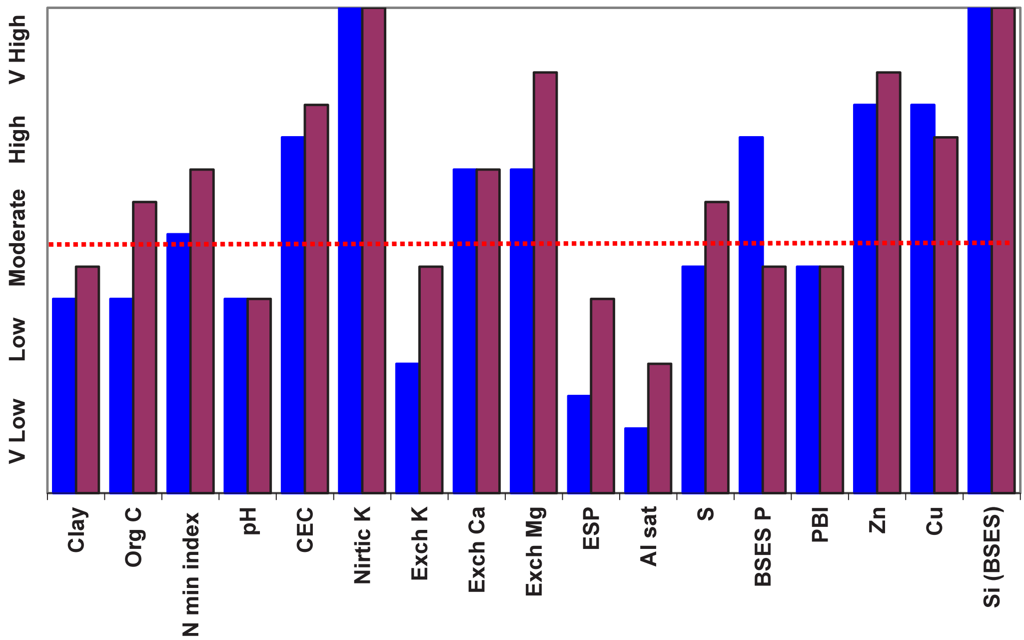
Riverbank alluvial landscape (Mororo)

Field appearance:
Topsoils are weakly structured brown clay loams to clays with a topsoil depth of 0.6-0.8 m or more. Subsoils exhibit a lighter dull yellowish brown colour and may have relatively clear boundaries to sand lenses.

Physical properties:
These soils are moderately permeable and generally have good surface drainage. Their elevated position on the floodplain and their depth of topsoil are beneficial because they are rarely waterlogged. Rooting depths are often in excess of 1 m. The watertable is generally at a significant depth below the surface.

Chemical properties:
Soil pH values are typically in the range 5.2 - 6.0. The CEC is average to slightly below average for Harwood cane soils. As with most Clarence cane soils the exchange complex is dominated by calcium and magnesium. The organic matter content is generally low resulting in moderately low N mineralisation potential. Because of a long history of cultivation and fertilizer inputs the available phosphorus status of these soils is usually high. The PBI values indicate moderate P sorbing capacity. Immediately available potassium may be medium to low. Potassium reserves are relatively high. Sulphur may be low in these soils. Silicon and micronutrients levels are high and there have been no instances of micronutrient deficiencies reported in these soils.

Riverbank alluvials compared with median analysis data for all Harwood cane soils



Nutrient management guidelines based on median values for Harwood riverbank alluvials:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	130	0	100	5	0	0	0
	Ratoon	0	150	0	100	5	0	0	0
180 tc/ha	Plant	0	170	0	100	5	0	0	0
	Ratoon	0	190	0	100	5	0	0	0
220 tc/ha	Plant	0	210	0	100	5	0	0	0
	Ratoon	0	230	0	100	5	0	0	0

Tillage and management:
These soils have moderate to few limitations for cane cultivation and are easily tilled to produce a good seedbed. If tilled when too wet, they are prone to compaction, and will produce large clods. Only cultivate when the soil at the bottom of the plough layer is drier than its plastic limit. Determine this in the field by hand rolling a small quantity of soil into a rod with a diameter about 1-2 cm. If the rod has cracks, then tillage is OK, if cracks form then the soil is too wet and compaction will result from tillage. These soils have a moderate to good water-holding capacity. Localised flooding may occur.

Environmental risk management:
Water movement can occur by surface drainage and infiltration. As there is a potential for N fertiliser loss through leaching, growers should consider the use of split fertiliser applications or a controlled release fertiliser. There is also a slight potential for off-site movement of suspended sediment down compacted traffic lanes following high intensity rainfall events. These soils are susceptible to stream bank erosion.

HARWOOD MILL AREA

Back plain soils

Dark structured silty clay soils with topsoil depth of 0.25 - 0.5 m.

Soil quality: Medium

Occurrence: These soils are found on level to gently undulating plains back from the river channels and comprise a significant proportion of the extensive alluvial plain and delta plain of the lower Clarence River. These soils occupy about 50% of the sugarcane area in the Harwood mill area.

Formation:
Soils are generally a combination of alluvium overlying older sediment. The thickness of the alluvium usually decreases with distance from the main channels. Subsoils often consist of different layers of alluvium. The type and order of these layers can vary considerably from site to site. Downstream of Maclean the alluvium usually overlies marine sediments.


Backplain soil profile (Woodford Is.)


Back plain landscape

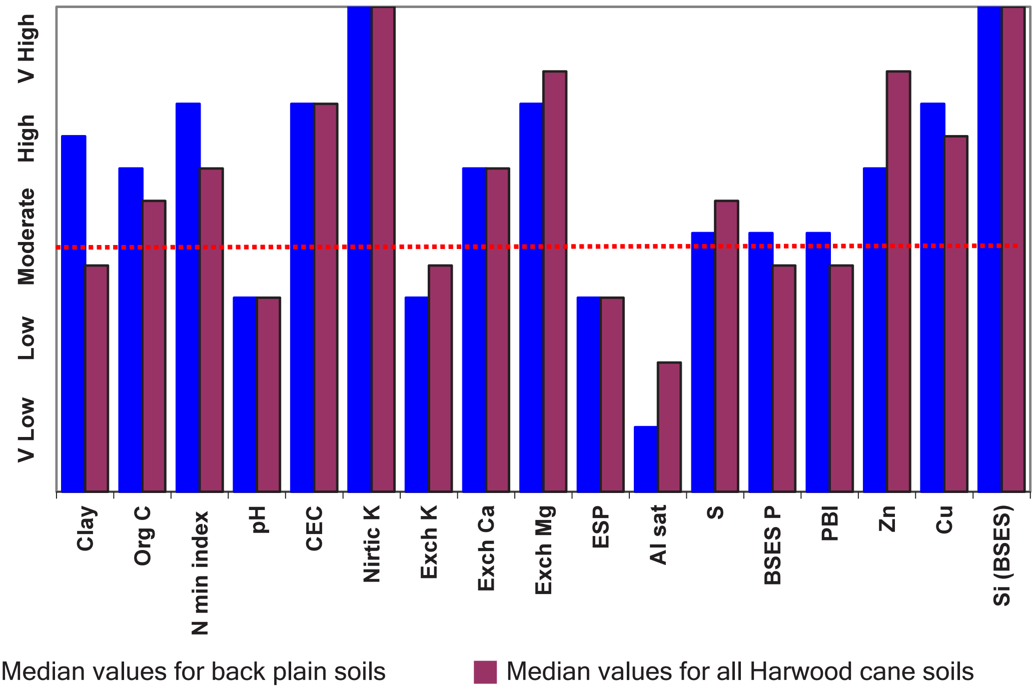
Field appearance:
Topsoils are generally dark, weakly to moderately structured silty clays with a topsoil depth of 0.25 - 0.5 m. Subsoils are medium clays and are commonly mottled.

