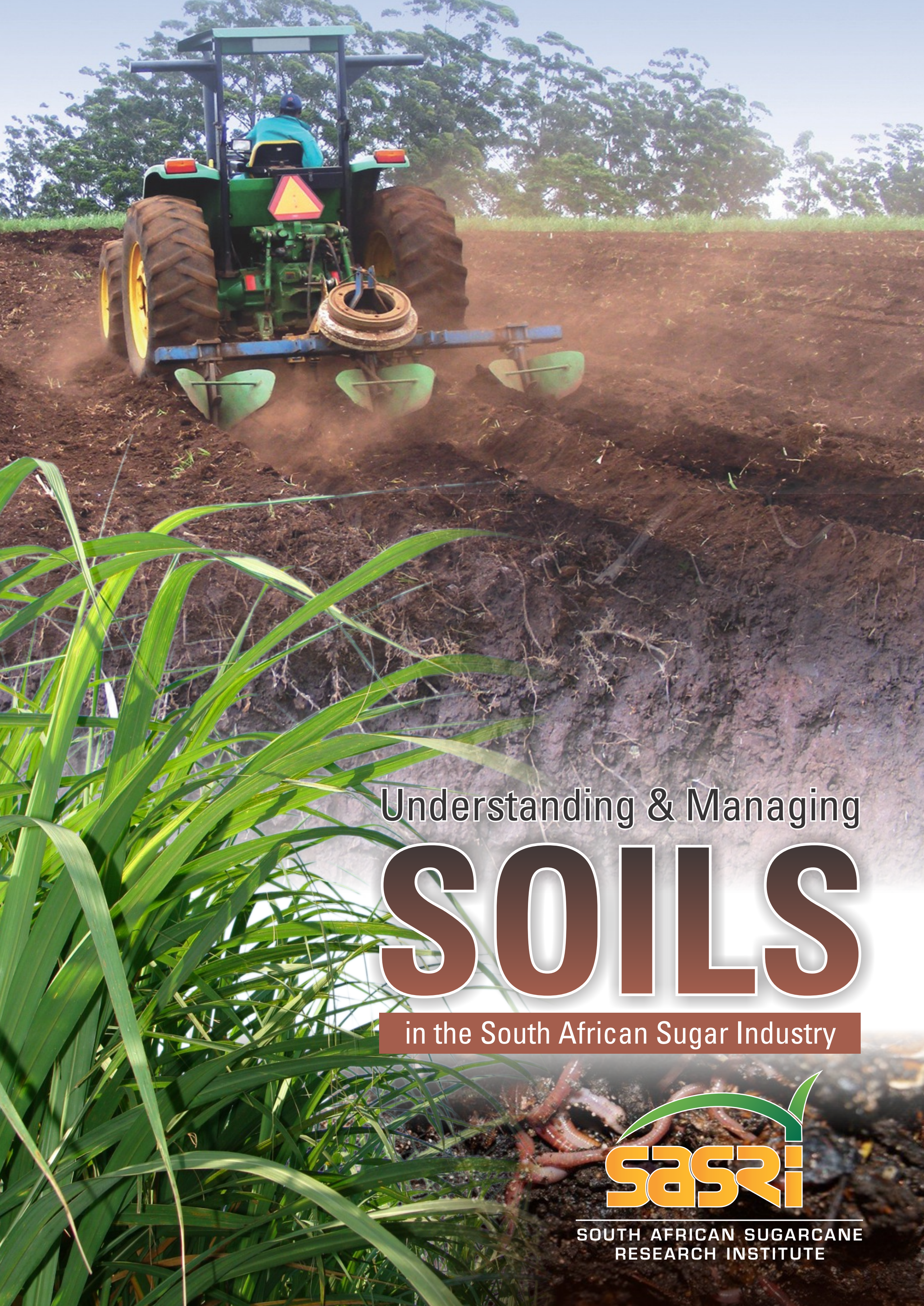

Understanding & Managing SOILS in the South African Sugar Industry

SASRI

SOUTH AFRICAN SUGARCANE
RESEARCH INSTITUTE

Understanding & Managing

SOILS

in the South African Sugar Industry

Published by

SOUTH AFRICAN SUGARCANE RESEARCH INSTITUTE

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Foreword

Complex systems are never easy to understand, and following the establishment of the foundations of soil science in the late 1800s, countless soil scientists have devoted their lives to understanding the origins, intricacies and interrelationships inherent in soils. With the establishment of the South African Sugarcane Research Institute (SASRI) in 1925 (then the South African Sugar Experiment Station), investigations into the soils of the newly developed sugar industry were initiated, culminating in a body of knowledge that has emanated from a series of eminent soil specialists.

Over these past 88 years, the diverse conditions in the industry have provided ample opportunities for research, and have enabled an intimate understanding of the relationship between sugarcane and its primary resource, leading to the development of a book that is so much more than just a soils handbook. Rather, this is a reference work that encompasses not only soil physical, chemical and biological properties and processes, but includes invaluable insights into the prerequisites associated with managing soils for their long term sustainability and sugarcane productivity. The vital role that nutrition plays in this process is not ignored. The team of authors behind this impressive initiative represents a set of complementary skills that collectively reflect more than 200 years of soils experience, and our research institute has the privilege of making this knowledge available to the industry.

Because soil health is fundamental to crop productivity, an understanding of the key features that contribute to maintaining the optimal environment for sugarcane growth is essential. Recognising the likely impact of sugarcane cropping practices on soils and as testimony towards enhancing a deep understanding of the soils in the sugar industry, a burning and trashing trial (BT1) was established in 1939 at Mount Edgecombe to assess the impact of long-term burning and trash management in relation to applied fertiliser on changes in soil fertility and leaf nutrient status. BT1, which is still in operation, is probably the longest running sugarcane trial in the world. The accumulated data from this work have gone a long way towards improving our understanding of the biology of soils in the industry. Further, the early work conducted in the root laboratory demonstrated the impact of various soil properties on root development and penetration, and entailed painstaking measurements of root growth in response to various treatments. These early research endeavours dedicated to the sugarcane industry have culminated in an enviable body of knowledge that continues to have significance today.

Although soil science has a way of becoming exceedingly complicated, the text, graphics and layout throughout this book make the content accessible and easy to understand. Regardless of soil type, geographic location or even the soil health philosophy that is adopted, every single sugarcane grower will benefit from the wisdom that this team of soil scientists presents. Beginning with a basic understanding of the physical properties of soil, the book moves on to deal with soil-water relationships, soil chemistry, soil biology, and the critical roles that organic matter and also managing soil acidity play in soil health. Plant nutrition and nutrient management provide a sound basis for diagnosing nutritional problems, while the issues surrounding soil salinity and sodicity that are commonplace in more arid environments are described, together with some simple solutions. The concluding chapter reflects on the importance of soil health assessments as a diagnostic tool for any grower and offers useful indicators to aid management.

The book makes no excuses for the fact that sugarcane is largely monocropped in South Africa, and engages with the reality of everyday farming in the sugar industry. It shows that, with an understanding of soils and commitment to their management to enhance soil health, long term sustainability of the industry can be achieved. When joining the industry in 2001, I was over-awed with the passion that emanated from all of the soil scientists – and their determination to explain every minute detail of every single interaction in the soils was exhausting and at times overwhelming. Since then I have learned that some soil scientists speak 'English' and have the remarkable ability to explain the complicated interactions in a manner that the rest of us can understand, and it is then that the magic happens – and a deep appreciation emerges. As a reference guide and a source of knowledge and good practice, this book is invaluable. Every sugarcane grower will be lost without it.

Carolyn Baker

Director:
South African Sugarcane
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About the Authors

Rianto van Antwerpen

Tarryn Wettergreen

Michael van der Laan

Rianto van Antwerpen is a graduate of the University of the Free State (BSc Agric, BSc Agric Hons, MSc Agric and PhD) who worked at the Tobacco and Cotton Research Institute in Rustenburg before joining SASRI in 1990. He is a soil physicist by trade and has worked with many crops. He has also worked on projects dealing with soil tillage, root growth, soil health, irrigation scheduling, the use of residue from various sources and soil management. Currently Rianto is a Senior Soil Scientist and Programme Manager at SASRI, and an Honorary Associate Professor at the University of the Free State. He also serves on councils of the Soil Science Society of South Africa (Vice President), the International Society of Sugarcane Technologists (Agronomy and Agricultural Engineering) and the South African Sugar Industry Agronomists' Association (Convenor).

Tarryn Wettergreen (nee Eustice) completed her MSc in Soil Science and Viticulture at Stellenbosch University in 2007. She joined SASRI in 2008 as a Soil Scientist, where she authored and co-authored several papers, posters and popular articles and has contributed to one international book chapter. Since November 2012, she has been employed at the South African Table Grape Industry (SATI) as Research Manager.

Michael van der Laan obtained his PhD from the University of Pretoria (UP) in 2009, following which he joined SASRI as a Systems Modeller. While at SASRI, Michael's research focused on water and nitrogen dynamics in sugarcane agro-ecosystems. In June 2012, Michael returned to UP where he is presently employed as a Senior Lecturer. Michael serves as an Associate Editor for the South African Journal of Plant and Soil, and Secretary for the International Commission on Irrigation and Drainage's Working Group for the Environment. Michael has published 10 peer-review journal articles and three book chapters, and his current research is on water footprinting, using irrigation to treat neutralised acid mine drainage, and the measurement and modelling of greenhouse gas emissions from agro-ecosystems.


Neil Miles

Neil Miles is currently a senior scientist at SASRI. Prior to his position with SASRI, he spent 28 years with the KZN Department of Agriculture, as a Research Scientist and Research Manager. His PhD, through the University of Natal, focused on the nutrition of intensive pastures. Neil played a leading role in the development of the Cedara Fertiliser Advisory Service, which he also managed for some 20 years. At SASRI, he manages the Fertiliser Advisory Service and conducts research relating to the optimisation of soil health and the nutrient requirements of sugarcane. In 2011 he was appointed an Honorary Research Fellow at the University of KwaZulu-Natal.


Ruth Rhodes

Ruth Rhodes obtained her BSc (Agric) at the University of Natal (Pietermaritzburg) before moving to the University of Cape Town to complete her MSc in Conservation Biology. After working abroad for two years, Ruth joined SASRI as a soil scientist in 2004. Her primary areas of research include the use of green manures to improve soil health in sugarcane systems, and crop nutrition. Ruth is passionate about sugarcane farming and improving fundamental soil management in the industry.


Annett Weigel

Annett Weigel is a soil scientist who completed her PhD at the Martin-Luther University in Halle, Germany, in 1992. After her graduation she worked for the Environmental Research Centre Leipzig-Halle, dealing with soil organic matter, its role in soil fertility and its interaction with the nitrogen cycle. In 1998 she joined the Environmental State Agency of the German State of Saxony-Anhalt, where she was responsible for developing a soil monitoring scheme in the scope of the German Soil Protection Act. Since 2007 she has been working at SASRI with focus on soil health, carbon and nitrogen dynamics of soils and improvement of nitrogen use efficiency.

Contents

Chapter 1

PHYSICAL PROPERTIES OF SOIL

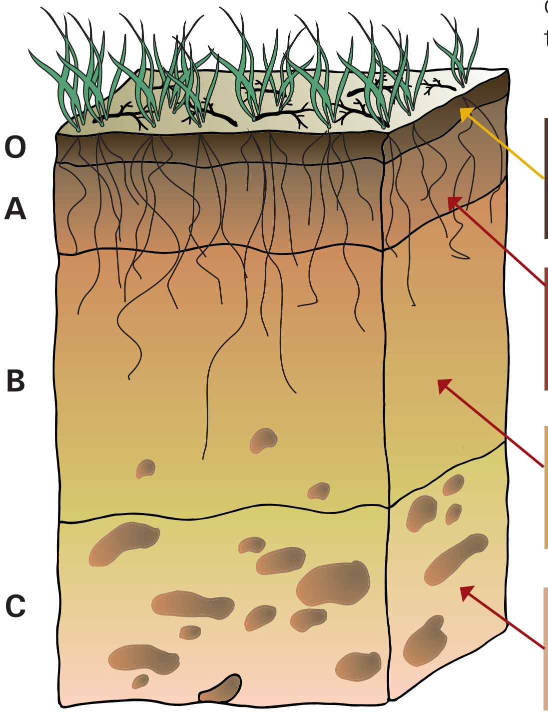
Physical Properties of Soils

The physical properties of soils influence soil water availability and movement through the profile, compactability, salt and nutrient transport and accumulation, and soil erosion. The physical structure of a soil can be altered by various management practices such as tillage, control of wheel traffic, organic matter additions and the quality of irrigation water applied. An understanding of soil physics is required to implement optimal soil management practices. This chapter discusses the following physical properties of the soil: soil horizons (colour, texture and structure), soil temperature, porosity and compaction, soil bulk density and soil depth, and the effect these factors have on the behaviour of the soil.

Soil horizons

Descriptions of soil horizons in terms of texture, colour and structure are used to emphasise the important physical features of a soil. These are discussed in more detail in the sections that follow.

A soil profile typically consists of a number of soil horizons (or layers), each with its own distinctive characteristics defined by colour, texture and structure. These horizons form the basis of describing and understanding soil. Well-developed soil profiles have three major horizons, referred to as A, B and C horizons (Figure 1.1). In some cases a layer rich in organic matter, referred to as an O horizon, may overlay the A horizon. Transition from one horizon to the next can be clearly distinct, or gradual, resulting in boundaries that are difficult to distinguish.



The O horizon is made up of dead leaves, branches and other organic debris on the soil surface.

The topsoil (A horizon) is darker in colour because of organic matter. It is the zone of maximum biological activity.

The subsoil (B horizon) accumulates clay minerals and is typically much lighter in colour due to lower organic matter levels.

The underlying layer (C horizon) consists of unconsolidated material and weathering rocks.

Figure 1.1. Major soil horizons and descriptions found in a well-developed soil profile.

Soil colour

Colour indicates the conditions acting on a soil during its formation and development, and is important for describing and understanding soils. The most important colours are black, light grey, dark grey, red, yellow, brown and dark brown. When describing the colour of a horizon it is important to state whether it is uniform or mottled. The colour of the soil helps to understand the physical properties of the soil (Table 1.1).

Table 1.1. Common soil colours and their significance.

Soil colour	Colour associations	Management implications
Uniform colour	Uniform climatic conditions have persisted for a long time, i.e. in mature soils.	Applies mostly to the topsoil layer. Normally soils that are easier to manage for optimum yields.
Black/dark brown	High organic matter and/or black clay minerals, e.g. mica.	Applies mostly to the topsoil layer. These soils have a high water and nutrient retention capacity and are more resistant to degradation and erosion than most other soils.
Grey	Associated mainly with soil layers low in organic matter with fresh unweathered minerals and bleached soils due to intensive leaching (or eluviation).	Applies mostly to the topsoil layer. These soils compact very easily and are susceptible to erosion. Water and nutrient retention properties are normally poor.
Mottling and blue-grey	Contrasting conditions, usually aerobic (with oxygen) and anaerobic (without oxygen) due to alternating periods of wetting and drying.	Applies mostly to the subsoil. Are mostly found in valley bottom areas, in which case the area should be allowed to revert to a wetland. Rooting depth is shallow and drainage poor.
Variegated	Recently weathered rock fragments mixed with soil and covered with clay skins.	Applies mostly to the subsoil. Root penetration is mostly restricted to old root channels. These soils are normally shallow and range between 200 and 500 mm.

Soil texture

Soils contain particles of different sizes. The mean size of the soil particles determines the soil textural classification, as shown in Table 1.2.

Table 1.2. Particle size limits between particle classes based on South African criteria.

Class	Diameter range (mm)	Visibility
Gravel	3.0 - 2.0	Naked eye
Coarse sand	2.0 - 0.5	
Medium sand	0.5 - 0.2	
Fine sand	0.2 - 0.02	Microscope
Silt	0.02 - 0.002	Electron microscope
Clay	0.002 - 0.0002	

The proportion of sand, silt and clay particles in a soil is used to determine the textural classification of a soil or soil layer. An easy method to establish the textural class of a soil involves the use of results from a laboratory and a texture triangle (Figure 1.2).

Example: Consider a soil with 60% sand (sum of coarse, medium and fine sand), 30% clay and 10% silt. Projection of any two of these components along their respective axes intersect in the block 'sandy clay loam', which is the textural classification of this soil.

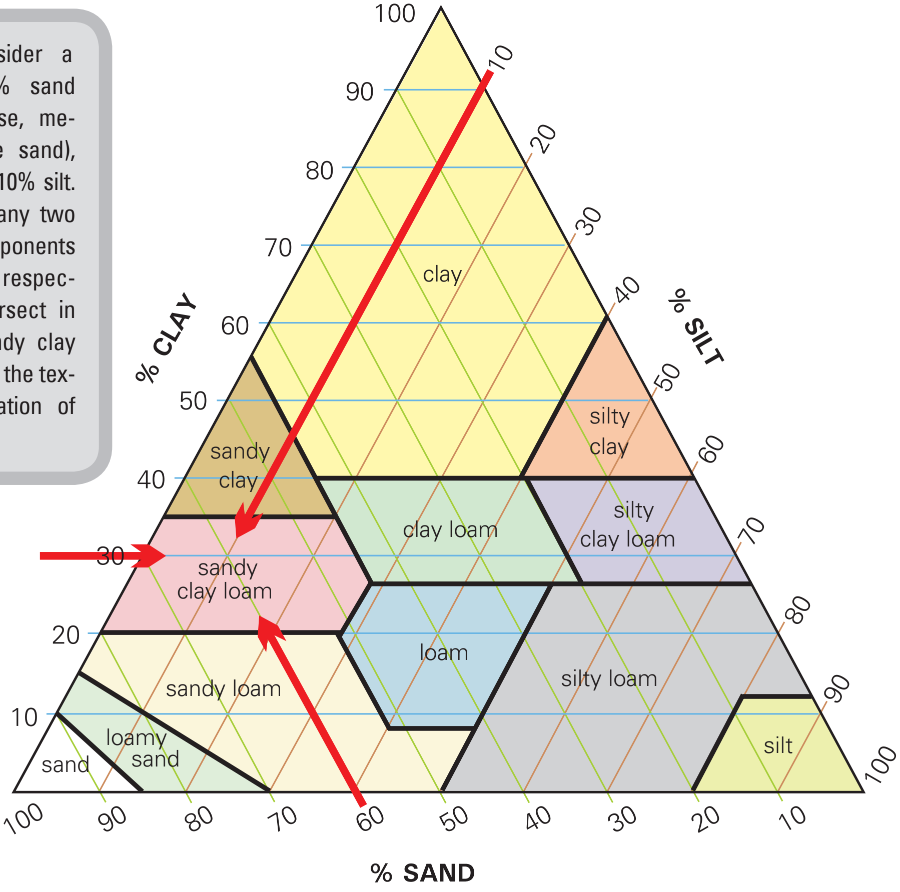
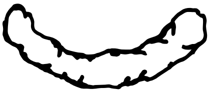
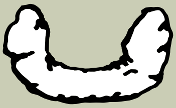
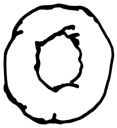


Figure 1.2. Soil textural classification system based on particle size distribution obtained from laboratory test results.

Where laboratory results are not available, the sausage test can be used to estimate soil clay content and thereby textural classification. This is done as follows:

- Take a handful of soil, add a bit of water if it is dry.
- Knead the soil and roll it between the palms of the hands as evenly as possible to form a sausage about 90 mm long and 7 mm thick.
- The objective is to bend the sausage without breaking it. Stop bending it the moment it starts to crack.
- Determine the classification of the soil using the description in Table 1.3.

Table 1.3. Soil textural classification system using a rough field method.

No sausage is possible	***Sand*** (<10% clay) No sausage can be rolled.
	***Loamy sand*** (10 - 15% clay) A weak sausage can be formed but cannot be bent without cracking.
	***Sandy loam*** (15 - 20% clay) Sausage can be bent into a banana shape before it will start to crack.
	***Sandy clay loam*** (20 - 30% clay) Sausage can be bent further than a banana shape before it will start to crack.
	***Sandy clay*** (35 - 55% clay) Sausage can almost be bent into a U-shape before it will start to crack.
	***Clay*** (>55%) Sausage can be bent into a complete circle without cracks.

Plant growth is not directly related to the precise textural classification of the soil, but rather to properties that are affected by soil texture such as soil water and nutrient retention (fertility), erosion susceptibility, permeability, porosity and mechanical strength. Table 1.4 summarises the effect of soil texture on selected soil properties.

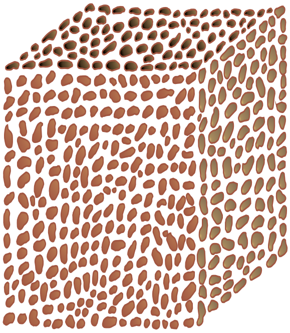
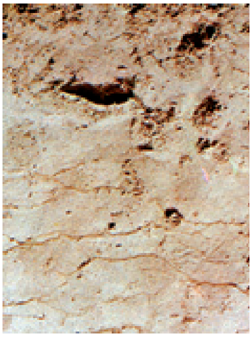
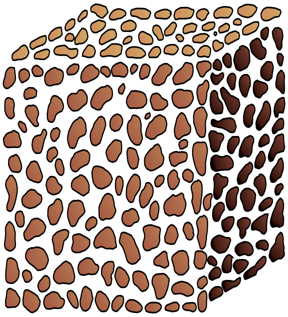
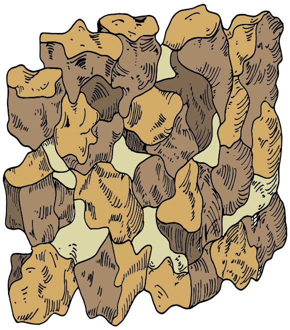
Table 1.4. Agricultural significance of soil textural classes.