Physical properties:
Although deep (over 2 m), these soils are poorly to moderately drained. Because of low slopes (0 to 3%) the surface drainage may be poor. The water table may be close to the soil surface and in localised areas may be permanently high.

Sodicity leading to poor soil structure may be an issue in the surface soil at some sites. Subsoils may be sodic and have elevated salt levels.

Chemical properties:
Soil pH values are usually in the range 5.0 - 6.0. The CEC is average to slightly above average for Harwood cane soils. As with most Harwood soils, the exchange complex is dominated by calcium and magnesium. The organic matter content is moderate resulting in moderate N mineralisation potential. For this soil type, levels of available phosphorus vary from site to site and some may be low to medium. The PBI values indicate moderate P sorbing capacity. Levels of immediately available potassium are moderate. Potassium reserves are high. Silicon and micronutrients levels are high and there have been no instances of micronutrient deficiencies reported in these soils.

Back plain soils compared with median analysis data for all Harwood cane soils



Nutrient management guidelines based on median values for Harwood back plain soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	110	20	80	0	0	0	0
	Ratoon	0	130	5	100	0	0	0	0
180 tc/ha	Plant	0	150	20	80	0	0	0	0
	Ratoon	0	170	5	100	0	0	0	0
220 tc/ha	Plant	0	190	20	80	0	0	0	0
	Ratoon	0	210	5	100	0	0	0	0

Tillage and management:

Generally moderate limitations for cultivation. Subsoils may be strongly sodic and some may have elevated salt levels. If tilled when too wet, they are prone to compaction, and will produce large clods. Only cultivate when the soil at the bottom of the plough layer is drier than its plastic limit. Determine this in the field by hand rolling a small quantity of soil into a rod with a diameter about 1-2 cm. If the rod has cracks, then tillage is OK; if no cracks form then the soil is too wet and compaction will result from tillage. Where subsurface soil is exposed as a result of laser grading, amelioration (lime or gypsum or mill mud) is likely to be required.

Environmental risk management:

Risks include high flood hazard, localised high water tables and the presence of potential acid sulphate subsoil.

HARWOOD MILL AREA

Back plain soils with shallow topsoil

Dark structured silty clays with topsoil depth no more than 0.25 m.

Soil quality: Medium to poor

Occurrence: These soils are found on level to very gently sloping delta plains of the lower Clarence River downstream of Maclean. They are typically found at some distance from the river channels. These soils occupy about 6% of the sugarcane area in the lower Harwood mill area.

Formation:
These soils consist of alluvium overlying marine sediments or sand. They generally occur at some distance from the main river channels thereby explaining the relatively thin layer of alluvium above the marine sediments. The marine sediments are generally potential acid sulphate materials.

Back plain (shallow topsoil) soil profile (Palmers Island)

Back plain (shallow topsoil) landscape (Palmers Island)

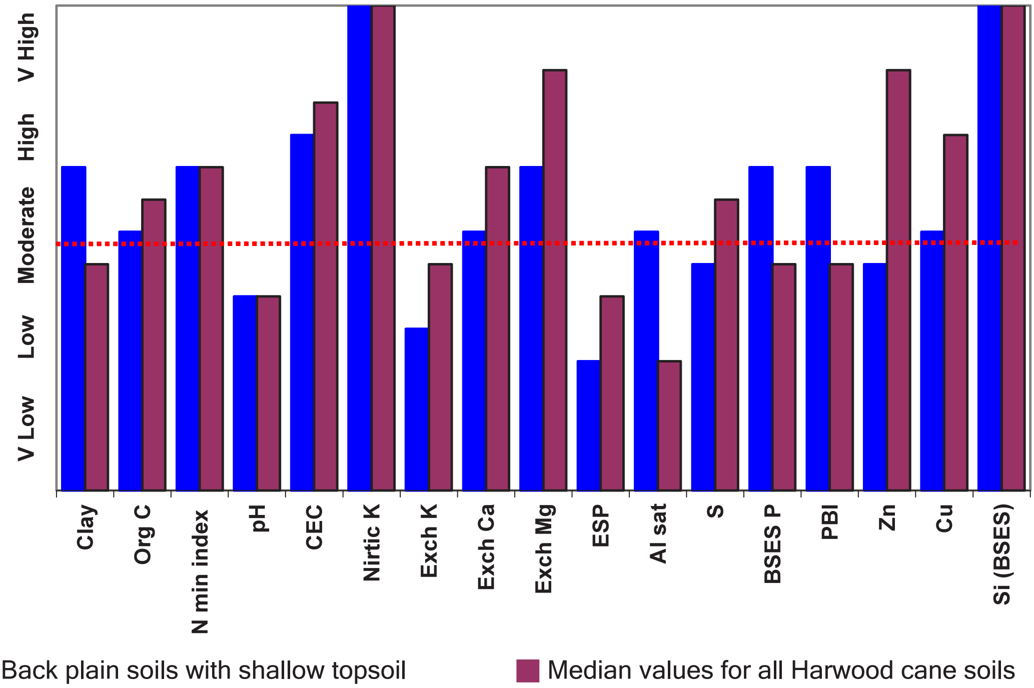
Field appearance:
Topsoils are generally brownish black, silty clays with weak to moderate structure. Topsoil depths are 0.1 - 0.25 m. Subsoils are often grey clayey sands with distinct orange mottles.

Physical properties:
Surface soil has low permeability. Clayey sand subsoils have low to moderate permeability. Because of low slopes (0 to 3%) the drainage of surface water is poor. The water table is generally close to the soil surface.

Subsoils are often sodic with elevated salt levels reflecting their marine origin.

Chemical properties:
Soil pH is relatively low but comparable with other Harwood soils. The CEC is average to slightly below average for Harwood soils. The exchange complex is dominated by acidity, calcium and magnesium. The organic matter content is moderate resulting in moderately low N mineralization potential. Levels of available phosphorus vary widely from site to site and some may be low to medium. The PBI values indicate moderate P sorbing capacity. Levels of immediately available potassium are moderate. Potassium reserves are high. Silicon and micronutrient levels are generally high. Although these soils are regarded as poor soils in terms of cane production, the chemical fertility of the surface soil is not too different to that of good and medium quality soils in the mill area.

Back plain soils with shallow topsoil compared with median data for all Harwood cane soils



Nutrient management guidelines based on median values for Harwood back plain with shallow topsoils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	120	0	100	0	0	0	0
	Ratoon	0	140	0	100	0	0	0	0
180 tc/ha	Plant	0	160	0	100	0	0	0	0
	Ratoon	0	180	0	100	0	0	0	0
220 tc/ha	Plant	0	200	0	100	0	0	0	0
	Ratoon	0	220	0	100	0	0	0	0

Tillage and management:
Limitations for cultivation include a soil structure, which can decline as a result of cultivation and poor trafficability after rain. Subsoils may be strongly sodic and have elevated salt levels. Where subsurface soil is exposed as a result of laser grading amelioration (lime or gypsum or mill mud) is likely to be required. The shallow topsoil is also a limitation for cane production. This, together with drainage issues, contributes to this soil type being classed as poor.

Environmental risk management:
Risks include high flood hazard and shallow water tables, and susceptibility to soil structure decline. Potential acid sulphate materials are often present 1-2m below the surface and pose little hazard unless disturbed. To minimise denitrification risk, improve drainage in the fertilised zone by mound planting/raised beds.

HARWOOD MILL AREA

Sandy (sandy loam and sandy clay loam) ridges
Massive to weakly structured soils

Soil quality: Medium

Occurrence: These soils occur as low ridges of coarser alluvium deposited approximately parallel to the river channels but they may be some distance back from the present channel. These soils occupy about 6% of the sugarcane area in the lower Clarence floodplain.

Formation:
Formed from alluvium, these sandy ridges are thought to be relict riverbank levees.


Sandy ridge soil profile (Woodford Island)

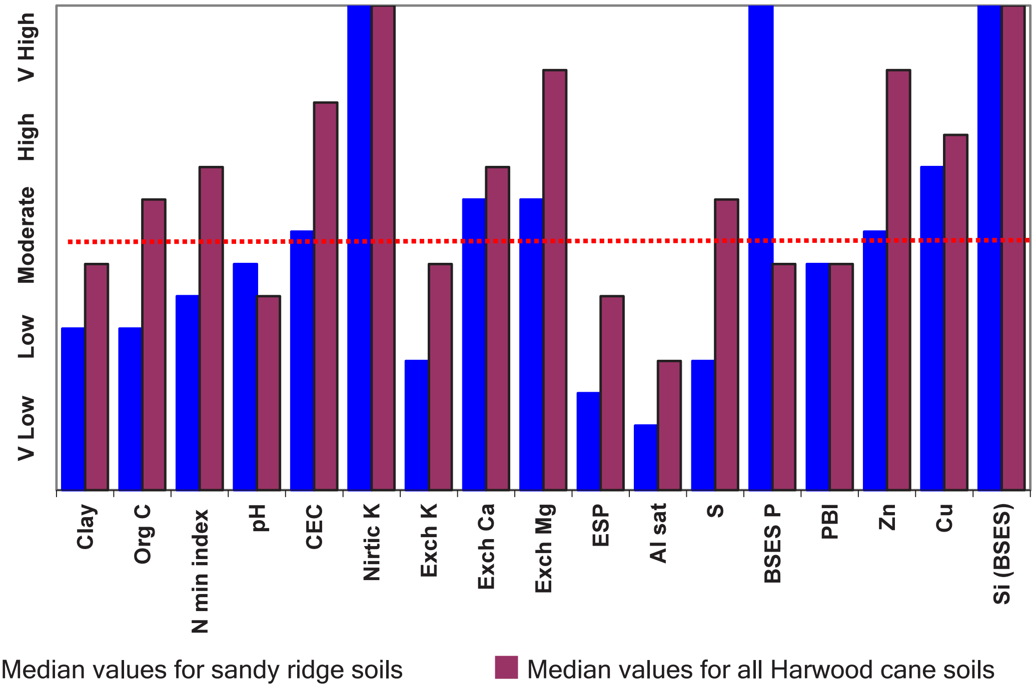

Sandy ridge landscape (Woodford Island)

Field appearance:
Topsoils are massive to weakly structured with sandy loam to sandy clay loam textures. Subsoils are reddish sandy clay loams.

Physical properties:
These soils are highly permeable and well drained. Water holding capacity is poor to moderate and cane is often water stressed in dry periods.

Chemical properties:
The soil pH values tend to be slightly higher than average and are typically in the 5.5 - 6.0 range. The CEC is below average for Harwood soils. The low organic matter content results in low N mineralization potential. The phosphorus status of these soils can be variable ranging from very high (where there has been a history of mill mud/ash application) to low. The very high BSES P median value in the figure below reflects a number of sampling sites with a history of mill mud/ash application. The PBI values indicate lower P sorbing capacity than other cane soils. Potassium reserves are relatively high and generally equivalent to those of other Harwood cane soils. Sulphur is commonly low in these soils and the majority of soil tests indicate the need for addition of sulfur in fertiliser. In a few cases, silicon levels may be low but micronutrients levels are generally adequate for sugarcane.

Sandy loam/sandy clay loam ridge soils compared with median data for all Harwood cane soils



Nutrient management guidelines based on median values for Harwood sandy ridge soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	140	0	100	10	0	0	0
	Ratoon	0	160	0	100	10	0	0	0
180 tc/ha	Plant	0	180	0	100	10	0	0	0
	Ratoon	0	200	0	100	10	0	0	0
220 tc/ha	Plant	0	220	0	100	10	0	0	0
	Ratoon	0	240	0	100	10	0	0	0

Tillage and management:

These soils are easily tilled but excessive tillage in dry conditions can lead to loss of soil moisture. They have low plant available water capacity and are prone to drought. Adverse pre-emergent herbicide effects are possible for some chemicals because of low organic C and sandy texture.

Environmental risk management:

As these soils are relatively free draining, there is potential for leaching. Growers should consider using a split application or a controlled release product to reduce the risk of nitrate leaching.

HARWOOD MILL AREA

Back swamp soils

Dark structured topsoils with elevated organic matter levels.

Soil quality: Poor

Occurrence: These soils occur in the lowest parts of the Clarence River floodplain and are found in broad open depressions that were formerly back swamps. They occupy less than 5% of the sugarcane area at Harwood.

Formation:
Although referred to as back swamp peats by some cane producers, very few, if any, of these soils in the cultivated cane area would be classified as true peats (organosols). These soils were former swamps before flood mitigation and drainage works occurred on the floodplain in the 1960s.