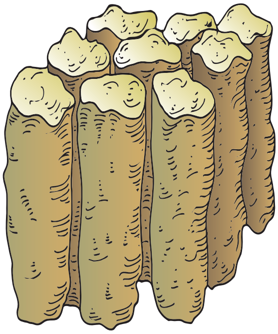
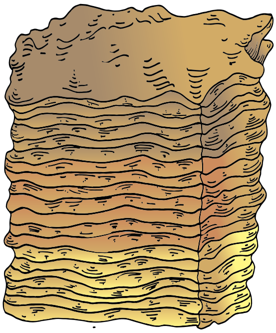
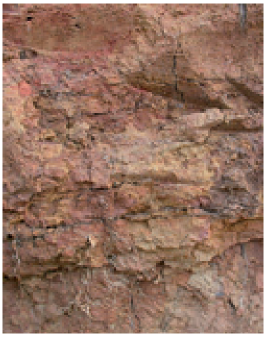
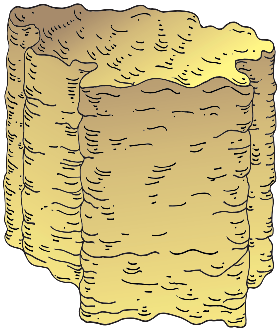
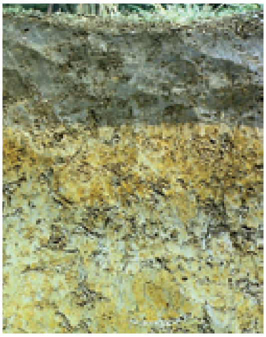
Soil property	Sand	Loam	Silty loam	Clay
Internal drainage	Excessive	Good	Fair	Fair to poor
Plant available water	Low	Medium	High	High
Nutrient retention	Poor	Low to medium	Medium to high	High
Tillability	Easy	Easy	Moderate	Difficult
Runoff potential	Low	Low to medium	Medium to high	High
Erosion hazard	High	Medium	Low	Low

Soil structure

Individual or grouped sand, silt and clay particles can arrange or group themselves to form larger clumps of soil called aggregates. Structure refers to the arrangement of these clumps or aggregates into structural units which can be held together either strongly or weakly. The stronger the structure, the greater the breaking force required. Structure is responsible for the formation of a network of pores (the main water storage area) and channels (passages for roots) in soils. Table 1.5 summarises the structures found in soils.

Table 1.5. Types of structure found in soils.

Structure type	Illustration	Comment
No structure	 	Structureless soils are normally very sandy, have a low water and nutrient retention capacity, erode easily and are low in organic matter.
Small aggregates and lacks recognisable structure shapes	 	Are well-drained and well-aerated with no restriction to root growth. Are amongst the best soils for agriculture production.
Blocky structure	 	Water and nutrient holding capacity is good and are found in moderate to high potential soils. Water and nutrients are less available and roots hardly penetrate the structure units.

Structure type	Illustration	Comment
Column and prismatic structures	 	Water and nutrient availability is significantly reduced, water infiltration rate is slow and these soils often develop a water table following prolonged rainfall events.
Platey structure	 	Structure units are much wider than their height. Although thin, root penetration and water infiltration is effectively reduced. They act similarly to corrugated sheets on a roof.
Massive structure	 	Clay content is high with no recognisable structure units. Water infiltration is extremely slow and no roots are found in it. It is the ideal underlying structure to site a dam.

Structure influences soil air, water and temperature and therefore the soil's ability to support microbial life and to act as a growth medium for plants. When considering soil structure, two concepts need to be kept in mind: (i) the aggregation of the soil (refers to the abundance of individual or groups of sand, silt and clay particles to form clumps) and (ii) firmness (the strength with which the soil particles are held together). For example, a highly structured but weakly aggregated soil can physically impede root growth and have low water availability. Conversely, some soils do not have well defined structural units but may be strongly aggregated (soil with many small crumbs). These are among the best soils for crop production.

Soil temperature

Temperature can affect a range of physical, chemical and biological processes in soils. At lower temperatures, biological and chemical processes occur more slowly and this, for example, results in slower absorption of water and nutrients by plants and slower decomposition of residues and organic matter. When temperatures are too low or too high, biological metabolic (respiratory) activity can cease altogether. The time to emergence of new growth of sugarcane following planting or ratooning is therefore highly dependent on soil temperature.

As solar radiation is the primary source of heat for soils, surface layers experience higher temperatures than deeper soil layers. Only about 10% of the total solar energy approaching the earth reaches the soil surface. A portion of this is reflected by the land surface and does not heat the soil. The reflected portion is lower for darker or rougher surfaces, and higher for lighter or smoother surfaces. The presence of a growing crop or mulch and the direction of the slope (termed aspect) will affect the amount of solar radiation that reaches a soil.

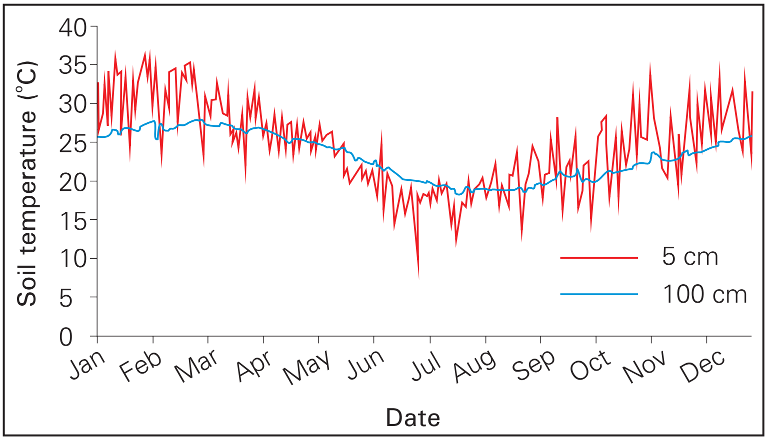


Figure 1.3. Soil temperatures measured at 5 and 100 cm depths in a soil under sugarcane cultivation in Pongola.

Heat is transferred from the upper soil layers to the deeper soil layers mostly by conduction. Soils differ in their specific thermal (heat) conductivity and therefore in the rate of heat transferral to lower layers. Wetter soils conduct heat better because heat passes through water faster than air, and compact soils also conduct heat more efficiently due to improved particle-to-particle contact.

Due to seasonal differences in solar radiation and atmospheric temperature, and time lags associated with the conduction of heat from shallower to deeper soil layers, soil temperatures fluctuate over space and time. Figure 1.3 shows seasonal soil temperatures at two depths. Layers closer to the surface experience greater extremes of temperatures (red line) compared to the deeper layer (blue line).

In regions prone to frost, the heat stored in soil water can reduce the chances of frost damage compared to a dry soil containing little water.

Soil bulk density, porosity and compaction

The bulk density of a soil describes how closely the soil particles are packed together (expressed as the dry mass of the soil in a known volume). The closer the particles are packed, the higher the bulk density. Bulk density is an important physical property of the soil that has an impact on effectiveness of heat conductance, water related soil properties and crop growth. High soil bulk densities will result in:

- improved conductance of heat to other areas in soils and therefore faster loss of water through evaporation from the surface

- reduced water infiltration rates
- longer periods of water-logging after rain or irrigation
- runoff and erosion
- reduced water holding capacity
- root growth impediment, and
- reduced exchange rates of soil gases such as carbon dioxide, methane and various nitrogen oxides.

These result in less optimal conditions for plant growth and cause yield loss. Soils with high bulk densities are referred to as compacted. This is most often caused by the use of mechanical equipment in the field. Figure 1.4 illustrates the changes that occur in the soil when compaction occurs. The illustration shows soil particles in an uncompacted soil (left). In this instance porosity of the soil is 48% of the total soil volume. When an external force such as a tractor tyre applies a downward force on the soil (right), the bulk density increases because the soil particles are squeezed closer together, i.e. the same mass of soil now fits into a smaller volume. In addition, the soil with the higher bulk density now has reduced pore space (porosity is reduced to 10%). Decreased porosity can have a number of consequences (see list above).

Compaction can occur near the soil surface or in deeper layers of the soil. Surface compaction is undesirable because it reduces water infiltration, increases water runoff and soil erosion which exports valuable topsoil and nutrients off the land. Furthermore, a compacted surface restricts seedling emergence, and soil aeration is poor, especially during wet periods. The development of a crust at the surface is a special type of surface compaction which has similar negative effects to those described above. This is caused by raindrops detaching soil particles, washing them into pores and causing soil pore blockages. Crusting occurs mainly in soils with low organic matter content, and these soils should therefore always be protected against crusting by making use of a surface layer of mulch.

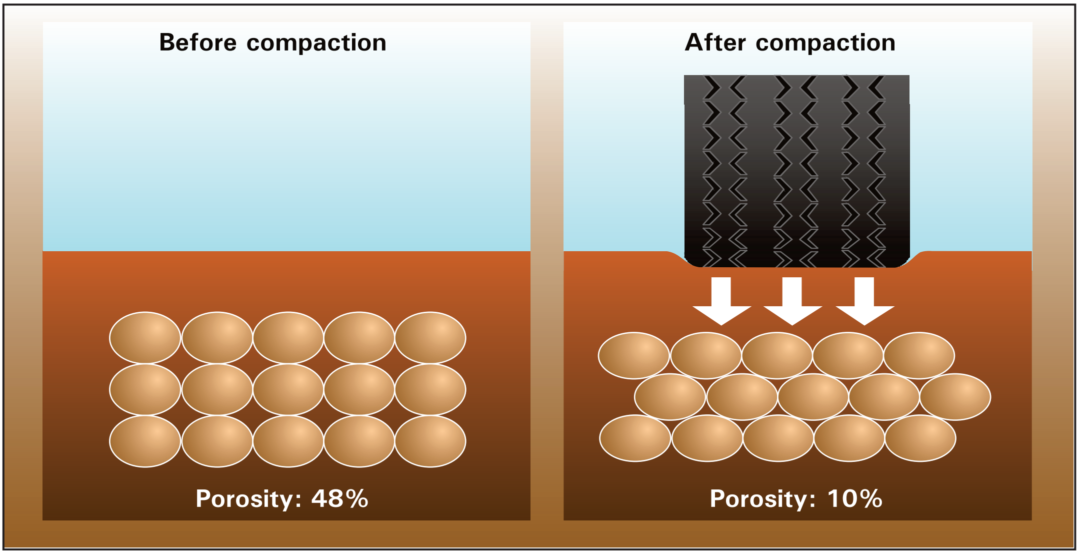


Figure 1.4. Arrangement of soil particles before and after compaction.

Compaction in the deeper soil layers is often referred to as a plough pan and is caused by the smearing action of a plough or the back wheel of a tractor running in the plough furrow during field preparation for planting. This has all the negative impacts mentioned earlier and reduces rooting depth and therefore plant water and nutrient availability (see Chapter 2).

Soils vary in their inherent bulk densities and typical values for uncompacted soils range from 0.9 (clayey soils) to 1.5 ton/m^3 (sandy soils), whereas compacted soils would have values ranging from about 1.4 (clayey soils) to 2.0 ton/m^3 (sandy soils), depending on the degree of compaction and soil type.

Measuring compaction and bulk density

Compaction is usually detected either by the resistance on a probe being pushed into the soil or measuring the bulk density of the soil. The resistance force is measured most accurately using a penetrometer which can be hand or machine operated, preferably when the soil water content is near field capacity. A more practical method to measure compaction is to push a sharp rod (5 mm stainless steel and 600 mm long) into the soil surface and take note of the depth of any change in resistance.

Bulk density measurements can be made in a number of different ways. Although taking an undisturbed core is the most popular method, other volumetric techniques or a nuclear density gauge can also be used.

Reducing infield compaction

Infield compaction is unavoidable as vehicles have to enter fields to extract cane. However, with careful planning, soil compaction can be confined to the interrow with the area used to grow sugarcane left uncompacted. This

Figure 1.5. A computer driven penetrometer used to detect the severity and depth of compacted layers in soil.

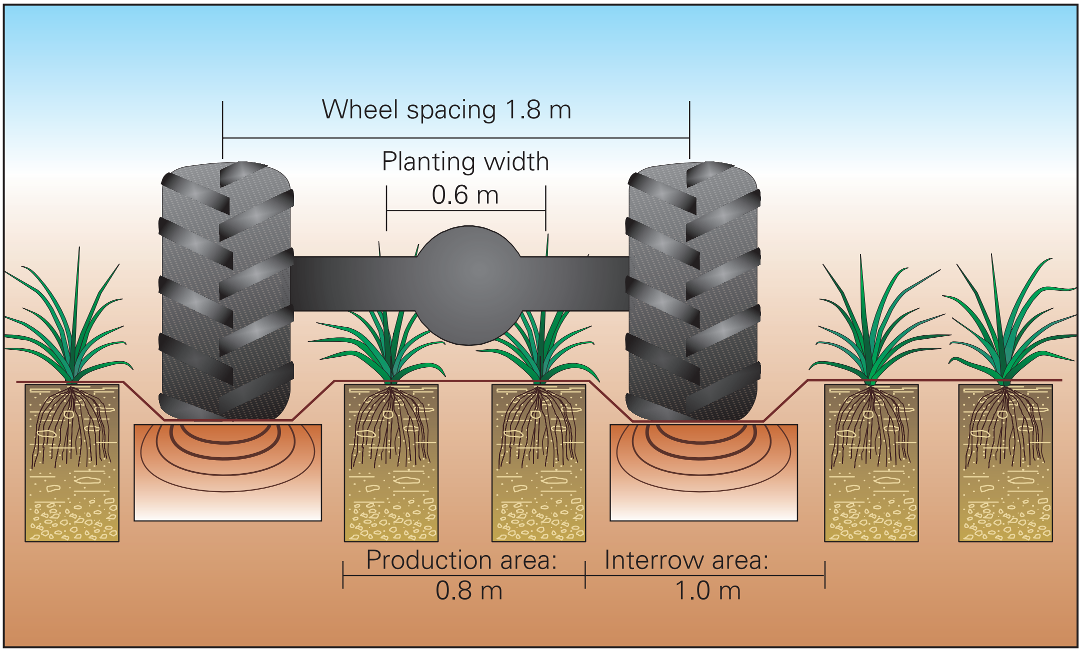


Figure 1.6. Sugarcane row spacing adapted to keep the wheels away from the crop.

means that field layouts should be planned around the wheel spacing of equipment with the aim that wheels should stay in the interrow and not drive over the crop (causing stool damage and the resultant yield loss). Thus, only the interrow area is compacted, and this will which have a negligible effect on crop yield (see Figure 1.6).

The same infield tracks should be used many times rather than creating new tracks. The first trip over the soil causes the most damage and subsequent trips are relatively much less damaging.

As far as possible, harvesting should take place under dry conditions. Wet soils compact more easily than dry soils which have a larger resistance to compaction. For example, grey sandy loams overlying impervious subsoil horizons (e.g. Longlands, Kroonstad and Katspruit forms, poorly drained) are more prone to compaction problems than red (e.g. Shortlands form, well drained) or black soils (e.g. Arcadia form, swell and shrink properties) due to their fine sandy nature and low organic matter content. To minimise the compaction hazard on susceptible soils, therefore, harvesting should preferably be carried out during the drier winter months.

Soil depth

The depth to which crop roots are able to explore the soil is very important as this will influence the amount of water and nutrients the crop has access to. Sugarcane has the potential to produce very deep root systems, reaching depths of more than 3 m (Figure 1.7, left). The rooting depth can be restricted by unfavourable physical conditions such as a shallow soil (hard rock close to the surface) or a highly compacted subsurface layer that is too hard to penetrate (Figure 1.7, right). Depth can also be restricted by a high soil water table or by unfavourable chemical conditions (such as very low pH and aluminium toxicity; see Chapter 6).

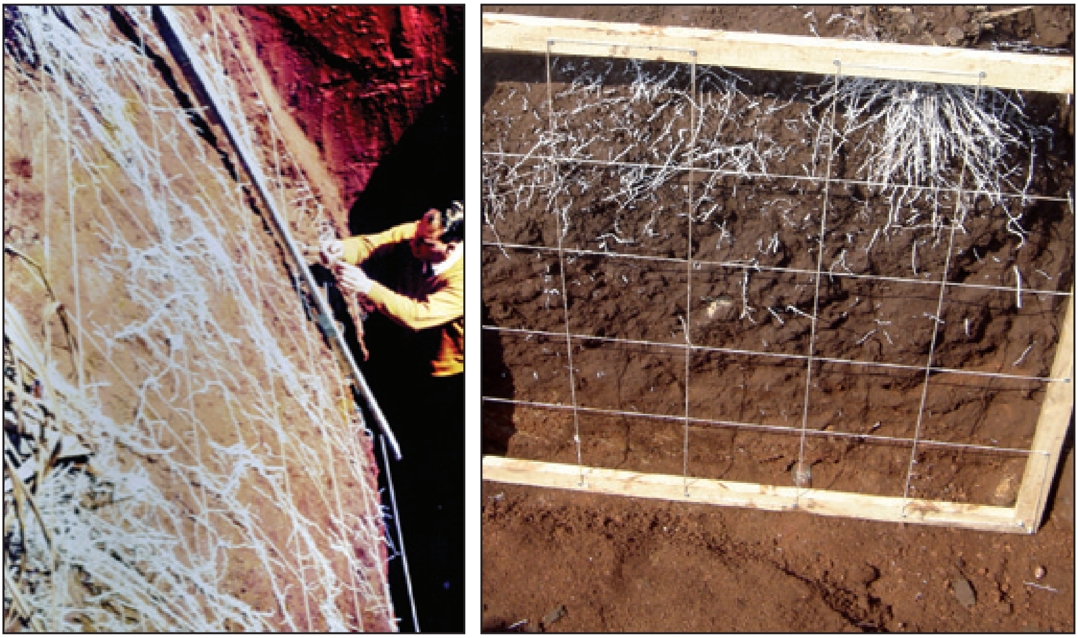


Figure 1.7. Distribution of sugarcane roots to a depth of 4 m in a red loamy sand (left) and roots restricted largely to the top 0.4 m in a red sandy clay loam (right).

SUMMARY

Soil physical properties have an effect on root and crop growth and therefore must be taken into account when implementing management practices. For example:

- Soil colour is a clue to its history and how it should be managed to obtain optimal yields.
- Texture affects most soil properties and has to be taken into account when planning activities such as fertilisation, irrigation and weed control.
- Soils structure has an impact on water infiltration and root distribution and should be accounted for in management strategies.
- Soils should be managed to sustain low bulk densities that are not detrimental to crop growth. Keep soil properties favourable for high water infiltration rates, water and nutrient storage capacities, gas exchange rates, low thermal conductance (to keep the soil cool) and maximum rooting depth.

FURTHER READING

Brady NC and Weil RR (2008). *The Nature and Properties of Soils*. 14th ed. Pearson Prentice Hall, New Jersey, USA.

Chapter 2

SOIL WATER RELATIONSHIPS

Soil Water Relationships

Water is an extremely valuable resource in sugarcane production and is often an important yield-limiting factor. Sugarcane is grown in the sub-humid to arid eastern parts of southern Africa. More than 80% of sugarcane is irrigated in countries such as Swaziland, Zimbabwe, Malawi, Mozambique and Tanzania, while in South Africa only 25% is irrigated. Thus, most of the South African industry is reliant on rainfall for production. In this chapter, important concepts to determine the water holding characteristics of a soil and management techniques to optimise soil water availability to the crop are discussed.

Figure 2.1. Irrigation systems should be carefully designed so that application rates do not exceed the final infiltration rate of a specific soil.

The soil water balance

As with a bank account, the amount of water in a soil can be monitored by keeping track of any gains and losses that occur (Figure 2.2). Water is added to the soil via irrigation and rainfall. Ideally, most of this water is taken up by the crop roots and transpired during biomass production. Unwanted losses include soil evaporation, wind drift, runoff and deep drainage, all of which should be minimised as far as possible to make best use of the available water.

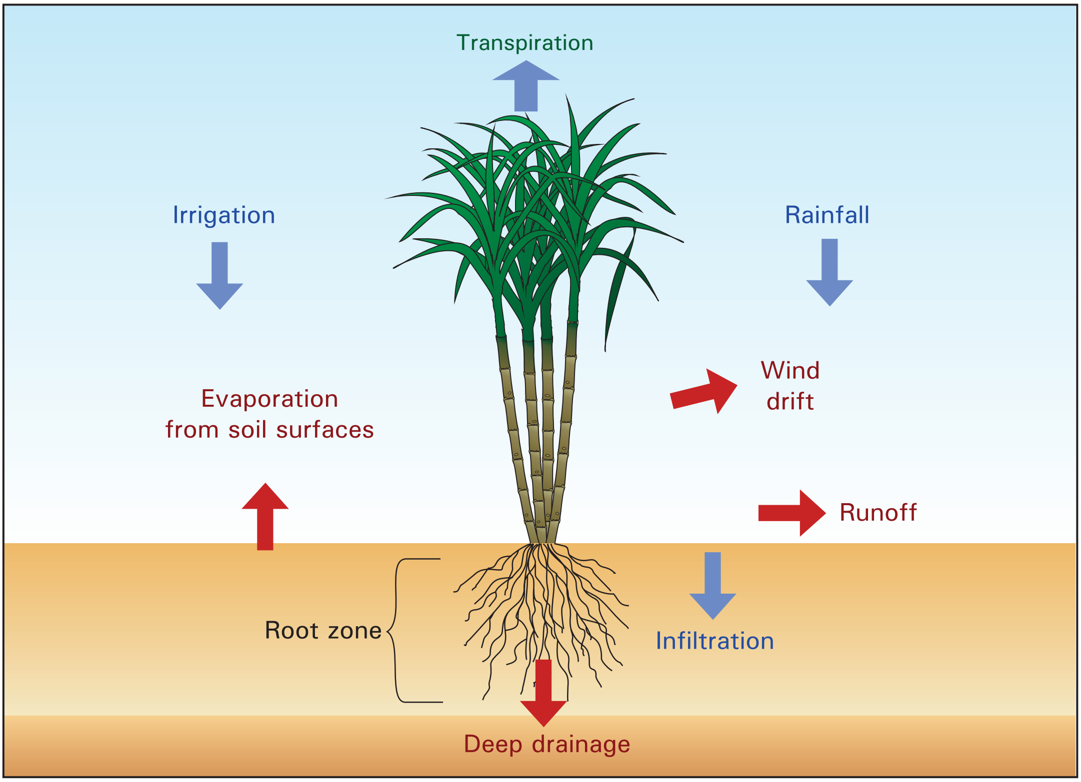


Figure 2.2. The soil water balance for a sugarcane crop.

Water holding capacity

Water holding capacity refers to the maximum amount of water a particular soil can hold within a specified depth (usually 1 metre). Water is held in the pores between soil particles. The forces of attraction between soil particles and water molecules keep the water from being lost through drainage. The strength of this force declines rapidly as distance from the soil particle increases. Water is therefore held less tightly at the centre of the pore than on the surface of the soil particle. As a result, the first water to be taken up by the plant comes from the centre of large pores. Water in small pores and closer to soil particles requires more energy for removal and is the last to be utilised by the plant. Pore size and the related water holding capacity of a soil are determined largely by clay content (see Box 2.1) and the bulk density of the soil. To a lesser extent, the organic matter content also influences how much water a soil can hold.

Box 2.1

Clayey soils tend to have smaller pores but a higher total pore volume compared to sandier soils. Therefore clayey soils have more pore space to store water.

However, at very high clay contents, the soil particles are so close to each other that they exert a very strong attractive force on the water in the pores. A high fraction of soil water is therefore unavailable to the plant in soils with a high clay content.

Soil water content

The soil water content levels which are important to farmers are shown in Figure 2.3 and discussed thereafter.

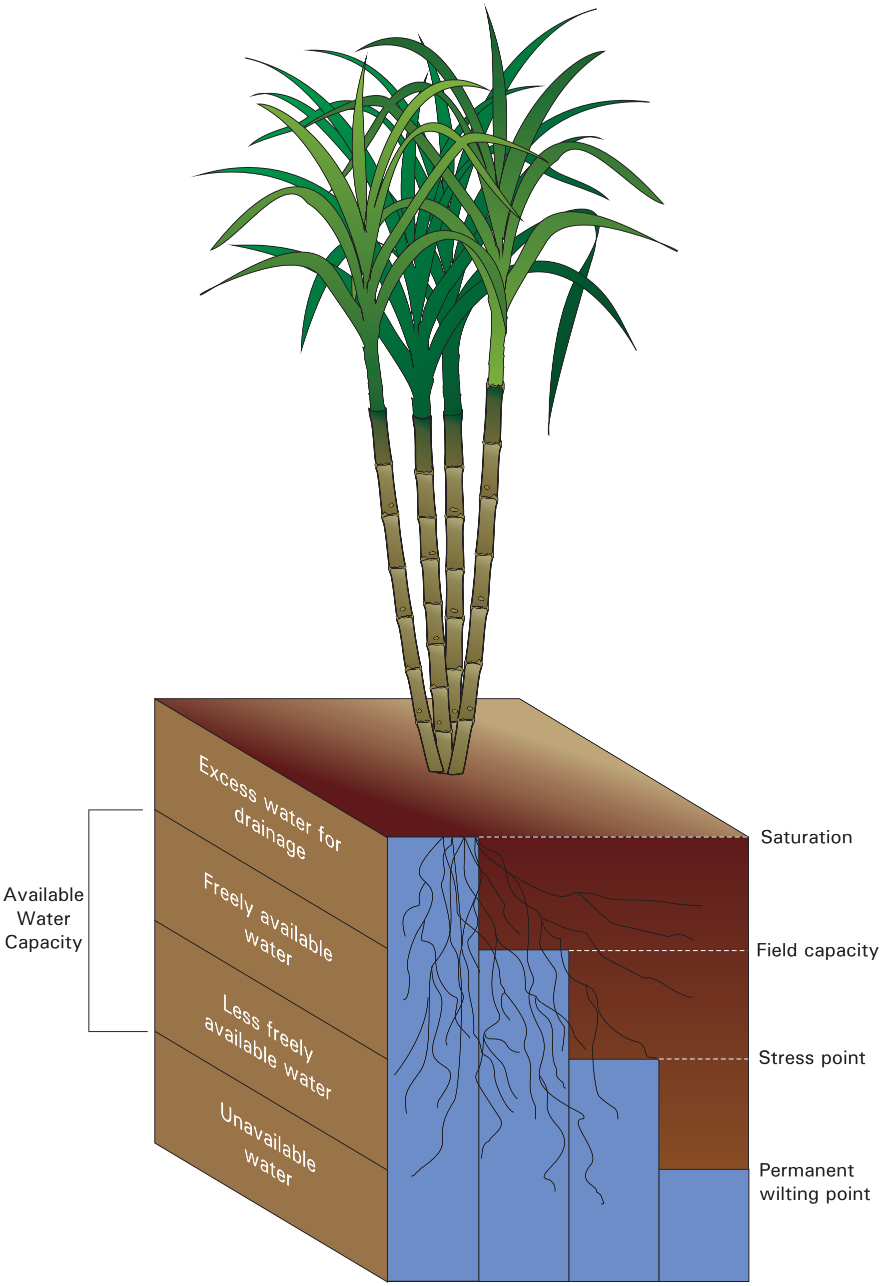


Figure 2.3. Four limits of laboratory-determined soil water content and the relationships between them.

Saturation (SAT)

This is the soil water content at which all soil pores are completely filled with water, i.e. there is no air present in the pores. This is undesirable, as plants need to take up oxygen through their roots. Under saturated conditions photosynthesis is reduced and most crops will die if they are exposed to these conditions for too long. Furthermore, saturated conditions may result in high runoff due to lowered infiltration rates.

Field capacity (FC)

Under very wet conditions, when the soil is saturated, water in the soil pores drains from the soil as a result of gravity and allows small amounts of air to enter and occupy some of the larger pores. Eventually this free drainage will cease at the point when the forces of attraction between the soil particles and water molecules are stronger than gravity and it is said that field capacity has been reached. Field capacity is thus the maximum amount of water a soil can hold against the gravitational force of the earth.

Stress point (SP)

As the soil profile continues to dry, the water content will eventually reach a point where the plant is unable to take up adequate water to satisfy the atmosphere's demand and will enter a state of stress. This point is normally first noticed under extreme conditions (e.g. high temperatures and strong winds) and will result in a short period of water stress during the hottest part of the day. At this point, soil water content has reached stress point. At soil water content levels above this point, water is freely available and uptake by the plant is determined by atmospheric demand; below this point, transpiration rate is governed largely by the rate of soil water flow to the roots as affected by inherent soil properties.

Permanent wilting point (PWP)

When soil water is depleted beyond the stress point, a condition will eventually be reached where the plant can no longer extract any water from the soil at any time of the day. At this point, soil water content has reached permanent wilting point. The plant will die if water is not applied immediately. Green plants which remain wilted at dawn indicate that permanent wilting point has been reached. Although the soil still contains some water at permanent wilting point, it is held as a thin film covering and held by particles at a force far greater than that exerted by the plant roots. This unavailable source of water is referred to as hygroscopic water.

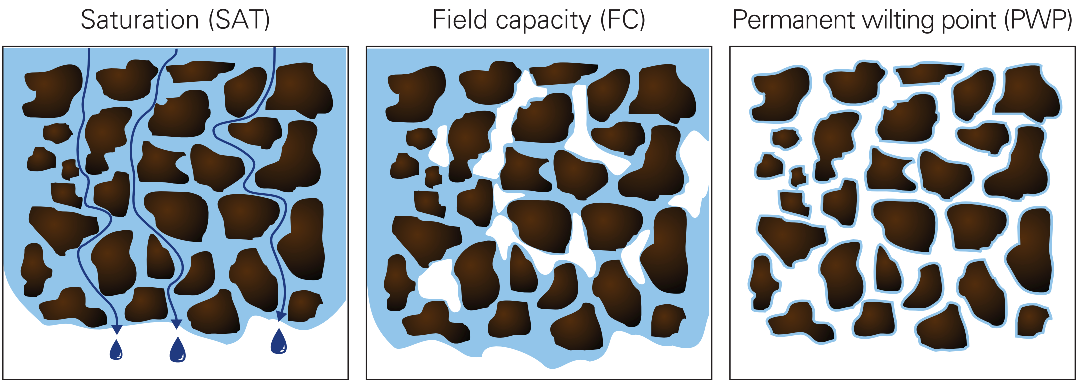


Figure 2.4. Three levels of soil water content[1].

Available water capacity (AWC)

This is the amount of water contained in the soil between field capacity and permanent wilting point and represents the amount of soil water available for crop uptake. This quantity of soil water is expressed per unit of soil depth (normally per metre depth) (see Table 2.1). This information can be obtained from soil sample laboratory results which include field capacity, permanent wilting point and available water capacity estimates.

Table 2.1. Typical available water capacity ranges based on clay content.

Clay content (%)	AWC range (mm/m)
< 7	< 80
7 to 15	81 to 100
16 to 35	101 to 140
36 to 55	141 to 180
> 55	< 180*

*see Box 2.1

Total available water (TAW)

As soils differ in depth and therefore their ability to store water, effective rooting depth is taken into account to convert available water capacity to total available water (see Table 2.2). Knowledge of the total amount of water a soil can hold is especially important in irrigation management. Total available water can be calculated on the farm using available water capacity provided the effective rooting depth (ERD) of a field is known (see Box 2.2).

The effective rooting depth represents the soil depth in which 85 to 90% of all plant roots are found. For sugarcane, a good estimate of effective rooting depth for deep sandy soils is 1.2 m, and 0.9 m for soils with high clay content (> 40% clay) (see Box 2.3). If an obstruction occurs within this depth then effective rooting depth is reduced to

Box 2.3

Sandy soils have a low water and nutrient storage capacity compared to clayey soils. This means that the roots have to explore a greater soil volume (and therefore depth) to take up sufficient amounts of water and nutrients.

Box 2.2

Example: Your soil samples have been submitted to a laboratory for water retention determination; these are the results:

Field Capacity (FC) = 27.6%

Permanent Wilting Point (PWP) = 14.3%

To calculate Available Water Capacity (AWC):

AWC = FC – PWP = 27.6% – 14.3% = 13.3%

Conversion: 13.3% x (1000 mm/m / 100%) = 133 mm/m

To calculate Total Available Water (TAW):

Effective Rooting Depth (ERD) = 0.8 m (measured in field)

TAW = AWC x ERD = 133 mm/m x 0.8 m = 103 mm

Table 2.2. Typical total available water (TAW), effective rooting depth (ERD) and available water capacity (AWC) values for soil forms commonly found in the South African sugar industry.

Soil forms	Texture	AWC (mm/m)	ERD (m)	TAW (mm)
Hutton	Sandy clay loam	± 140	1200	± 168
Shortlands	Clay	± 120	1200	± 144
Arcadia	Clay	± 140	900	± 126
Rensburg	Clay	± 140	600	± 84
Bonheim	Clay	± 130	900	± 117
Kroonstad	Sandy loam	± 120	600	± 72
Longlands	Sandy loam	± 120	600	± 72
Fernwood	Sand	± 80	1200	± 96
Glenrosa	Loamy sand	± 100	600	± 60
Estcourt	Sandy loam/clay	± 120	600	± 72

Caution: Table 2.2 illustrates examples only; for the calculation of total available water, see Box 2.2.

the depth of the obstruction. The obstruction may be due to physical factors (for example, hard rock or a compacted layer, a water table or a sudden increase or decrease in clay content) or a chemical factor (such as the presence of aluminium toxicity in acid soils or salinity in alkaline soils). Typical total available water values for common South African soil forms are shown in Table 2.2.

Infiltration

Infiltration refers to the movement of water into the soil from the surface. The rate at which water infiltrates the soil surface is an inherent property of that soil and needs to be taken into account in the design of a new irrigation system. It is related to:

- internal properties, which include texture (Figure 2.5) and layering within the profile
- initial wetness
- surface cover, and
- biological factors, in particular channels created by earthworms (see Chapter 4) and roots.

Internal soil properties

- *Texture:* This property generally plays the most important role in influencing infiltration rates through determining the maximum flow rate of the soil. As a result, sandier soils have much higher infiltration rates than clayey soils (Figure 2.5).

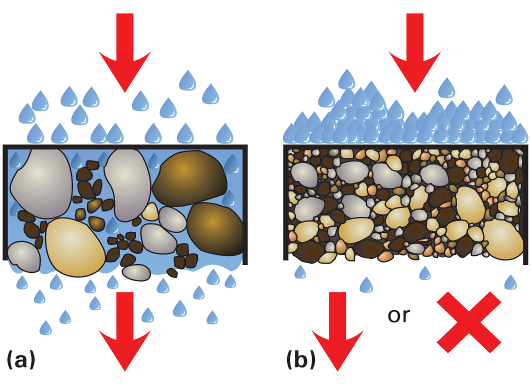


Figure 2.5. Water infiltration affected by texture in a sandy soil (a) and a clayey soil (b)(2).

- *Layering:* A uniform soil profile will have very much the same internal soil water flow rate throughout and is therefore more conducive to uninterrupted water flow in the profile. Conversely, duplex soils usually have fairly sandy topsoils overlying a high clay content layer which is less permeable and causes, after quick initial infiltration, a sudden decrease as water reaches this layer.

- *Biological influences:* Biological systems (tree roots and insects) have the capacity to create large channels (> 2 mm in diameter) which act as passages to carry large amounts of water more quickly into deeper subsoil layers.

Initial wetness

Infiltration rate is a function of soil water content, with highest infiltration occurring at the lowest soil water content and *vice versa*. The infiltration rate into a dry soil decreases with time until it reaches a constant minimum infiltration rate which is termed final infiltration rate (Figure 2.6). As infiltration decreases, runoff increases if the application rate is kept constant. The direct result of runoff is soil erosion and nutrient loss. Irrigation systems should therefore be carefully designed so that application rates do not exceed the final infiltration rate of a specific soil.

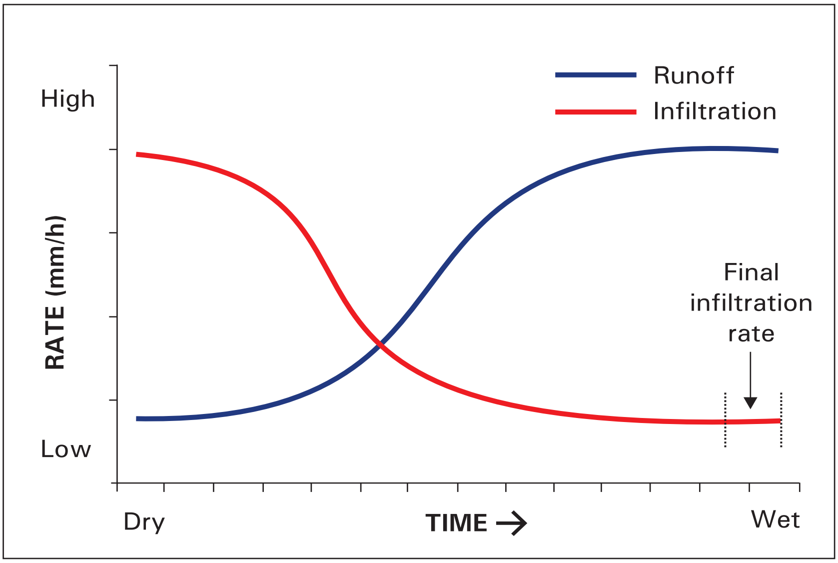


Figure 2.6. Variable infiltration rate with time.

Surface cover

Surface cover plays a very important role in infiltration. When water droplets from rain or overhead irrigation fall onto bare ground the structural units are broken down into a thin compacted layer (crust) through which water moves very slowly (Figures 2.9 and 2.10). With, for example, a trash blanket, this particle displacement is prevented as the trash absorbs the shock of the droplets. A cover crop or a canopied crop also acts as an excellent surface cover.

Soil water flow

Soil water flow (or conductivity) refers to the rate at which water flows through soil. Once water has entered the soil surface (infiltration), redistribution may be vertical or horizontal.

Factors affecting soil water flow rates

- *Soil texture:* Sands generally have high (fast) water flow rates whereas clays have lower rates. The range of water flow rates as affected by soil texture is shown in Table 2.3.

- *Pore size:* Soil water flow rates are very sensitive to changes in pore size distribu-

Table 2.3. Typical water infiltration and flow rate values for a range of soil textural groups.

Soil textural group	Infiltration/flow rate (mm/h)	Rating
Coarse sand	>15	Rapid
Sandy loam	15 - 10	Moderate
Fine sandy loam	10 - 5	Slow
Clay	<5	Very slow

tion. For this reason, any increase in the size of pores (i.e. channels left by decaying roots, earthworms and termite activity) may increase internal water flow rates by several orders of magnitude. Conversely, any deterioration in pore size distribution such as by compaction, dispersion or swelling of clay can have an adverse effect on flow rates.

Deep drainage

This is important in soils since it represents the loss of valuable water from the root zone, but is also essential in providing pore space for root aeration following saturated conditions. Soils which are poorly drained are often permanently wet and difficult to till, and plant growth is stunted as a result of poor aeration and lack of nutrient uptake.

Figure 2.7. Waterlogging can be reduced by the installation of artificial drainage systems.

In addition, salts may tend to accumulate due to the application of irrigation water containing salts. Drainage should therefore be timed to get rid of excess salts, while taking care to prevent the loss of valuable nutrients.

Soil water can also move vertically upwards when soil layers above are drier, and this is known as capillary flow. Soil texture is an important factor determining the extent of capillary flow, which is higher in clayey soils.

Artificial drainage

When the natural drainage of a soil limits profitable crop production, artificial drainage systems can be installed to reduce waterlogging – provided the area is not classified as a wetland. In such systems, drain spacing will be markedly dependent upon internal soil water flow rates. Soils with a low internal flow rate will need a close drain spacing (i.e. 10 - 15 metres). Such a drainage system will be expensive and possibly uneconomical.

Soil erosion

Soil erosion by water involves the detachment of soil particles by raindrop impact followed by transportation. By removing the most fertile topsoil (see Figure 2.8), erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of productive land. Even in deep soils, loss of the topsoil is often not conspicuous but is nevertheless potentially very damaging. Severe erosion is commonly associated with the development of temporary or permanently eroded channels or gullies that can fragment land. Runoff is the most important direct driver of soil erosion.

Losses of 20 - 40 tons/ha in individual storms may happen once every two or three years and losses of more than 100 tons/ha have been measured in extreme events. With a very slow rate of soil formation, any soil loss of more than 1 ton/ha/yr can be considered irreversible within a time span of 50 - 100 years. The main causes of soil erosion are:

- inappropriate agricultural practices (ploughing downhill, bare surfaces, crusts, compaction)
- deforestation, bare soil surfaces (especially on slopes)
- overgrazing
- fires, and
- construction activities.

Figure 2.8. Soil erosion from an unprotected surface.

Causes of soil erosion on agricultural lands

- *Lack of organic matter:* Organic matter is an important building block of soil structure. If it is depleted or lacking, soil particles are easily detached and can block soil pores which are essential for water infiltration.
- *Impact of water droplets:* Water droplets from rainfall or irrigation fall at about 50 km/h. The impact of the raindrop breaks soil aggregates apart, separating individual sand, silt and clay particles. These particles fill the soil pores (forming a crust) and reduce infiltration (Figures 2.9 and 2.10). Once the rainfall/irrigation rate is faster than infiltration, runoff takes place, eventually leading to soil erosion.
- *Over-irrigation:* Irrigation volumes in excess of the water holding capacity of the soil and irrigation rates above the natural infiltration rate of the soil can lead to increased runoff and erosion.
- *Unprotected soil surface:* An unprotected surface of vulnerable/sensitive soils (sandy soils and soils with low organic matter content) can lead to crust development, leading to reduced infiltration and increased erosion.
- *Cultivation of shallow soils:* Soils shallower than 400 mm should not be cultivated due to the high runoff probability and limited water retention capacity.
- *Cultivation of steep slopes:* Significantly higher erosion rates are likely on slopes steeper than 12%.

Problems caused by soil erosion in agricultural soils

- *Loss of valuable topsoil:* In agriculture topsoil is considered to be ten times more valuable than the subsoil. When soil is removed from a field it includes not only the soil particles, but also nutrients and soil organic matter.

- Reduction in soil quality due to *deposition of less valuable soil* from up-slope onto more valuable soil in valleys.
- Reduction of field size when *gully erosion* reduces arable land surface area.
- *Non-point source pollution of streams and surface water bodies:* Types of non-point source pollution include sediment, nutrients, salts and pesticides.

Erosion causes a slow but steady, non-linear *productivity decline*. For example: if 5 cm soil is lost it could result in a 5 - 15% decline in productivity, but if 10 cm soil is lost the decline in productivity is likely to be 10 - 35%.

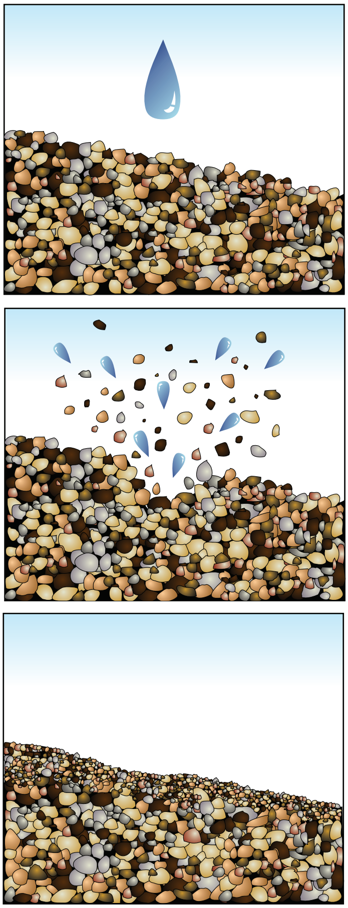


Figure 2.9. Crusting caused by water droplets.