Back swamp soil (Woodford Island)

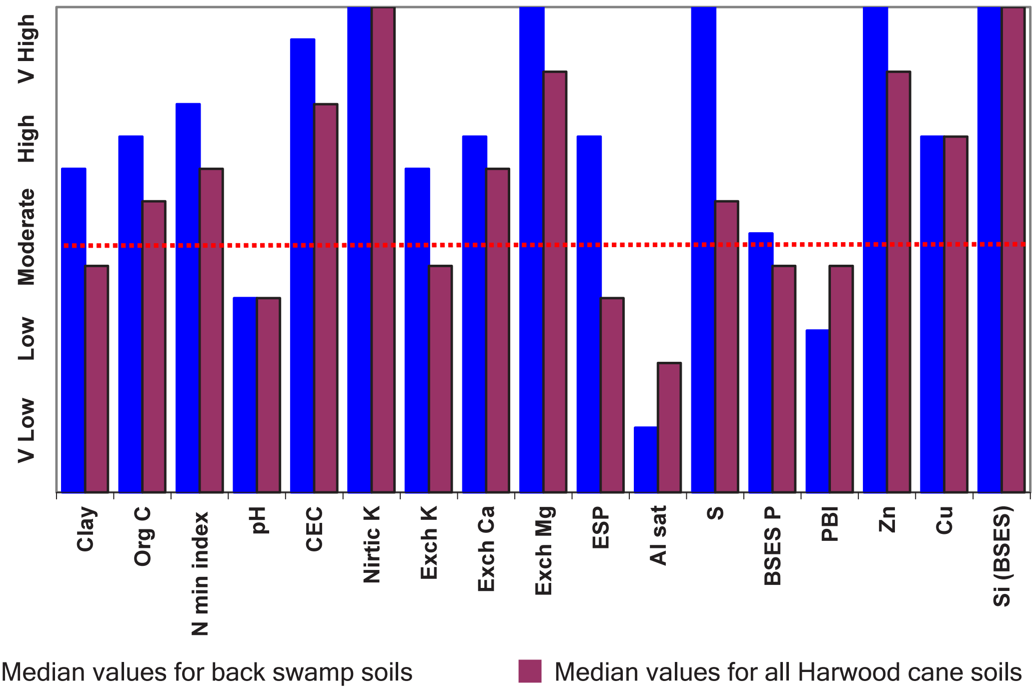
Back swamp landscape (Woodford Island)

Field appearance:
In cultivated cane areas, a dark brownish black topsoil 5 to 10 cm thick overlies brownish grey to grey subsoil. In uncultivated areas, the topsoil may comprise around 5 to 15 cm of dark undecomposed organic matter.

Physical properties:
Surface water drainage is poor due to its low position in the landscape. The water table is generally close to the soil surface and subsoils are often saturated throughout the year. Subsoils are commonly sodic with elevated salt levels. Surface soils are also usually saline.

Chemical properties:
Soil pH of the surface soil ranges from 4.6 to slightly over 6. The CEC is usually above average for Harwood soils. The exchange complex is dominated by acidity, calcium and magnesium. Organic matter levels are higher than average but most are lower than the peat soils found in the Condong mill area. Available phosphorus is low to medium but can vary due to P fertiliser history. PBI values indicate moderate P sorbing capacity. Levels of immediately available potassium are usually moderate to high. Potassium reserves are high. Salinity levels range from slightly elevated to very high. Silicon and micronutrients levels are adequate and there have been few instances of micronutrient deficiencies reported in these soils. These are often potentially acid sulphate soils.

Back swamp soils compared with median analysis data for all Harwood cane soils



Nutrient management guidelines based on median values for Harwood back swamp soils:

District Yield Potential	Crop situation	Gypsum t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	4	110	20	0	0	0	0
	Ratoon	0	130	0	0	0	0	0
180 tc/ha	Plant	4	150	20	0	0	0	0
	Ratoon	0	170	0	0	0	0	0
220 tc/ha	Plant	4	190	20	0	0	0	0
	Ratoon	0	210	0	0	0	0	0

Tillage and management:

There are moderate limitations when cultivating these soils as their organic matter levels contribute to good soil structure. With regular cultivation, organic matter and soil structure will decline. Although sodic, the elevated to high salt levels keep the soil flocculated and good physical seedbeds can be produced. Where surface soil salt levels have been reduced by drainage, soil structural problems can occur due to sodicity. Subsoils are strongly sodic and have high salt levels. Where subsurface soil is exposed as a result of laser grading, amelioration (lime or gypsum or mill mud) is likely to be required. The use of raised beds will provide improved drainage and assist in reducing salt levels in the surface soil. With a reduction in salt levels and improved drainage these soils would then be regarded as good soils.

Environmental risk management:

Risks include high flood hazard and shallow water tables throughout the year. Soils are deep (over 2m), but potential acid sulphate soil materials are often present 1-2 m below the surface, but do not pose a risk unless disturbed. To minimise the denitrification risk, growers should improve drainage in the fertilised zone by mound planting/raised beds.

HARWOOD MILL AREA

Hill soils

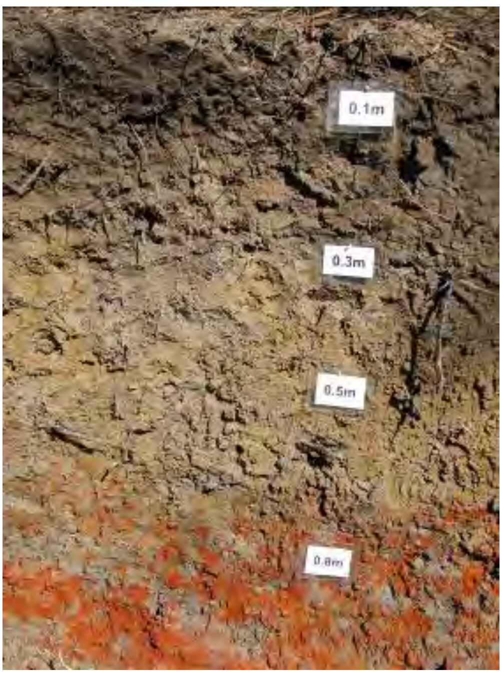
Yellow and red duplex soils and sandy or shallow, stony soils.

Soil quality: Poor

Occurrence: These soils occur on low hills surrounding the lower Clarence floodplain. They have slopes typically around 2 - 15%. These soils occupy less than 12% of the sugarcane area in the lower Clarence floodplain.

Formation:
These soils, where used for cane production in the lower Clarence, have developed on sandstone, siltstone, claystone or conglomerate.

Hill soils landscape (Tyndale)