Recommendations for preventing soil erosion

- Ensure that the surface is covered at all times (especially on slopes).
- Ensure that properly constructed contours are in place. The slope should not be more than 1 m over a distance of 150 m.
- Do not plough up and down hills – follow the contours.
- Ensure that properly constructed waterways are in place.
- All soils on slopes steeper than 12% should have contours to guide surface water to waterways and should be surface protected (grass in waterways and trash or tops covering fields) to prevent the formation of crusts and reduce the speed of runoff water. Effective conservation of wetlands and watercourses ensures that water sources are maintained and soil erosion is minimised. For example, a well-conserved wetland acts like a sponge, slowing water flow during heavy rainfall (thereby reducing downstream erosion) and releasing water slowly for a more constant supply.
- Schedule irrigation to ensure over-irrigation does not take place. Never allow the irrigation application rate to exceed the soil's infiltration rate.

Figure 2.10. Surface crust.

- Practise minimum tillage (i.e. disturb the soil as little as possible and plough or rip only when it is really necessary). Minimum tillage should be practised on all slopes greater than those listed below:
  - Slopes > 10% on erodible soils, i.e. shallow soils with a sandy topsoil layer;
  - Slopes > 13% on moderately erodible soils, i.e. deep soils with a sandy topsoil layer;
  - Slopes > 16% on resistant soils, i.e. soils with a high clay content.
- Harvest alternate fields on a hill.

SUMMARY

- Water is an extremely valuable resource in sugarcane production and is often an important yield-limiting factor. Unwanted losses of water occur through soil evaporation, runoff, deep drainage and wind drift, all of which should be minimised as much as possible to make best use of the available water.
- Soil Water Content is an important concept for farmers. It describes the degree to which water in the soil is available to plants, and is related to the concepts of Saturation, Field Capacity, Stress Point and Permanent Wilting Point.
- Soils differ in depth and texture and therefore their ability to store water. Effective rooting depth is taken into account to determine total available water for crop uptake. Knowledge of the total amount of water a soil can hold is especially important in irrigation management.
- The rate at which water infiltrates the soil surface is an inherent property of that soil and needs to be taken into account in the design of a new irrigation system. It is related to structure and variations in texture within the profile, initial wetness, surface cover and biological factors, in particular channels created by earthworms and roots.
- Erosion caused by runoff water can lead to significant soil degradation, soil productivity loss and, where soils are shallow, may lead to an irreversible loss of natural farmland. Erosion is exacerbated by lack of organic matter, over-irrigation, unprotected soil surfaces, cultivation of shallow soils and cultivation of steep slopes.

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Chapter 3

SOIL CHEMISTRY

Soil Chemistry

Soil chemistry concerns the chemical reactions that occur at the interface between soil particles and the soil solution (water) surrounding these particles. These reactions have a profound influence on nutrient availability to growing plants and, furthermore, influence soil biological and physical properties. The purpose of this chapter is to provide a brief overview of important chemical reactions and processes in soils, with emphasis on plant nutrition.

Composition of soils

Soil consists of finely weathered rock material and larger rock fragments, water, air spaces, plant nutrients and organic matter, together with a living component of bacteria, fungi, algae and higher forms of plant and animal life. The typical composition of a healthy soil on a volume basis is shown in Figure 3.1.

Solid materials in the soil comprise about 50% of the volume. The spaces between the solid particles are called pores; typically, water fills the smaller pores, while the larger pores contain air. The solid portion comprises both *inorganic material* and *organic matter*. The inorganic material consists of sand, silt and clay particles.

The clay and organic matter portions of the soil are of great importance in terms of soil function. They have a major effect on pore size distribution, and thereby on aeration and water storage and movement. In addition, clay and organic matter play a critical role in retaining nutrients in the soil and regulating their availability for plant uptake. The nature and function of organic matter in soils are dealt with in detail in Chapter 5.

Soil water is more accurately called *soil solution* because inorganic and organic chemical constituents are dissolved in the water.

Box 3.1. Organic matter and inorganic material

Organic matter comprises carbon-containing compounds and molecules that have their origin in living matter.

Inorganic material is composed mainly of elements other than carbon.

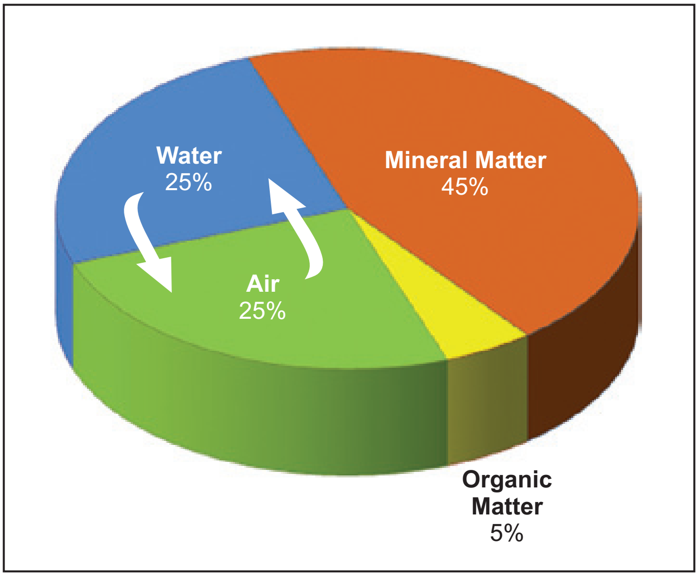


Figure 3.1. Composition of a typical healthy soil on a volume basis.

In addition to being the source of water for plant growth, the soil solution acts as the source of almost all nutrients taken up by plant roots (small amounts of certain nutrients can be absorbed through the leaves of plants). Plant roots are only able to absorb nutrients that are dissolved in the soil solution. Since the concentration of nutrients in the soil solution at any one time is low relative to overall plant requirements, nutrients in the soil solution must be constantly replenished from reserves residing on and in solid particles (clays and organic matter).

Cation exchange capacity

Clay particles carry negative and sometimes, at low pH, small amounts of positive charge. The negative charge on clay particles holds those nutrients that are positively charged (i.e. cations; see Box 3.2 and Table 3.1). The total of negative charges per mass of soil is termed the *cation exchange capacity* (CEC). Sand and silt particles carry little or no charge, and are therefore referred to as being 'chemically inactive'.

Organic matter in soils also carries a negative charge and it may contribute significantly to the overall soil CEC. *This means that total soil CEC is the sum of the CEC of the clays and the CEC of the organic matter*. In soils with a medium to high clay content, the bulk of the CEC resides on the clays. However, in sandy

Box 3.2. Cations and anions

A normal atom or molecule has an equal number of protons and electrons; thus, charges balance and the net charge is zero. However, when a shortage or excess of electrons occurs, the atoms or molecules carry a net charge and are called *ions*.

Examples are the positively charged potassium ion (K^+), or the negatively charged nitrate ion (NO_3^-). Positively charged ions are called *cations*, and negatively charged ions, *anions*. The number of un-neutralised charges (+ or -) associated with the ionic form of an element is called its *valency* state. Thus K^+ has a valency of 1, whereas Ca^{2+} has a valency of 2.

Table 3.1. Cations and anions of importance in the management of soil fertility.

Cations		Anions or neutral molecules	
Nutrient or element	**Chemical symbol**	**Nutrient or element**	**Chemical symbol**
Calcium	Ca^{2+}	Nitrogen	NO_3^- (nitrate)
Magnesium	Mg^{2+}	Phosphorus	$H_2PO_4^-$, HPO_4^{2-} (phosphate)
Potassium	K^+	Sulphur	SO_4^{2-} (sulphate)
Sodium	Na^+	Silicate	SiO_3^{2-} (silicate)
Aluminium	Al^{3+}	Molybdenum	MoO_4^{2-} (molybdate)
Hydrogen	H^+	Boron	H_3BO_3 (boric acid)
Zinc	Zn^{2+}	Chlorine	Cl^- (chloride)
Copper	Cu^{2+}		
Manganese	Mn^{2+}		
Iron	Fe^{2+}		
Nitrogen	NH_4^+ (ammonium)		

soils with little clay, organic matter may account for much of the CEC.

CEC is thus a measure of the total quantity of negative charges per unit weight (or volume) of soil. It is commonly expressed in units of milli-equivalents per 100 g of soil (meq/100 g), or in centimoles per kg or per litre of soil (cmol(+)/kg or cmol(+)/L). The magnitude of the CEC is determined largely by the amount and type of clay and the organic matter content of the soil. It can vary widely in soils, but generally lies in the range of 3 - 35 cmol(+)/kg.

Important clay types found in soils and their typical CECs are listed in Table 3.2. Two of the most common clays are kaolinite and montmorillonite. Kaolinite is found in red or reddish-brown soils (ferralitic soils) which have developed over long periods of time in relatively moist environments. Montmorillonite occurs in grey to black, heavy clay soils (vertisols). In many soil types the clay fraction does not comprise a single dominant clay type, but is a mixture of a range of clays.

There are two practical ways of increasing CEC, and thereby the ability of the soil to hold nutrient cations, such as Ca^{2+}, Mg^{2+}, K^+ and NH_4^+:

1. Through regular additions of organic matter (green manures, animal manures, filtercake, compost, trash, biochar). Sandy soils, in particular, tend to benefit enormously from organic matter additions, which improve both CEC and water retention.

2. Liming of acid soils increases CEC. This is an important benefit of liming and is due to the fact that, as H^+ on organic matter and clays is neutralised by lime, the negative charge on the surfaces of the organic

Figure 3.2. The amount and type of clay and the organic matter content of a soil determines the CEC of that soil.

Table 3.2. Typical cation exchange capacities of clays and organic matter.

Clay / Organic matter	Cation exchange capacity (cmol(+)/kg product)
Organic matter	200 - 400
Vermiculite	100 - 150
Montmorillonite	80 - 150
Illite (Mica)	20 - 40
Chlorite	10 - 40
Kaolinite	3 - 15
Hydrous oxides of iron and aluminium	0 - 6

matter and clay is increased. In the case of organic matter it has been found that the CEC will typically increase from around 100 cmol(+)/kg at pH 4 to 200 cmol(+)/kg at pH 7.

Exchangeable ions

Clays and soil organic matter have vast surface areas per unit weight. This, combined with their negative charge characteristics, allow clay and organic matter particles to function as a chemical reservoir for plant nutrients. Important plant nutrient cations and anions are listed in Table 3.1.

Cations

The negative charge on clays and organic matter (CEC) must be satisfied by an equal number of positive charges. This is accomplished by cations in the soil solution being attracted to the negatively charged surfaces. In this way the CEC is in a sense a measure of the soil's nutrient storehouse: nutrient cations are *adsorbed* (held by electrostatic forces) by the negative charge of the CEC and released when necessary to the soil solution, from which the roots are able to absorb them (Figure 3.3). In general, the higher a soil's CEC, the greater its capacity to meet plant nutritional needs without frequent fertiliser additions.

Cations held in largest concentrations on the CEC are calcium, magnesium, potassium, sodium, ammonium, hydrogen and aluminium (the last two cations are present in significant amounts only in acidic soils – see Chapter 6). All these cations are termed 'exchangeable cations' since one cation held on the solid phase (clay or organic matter) may be exchanged with another cation in the soil solution. For example, when potassium fertiliser is applied to the soil, some of the K^+ will move onto the CEC in exchange for another cation which will move into the soil solution.

Direct measurement of CEC in the laboratory is a laborious and time-consuming procedure. However, the sum of the most relevant exchangeable cations Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+ and Al^{3+}, often referred to as the effective cation exchange capacity (ECEC), provides a reasonably reliable estimate of CEC, provided soils are not saline. In saline soils the dominant cations are mainly Na and Ca and they are not only connected to most of the negative charges in soil particles but the excess is also present in large quantities in the soil solution.

The major effect of clay content, clay type and organic matter content on the ECEC of soils is illustrated by the data for three KwaZulu-

Natal soils shown in Table 3.3. The Arcadia soil with a high content of montmorillonitic clay and organic matter has a large ECEC of 26.1 cmol(+)/kg. In contrast, the Inanda soil, which is also high in clay and organic matter, has a low ECEC value of 6.1 cmol(+)/kg. This is due to the clay fraction of this soil being dominated by kaolinite and oxides of iron and aluminium which carry little negative charge. The Cartref soil, with a mixture of clay types, has a very low ECEC due to low clay and organic matter content. An important question is how the ECECs of the Inanda and Cartref soils could be increased. In the case of the Inanda soil, the pH increase resulting from moderate lime applications will result in significant improvements in ECEC. In the Cartref soil, on the other hand, organic matter additions (compost, filtercake, manures) would be the most effective approach to address the low ECEC.

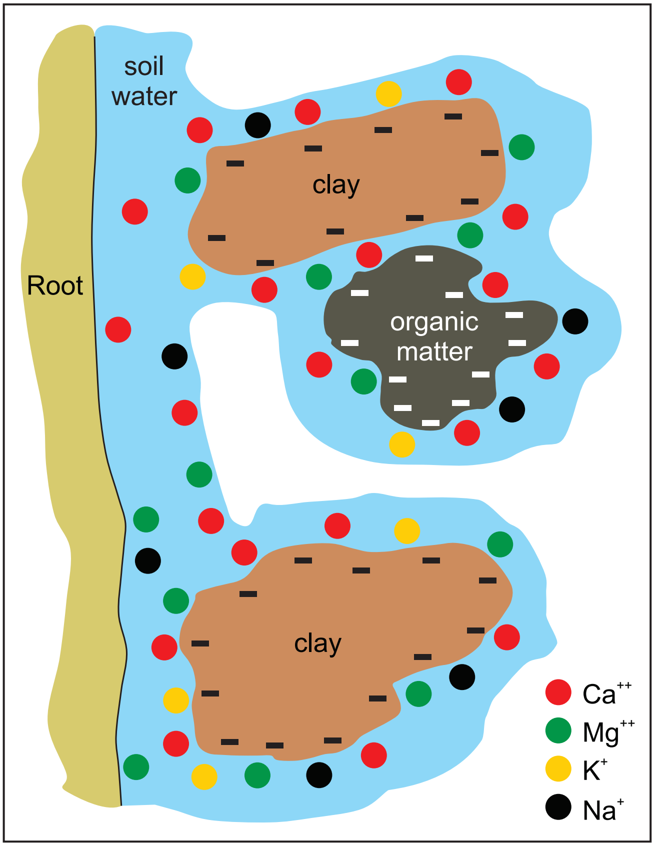


Figure 3.3. Illustration of the soil-root environment with cations held onto clays and organic matter.

Anions

The reactions of different anions in soils vary widely. In contrast to cations, most of the anions form chemical bonds with soil particles, while the reactions of nitrate and chloride with soil particles are mainly by electrostatic attraction or repulsion.

Anions forming chemical bonds with soil particles include phosphate, sulphate, silicate and molybdate. Phosphate and molybdate tend to bond very strongly to clay particles, particularly at low soil pH . Sulphate and silicate are held less tightly and, in sandy soils, may move relatively freely with the soil water. The strong tendency of phosphate to bond with clays reduces the plant-availability of phosphorus supplied in fertilisers. This process, commonly referred to as 'phosphorus fixation', is of considerable economic significance in crop production. High phosphorus-fixing soils require the application of phosphorus at rates well in excess of crop requirements to nullify fixation effects and ensure that sufficient phosphorus remains available for plant uptake. Phosphorus fixation increases with increasing clay content of soils, and is particularly marked in naturally acidic high clay soils.

Nitrate does not bond chemically to soil constituents, and being negatively charged, is repelled by the negative charge on clay and organic matter particles. As a result, nitrates move freely with soil water and, in times of heavy rainfall (or

Table 3.3. Effective cation exchange capacity (ECEC) of three KwaZulu-Natal sugarcane soils, showing the major role of clay content, clay type and organic matter content on ECEC.

	Soil form		
	Arcadia	**Inanda**	**Cartref**
Location	North Coast	Eston	Upper Inanda
Effective cation exchange capacity (cmol(+)/kg)	26.1	6.1	3.1
pH_{water}	7.31	5.01	5.23
Dominant clay type	Montmorillonite	Kaolinite and iron/ aluminium oxides	Mixed
Clay (%)	58	45	11
Organic matter (%)	5.1	5.6	2.1

where irrigation is excessive), nitrates may be lost from the rooting zone through leaching.

The subsoil of highly weathered soils may sometimes have a net positive charge (*anion exchange capacity*) resulting in some retention of nitrates in this zone by electrostatic attraction. Deep-rooted crops such as sugarcane are able to make use of nitrates held in this way in subsoils.

Soil water and nutrient uptake

Continuous availability of water to roots is essential for nutrient uptake. Water acts as a medium through which nutrients are transported to the root surface for uptake. Therefore, where water is limiting, crop growth may be restricted not only by moisture stress, but also by limited availability of nutrients. This has important implications for

Figure 3.4. Water transports nutrients to the root surface for uptake.

the topdressing of nutrients in the production of sugarcane and other crops. Topdressed nutrients such as phosphorus and potassium are essentially immobile in all but very sandy soils. Thus these nutrients are often retained in the top 20 - 40 mm of soil, and when this soil layer dries out, these nutrients are unavailable for uptake by the crop. On the other hand, excessive water in the soil is detrimental to plant growth. The resultant poor aeration leads to reduced root growth. In addition, waterlogging may lead to major losses of nutrients through leaching (particularly of nitrogen, potassium and sulphur) and nitrogen loss by denitrification.

SUMMARY

Chemical reactions and processes occurring in the soil have a significant influence on nutrient availability to growing plants.

- The cation exchange capacity (sum of negative charges) on clays and organic matter acts as an important ‘reservoir’ for plant nutrients.
- Wide variations in cation exchange capacities are encountered in soils depending on organic matter, clay type and clay content.
- The low cation exchange capacities of sandy and naturally acid soils imply poor cation retention, and therefore a need for more frequent additions of nutrients such as potassium.
- Soil clay content, type of clay and soil pH has a major bearing on phosphorus fixation and therefore long-term crop phosphorus requirements.
- Nutrient uptake by roots is through the medium of soil water. Thus, any limitation in water availability in the rooting zone will have a profound effect on the supply of nutrients to the crop.

Chapter 4

SOIL BIOLOGY

Soil Biology

The soil is a living system and thus vulnerable to changes. Not only does the soil produce food for almost all life forms on earth, it also provides a living space for millions of organisms, each with a defined role in the functioning of soils. In order to keep soils healthy and fertile, one must understand how to keep the complex living component in the soil diverse and alive.

Life forms in the soil

The soil ecosystem is tremendously diverse. A healthy soil contains a large number of different species. The best way to begin to understand this large and differentiated community is to group them according to their properties, nutrition and functions in the soil.

Soil organisms can be grouped into the following size categories: megafauna, macrofauna, mesofauna, microfauna and microflora (Table 4.1). Bacteria, fungi, algae and actinomycetes belong to the soil microflora. Together with the microfauna, they form the group of soil microorganisms (soil microbes), which are dominant in terms of number and function. Most of

Box 4.1. Life in the soil

Up to 5 tons of soil animals live in one hectare of soil. In fact, 1.5 times as many individual organisms can be found in a tablespoon of soil as there are people on earth.

Figure 4.1. A diverse range of life forms exist in a healthy soil.

the soil organisms are not visible to the naked eye and can only be seen using a microscope.

The role of soil organisms for various soil functions

Soils are able to fulfil the transformation and nutrient cycling function in our global ecosystem through the activities of soil organisms. This comprises the following processes:

Decomposition is the breakdown of plant and animal residue into different organic and inorganic compounds. Earthworms and arthropods begin the process by shredding these residues, thereby reducing the material to the right size for other decomposers. They also distribute the material in the soil thus making it available for other decomposers. Fungi and actinomycetes are able to degrade complex organic compounds, such as cellulose and lignin, whilst bacteria work more on the simple organic compounds such as sugars. Soil organisms decompose organic matter more quickly under warm, moist conditions than under cold or dry conditions.

Mineralisation refers to the conversion of decomposed organic matter into inorganic compounds (nutrients) that may be used by plants (e.g. protozoa and nematodes excrete excess nitrogen into the soil when they eat nitrogen rich bacteria and fungi). Plants primarily need simple inorganic forms of each nutrient. Soil organisms create many of these plant-available nutrients thereby enabling the soil to be the growth medium for the plants.

Nutrient cycling: Through the various processes described in Table 4.1, nutrients are cycled continuously through the soil ecosystem, and its soil organic matter (SOM) is able to store or release nutrients. Soil organic matter is made up of decomposed organic matter and living and dead soil micro-organisms. It is a big reservoir of carbon, nitrogen and other nutrients and influences almost all soil properties. Due to the formation of so-called clay humus complexes, the soil gets its crumbly structure (see Chapter 5).

Box 4.2. Earthworms

Earthworms can be regarded as a farmer's best friend.

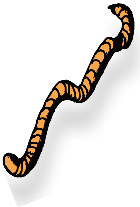
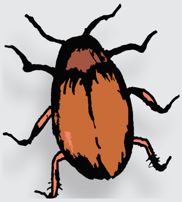
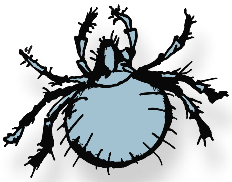
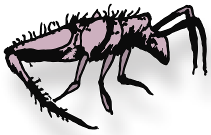
The burrowing of earthworms improves the physical properties of the soil, creating channels through which plant roots may more easily penetrate the soil.