Yellow duplex soil profile

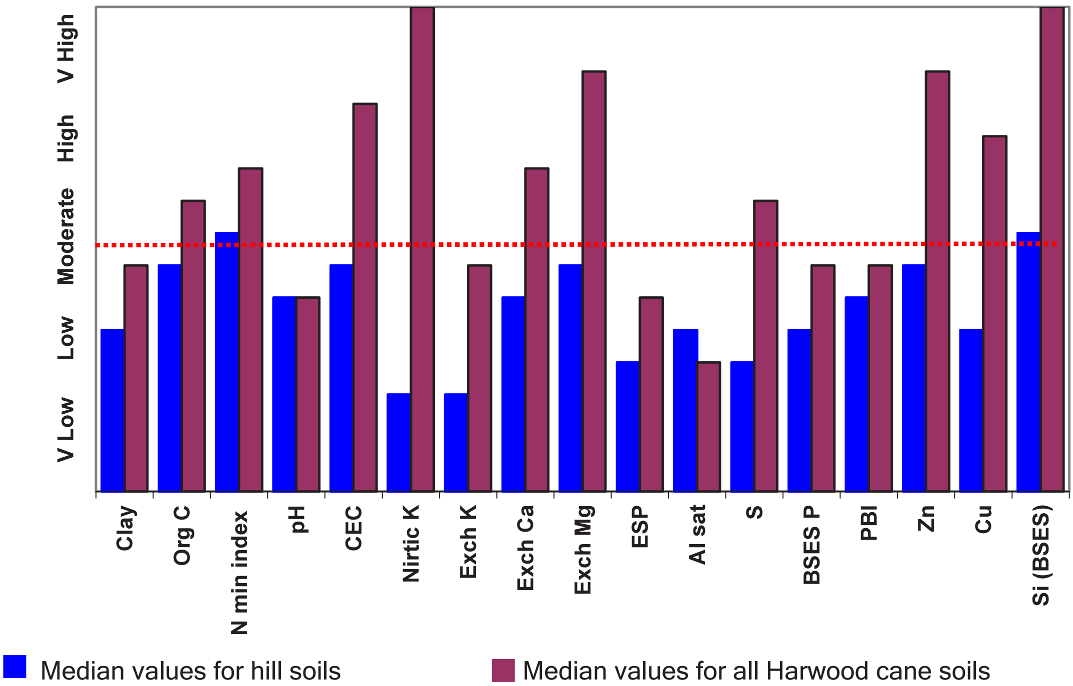
Field appearance:
A wide variation from extremely shallow stony soils to sandy soils to deeper duplex soils occurs. The duplex soils have reddish grey, loam topsoils (0.1-0.3 m) with a clear irregular boundary to greyish yellow or greyish red light to medium clay subsoil. Deeper duplex subsoils may exhibit mottling.

Physical properties:
Soil depth varies from less than 0.3m for shallow stony soils to greater than 1m for the yellow and red duplex soils.

Drainage of surface water is good because of steep slopes. The duplex soils have a moderate plant available water capacity, but the sandy soils and shallow, stony soils have a very poor water holding capacity.

Chemical properties:
Soil pH values range from extremely acidic (e.g. 4.6 - 5.0) for sands to mildly acidic (5.5 - 6.5) for some of the hill soils. CEC is below average for Harwood cane soils. The low organic matter content results in low N mineralization potential. The phosphorus status of these soils needs to be monitored and levels may be low to very low. The PBI values indicate low P sorbing capacity. Although calcium and magnesium are generally adequate for cane production, the levels of immediately available potassium are commonly low. Potassium reserves are moderate but generally lower than other Harwood soils. Sulphur is commonly low in these soils. In a few cases, silicon levels may be low. Micronutrient levels are generally adequate for sugarcane. The shallow stony soils and sandy soils are usually very low in N, P, K, S, Ca and possibly Mg.

Hill soils compared with median analysis data for all Harwood cane soils



Nutrient management guidelines based on median values for Harwood hill soils:

District Yield Potential	Crop situation	Lime t/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Mg kg/ha	Cu kg/ha	Zn kg/ha
140 tc/ha	Plant	0	130	20	120	10	0	0	0
	Ratoon	0	150	10	120	10	0	0	0
180 tc/ha	Plant	0	170	20	120	10	0	0	0
	Ratoon	0	190	10	120	10	0	0	0
220 tc/ha	Plant	0	210	20	120	10	0	0	0
	Ratoon	0	230	10	120	10	0	0	0

Tillage and management:

As surface soil can be hardsetting, trash retention and/or mill mud application will aid moisture retention. Adopting minimum tillage and controlled traffic farming systems is advisable. Localised rocks are a hazard. These soils have low nutrient status and low to moderate plant available water capacity and are therefore prone to drought.

Environmental risk management:

Risks include sheet and gully erosion. As these soils are relatively free draining there is potential for leaching. Growers should therefore consider split applications of N or controlled release products.

CHAPTER 4

Nutrient requirements for specific blocks of sugarcane

The guidelines for managing nutrient inputs according to soil type (Chapter 3) should be refined for specific blocks of cane by making use of some important tools such as soil testing, leaf analysis, juice analysis, and an integrated nutrient management package.

Soil testing

Soil testing provides useful information about the chemical (and some physical) properties of a soil and serves as a basis for determining specific nutrient inputs for a particular block of sugarcane. There are four important steps involved in this process, and each one needs to be carried out with care to ensure meaningful results.

Step 1: ***Sample collection***
Collect soil samples according to the guidelines provided in Appendix 2.

Step 2: ***Sample analysis***
Submit samples to a reputable laboratory for analysis.

Step 3: ***Interpretation of results and calculating nutrient inputs***
Ensure sound interpretation of the results and appropriate fertiliser recommendations by having an understanding of the basic process and getting advice from capable advisers such as extension officers.

Step 4: ***Fertiliser applications***
Apply fertilisers at the appropriate rates and keep records of nutrient inputs.

Interpretation of soil test values

With the exception of N, soil tests are interpreted by comparing the actual soil analysis data with established critical values. As shown in Figure 4.1, a critical value for a particular nutrient is that soil test value above which any further yield response to the applied nutrient is unlikely.

Soil test results therefore indicate those nutrients that are present in adequate quantities (and are readily available to the crop), and those nutrients that are lacking (and need to be applied). As indicated in Chapter 2 nitrogen requirement is based on the yield potential for the district and the N mineralisation index, which depends on the organic carbon content (%) of the soil. Actual soil test values are interpreted by using the information provided in Chapter 2.

An example of a soil test report for a clay soil from Broadwater (Table 4.1) shows the numerical soil test values from a commercial laboratory (column 2). These values are used to assess the amount of each nutrient required by the crop for optimum production.

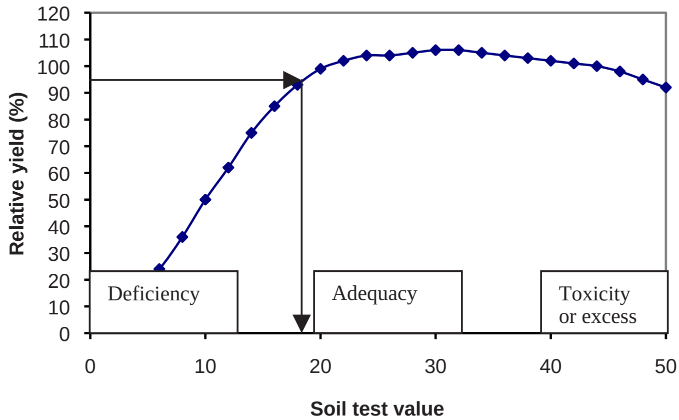


Figure 4.1 - An example of a nutrient response curve for sugarcane

Table 4.1 - Example of a soil test report from a commercial laboratory for a clay soil from Broadwater

SOIL TEST SUMMARY REPORT				
Mr Joe Bloggs Broadwater NSW 2472				
Sample No. Test Code		0123456 67		
Paddock Name		24A		
Sample Depth (cm)		0-20		
Sample Date		1/12/2010		
Analyte / Assay	Unit	Value		
pH (1:5 water)		5.30		
Organic Carbon (OC)	%	2.70		
Phosphorus (BSES)	mg/kg	22		
Phosphorus Buffer Index (PBI-Col)		100		
Potassium (Amm-acet.)	meq/100g	0.28		
Potassium (Nitric K)	meq/100g	0.95		
Sulphate Sulphur (MCP)	mg/kg	28.0		
Calcium (Amm-acet.)	meq/100g	5.50		
Magnesium (Amm-acet.)	meq/100g	7.70		
Silicon (BSES)	mg/kg	480		
Silicon ($CaCl_2$)	mg/kg	68		
Copper (DTPA)	mg/kg	0.60		
Zinc (DTPA)	mg/kg	0.5		
Zinc (HCl)	mg/kg	1.0		
Cation Exchange Capacity	meq/100g	19.60		
Sodium % of Cations (ESP)	%	3.60		
Soil Texture		Clay		
Soil Colour		Brown		

Appropriate nutrient inputs for this soil test report are calculated as follows for a 2-year crop with a district yield potential of 180 t/ha. The guidelines in Chapter 2 are used for this purpose.