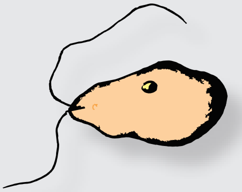
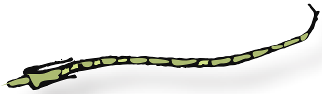
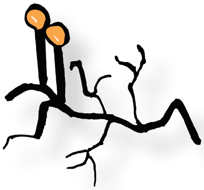
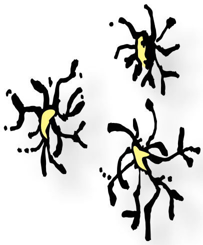
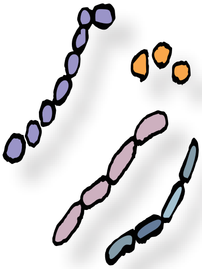
In addition to increasing soil porosity and aeration, this activity also improves soil drainage and water penetration while eliminating hardpan conditions.

Earthworms may also enhance soil structure through the formation of aggregates. Secretions in earthworm intestines cement soil particles together into aggregates which aid in erosion control. They don't like acidic sands, but they love organic matter. Many of them are killed by intensive cultivation practices.

Another important function of soils is the **filter function.** Through the soil's storage abilities and structure, and through the degrading activity of some specialised microbes, the soil acts as a water filter – playing a major role in the global water cycle. Soil with a well-developed, crumbly structure has a high infiltration rate and a favourable water holding capacity (see Chapter 2). In a soil with a balanced community of soil organisms, the water leaving the soil as ground water will be free of pollutants or excess nutrients.

Table 4.1. Size, numbers and functions of soil organisms.

Size	Soil Organism Group	Typical Numbers	Function
Megafauna (>20 mm)	Mammals	0.01/m^2	 Burrowing and shredding residues, creating channels.
	Earthworms	50/m^2	 Burrowing and shredding of residues, improving soil structure through excrements.
Macro-fauna (2 - 20 mm)	Arthropods (insects, larvae, spiders) and snails	100/m^2	Shredding plant residues thereby making them more accessible to bacteria and fungi. Enhancing soil structure by creating faecal pellets and by burrowing.   
Mesofauna (0.2 - 2.0 mm)	Arthropods (mites, springtails)	1 - 10/g soil	Decomposing organic matter, feeding on micro-organisms resulting in population control.  
Microfauna (0.002 - 0.2 mm)	Nematodes	10 - 100/g soil	 More than 15 000 different species. Most of them are useful decomposers, though some species feed on roots and cause damage to the crop.

Size	Soil Organism Group	Typical Numbers	Function
Microfauna (0.002 - 0.2 mm)	Protozoa	up to 1000/g soil	Stimulating and controlling growth of bacteria, releasing ammonium.  
Microflora (0.002 - 0.2 mm)	Algae	up to 100 000/g soil	Forming lichen together with fungi, contributing to soil building. Some fix nitrogen.  
	Fungi	up to 1 million/g soil	 Decomposing resistant organic matter. Some form hyphae which increase contact of plant roots with soil (mycorrhizal relationship).
	Actinomycetes	up to 100 million/g soil	 Grow as filaments, decomposition at moderate to high pH, creating substances that help bind soil aggregates.
	Bacteria	up to 1 billion/g soil	 Mineralisation of organic compounds, food source for nematodes and arthropods.

The food relations and interactions between soil organisms are very complex and a high diversity ensures a high resilience of the system. Only plants are primary producers of food due to their ability to use sunlight for producing biomass. The majority of all soil organisms are consumers that cannot make their own food. They meet their energy demand by feeding on living or dead organic substances. Some soil organisms are independent of each other while others benefit or inhibit each other. Symbiotic relationships (i.e. benefiting both parties) also exist between certain plants and soil organisms. For example, mycorrhizal fungi live on the plant's roots. The hyphae they create help the plant absorb water and nutrients and, in return, the fungi receive energy in the form of sugars from the plant[1]. Due to symbiosis with nitrogen fixing rhizobium bacteria, legumes can make use of additional nitrogen from the atmosphere.

Diversity is key for a well-balanced soil ecosystem. Processes such as the decomposition of litter (crop and root residues) may require the action of several organism groups. Many of the soil organisms are highly specialised: their nutrition is based on just one group of elements. Thus they depend on others to decompose products. The loss of such specialists or single organism groups can disturb soil processes tremendously, i.e. the absence of a very small soil macrofauna group can reduce the decomposition of the litter distinctly. In a balanced, diverse system many organisms perform a similar role; the system is not dependent on just a few for that function. Additionally, in a balanced system the populations of harmful nematodes or insects are biologically controlled by beneficial organisms. The more diverse and complex a system is, the more resilient and sustainable it will be.

Box 4.3. **'Wonder' products**

There are many new so-called 'biological' products on the market, which promise rapid improvements in soil fertility and greater yields. Be cautious. Real and sustainable improvements to soil health occur over a period of time and result from a programme of good management practices.

Promoting diversity in soils

The quantity, activity and the composition of the community of soil organisms vary according to relief, vegetation, soil properties, soil depth, climate (temperature, moisture) and season. Large, highly differentiated and stable communities will form under optimum climatic and soil conditions with no disturbance. Any change in the conditions, with or without human influence, will change the soil ecosystem and thus change the functioning of a soil. The soil community under a farming system will be different from that of virgin soils. In particular, the diversity within the community would probably have declined whilst the number of the soil organisms could be maintained due to good, sustainable management. The following measures support diverse life in soil:

1. Temperature and moisture can be kept more stable under conservation agricultural systems, such as no-till systems, constant plant covers and mulch layers (see Chapter 5).
2. Conservation tillage systems will also promote megafauna, such as arthropods and, in particular, the earthworm

population. Many studies have shown that the farmer's best friend, the earthworm, is killed by the plough and its population recovers in no-till systems (Figure 4.2).

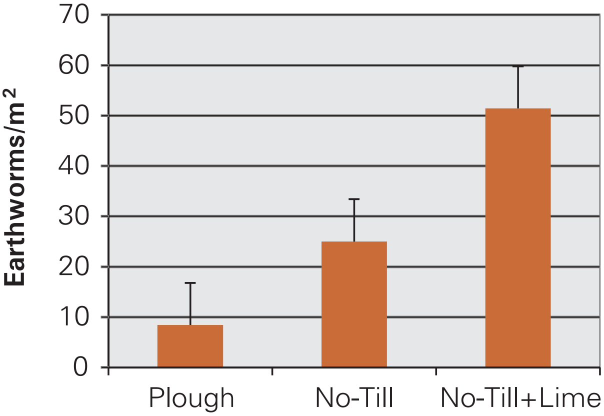


Figure 4.2. Influence of no-till and liming on earthworm abundance in a long-term trial at Cedara[2].

3. Available food plays a major role. The amount and activity of soil organisms show a strong relationship with soil organic matter (SOM) content (Figure 4.3). All farming practices which preserve or increase the SOM level in soil (e.g. use of organic manure, varied crop rotation) will also promote populations of soil biota (see Chapter 5).

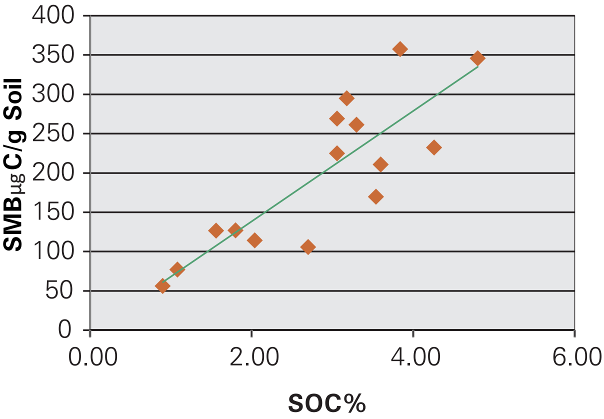


Figure 4.3. Relationship between soil organic carbon (SOC) and soil microbial biomass (SMB) from sugarcane fields.

4. Not only the number but also the diversity of the soil organisms is an important factor. The diversity of the soil community is higher in a diverse ecosystem with a highly differentiated plant community (a monoculture will provide only one food source and thus result in limited diversity). The use of pesticides and herbicides will also shift the soil ecosystem. A diverse agricultural system (including crop rotations and green manure crops) means less pest and disease pressure, requiring lower application of chemicals.

5. Populations of soil organisms decline with soil depth. Most of them live in the topsoil. A lot of topsoil (including soil organisms) is lost through erosion. All measures which prevent erosion will also sustain soil life.

6. The use of heavy machinery at inappropriate times will compact the rooting zone – the space where most soil life exists. This compaction has the effect of reducing air and water supply and thereby supressing root growth.

Checking soil biological properties

There are several field indications of biological soil life:

Look at soil colour and structure. A dark colour usually indicates favourable SOM status, as does a crumbly soil structure.

Count earthworms. Earthworm numbers are highly variable between soil types but this simple indicator is sensitive to organic matter supply and a low soil pH. You should find 2 to 5 earthworms in a spade of soil.

Smell: Does your soil have the typical earthy smell? This is particularly noticeable after rainfall, and gives an indication that your soil is still active.

Observe: Most of the soil organisms are not visible to the naked eye, but one can see their activity. A soil with an active soil life will decompose crop and root residues and trash or other mulch layers quite rapidly.

Box 4.4. The smell of soil

The wonderful 'earthy' smell of newly ploughed ground is believed to result from chemicals produced by micro-organisms. One of these chemicals, called geosmin, is produced by actinomycetes – organisms that have some properties of both bacteria and fungi.

Discuss your observations with others. They may have had similar experiences and could give some advice.

In the laboratory, a complete soil assessment (see Chapter 11) should be done when a soil shows signs of low productivity. There is no single indicative value for such an assessment. It is a combina-

Figure 4.4. The level of biological soil life can be established by a few basic observations in the field, for example, looking for earthworms.

tion of physical, chemical and biological soil properties, which gives clues regarding the causes of possible imbalances in the soil system.

Direct measurement of the number and diversity of soil micro-organisms is almost impossible due to their high diversity and the operation will be time consuming. Thus, the majority of measurements are indirect and they measure metabolic (respiratory) products such as carbon dioxide.

Measuring soil respiration, i.e. the amount of carbon dioxide produced from a soil sample, gives an indication of the activity of soil microbial organisms and allows for some conclusions to be made about its quality. The quantity of soil micro-organisms is measured by means of biomass carbon and ranges between 0.01 and 1.35% of soil mass[3]. A more specific analysis is quantification and identification of nematodes through microscopic counting. Nematode species include fungal, bacterial and root feeders. The ratios between these species are an indication of the level of soil disturbance. However, biological soil measurements will only provide valuable and plausible results if the following principles for soil sampling, transport and storage are considered:

- Soil micro-organisms are sensitive to changes in temperature, rainfall and food availability. Seasonal time of sampling should meet the objectives for quantification. The best time for sampling is in spring after the first rains.
- Fertilisation (mineral or organic) will influence the microbial community immensely within days of application. Avoid sampling soon after fertiliser application.
- Most soil micro-organisms live in the upper, more fertile part of the topsoil. The recommended sampling depth is either 0 - 10 cm or 0 - 20 cm.
- A larger number of micro-organisms are normally found in the direct vicinity of the cane stool (roots). Do not collect samples more than 20 cm away from the cane stool.
- Micro-organisms are alive. Allow them to breathe. Use the boxes/containers supplied by the laboratory. Do not use closed plastic bags or containers.

Figure 4.5. An abundance of earthworms is a good indication of high soil organic matter.

- Soil micro-organisms are very sensitive to changes in their environment. Submit fresh, field-moist samples for analyses. Keep samples cool (best done by using a cooler box) and transport immediately to the laboratory. Avoid exposure to heat (e.g. being left in a bag in the sun or in the back of an open delivery vehicle).

SUMMARY

- In order to keep soils healthy and fertile, one must understand how to keep the complex living component in the soil diverse and alive. It is the only way to sustain yields in the long-term.
- Due to the action of soil organisms, the soil is able to decompose organic matter and to provide nutrients for plant growth. The excrement of soil organisms contributes to good soil tilth which enhances crop growth.
- Better management of the soil biological community results in reduced input costs due to lower pesticide requirements.
- There are several measures that a farmer can implement to promote diversity of soil life and thereby enhance the health of the soil. The basic principle of all measures is to provide suitable living conditions such as food (organic matter input), stable temperature and moisture (soil cover) and living space (conservation tillage, erosion protection) for soil organisms.
- There are some field indicators for soil biological life such as earthworm appearance and decomposition rate of organic matter. A more specific analysis can be done through a laboratory assessment. A specific sampling routine needs to be followed.

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Chapter 5

ORGANIC MATTER

Organic Matter

Although in most soils, organic matter constitutes only 1 - 5% of the total soil mass, it plays a major role in maintaining soil productivity by ensuring that the soil remains healthy and fertile. The world-wide decline of soil organic matter is recognised as a serious threat to agricultural production. Management practices that conserve or accumulate organic matter in soils are therefore of great importance. In addition to improving soil productivity, the preservation of organic matter contributes to the reduction of carbon dioxide in the atmosphere, and thereby mitigates global warming.

Composition and organic matter pools

Soil organic matter is made up of living material, or decomposing remains, of plants, animals, insects or soil organisms. It consists of complex organic compounds, and contains substantial amounts of carbon (50 - 60%), as well as oxygen (30 - 40%), hydrogen (5%), nitrogen (4%), sulphur (1%) and other nutrients[1].

Organic matter consists of three distinct fractions – living organisms, fresh residues and well-decomposed residues. These three fractions of organic matter have been described as 'the living', 'the dead' and the 'very dead'[1].

- *The living*: This is made up of micro-organisms (e.g. bacteria, fungi, algae, etc.), living plant roots, insects, earthworms and larger animals (e.g. moles and frogs). Earthworms, insects and

Figure 5.1. Organic matter plays a major role in maintaining soil productivity.

some of the larger animals help to break down and mix the organic matter in the soil (see Chapter 4).

- *The dead*: This fraction comprises relatively fresh residues of dead micro-organisms, insects, earthworms, plants, roots, and manures. These are all easily decomposed by soil micro-organisms, and act as a source of food for soil organisms and nutrients for growing plants (see Chapter 4).
- *The very dead*: This is made up of well-decomposed organic matter (often referred to as humus). This fraction is closely associated with soil clays, and as a general rule, the higher the clay content of the soil, the higher the capacity of the soil to store humus. The humus fraction is the most stable component of the soil organic matter, and it plays a major role in improving soil structure.

More specifically, organic matter is comprised of organic compounds such as lignins, proteins and fats and waxes which all have different decomposition rates depending on the complexity of the molecules. Based on their ease of decomposition, at least two major 'pools' have been identified. In the decomposable or labile pool mainly 'the living' and 'the dead' organic matter fractions interact and undergo transformations in the short term. The stable organic matter pool consists of well decomposed material ('the very dead'), and thus is much less involved in decomposition processes (Figure 5.2).

Laboratory determinations of the soil organic fraction generally involve the measurement of organic carbon (C). Conversion of measured organic C percentage values to organic matter percentages involves multiplying the C value by a factor, usually 1.72. The organic matter content of soils is usually reported as a percentage (%) of soil mass or in grams per kilogram soil (g/kg) (see Box 5.1).

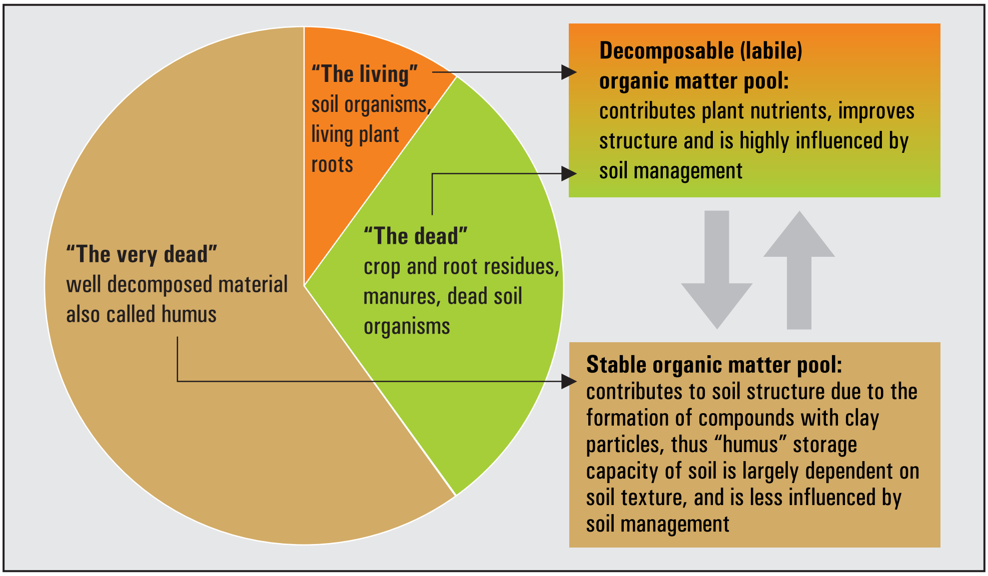

Figure 5.2. Soil Organic Matter fractions and their relationships.

Role of organic matter in soils

Organic matter is a major factor in soil health and productivity because it has a positive influence on physical, chemical and biological properties. The major beneficial effects are summarised in Figure 5.3.

Soil structure and water retention

Organic matter has been found to play a key role in improving soil structure. The fraction of organic matter described above as 'the very dead' (humus) is able to bind to clay particles, which positively affects particle aggregation and consequently soil porosity. The result is a decrease in soil bulk density and increases in pore volume, water holding capacity and infiltration rate (see Chapter 2). In addition, crop and root residues and organic amendments (the 'dead') added to the soil also improve soil structure.

Box 5.1. Converting between Organic Carbon (C) and Organic Matter (OM)

OM (%) = C% x 1.72

Example: If a soil contains 1.6% organic carbon, how much organic matter is present?

OM (%) = 1.6% x 1.72 = 2.8%

The effects of organic amendments on the bulk densities of two sugarcane-growing soils with very different clay and organic matter contents are shown in Figure 5.4.

The lower bulk density of the Shortlands compared to the Fernwood is attributed to its higher clay and organic matter contents. In a laboratory experiment conducted on various textured soils, the application of 40 ton/ha filtercake and 40 ton/ha farmyard manure decreased the bulk density of the Fernwood by 8% and 17% respectively and by 5% and 7% respectively for the Shortlands soil. These data highlight the potential bene-

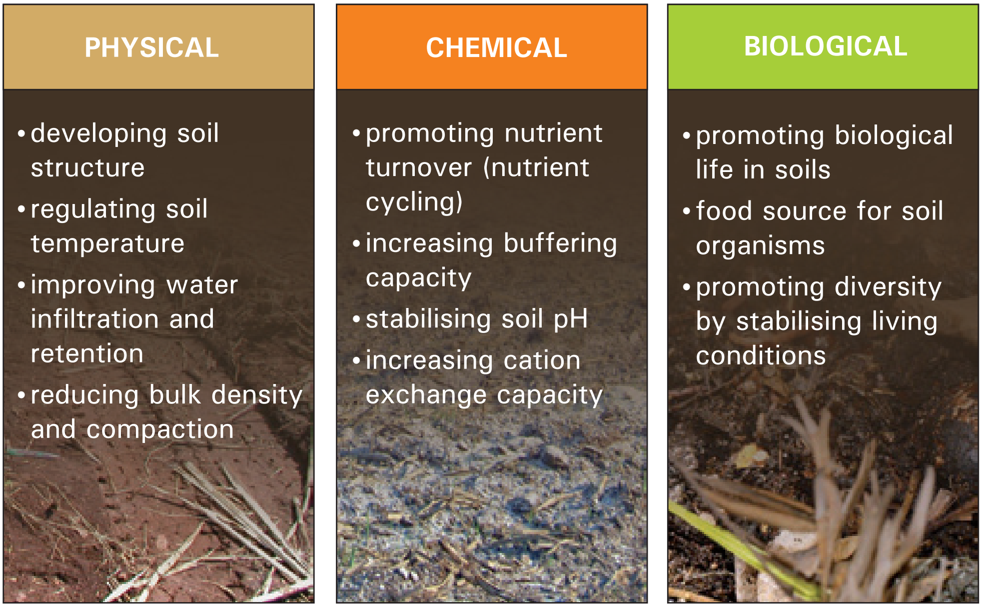

Figure 5.3. Role of organic matter in soils.

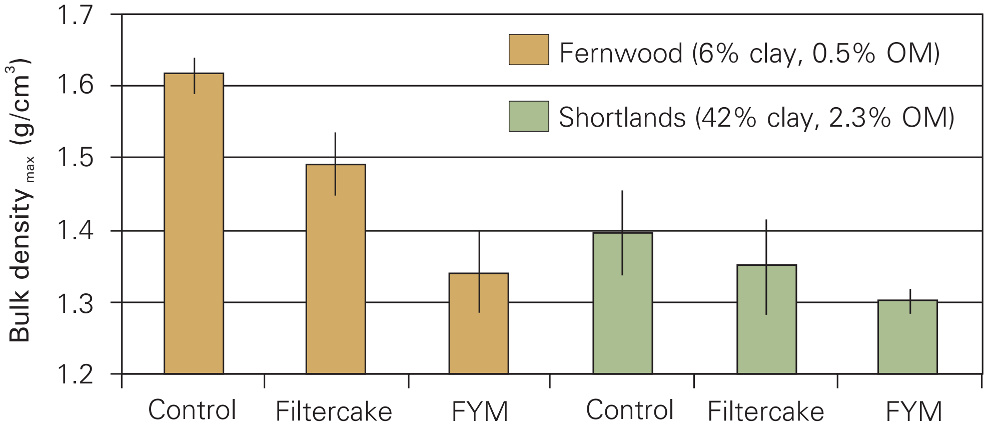

Figure 5.4. Bulk density of a Fernwood and a Shortlands soil with and without organic amendments (FYM = farmyard manure)[2].

fits of organic matter additions to reduce the compactability of soils.

The positive effects of organic matter on soil structure include improved water infiltration and retention, thereby rendering crops less susceptible to drought stress. In addition, improvements in structure render soils more resistant to compaction by infield traffic.

Nutrient release

Another important role of organic matter is that it is a reservoir for plant nutrients, and as it decomposes, nutrients are released into the soil in a form which can be used by plants. This process is called mineralisation (see Chapter 4). The presence of organic matter in the soil can have either a direct or indirect effect on the availability of essential plant nutrients:

- Direct: Organic matter serves as a store for N, P, S and a number of micronutrients. It acts as a 'slow-release' source of these nutrients for plant uptake.
- Indirect: Soil organic matter buffers the soil pH and contributes to the cation exchange capacity (CEC) of the soil (see Chapter 3), and is therefore able to reduce nutrient losses as a result of leaching.

While acting as a food source for a large diversity of soil organisms, organic residues present in the soil are decomposed. Nutrient compounds bound up in organic matter will be used by the soil organisms to cover their nutritional needs. Nutrients in excess of those required by the micro-organisms will be released to the soil (mineralised) in plant available forms. If, however, the nutrients in the organic residues are insufficient to supply the needs of the micro-organisms they will draw on the soil stores and may even use some of the nutrients supplied to the soil as mineral fertilisers. Under these circumstances, plant-available nutrients are converted to plant-*un*available nutrients, a process known as immobilisation (Figure 5.5).

Mineralisation and immobilisation play a particularly important role in nitrogen nutrition. When the nitrogen content

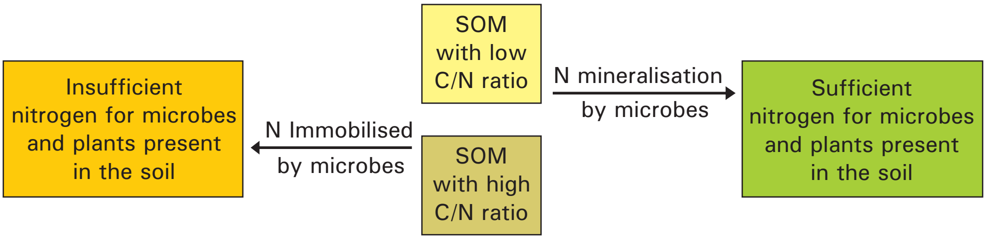

Figure 5.5. Mineralisation and immobilisation of plant available nutrients.

of decomposing organic residue is low, micro-organisms will draw on extra inorganic nitrogen reserves in the soil, thus immobilising the nitrogen available to plants (mineral nitrogen). Under these circumstances, the crop can suffer from nitrogen deficiencies even if mineral nitrogen fertiliser has been applied to satisfy the recommendations for the crop. When additional organic matter with a high nitrogen content (e.g. fresh, green plant residues, farmyard manure, slurries) is added to the soil, the C:N ratio is low (or narrow) and the nutrients are readily mineralised. For this reason the nutrient composition of the organic matter added to the soil, in particular the carbon-nitrogen (C:N) ratio of the materials, is of special importance.

Bearing this information in mind, it is essential that growers are aware of C:N ratios of organic residues in order to predict the effect they will have on the N balance in the soil. A C:N ratio of 25:1 has been identified as a critical threshold. At higher C:N ratios, the microbes need to take up additional N from the soil pool[3]. The nitrogen will be immobilised by micro-organisms and additional nitrogen will have to be added to the soil. However, the immobilisation is only temporary: during the decomposition process of the organic amendment the nitrogen will be slowly released and will become plant available again.

In Box 5.2 two examples of C:N ratio calculations are presented: sugarcane trash has a rather high (or wide) C:N ratio and when incorporated would need additional mineral N. In contrast, chicken litter has a narrow C:N ratio and releases the N quite quickly.

For most organic amendments, the average nutrient content values and C:N ratios are published, but it is always advisable to have amendments tested in the laboratory before application to sugarcane fields. Some examples for average C:N ratios are presented in Table 5.1. For more information about the management of various organic amendments, see Chapter 8.

Box 5.2. Calculating C:N ratios

$$\text{C:N} = \frac{\text{(Carbon content (\%)}}{\text{(Nitrogen content (\%)}}$$

Example 1: Sugarcane trash

C content (%)	N content (%)
40	0.3

$$\text{C:N} = \frac{40}{0.3} = 133.33$$

Example 2: Chicken litter

C content (%)	N content (%)
39	3.82

$$\text{C:N} = \frac{39}{3.82} = 10.2$$

Buffering capacity

Organic matter is able to take up or release hydrogen ions (H^+), with the result that it is able to stabilise the pH of the soil. When soils have plenty of organic matter, any major changes in pH are buffered by the ability of the organic matter to take up hydrogen ions under acidic conditions or release them when conditions become basic.

Cation exchange capacity

Organic matter increases the cation exchange capacity of soils (see Chapter 3), thereby improving the retention of nutrients that would otherwise leach out of the soil profile. In addition, increased cation exchange capacity binds chemicals that are potentially harmful to the environment (e.g. certain pesticides and herbicides), preventing them from entering the soil solution and leaching into water sources.

Table 5.1. Selected organic amendments and their average C:N ratios.

Organic amendment	Average C:N ratio
Legumes, fresh grass cuts	10 - 12
Green manure crops	10 - 20
Poultry manure	10
Poultry litter, dairy manure	15 - 20
Compost	20 - 50*
Maize stover	>60
Wheat straw	>80
Sugar cane trash	60 - 120
Fresh sawdust	>400

*depending on input ingredients and level of decomposition

Factors influencing the accumulation and depletion of organic matter in soils

The capacity of soil to accumulate and store organic matter is determined by climate, topography, soil texture, land use, organic matter inputs and tillage practices. Climate, topography and soil texture are permanent (natural) features which can hardly be managed. However, land use, soil inputs and tillage are management-related, and as a result are influenced by farmer decisions and policies (e.g. conservation of wetlands and natural vegetation)[4, 5].

Natural factors

Climate

Temperature and moisture are the two climatic variables with the greatest influence on organic matter accumulation or depletion in the soil. Temperature affects organic matter production through its effect on plant growth and microbial activity. Lower temperatures result in reduced microbial activity, so when plants produce organic matter (leaves and roots) at a rate greater than at which the micro-organisms are able to decompose them, an accumulation of organic matter occurs. In contrast, when temperatures are high, microbial activity increases and the micro-organisms decompose the organic matter produced by the crop more quickly. There is therefore a tendency for soils in cool climates to have higher organic matter levels than soils in warmer climates.

Organic matter increases with increasing wetness in soils. In very humid climates, the conditions in the soil can become anaerobic, and this lack of oxygen inhibits the decomposition of the soil organic matter. Therefore, despite the high temperatures experienced in tropical rainforests, the soil organic matter levels are often high. The same is true for soils in wetlands and swamps, where peat soils will often develop as a result of the inherent poor drainage.

Topography

Topography can also play a major role in the accumulation or depletion of organic matter. Accumulation often occurs at the foot of a slope for two primary reasons:

- Conditions are wetter than at the upper- or mid-slope.
- Organic matter is transported to the lowest point in the landscape via runoff and erosion[6].

Soil texture

There is often a strong relationship between soil texture and the organic matter content of soils (Figure 5.7). Soils high in clay and silt are able to retain organic matter better than sandy soils. The main reason for this is that clay and silt particles have larger surface areas (per unit volume) than sand particles and are therefore able to protect the organic matter against decomposition by oxidation. Another reason may be the better soil structure of loamy and clay soils and an associated increased ability to retain water and nutrients resulting in higher biomass production (more crop and root residues) and therefore higher organic matter levels.

The relationships between clay and organic matter content, such as the one

Figure 5.6. Regular intensive tillage leads to a decrease in soil organic matter.

shown in Figure 5.7, are influenced by a number of factors, including climate, land use system and clay type. These relationships therefore often vary widely from region to region.

Human activities

Land use and tillage

Undisturbed soils are in equilibrium with respect to the accumulation and depletion of organic matter, which is determined by natural factors as described above. The conversion of soils from their natural state to a cultivated state (agricultural land) has generally led to a decline in organic matter: forests have been cut or burned, plains have been ploughed and wetlands have been drained.

The greatest causes of organic matter depletion are tillage and a lack of return of organic residues to the soil. In this respect, excessive exploitation of the soil by intensive agricultural production and overgrazing leads to infertile and unproductive soils. In Africa's dry climate, the consequence of this is desertification, which affects about 46% of Africa. The region that has the highest propensity is located along the desert margins and occupies about 5% of the African land mass. It is estimated that about 22 million people (2.9% of the total African population) live in this area[7]. Growing food demand due to a growing population requires that poor and over-farmed lands need to be replaced by previously unfarmed land. The consequence is further depletion of organic matter from

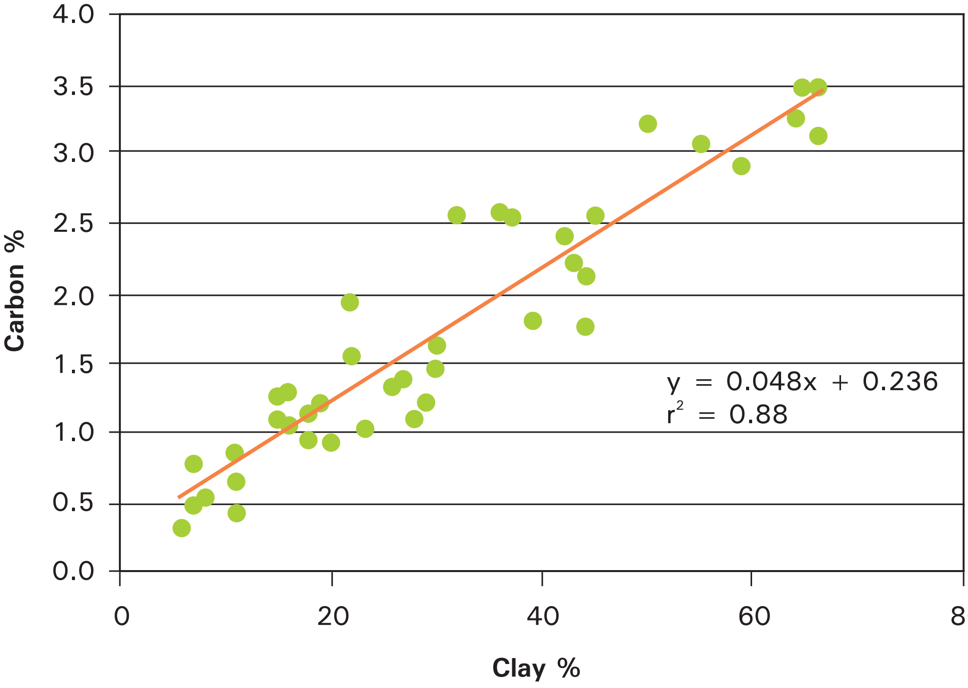

Figure 5.7. The relationship between soil organic carbon and clay content in sugarcane topsoils of the Midlands North and South extension regions of KwaZulu-Natal, South Africa (source: N Miles, 2008)[4].

soils. This trend is a serious concern and needs to be reversed.

Soil organic matter decreases when soils are subjected to regular intensive tillage, in particular, and this decline is a result of the following:

- Tillage breaks up soil aggregates, exposing previously protected organic matter to breakdown by micro-organisms.
- Tillage alters the micro-climate of the soil (differences in moisture content and temperature occur), and there is improved aeration which results in greater mineralisation of organic matter.
- The litter layer is lost and with it the number and diversity of soil organisms will decline rapidly.
- Tillage results in erosion of finer particles that are usually rich in organic matter.

Soil balance

Agricultural management systems often return insufficient amounts of organic matter to sustain the soil organic matter levels. Dense, non-varied crop rotations or monocultures, and crops with high harvest indices (i.e. a large portion of the plant is removed from the field) leave very little and less diverse residues. The food source for micro-organisms becomes unbalanced and scarce and the soil organisms decline in numbers and diversity. In addition, the burning of residues is a common field practice to control insects and diseases or to make harvest easier. In some farming systems the residues are removed or used for other purposes. The majority of agricultural systems do not compensate the off-take (removed organic matter, including the harvested product) with suitable organic amendments such as farmyard manure or green manures. In intensive

Figure 5.8. Non-varied crop rotation or monocultures contribute to the decrease in soil organic matter.

farming systems with a low return of residues and no organic inputs, organic matter will decline with consequences for soil productivity and soil health.

Management practices that promote retention and accumulation of organic matter

Soils receiving little or no disturbance coupled with adequate inputs of crop residues, manures and other organic by-products favour the retention and accumulation of organic matter.

Agricultural management practices have been ranked according to their effect on organic matter by Dick and Gregorich (2004)[5], resulting in a list of 10 major management systems. The first (no soil disturbance, optimised organic matter input) is rated at 100 and causes the highest C accumulation. Intensive tillage with bare summer fallow and little nutrient input will lead to rapid organic C rundown and is rated at 10 (Table 5.2.).

The majority of sugarcane soils have lost tremendous amounts of organic matter in past decades. The combined impact of growing cane as a monoculture, not recycling mill wastes, excessive tillage and burning at harvest have all impacted negatively on the organic matter equilibrium (or balance). If the soil management practices of the South African sugar industry are ranked on the list shown in Table 5.1, they are positioned relatively low down on the list (somewhere between 20 and 40).

There are many ways to manage land so that organic matter is preserved and accumulated (Box 5.3). For example,

Table 5.2. Management systems that affect organic matter levels, from the most preserving (assigned a value of 100) to the most degrading (assigned a value of 10) (Dick and Gregorich (2004) adapted by Miles, *et al* (2008)[4,5]).

Rating	Management System
100	Improved permanent pastures with animal grazing. This system leaves all materials on site.
90	No-tillage rotation with row crops alternating with legumes and soil treated with manure.
80	No-tillage rotation with continuous row crops and manure additions.
70	Conservation tillage with long-rotation sequences that include green manures and animal manures.
60	Plough tillage with rotation sequences that include green manures and animal manures.
50	No tillage with grain and residues (for fuel and feed) harvested.
40	Conservation tillage with continuous row crops.
30	Intensive tillage with continuous row crops.
20	Intensive tillage with continuous row crops on sloping lands (grain and residues harvested).
10	Intensive tillage with mechanical summer fallow in alternate years with little nutrient input.

shifting to a reduced tillage system and applying manures to the land will increase the rating to 80 (Table 5.2).

One of the easiest methods of accumulating organic matter in the soil is by leaving residue (i.e. trash) on the soil surface at harvest. Despite nutrient levels in trash being relatively low compared to green and farmyard manures, trash has a positive effect on soil structure and water holding capacity. By forming a mulch layer, trash prevents the soil from drying out. A trash blanket can conserve about 100 mm of soil water per year. It creates a stable environment in which soil organisms can thrive. In addition the trash blanket reduces soil erosion. All these aspects have a massive positive effect on organic matter levels and thus soil fertility.

Application of inorganic fertilisers at recommended rates has a positive effect on organic matter levels. The increased plant biomass as a result of fertiliser application causes an increase in the returns of organic material to the soil in the form of decaying roots, litter and crop residues[4].

One must keep in mind, however, that increasing organic matter levels in soil is a long-term process. If not persisted with, all of the measures listed above will show only short-term effects.

Figure 5.9. Burning at harvest removes large amounts of organic matter from the field.

Box 5.3. Management practices which promote conservation and accumulation of organic matter

- Conservation tillage practices (no-till, reduced tillage).
- Use of green manure crops in crop rotations (e.g. sunn hemp, black oats).
- Crop rotations and intercropping with legumes (e.g. soybeans, alfalfa).
- Application of farmyard manures, chicken litter, pig slurry and/or composts.
- Application of mill wastes (e.g. CMS, filtercake, fly ash).
- Balanced mineral fertilisation (in particular lime and nitrogen).
- Preserving crop residues (e.g. trashing instead of burning) and keeping the soil covered.

SUMMARY

- Organic matter is a major contributor to soil fertility and soil health.
- It is a food source for micro-organisms, which release nutrients into the soil in a plant available form.
- Organic matter increases the soil's cation exchange capacity and improves soil structure by binding soil particles.
- The presence of organic matter in the soil increases water infiltration, improves water holding capacity and reduces erosion.
- The C:N ratio of organic matter added to the soil should be determined, as it provides an indication of the availability of nitrogen, allowing for effective nutrition management.
- Accumulation and depletion of organic matter in soils is influenced by natural factors (climate, topography, soil texture) and human activities (cultivation practices).
- There are a number of management practices which contribute to the preservation and accumulation of organic matter in the soil thereby improving soil fertility and soil health in the long-term.

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Chapter 6

SOIL ACIDITY AND ITS MANAGEMENT

Soil Acidity and its Management

Soil acidity is a widespread problem in areas receiving high rainfall. Soils in these areas are often naturally acidic, with a number of agricultural practices further promoting the development of acid conditions. In the South African sugar industry, soils in the rainfed cropping areas of KwaZulu-Natal are generally acidic, while in the northern irrigated areas (Pongola region and Mpumalanga province) as well as in other southern African countries, soils tend to be more neutral or even alkaline.

Tolerances of agricultural plants to soil acidity

Agricultural crops vary widely in their tolerances to soil acidity (Figure 6.2). Certain vegetables and temperate legumes are highly sensitive to acid soil conditions, while crops such as cowpeas and sugarcane are highly tolerant. Nevertheless, severe soil acidity has been shown to limit the growth of all species, including sugarcane. The management of soil acidity is thus an essential component of agricultural production practices.

It is noteworthy from the rankings in Figure 6.2 that green manure crops commonly used in sugarcane production are more sensitive to soil acidity than sugarcane itself. Not surprisingly, therefore, experience suggests that the poor growth of green manures in sugarcane rotations may frequently be due to acid soil limitations.

Figure 6.1. Soil acidity can be corrected through the incorporation of lime into the soil.

Human activities promoting soil acidification

Although acid soils occur widely in nature, the following human activities may markedly accelerate the acidification of soils:

1. Acid rain, resulting from atmospheric pollution by industry.
2. The use of nitrogenous fertilisers, particularly when applied in excess of immediate crop requirements.
3. The removal of basic nutrients (calcium, magnesium and potassium) from the soil in harvested crops and animal products.
4. Accelerated decomposition of organic matter as a result of soil tillage.

Soil pH and its measurement

The pH scale is a special scale for expressing hydrogen ion (H^+) concentration. The scale runs from 0 to 14, with lower values reflecting acidity and higher values alkalinity (alkaline conditions are also referred to as 'basic'). A value of 7.0 represents neutrality (neither acidic nor alkaline).

Methods of measuring soil pH often differ from one laboratory to another. Importantly, the pH value of a particular soil may vary considerably depending on the method of measurement, and for this reason soil test reports need to specify the method employed. In brief, pH methods involve the use of either (a) a suspension (mixture) of soil and distilled water, or (b) a soil and a salt solution. Salt solutions commonly used are 1 *M* KCl (potassium chloride) or 0.01 *M* $CaCl_2$ (calcium chloride). Soil pH measured in a salt solution is generally lower than that measured in distilled water. Approximate conversions between the various measurement methods are as follows:

$$\mathrm{pH(CaCl_2)} = \mathrm{pH(water)} - 0.75$$

$$\mathrm{pH(KCl)} = \mathrm{pH(water)} - 1.00$$

$$\mathrm{pH(CaCl_2)} = \mathrm{pH(KCl)} + 0.25$$

The pH(water) values of most soils fall in the range 4.0 to 9.0 (Figure 6.3), while those of most productive soils are in the range 4.5 to 8.5.

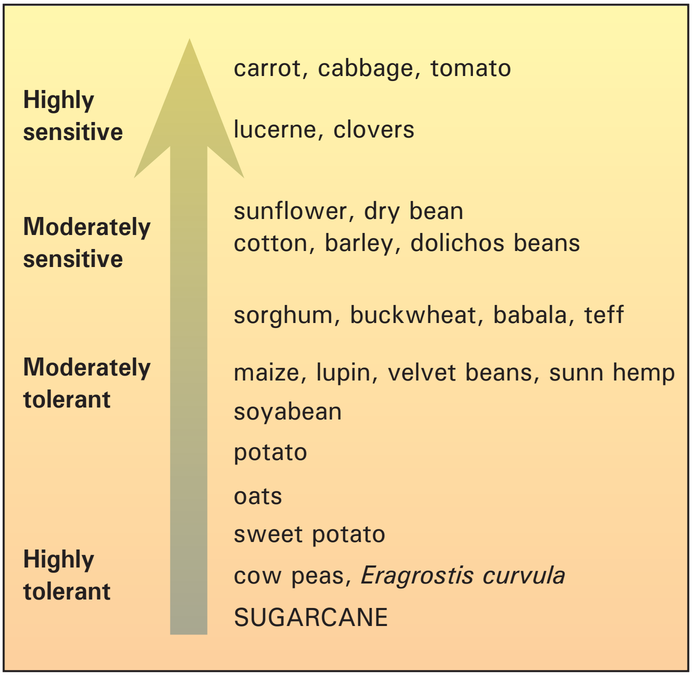

Figure 6.2. Relative tolerances of crop and vegetable species to soil acidity.

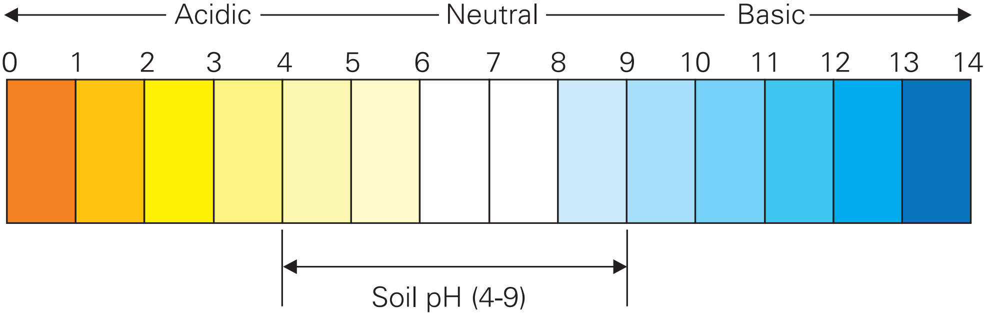

Figure 6.3. The pH range in which the pH(water) values of most soils occur.