Nitrogen

The **N** requirement is **160 kg N/ha** because the N mineralisation index is VERY HIGH due to an Org C (%) value of 2.7%. This requirement is appropriate for plough-out replant cane and ratoon cane. For plant cane following a grass or bare fallow, the N requirement is **140 kg N/ha.**

Phosphorus

The **P** requirement for plant cane is **20 kg P/ha** because the BSES P value is 22 mg/kg and the P sorption class is LOW as indicated by a PBI of 100. Maintenance dressings of P at a rate of **10 kg P/ha** are also required in subsequent ratoon crops.

Potassium

The **K** requirement for plant cane is **80 kg K/ha** because the Nitric K value is 0.95 me% (greater than 0.7 me%), the texture is described as a clay (more than 36 % clay) and an exchangeable K value of 0.28 me%. **100 kg K/ha** is needed for each ratoon crop.

Sulphur

The **S** requirement is zero for the plant and all ratoon crops because the soil sulphur value is 28 mg/kg.

Magnesium

The **Mg** requirement is zero for the plant and all ratoon crops because the exchangeable Mg value is 7.7 me%.

Copper and zinc

Although leaf analysis is the preferred means of determining micronutrient requirements, the soil tests indicate that neither zinc nor copper are required because both the BSES zinc and DTPA copper soil test values are greater than the values shown in Table 2.18.

Silicon

Silicon is not required because both soil tests (BSES and $CaCl_2$) are above the respective critical values shown in Table 2.19.

Lime

No lime is required if only sugarcane is to be grown based on Table 2.12. However, if a legume fallow crop is proposed then 5 t lime/ha is required because the soil pH is below 5.5 and the CEC is 19.6 me% (more than 16 me%).

A summary of the nutrient requirement for the entire crop cycle in this example (Plant crop and three successive ratoons) is as follows:

Crop	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Si (as mill mud/ash (t/ha)	Lime prior to planting (t/ha)
Plant cane	140	20	80	0	0	0	0
Ratoon crops	160	10	100	0	0	-	-

Leaf analysis

Leaf sampling offers an appropriate means of checking on the adequacy of fertiliser recommendations and nutrient inputs to a block of sugarcane. It allows adjustment of fertiliser rates in the subsequent crop (or in the current crop if the cane was young enough at the time of sampling). It also allows possible nutrient problems associated with ‘poor cane’ to be identified and is an important tool for monitoring nutrient trends at different scales (cane block, farm and region). Leaf sampling instructions are supplied in Appendix 3.

Leaf analysis results are interpreted according to the third leaf critical values shown in Table 4.2. It should be noted that third leaf N values decrease as the season progresses.

Table 4.2 - Third leaf nutrient critical values for sugarcane

Nutrient	Month of sampling	Third leaf critical nutrient value (%)
N	Nov - mid Jan	1.9 %
	Mid Jan - Feb	1.8 %
	Mar - May	1.7 %
P	Nov - May	0.19 %
K		1.1 %
Ca		0.2 %
Mg		0.08 %
S		0.13 %
Cu		2 mg/kg
Zn		15 mg/kg
Mn		15 mg/kg
Si		0.55 %

An example of a leaf analysis report is shown in Figure 4.2. Apart from showing the actual analysis data and appropriate critical values for the full range of nutrients, the bar graphs provide an easy to understand interpretation, with the red dotted line indicating satisfactory levels. Statements below the bar graph add to this interpretation.

In this example, the leaf analysis results are alerting Mr Bloggs to the following:

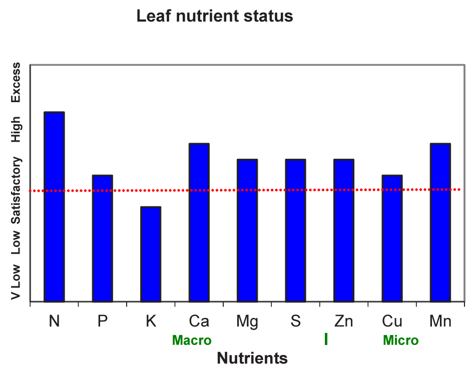
- The third leaf N value is high. This reflects the high N availability in the soil from a possible combination of applied fertiliser and N mineralised from soil organic matter.
- The third leaf P, Mg, S, Cu, Zn and Mn values are all satisfactory.
- The third leaf Ca value is moderate to high, and reflects the generally high base status of NSW soils.
- The third leaf K value is marginally low. The relatively high Ca + Mg maybe affecting the uptake of K. No additional K fertiliser is indicated for the next crop.

BSES Leaf Analysis Service, Private Bag 4, Bundaberg DC 4670

Sample No.	7351
Name	Joe Bloggs
Address	Pacific Highway, Condong
Mill	Condong
Farm No.	6541
Block	24A
Age (months)	7
Sampling date	20/01/2011
Crop	1R
Variety	Q208

Leaf data		Critical:
Nitrogen (N)	2.32 %	1.8 % *
Phosphorus (P)	0.20 %	0.19 %
Potassium (K)	1.00 %	1.1 %
Calcium (Ca)	0.45 %	0.2 %
Magnesium (Mg)	0.20 %	0.08 %
Sulphur (S)	0.21 %	0.13 %
Zinc (Zn)	22 mg/kg	15 mg/kg
Copper (Cu)	5 mg/kg	2 mg/kg
Manganese (Mn)	88 mg/kg	15 mg/kg
Iron (Fe)	88 mg/kg	
Silicon (Si)	1.21 %	0.55 %

Nutrients applied



Remarks:

* Leaf N critical value depends on the date and age of cane at sampling.
# One or more of the macro nutrients are below satisfactory levels

Analysis of the leaf sample was undertaken by the Fertiliser Advisory Service Laboratory of the South African Sugar Research Institute at Mount Edgecombe.

Warning: Our tests, inspections and recommendations should not be relied on without further, independent inquiries. They may not be accurate, complete or applicable for your particular needs for many reasons, including (for example) BSES Limited being unaware of other matters relevant to individual crops, the analysis of unrepresentative samples or the influence of environmental, managerial or other factors on production.

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Figure 4.2 - Example of a leaf analysis report

Juice analysis

Juice analysis has been proposed as a means of identifying nutrient imbalances in sugarcane. For instance, it has been reported that amino N levels in cane juice are indicative of high N application rates and also contribute to increased colour in sugar. However, the absence of critical values for N and other nutrients have not enabled this technique to be used for developing routine fertiliser recommendations.