Growth constraints on acid soils

For most agricultural plants, the high concentrations of hydrogen ions (H^+) occurring in acid soils do not present a direct growth limitation. Rather, soil acidity problems tend to be associated with the changes in soil chemistry which occur with decreasing soil pH. These effects are summarised below.

Aluminium and manganese toxicities

Under acid conditions, the aluminium (Al) and manganese (Mn) contained in clays and clay-like particles become more soluble. Elevated concentrations of these elements in the soil solution are toxic to plant roots. In southern Africa, Al toxicities are more widespread than Mn toxicities, and give rise to restricted and abnormal root development. Typically, roots become thick and stubby and there is little development of the all-important fine roots (Figure 6.4). Resultant inefficient root systems may drastically reduce yields through impeded water and nutrient uptake.

The typical relationship between soil pH and the solubility of Al is shown in Figure 6.5. It is important to note that Al is essentially insoluble at pH(water) values of

Figure 6.4. Maize roots exhibiting severe aluminium-toxicity symptoms (left), and poor penetration of sugarcane roots into a severely acidic subsoil (right).

greater than about 5.5, but its solubility increases exponentially with decreases in pH below this level.

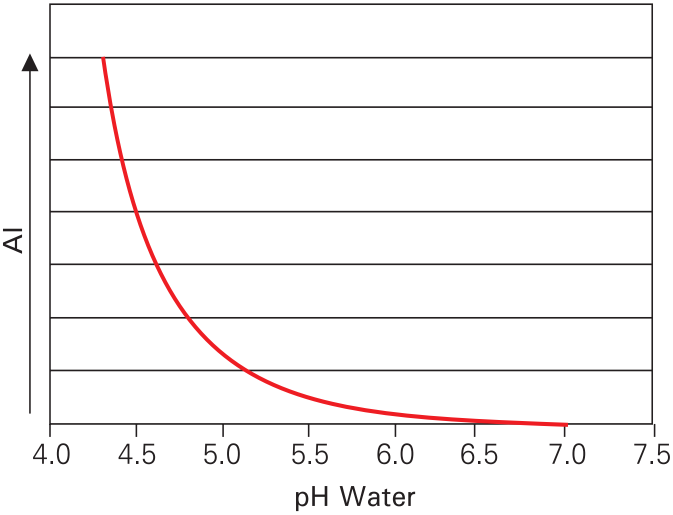

Figure 6.5. Typical variation in aluminium (Al) solubility with soil pH.

Deficiencies of calcium and magnesium

Levels of calcium (Ca) and magnesium (Mg) in acid soils are often very low, and may pose a limitation to plant growth. In rainfed sugarcane in KwaZulu-Natal in particular, high concentrations of Al and associated limiting concentrations of Ca in subsoils are widespread. These conditions restrict root development in subsoils and render crops more susceptible to drought and nutritional stress.

Micronutrient deficiencies

Deficiencies of micronutrients, in particular molybdenum (Mo) and zinc (Zn), frequently limit plant growth on acid soils. In the case of Mo, most soils contain adequate reserves of this nutrient for plant growth, but its *availability* for plant uptake decreases sharply with decreasing pH.

Soil biological activity

Acid soil conditions impact negatively on soil biological activity. Evidence of this is retardation in the break-down of surface-applied organic matter (e.g. trash) on acid soils. In this context, it is noteworthy that most beneficial earthworm species appear to be sensitive to soil acidity, and liming frequently results in a rapid increase in earthworm populations.

Measurement of the aluminium toxicity hazard

Since Al toxicity is generally the principal limitation to plant growth in acid soils, the reliable measurement of the Al toxicity hazard is of great importance. In most routine soil testing laboratories, Al is measured by a simple and reliable procedure that includes some hydrogen (H^+), and the measured value is termed the 'exchangeable acidity' ($Al^{3+} + H^+$). For most agricultural soils, the H^+ component of this parameter comprises less than 5% of the value.

Scientists have found that the degree to which plant roots are affected by Al toxicity depends on the relationship between the quantity of exchangeable Al and the quantity of exchangeable bases, rather than on the level of exchangeable Al alone. The Al toxicity hazard is therefore represented by the 'soil acid saturation', which is calculated as follows (with all concentrations expressed in $cmol_c/L$, *not ppm or mg/L*):

$$\text{Acid Sat \%} = \frac{(Al+H)}{(Al+H)+Ca+Mg+K+Na} \times 100$$

The Al toxicity hazard increases with increasing soil acid saturation. Research has shown that Al-tolerant crops such as sugarcane and cowpeas can perform well at acid saturations of 20 - 40%, while aluminium-sensitive crops such as sunflowers, lucerne and most vegetables require acid saturations of less than 10%.

Correction of soil acidity

Diagnosis of the problem

As noted earlier, crops growing on acid soils frequently suffer from reduced water and nutrient uptake, and it is not uncommon to see affected plants displaying symptoms of drought stress even in relatively moist soils. Furthermore, because of difficulties in taking up nutrients such as phosphorus, magnesium and molybdenum under acid conditions, symptoms characteristic of the deficiencies of these nutrients may occur. Unfortunately, however, plant symptoms are often not well-defined, and soil analysis remains the only reliable means of identifying soil acidity problems and establishing lime and gypsum requirements.

Soil sampling

Since the *incorporation* of lime and gypsum is possible only prior to planting, soil samples should be taken well before the planting operation. This will allow sufficient time for the samples to be processed in the laboratory, and for amendments to be ordered and incorporated into the soil. A useful strategy adopted by an increasing number of farmers is to take soil samples after the penultimate harvest (i.e. at the commencement of growth of the last ratoon before the planned replanting). This ensures adequate time for analyses and ordering of supplies.

Topsoil samples should be taken with a Beater auger (Figure 6.6), while subsoil samples should be taken with a screw-in type auger, or from the faces of soil pits (see Chapter 9 for a detailed outline of recommended sampling procedures).

Initial evidence of excessive soil acidity is frequently in the form of patches of weak crop growth in an otherwise healthy (good) stand. For the optimisation of production, it is essential that these weak areas are remediated. With

Figure 6.6. The use of the Beater auger for routine soil analyses ensures that a constant sampling depth is maintained.

this in mind, soil samples should be taken from these weak patches during the early growth stages of the crop when the poor growth is clearly visible. Samples taken from the whole field after removal of the crop may be biased by the more favourable soil conditions in the good areas. Once the problem has been accurately diagnosed, the poor areas may be effectively treated, either by liming them separately or liming the field as a whole.

Lime and gypsum

Lime and gypsum are chemically very different products, and consequently their effects on soil properties are quite dissimilar.

Liming materials

Limes are calcium and magnesium carbonates, oxides, hydroxides and silicates of varying purity. The anion (negatively charged molecule) in the liming material neutralises H^+ and Al^{3+} in the soil solution and on the soil CEC. The dominant effects of lime on soil properties are:

a) an increase in soil pH;

b) a decrease in exchangeable acidity;

c) an increase in Ca and Mg levels and their availability to crops;

d) a decrease in soil acid saturation.

Data reflecting the effects of lime addition to a Hutton soil are presented in Table 6.1.

Research has shown that on soils with more than about 15% clay, lime incorporated into the topsoil is essentially immobile, and thus has little or no impact on subsoil acidity. Furthermore, incorporation of lime into subsoils by deep ploughing or other mechanical means has often been found to be impractical and uneconomical. Thus lime tilled into the topsoil to a depth of 20 - 30 cm is effective in counteracting acidity in this zone. However, it has little effect on acidity below the zone of incorporation. Furthermore, the efficacy of topdressed (not incorporated) lime is considerably less than that of incorporated lime.

Lime type and quality

In the agricultural context, 'lime' refers to any product in which the Ca or Ca and Mg compounds are able to neutralise soil acidity. Carbonates of Ca and Mg are the most widely used for this purpose. Dolomitic lime contains 15% or more magnesium carbonate, and calcitic lime less than this. In addition to natural carbonates, various by-products of industrial processes are frequently used as liming materials; these include calcium oxide (burnt lime), calcium hydroxide (slaked lime) and calcium silicate (slag).

Table 6.1. Effect of dolomitic lime on the chemical properties of a Hutton soil (43% clay).

Lime rate (t/ha)	Soil test data				
	Ca (mg/L)	Mg (mg/L)	Al + H ($cmol_c$/L)	Acid Sat (%)	pH (water)
0	380	70	1.01	19.5	5.27
4	776	122	0.17	2.5	5.78

The effectiveness of different liming materials varies widely, with the following factors being particularly important in this regard:

a) *Chemical purity*. The presence or otherwise of non-reactive materials such as sand and clay greatly affects the neutralising value of the lime.

b) *Chemical composition.* The nature of the calcium and magnesium compounds present.

c) *Fineness.* Lime particles larger than 0.84 mm in diameter are of little value. Very coarse liming materials are completely ineffective.

d) *Hardness.* The solubility, and hence neutralising value, of lime depends on whether it is derived from hard crystalline material or from softer relatively unconsolidated material.

Where uncertainty exists as to the quality of a particular liming material, a sample should be submitted for analysis.

The value of dolomitic lime as a magnesium fertiliser needs to be borne in mind. Although several Mg fertilisers are commercially available, they tend to be prohibitively expensive, with dolomitic lime invariably being the most cost-effective means of increasing soil Mg levels. For this reason dolomitic lime should be used in preference to calcitic lime wherever lime is required and soil Mg levels are less than soil Ca levels.

Gypsum

Gypsum is calcium sulphate, and as such, is a neutral salt. It is a valuable calcium and sulphur fertiliser. However, as shown in Table 6.2, gypsum has little or no effect on soil pH or exchangeable aluminium, although the large amounts of calcium in gypsum do tend to lower soil acid saturation levels to some extent.

A particular advantage of gypsum is that, in contrast to lime, it is relatively mobile in soils. Gypsum incorporated in the topsoil will move downwards into the subsoil within a season or two, and thereby render the subsoil more hospitable for root growth. Specific benefits of gypsum in subsoils include:

a) an improved calcium supply for root development

b) decreases in the aluminium toxicity hazard through the formation of aluminium-sulphate complexes.

Since gypsum is not nearly as effective as lime in counteracting acidity, it should

Table 6.2. Effects of lime and gypsum on the properties of a Griffin topsoil (33% clay).

Treatment	Ca (mg/L)	Mg (mg/L)	Al + H ($cmol_c$/L)	Acid Sat (%)	pH (water)
Control	232	161	0.95	26	5.3
Dolomitic lime (5 t/ha)	424	295	0.38	7	5.8
Gypsum (4 t/ha)	487	97	1.04	23	5.3

not be used as a substitute for lime in the correction of topsoil acidity. Furthermore, where gypsum is applied, the lime used to neutralise topsoil acidity should be dolomitic, since gypsum causes magnesium to leach out of the topsoil (the data presented in Table 6.2 clearly illustrate this effect).

Use of lime and gypsum – practical considerations

1. *Timing and moisture*. In liming soils for crop establishment, two important factors should be kept in mind: (i) most limes take a month or more to react, and (ii) moisture is necessary for the neutralisation reaction to take place. Therefore, application of lime a week or two before planting, particularly where the soil is severely acidic and the moisture status is low, will not prevent acidity damage to the young crop.
2. *Spreading and incorporation*. It is absolutely essential that the lime and gypsum are uniformly spread, and that tillage operations ensure thorough mixing into the soil. Discing or harrowing followed by mouldboard ploughing is advocated to achieve adequate mixing.
3. *Lime rate*. A frequently asked question is, "What is the maximum amount of lime that can be applied at any one time?" The answer is that, provided it is thoroughly incorporated into the soil, all the needed lime can be applied as a single dressing. In field trials, rates of lime of up to 15 t/ha in one application have been applied without any detrimental effect on the crop or soil.
4. *Liming and no-till*. Since lime is relatively immobile in soils, surface-applied lime is not as effective as

Figure 6.7. Lime and gypsum should be applied uniformly and incorporated into the soil via tillage operations.

incorporated lime in the neutralisation of soil acidity. This presents difficulties in managing soil acidity in no-till systems. Before converting from conventional tillage to no-till, therefore, it is essential that soil acidity problems be addressed by incorporating adequate amounts of lime. Furthermore, in no-till operations, it is advisable to prevent acidity problems by topdressing with low rates (1 - 2 t/ha) of lime when soil tests indicate that acidity is on the increase. The topdressed lime will, with water movement and the assistance of earthworms, gradually be moved into the soil.

SUMMARY

- Management of soil acidity is essential in sugarcane farming, as severe acidity limits growth.
- Soil acidity can lead to aluminium and manganese toxicity, deficiencies in calcium and magnesium, reduced availability of micronutrients and reduced soil biodiversity.
- Soil sampling and analysis is the only reliable means of identifying soil acidity problems and establishing lime and gypsum requirements. Both top and subsoil sampling must be undertaken to fully characterise the acidity status of the soil.
- The dominant effects of lime on soil properties are an increase in pH; a decrease in exchangeable acidity; an increase in Ca and Mg availability and a decrease in soil acid saturation.
- Gypsum, being more mobile in soils than lime, is useful for addressing acidity problems in subsoils. Gypsum is also a valuable source of calcium and sulphur for plant nutrition.

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Chapter 7

PLANT NUTRITION

Plant Nutrition

Rigorous management of the nutrition of the crop is one of the most vital aspects of sugarcane farming. Crops have site-specific fertiliser needs, which are directly related to soil properties and yield potential. Inadequate nutrition will limit yields, while excessive application of fertiliser will reduce profit margins and may lead to environmental pollution. An understanding of the roles of various nutrients and their effects on the crop is key to striking the right balance. Plants with a deficiency or imbalance of nutrients will show various deficiency symptoms, which have been summarised in Table 7.2. towards the end of the chapter.

The nutrients required by plants for healthy growth can be divided, according to crop demand, into ‘macronutrients’ and ‘micronutrients’.

Macronutrients

Macronutrients are taken up in large quantities by the plant. They include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). Silicon (Si) is not commonly listed as a macronutrient, as it is not strictly essential to plant growth. It is, however, included here with the macronutrients due to its role in maintaining crop health, as well as the quantities in which it is taken up by the sugarcane crop. Figure 7.1 provides an overview of the macronutrients typically taken up by a 100 ton/ha sugarcane crop.

Nitrogen

Nitrogen (N) is essential for sugarcane growth. It is an integral component of proteins, and plays a central role in the enzymatic processes that occur in the sugarcane crop. Abundant N promotes luxuriant vegetative growth, and a crop well-supplied with N is a deep green colour in summer. A shortage of N can be identified by a general yellowing of the cane leaves and reduced growth (Figure 7.2).

Good timing is of utmost importance when applying N. Because N promotes vegetative growth, having too much N available at the end of the crop cycle can inhibit natural ripening of the plant, resulting in lower cane quality and decreased sucrose yields. There is also evidence that excessive N leads to increased eldana damage. Applying N at a time when the crop is not able to use it is risky too, as this leads to increased opportunity for N losses (Box 7.1).

Nitrogen fertilisation practices are further complicated by soil type: soils naturally release varying amounts of N each year, depending on the amount of

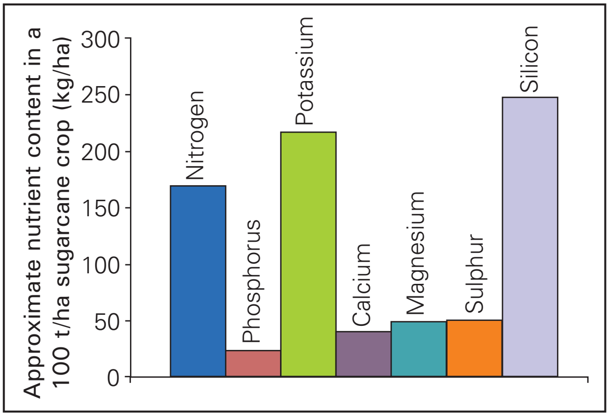

Figure 7.1. Approximate macronutrient content (kg/ha) in a 100 t/ha sugarcane crop.

Figure 7.2. Symptoms of nitrogen deficiency in sugarcane. Note the yellowing of the older leaves, with tips and margins dying off prematurely.

organic matter present in the soil and prevailing weather conditions. Table 7.1 illustrates this point.

In addition to the application of inorganic fertilisers and organic nutrient sources, certain management practices such as green manuring (see Chapter 8) can have a big impact on the amount of N available to the crop. The atmosphere comprises 80% N. This N can be captured in the soil directly from the atmosphere by planting legumes during fallow periods. Legumes 'fix' or capture N with the help of bacteria. When the legumes die off, this N is made available to the following cane crop as the legume decomposes.

Phosphorus

Phosphorus (P) plays a key role in the plant's energy supply chain, and in establishing a healthy root system. For this

Box 7.1. Nitrogen loss

Nitrogen can be lost from the soil in a number of ways. Three of the most common ways are through:

- volatilisation – where ammonia from N fertiliser (particularly urea) is lost to the atmosphere as a gas
- denitrification – where waterlogging reduces oxygen concentrations in the soil, leading to chemical and biological reactions resulting in the loss of N to the atmosphere as a gas, and
- leaching – where N (in the form of nitrate) moves down through the soil until it is beyond the reach of the cane roots.

Management decisions can have a big impact on the amount of N lost via these pathways.

Table 7.1. Nitrogen release from soils with different organic matter contents[1]. Note that N release will differ in different soils and regions.

Bioclimatic region	Soil form	Clay (%)	Organic Matter (%)	N released (kg/ha/crop)
Coastal Lowlands	Cartref	5	0.6	16
Lowveld	Arcadia	61	2.5	54
Midlands	Inanda	29	5.4	117
Midlands	Inanda	47	8.6	162

reason, it is very important for germinating crops. Phosphorus is not mobile in the soil, and should be applied in the furrow at planting so that it is immediately available to the newly developing roots. Furrow application (as opposed to broadcasting) reduces P fixation (Box 7.2).

Box 7.2. Phosphorus fixation

Some highly weathered soils can 'fix' or bind P, making it less available for plant uptake. This, in turn, necessitates the application of higher rates of P fertiliser to ensure a sufficient supply to the crop. It is important, however, to ensure that P is not supplied in excess of crop requirements; excess P can have negative environmental impacts through the pollution of water sources. Some laboratories can measure the extent of P fixation in a soil, allowing greater accuracy in P fertiliser recommendations.

Potassium

Potassium (K) is one of the two nutrients (the other being silicon) that is taken up in greatest amounts by the sugarcane plant. A high yielding cane crop may take up in excess of 300 kg/ha of K. Potassium plays an important role in balancing positive and negative charges within plant cells. It also controls internal pressure (turgor) in various cells - for example, the stomatal guard cells, which open and close to control the amount of water lost to the atmosphere from the leaves. For this reason, K deficient crops lose more water and are more drought sensitive.

Potassium is also highly mobile in the plant, and therefore plays an important role in binding to and transporting sugars from the leaves to the stem. Potassium can be leached in sandy soils, but there is little K movement in clays and loams. Potassium deficiency (Figure 7.3) can reduce germination percentage and cane yields, while excess K can induce magnesium deficiencies. Plants deficient in K are generally less resistant to diseases, while an adequate K supply also improves cold tolerance[2].

When K is readily available in the soil, sugarcane plants tend to take it up in larger amounts than necessary. This is called luxury uptake, and can become problematic in the milling process, where high levels of K can reduce the amount of sugar recovered [3].

Calcium

Calcium (Ca) is important for sugarcane growth in two primary ways: first, as a nutrient which activates numerous enzymes and plays important structural roles, and second in mitigating the effects of toxic aluminium in soils. Many

Figure 7.3. Symptoms of potassium deficiency in sugarcane. Note the tips and margins of the older leaves dying back.

of the soils in the rainfed portion of the industry are deficient in Ca, and should be tested (see Chapter 9) and ameliorated accordingly. Calcium deficiencies may be corrected by the application of lime or gypsum (see Chapter 6).

Magnesium

Magnesium (Mg) is essential because it is involved in photosynthesis. One of its most familiar functions is in the structure of chlorophyll molecules, and it also activates many enzymes and regulates cellular pH and the balance between positively and negatively charged molecules within the plant.

Magnesium is required in lower amounts than the first four macronutrients mentioned, but a deficiency of Mg can nonetheless have serious consequences. The uptake of Mg can be strongly depressed by other cations (such as K, ammonium, Ca and Mn), as well as low soil pH levels. For this reason, Mg deficiency can be fairly common, even if sufficient amounts are present in the soil. Magnesium deficiencies may be corrected by the application of dolomitic lime (see Chapter 6).

Sulphur

A cane crop can remove in the order of 30 - 45 kg sulphur (S) per ha. It is essential for the synthesis of amino acids, proteins and vitamins. Sulphur has not traditionally received a lot of attention in South African sugarcane fertiliser advice because a) it is difficult to measure in the soil, and is consequently not often shown or reported in routine soil analyses and b) it has, in the past, been a component of many fertilisers, so growers have inadvertently been applying it along with their other nutrients. However, a number of factors have caused S deficiencies to become more pronounced in recent years. These include the increased use of high grade, essentially S-free fertilisers; less S inadvertently supplied via air pollution (‘acid rain’), due to the advent of lower-sulphur fuel and energy sources[4]; and more frequent cropping due to shorter crop cycles to suppress the stalk borer eldana, resulting in greater removals of S in the harvested crop.

Sulphur supply from soils is generally related to its organic matter content, and in this respect factors controlling its availability are similar to those regulating N supply: sandy, low organic matter soils are low in both N and S, while clay soils with higher organic matter contents usually have higher levels of both N and S. Sulphur can be supplied in superphosphate, if P is required, or else in gypsum, which contains 15 - 18% S. Ammonium sulphate or ammonium sulphate nitrate (ASN) are also effective S carriers, although they severely acidify soils and are more costly than other N sources.