SIX EASY STEPS nutrient management package

Analytical results for a single soil or leaf sample are of limited value. Of much more benefit is the concept of integrated nutrient management, which includes the use of a range of different activities for determining nutrient inputs to a particular cane block. In brief the integrated nutrient management package is the SIX EASY STEPS, which comprise:

1. Knowing which soils occur in each block of your farm.
2. Understanding the properties of each soil and the nutrient processes and loss pathways likely to occur in each soil.
3. Regular soil testing (blocks should be sampled before every crop cycle).
4. Developing a nutrient management plan for each block using the current guidelines.
5. Checking on the adequacy of nutrient inputs using leaf analysis or on-farm replicated strip trials.
6. Maintaining a good record keeping system, which enables informed decisions to be made based on block histories and longer-term nutrient management strategies.

Implementation of this system on-farm will lead to best practice nutrient management and sustainable sugarcane production.

Concluding remarks

Soils are complex physical, chemical and biological systems which store and release nutrients for crop growth and are not simply for holding up cane plants. When developing nutrient guidelines it is essential to take into account three things.

1. The amount of nutrients contained in different soils.
2. The rates of nutrient release by different soils.
3. The reactions between soils and fertilisers.

This complexity is appreciated by NSW cane growers who have a good understanding of the diversity of soil types occurring on their farms and recognise that different management practices are needed for each soil. The information presented in this booklet is intended to reinforce this local soil knowledge and provide an easily understood system for soil and nutrient management. It focuses much more than past systems on the chemical, physical and biological properties of different soils.

The SIX EASY STEPS philosophy focuses on the management of different soils to enhance their ability to store and supply a wide range of nutrients to the crop. It emphasises the importance of improving levels of soil organic matter and has the long-term goal of improving soil fertility through the enhancement of natural soil processes and nutrient cycles. It differs from previous approaches in the following ways:

- The nutrient management guidelines take into account the release of N, P and S in the soil through the mineralisation of soil organic matter. Because of this, N guidelines in particular are lower than previous recommendations. This is particularly important given concerns about elevated levels of nitrate in local streams.
- There is recognition that soils differ in their capacity to sorb added P fertiliser and render it less available to sugarcane crops. It is therefore important to interpret the standard BSES P test in conjunction with PBI values.
- The K guidelines are broadly similar to previous recommendations but take into account differences in soil texture. In many cases, they are higher than previous K application rates and recognise the low exchangeable K and high Nitric K levels in many NSW cane soils.

The authors hope that this booklet will improve the local awareness and understanding of different soils and how they can be managed for sustainable sugarcane production. Guidelines for interpreting soil and leaf test values are also provided. Growers are encouraged to make greater use of these important nutrient management tools.

How to determine soil texture

The texture of a soil is defined as the relative proportions of sand, silt and clay particles in the soil. In the laboratory, the particle size distribution is determined by measuring the percentages of each of these particles in a particular soil. In the field, the field texture grade of a soil (sand, sandy loam, loam, clay loam, silty clay loam, clay, etc) can be estimated by observing the behaviour of a small handful of soil, moistened with enough water to ensure that a ball (bolus) can be formed with kneading and then pressed between thumb and forefinger to produce a ribbon. The texture is determined by noting certain characteristics of the moistened soil and comparing the length of this ribbon (mm) with the ranges indicated in the following table.

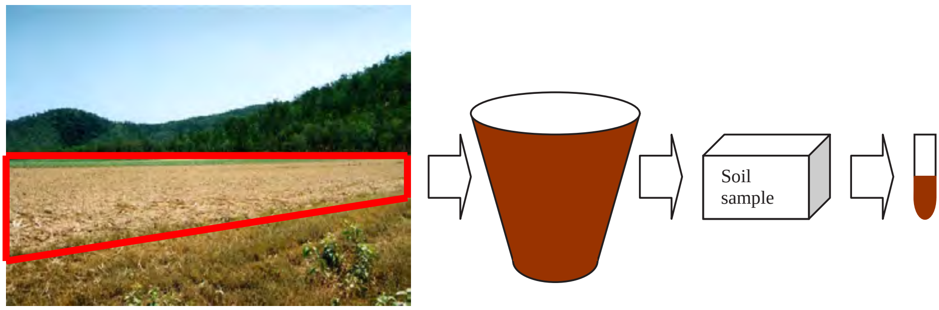
Forming the ball (bolus) of soil and pressing it into a ribbon

Below: Simplified guide to determining soil texture.

Characteristics of the soil bolus and ribbon	Length of the ribbon (mm)	Textural grade	Approximate clay %
Sandy feel, no coherence with single grains sticking to fingers	Nil	**Sand**	**0 - 10**
Sandy feel, slight coherence, with discolouration of fingers	5-15	**Loamy sand**	**5 - 15**
Sandy feel, slight coherence	15-25	**Sandy loam**	**10 - 20**
Spongy, greasy feel, with coherence, but no obvious sandiness of silkiness.	25	**Loam**	**10 - 24**
Smooth, silky feel, with distinct coherence	25	**Silt loam**	**10 - 24**
Sandy feel but with distinct coherence	25-40	**Sandy clay loam**	**20 - 30**
Smooth feel with strong coherence and no obvious sand grains	40-50	**Clay loam**	**25 - 40**
Smooth, silky feel with distinct coherence	40-50	**Silty clay loam**	**25 - 40**
Easily moulded with sandy feel	50-75	**Sandy clay**	**25 - 50**
Easily moulded with smooth and silky feel	50-75	**Light clay / silty clay**	**35 - 45**
Easily moulded (like plasticine), smooth feel, but with resistance to shearing.	+75	**Medium / heavy clay**	**> 45**

How to take a soil sample

Soil tests in the laboratory are carried out on a 10 g sample, which is taken from about 500 g of soil submitted to the laboratory. Usually this 500 g sample is a sub-sample of about 10 kg of soil which ideally should be sampled from a block of cane (average 2 hectare area) which contains about 6 000 tonnes of soil in the plough layer.

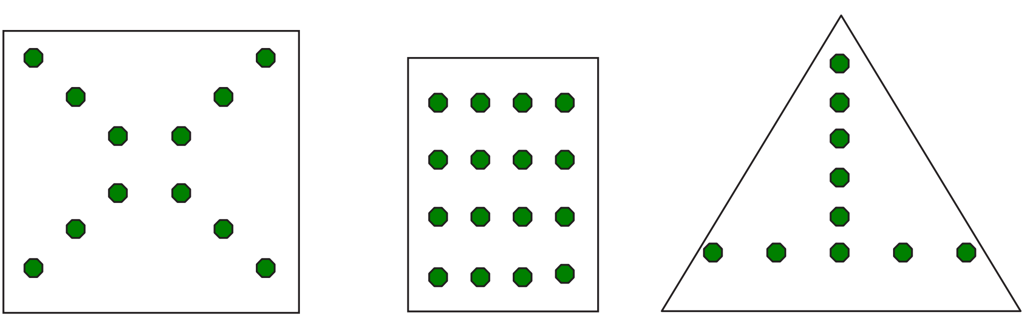


Soil: 6 000 tonnes 5 -10 kg 500 g 10 g

The ten grams of soil analysed in the laboratory is a sub-sample of the soil sample collected in the field and represents around 1.6 parts per billion. In view of this it is extremely important that a soil sample is representative of the volume of soil from which it is collected. This is achieved by collecting adequate soil from the block being sampled using a standard procedure.

Soil sampling procedure

- Determine the area that is to be sampled. Ensure that the area (or block) being sampled does not exceed 2 or 3 hectares and that it is relatively uniform in soil type. In large blocks consider taking multiple samples and if a block consists of more than one distinct soil types sample each separately. Avoid sampling areas that differ in terms of crop growth or where large amounts of mill mud or other ameliorants have been dumped. Again, sample such areas separately if necessary.
- Sampling is traditionally undertaken using an auger (either a turning auger or a soil coring tube) to a depth of 20 cm.
- At least 10 or 12 ‘augerings’ should be collected from the area, using a zig-zag or grid pattern. The basic principle is that more ‘augerings’ are better than less.



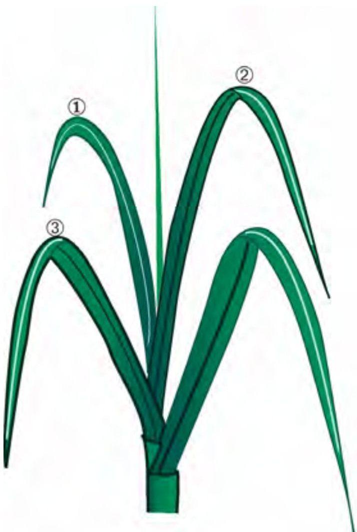
Some suggested sampling patterns within cane blocks of different shapes.

- Whilst there is some debate as to where soil samples should be taken in relation to the cane row or inter-row, we suggest that all samples be taken from the shoulder of the cane row, approximately mid-way between the centre of the cane row and the centre of the inter-row. By following this rule you will avoid sampling the highly compacted centre of the inter-space where there are likely to be fewer roots. You will also avoid sampling the centre of the cane row where you are likely to encounter the cane stool and/or residual plant cane fertiliser.
- If possible, take soil samples in the last ratoon crop just after harvest. You should then have sufficient time to apply lime and/or soil ameliorants to the fallow, well before planting.
- All sub-samples should be collected in a good-quality plastic bag or a clean plastic bucket to form a single composite sample. After collection, the soil should be mixed thoroughly to ensure uniformity of the sample.
- Preferably the complete sample should be dispatched to a reputable laboratory for analysis. If the sample is too cumbersome, however, a portion (500 g – 1 kg) should be sub-sampled for analysis. Ideally this should occur after air-drying and initial sieving. However, such facilities are not always available.
- Supply as many details as possible on a label and on the sample bag itself to ensure that the sample can be easily identified, and that meaningful interpretation of the results is possible.

Remember: Care should be taken to ensure that the sample is not contaminated. Cleanliness is most important. Always ensure that the auger is cleaned between sampling different blocks, that any buckets used are clean and that new plastic bags are used. Do not use a soil sampler or shovel made from galvanised iron or a bucket with a galvanised handle if the soil is to be hand-mixed, otherwise zinc contamination could occur.

How to take a leaf sample

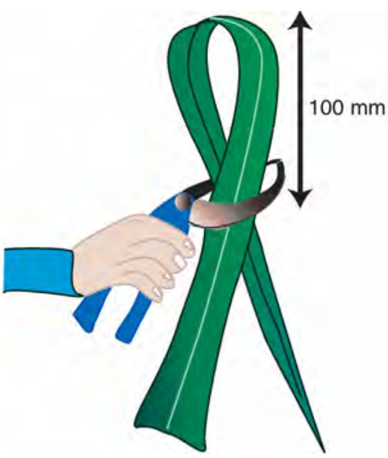
STEP 1

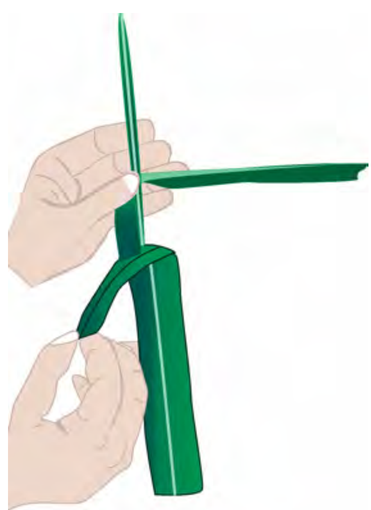


- Select leaves from stalks of average height.
- Sample the third leaf from the top of the stalk (as shown on the diagram). Counting from the top of the plant, the first leaf is the one that is more than half-unrolled. The third leaf usually corresponds to the top visible dewlap.
- Collect 30 - 40 leaves at random from across the entire block of sugarcane being sampled.

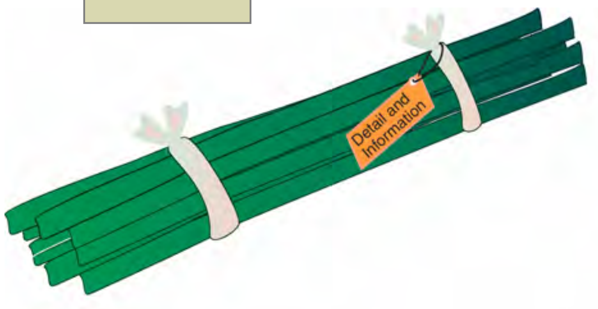
STEP 2

- Fold the leaves in half (top to base) and cut a 100-200 mm length from these folded leaves (giving a total 200-300 mm section of each leaf). Retain these middle 200-300 mm sections of the leaf blades and discard the remaining top and bottom sections.
- Strip out and discard the midrib from each 200-300 mm section.





STEP 3



- Bundle the leaf strips together and attach a label with sample details.
- Place the sample in a cool environment (polystyrene cooler) until it can be dried in an oven (at about 60^{0}C) or in a dry well-ventilated area.
- Once the sample is dry, place it in a clean paper bag or envelope, and send it to reputable laboratory for analysis.

To ensure meaningful interpretation of the analysis results, make sure that the following guidelines are adhered to:

- Cane is sampled during the prescribed leaf-sampling season (December to April).
- Cane is the correct age (3-7 months) at the time of sampling.
- Cane has been growing vigorously during the month prior to sampling.
- Cane is not affected by moisture stress at the time of sampling.
- Cane is also unaffected by any other factors, such as disease, insect damage, etc.
- Six weeks has passed since fertiliser applications.

It is important that leaves are sampled correctly and that all the details requested by the testing laboratory are supplied as accurately as possible. This will enable meaningful interpretation of the analysis results.

FURTHER READING

The material covered in this booklet includes information drawn from various sources. This expertise and knowledge is gratefully acknowledged, particularly in relation to the following publications and/or reports. The list also provides details of some further reading options.

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