Silicon

Silicon (Si) is an anomalous nutrient: it is often taken up in greatest amounts by the cane crop (Figure 7.1), and yet it is not classified as an 'essential' element because most plants can grow without Si. Nonetheless, Si plays such an important role in the functioning and health of the plant that it has been classified as a 'functional' plant nutrient.

Silicon has received a lot of research attention in recent years. It has been found to increase yields of a number of plant

Figure 7.4. Pot trial to test the effects of nitrogen and silicon nutrition on resistance of various sugarcane varieties to the stem borer *Eldana saccharina* and to sugarcane thrips *Fulmekiola serrata*.

species – including sugarcane – often due to its role in hardening or reinforcing leaf and stem walls. Increased Si deposits in the leaves and stem aid in maintaining plant erectness, reducing lodging and resisting attacks by fungi and pests – amongst other benefits. One of the best known benefits of Si in South African sugarcane is the reduction of eldana damage due to hardening of the stalk rind[5,6]. A physical barrier, reinforced by Si deposits, makes the rind so hard that fewer eldana larvae can pierce it; in fact, their mandibles can become severely and visibly worn by the hardened rind. Increased time spent attempting to bore through the stalk rind makes the larvae more vulnerable to predators. Silicon is also believed to contribute to improved frost tolerance and reduced moisture stress.

Soil silicon is also anomalous in another way. Although Si is the second most abundant element in the earth's crust (after oxygen), and is the main constituent of most soils – especially quartz sands – Si in the sugarcane plant is often below threshold levels in South Africa, especially on sandy, acid soils. Generally, high Si availability is associated with soils with a high pH.

Although a number of different Si fertiliser sources have been tested, the most economical sources are slags which may also contain significant amounts of Ca and Mg, and as such can potentially be effective liming agents.

Micronutrients

Micronutrients are either a) essential for plant growth in small quantities or b) improve growth but are not necessarily essential. Whereas tens of kilograms of the macronutrients are usually taken up by the cane crop per hectare, typically only a few grams of the micronutrients are taken up (Figure 7.5). Micronutrient deficiency symptoms are presented in Table 7.2.

Zinc

Zinc (Zn) is essential for the regulation of plant growth and the activity of various enzymes. Amongst the micronutrients, Zn is the one most frequently deficient and areas of Zn deficiency have been noted throughout the world, for a range of crops. Zinc deficiency in the South African sugar industry was first recognised in the early 1960s, where it was largely confined to soils derived from Natal Group Sandstone, both in the KwaZulu-Natal Midlands and on the coastal hinterland[7]. Over-application of lime, leading to high soil pH, can reduce the availability of Zn to plants.

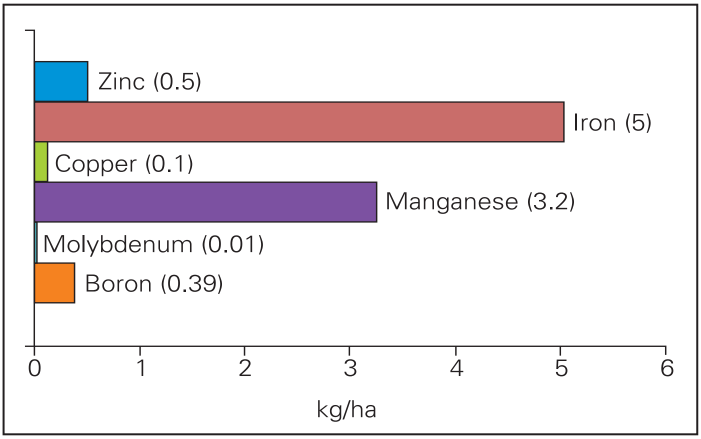

Figure 7.5. Approximate micronutrient content (kg/ha) in a 100 t/ha sugarcane crop.

A number of fertiliser blends contain Zn, and zinc sulphate (22% Zn) can also be applied to ameliorate the problem especially when used in the furrow. Zinc deficiency can be identified by soil analysis.

Iron

Iron is essential for the production of chlorophyll and is a vital plant nutrient, albeit in low quantities. Iron deficiency symptoms – areas of pale yellow or white cane (Figure 7.6) – are called 'ratoon chlorosis', which is commonly seen between October and December, particularly after periods of overcast conditions. Two kinds of chlorosis have been identified:

- *Alkaline chlorosis* occurs in regions where soil pH is high (typically pH > 7.5), either due to repeated high applications of liming materials or due to natural free limestone in the soil. Alkaline chlorosis occurs commonly in the Mount Edgecombe area due to excessive application of liming materials.
- *Acid chlorosis* occurs under acid soil conditions, where Fe deficiency results from excessive manganese uptake under cool wet growing conditions. Acid chlorosis occurs more commonly in the KwaZulu-Natal Midlands.

Both alkaline and acid chlorosis can be treated with applications of ferrous sulphate, sprayed onto the plants at the five to six leaf stage (see Chapter 8). There is no effective soil treatment for alkaline chlorosis, though acid chlorosis can be prevented through the use of dolomitic lime.

Figure 7.6. Symptoms of iron deficiency or 'ratoon chlorosis' in sugarcane characterised by yellow/white stripes in the interveinal areas.

Copper

Copper (Cu) is essential for the activity of various enzymes, including those responsible for respiration and photosynthesis. Copper availability to plants is generally reduced by high soil pH and high organic matter content. Copper deficiency is seldom encountered in South African sugarcane crops, but when diagnosed it can be corrected by a foliar spray of copper sulphate (see Chapter 8).

Manganese

Manganese (Mn) has both positive and negative effects on sugarcane growth. It is vital for plant growth as an activator of various enzymes, particularly those involved in cellular respiration and protein synthesis. However, too much Mn can induce Fe deficiency, as mentioned earlier.

Manganese becomes more available in the soil at low pH values (pH < 5.5), and it is in this pH range that Fe deficiencies can occur. Manganese is generally found in sufficient quantities in South African soils, but its uptake by plants can be inhibited by various factors, including soil pH in the range of 6.5 to 8.7. Low pH in certain soils may increase Mn solubility, resulting in toxic levels of Mn. This could inhibit plant growth. Manganese toxicity on acid soils can be alleviated by liming.

Molybdenum

Although molybdenum (Mo) is needed by the plant in extremely small quantities, it is nonetheless essential to sugarcane for N metabolism. Interestingly, it is also needed by legumes for N fixation, especially under conditions of low pH. Molybdenum is not routinely measured in soil or leaf samples, but if deficiency is suspected, it can be corrected by the application of sodium molybdate (39.7% Mo). Molybdenum becomes less available in the soil below pH 5.5, so the application of lime to raise the pH is another method of increasing plant available Mo. It is also found in trace quantities in many dry bulk blend fertilisers. Molybdenum toxicity is rare in South African soils.

Boron

Boron (B) is essential for sugar translocation, protein synthesis and cell wall formation, but it can also become toxic, and the range between ‘sufficient’ and ‘toxic’ B levels is very small. It is thus easy to over-supply, and extreme caution should be exercised when applying this nutrient. Boron is most likely to be deficient on well-drained, sandy soils, or soils where the over-application of lime has raised the pH above 6. If a deficiency is diagnosed, it can be corrected by the application of various B compounds (see Chapter 8).

Deficiency and toxicity symptoms

Visual deficiency and toxicity symptoms are of limited value for diagnostic purposes, as other factors such as climate, diseases, pests, chemicals and deficiencies of other nutrients may contribute to the observed symptoms. Accurate establishment of a deficiency should be determined by taking a leaf or soil sample (see Chapter 9).

Table 7.2. Visual nutrient deficiency and toxicity symptoms in sugarcane[8].

Nitrogen (N)
Leaves affected: Older leaves in particular
Deficiency symptoms: • General yellowing of the cane • Slower growth • Tips and margins of older leaves die off prematurely (see Figure 7.2)
Phosphorus (P)
Leaves affected: Most pronounced in older leaves
Deficiency symptoms: • Leaf tips and margins can turn red or purple in direct sunlight • Leaves narrower and shorter than usual • Whole crop can turn dark green to blue-green • Tillering can be reduced to zero under severe shortages
Toxicity note: • Excess P can induce deficiencies of micronutrients such as Zn and Fe
Potassium (K)
Leaves affected: Older leaves affected
Deficiency symptoms: • Leaf borders and tips start to die back (see Figure 7.3) • Older leaves may be entirely brown or ‘fired’ • Red discolouration occurs on the midrib • Spindles become distorted, bunching the top leaves together to give a ‘witch’s broom’ effect
Calcium (Ca)
Leaves affected: Both older and younger leaves affected
Deficiency symptoms: • Older leaves: mottled, ‘rusty’ appearance • Younger leaves: leaf tips curl under, giving a ‘hooked’ appearance • Spindles die back at the tip and along the edges; tiny yellow lesions form with dead centres • Rind becomes soft, stalks slender and rapidly tapering
Toxicity note: • Ca toxicity rare • Excessive calcitic lime might result in other nutritional problems associated with high pH

Magnesium (Mg)
Leaves affected: Older leaves affected
Deficiency symptoms: • Mottling starts at the leaf tip and along the margins • ‘Rusty’ appearance • Stalk may show internal browning
Toxicity note: • Mg toxicity is rare, though very high levels are reported to suppress uptake of other cations such as K
Sulphur (S)
Leaves affected: Younger leaves affected
Deficiency symptoms: • Leaves become uniformly yellowed; may develop a faint purplish tinge • Apical meristems remain alive; immature leaves yellow but do not wilt • Stalks slender
Toxicity symptoms: • Younger leaves: yellow streaks run full length of leaf blade; tips and margins die off • Older leaves not affected • Symptoms occur 3 - 7 days after exposure
Silicon (Si)
Leaves affected: Older leaves affected
Deficiency symptoms: • Minute circular white leaf spots (‘freckles’) • Poor tillering • Older leaves die prematurely
Zinc (Zn)
Leaves affected: Younger leaves affected
Deficiency symptoms: • Yellow streaks appear along veins of leaf blade, gradually widening until only the leaf margin and midrib remain green • Leaves noticeably short, and wide at the mid-point • Light green longitudinal strips along leaf margins, dark green midrib • Reduced tillering, shorter internodes, stalks less turgid • Deficiency accentuated by high soil pH, sodic soils or after high applications of banded phosphates and potassium chloride • Functioning of P may be impaired by Zn deficiency

Iron (Fe)

Leaves affected: Younger leaves affected

Deficiency symptoms:

- Leaves show pale yellow or white stripes in interveinal areas, gradually becoming uniformly white where deficiency is acute (see Figure 8.5)
- Patchy growth and reduced yields due to lowered chlorophyll content

Copper (Cu)

Leaves affected: Younger leaves affected

Deficiency symptoms:

- Apical meristems remain alive; immature leaves yellow and wilt
- Green blotches appear; leaves eventually bleach, becoming paper-thin and rolled
- Stalks can develop ‘droopy-top’ disease, where reduced turgor gives the plant a wilted appearance
- General vigour and tillering reduced
- Cu deficiency usually observed in young plants where root system is not yet fully developed

Manganese (Mn)

Leaves affected: Younger leaves affected

Deficiency symptoms:

- Apical meristem remains alive; immature leaves show varying degrees of yellowing but do not wilt
- Yellowing between the veins from tip to middle of leaves; these stripes may bleach and leaves may fray in the wind

Toxicity symptoms:

- Low pH in certain soils may result in Mn toxicity, due to increased Mn solubility. Plant growth is reduced. Dead spots (‘leaf freckle’) appear on leaf blade

Molybdenum (Mo)

Leaves affected: Older leaves affected

Deficiency symptoms:

- Short longitudinal yellowed streaks on apical third of the leaf (i.e. closest to the tip); leaves can start to die back
- General symptoms similar to those of mild Pokkah Boeng disease

Boron (B)
Leaves affected: Younger leaves affected
Deficiency symptoms: • Leaves become distorted and yellowed • Translucent lesions or 'water sacks' form between the veins • Ladder-like lesions on the leaves and serrations on the leaf edges • Apical meristems die • Similar to Pokkah Boeng disease or herbicide damage
Toxicity symptoms: • Yellowing (but not wilting) of tips and margins of immature leaves, progressing from the base to the tip • Leaf tips may be severely burned • Apical meristems remain alive

SUMMARY

- Nutrients essential for crop growth can be divided into macronutrients and micronutrients.
- Macronutrients are taken up in large quantities and include nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and sulphur (S).
- Although not usually regarded as a macronutrient, silicon (Si) plays an important role in the plant and can be taken up in large quantities.
- Micronutrients are those nutrients that are either essential in small quantities or those that will improve plant growth but are not necessarily essential. Important micronutrients for sugarcane are zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo) and boron (B).

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Chapter 8

NUTRIENT APPLICATION AND MANAGEMENT

Nutrient Application and Management

In this chapter, the composition of commonly used inorganic fertilisers is described, followed by an explanation of important fertiliser calculations that will assist in establishing the amount and type of fertilisers to apply. Much attention is devoted to the timing and placement of fertiliser as this can have important consequences on cane yield and nutrient use efficiency. Various application methods are described. The chapter ends with a section on the use and application of a range of organic amendments.

Inorganic fertilisers

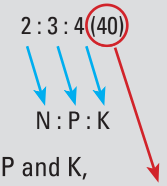
The fertilisers applied most commonly by sugarcane growers are those which include one or more of the three primary nutrients, nitrogen (N), phosphorus (P) and potassium (K). Fertilisers often contain bulking and stabilising ingredients, meaning that only a certain percentage of the fertiliser comprises the nutrient itself; this percentage is usually shown next to the name of the fertiliser (e.g. 'superphosphate 10.5%' fertiliser contains 10.5% P).

Fertilisers are classified as *straights, compounds* or *blends*.

- Straights contain only one of the macronutrients; for example, urea or LAN, which supply only N.
- Compounds contain two or more of the macronutrients in a single particle

Figure 8.1. The timing and placement of fertilisers can have important consequences for cane yield and nutrient use efficiency.

Box 8.1. South African blends



Ratios of N, P and K, which together make up 40% of this fertiliser.

(e.g. monoammonium phosphate – MAP – which contains both N and P).

- Blends are mixtures of particles of different chemical compounds. Blends supply two or more of the macronutrients. In South Africa, blends typically do not have a specific name, but are simply identified by three numbers, which reflect the N, P and K ratio in the product. For example, 2:3:4 (40) contains 2 parts N, 3 parts P, 4 parts K, and these three nutrients in total make up 40% of the entire contents of the bag (Box 8.1).

Table 8.1 lists some of the commonly used fertilisers in South Africa. Many growers prefer to apply a blend of nutrients, to reduce the number of application events. Such blends supply various amounts and concentrations of the three main nutrients, N, P and K. Other sources of nutrients include various by-products of the sugarcane and other industries; these are discussed later in this chapter.

Nitrogen carriers

A 'carrier' is the term used to describe the fertiliser material containing the plant nutrients. The commonly used N carriers in the South African sugar industry are urea, limestone ammonium nitrate (LAN) and ammonium sulphate nitrate (ASN). Other products such as diammonium phosphate (DAP) and monoammonium phosphate (MAP) also contain some N (Table 8.1). Anhydrous ammonia supplies N in gaseous form; it is injected into the soil and can be an effective carrier, provided the soil conditions are suitable.

Urea is generally the most cost-effective and widely used N carrier in the South African sugar industry. Large amounts of the N in urea can, however, be lost through volatilisation (i.e. lost to the atmosphere before the plants can access it) on certain soils. For this reason, SASRI's Fertiliser Advisory Service (FAS) recommends the use of LAN (rather than urea) on very sandy soils, soils with a high pH, or soils covered with a trash blanket.

Different N fertilisers cause varying degrees of soil acidification. The choice of N carrier depends on various soil properties, as well as price.

Phosphorus carriers

'Straight' P carriers such as superphosphate ('supers') are seldom used by growers as they are an expensive form of P. More often, compounds (such as MAP or DAP) or blends are used, so that P is applied simultaneously with N and/or K.

Potassium carriers

Potassium chloride (KCl; 50% K) is the most popular choice of K carrier in the sugar industry. Potassium sulphate (40% K) is an alternative K source, which includes S and no chloride; it can, however, be prohibitively expensive.

Table 8.1. Selected macronutrient content of some commonly used inorganic fertilisers in South Africa.

Fertiliser	Urea-based*	LAN-based*	% N	% P	% K	% S
Urea			46.0	-	-	-
Limestone ammonium nitrate (LAN)			28.0	-	-	-
Ammonium sulphate			21.0	-	-	23.0
Ammonium sulphate nitrate (ASN)			27.0	-	-	12.8
Superphosphate (10.5 %)			-	10.5	-	10.2**
Potassium chloride (KCl)			-	-	50.0	-
Potassium sulphate			-	-	40	17.6
Diammonium phosphate (DAP)			18.0	20.0	-	-
Monoammonium phosphate (MAP)			11.0	22.0	-	-
Ammoniated Supers (AMP)			3.8	12.2	-	9.8
Anhydrous ammonia			82.0	-	-	-
1:0:1 (36)		LAN	18.0	-	18.0	-
1:0:1 (48)	Urea		24.0	-	24.0	-
2:0:3 (38)		LAN	15.2	-	22.8	-
2:0:3 (49)	Urea		19.6	-	29.4	-
2:3:2 (22)	Urea		6.3	9.4	6.3	-
2:3:4 (30)	Urea		6.7	10.0	13.3	-
2:3:4 (40)	Urea		8.9	13.3	17.8	-
3:1:4 (39)		LAN	14.6	4.9	19.5	-
3:1:4 (45)	Urea		16.9	5.6	22.5	-
3:1:5 (38)		LAN	12.7	4.2	21.1	-
3:1:5 (45)	Urea		15.0	5.0	25.0	-
4:0:5 (38)		LAN	16.9	-	21.1	-
4:0:5 (48)	Urea		21.3	-	26.7	-
4:1:0 (32)		LAN	25.6	6.4	-	-
4:1:0 (42)	Urea		33.6	8.4	-	-
4:1:6 (38)		LAN	13.8	3.5	20.7	-
4:1:6 (47)	Urea		17.1	4.3	25.6	-
5:1:5 (36)		LAN	16.4	3.3	16.4	-
5:1:5 (46)	Urea		20.9	4.2	20.9	-
6:1:7 (38)		LAN	16.3	2.7	19.0	-
6:1:7 (47)	Urea		20.1	3.4	23.5	-
6:1:8 (37)		LAN	14.8	2.5	19.7	-
6:1:8 (46)	Urea		18.4	3.1	24.5	-

* blends containing N can be urea-based or LAN-based. LAN-based products are generally preferred where volatilisation potential is high.

** may vary with product formulation.

Fertiliser calculations

When soil samples are sent to a laboratory such as SASRI's Fertiliser Advisory Service (FAS), the results usually include a recommendation on the amount of N, P and K required for the field, in kg/ha. Some laboratories, including FAS, also indicate the type and amount of fertiliser that can be applied in order to supply these nutrients in the correct amounts and ratios. Not all laboratories, however, indicate which fertilisers should be used; it is therefore important for users to perform these calculations themselves. The examples that follow show some useful calculations when considering the amount and type of fertilisers to apply. Note that most fertilisers are supplied in 50 kg bags, so many of the answers are rounded off to indicate the number of bags to be purchased.

Calculating the amount of each nutrient in a specific blend

Assume you have a fertiliser blend 2:3:4 (40) and you want to calculate the percentage of N, P and K present:

N: 40% x 2/(2+3+4) = 8.9% N

P: 40% x 3/(2+3+4) = 13.3% P

K: 40% x 4/(2+3+4) = 17.8% K

Total N + P + K = 40%

Therefore, in 100 kg of 2:3:4 (40), there will be 8.9 kg N, 13.3 kg P and 17.8 kg K.

Figure 8.2. Farmers need to perform a few basic calculations to establish the amount and type of fertilisers they need to purchase.

Calculating the amount of fertiliser to apply

Example 1: *Mr Zungu needs to apply 20 kg/ha of P to his field. The field is 1 ha. He decides that he will use superphosphate (10.5%). How many bags of superphosphate does he need to buy?*

Superphosphate has 10.5% P

20 kg/ha x (100/10.5) x 1 ha = 190.5 kg superphosphate to be applied to his 1 ha field.

Superphosphate comes in 50 kg bags, so 90.5 kg ÷ 50 kg = 3.81 bags.

He cannot order 3.81 bags from the supplier, and therefore needs to round up and buy 4 bags of superphosphate.

Example 2: *Mr Blamey needs to apply 120 kg N/ha to his field. The field is 5.3 ha. He decides that he will use urea. How many bags of urea does he need to buy? How much will this cost him, if the current price of urea is R5 000 per ton?*

Urea has 46% N

120 kg/ha x (100/46) x 5.3 ha = 1 382.6 kg urea to be applied to his field of 5.3 ha.

Urea comes in 50 kg bags, so

1 382.6 kg ÷ 50 kg = 27.65 bags.

He cannot order 27.65 bags from the supplier; he therefore needs to round up and buy 28 bags of urea.

Assume that each ton of urea costs R5 000. 1 ton = 1 000 kg.

One kg of urea therefore costs

R5 000 ÷ 1000 = R5 per kg of urea.

One bag (50 kg) of urea therefore costs

R5 x 50 = R250 per bag.

He needs to buy 28 bags; therefore he will spend R250 x 28 = R7 000 on the urea he needs for his field.

How much do the nutrients cost in each type of fertiliser?

Which carrier is cheaper, per unit N: urea, or LAN? Assume that the current price of urea is R5 000 per ton, while LAN costs R3 660 per ton.

Each ton of urea costs R5 000. 1 ton = 1 000 kg.

One kg of urea therefore costs

R5 000 ÷ 1 000 = R5 per kg of urea.

Urea contains 46% N, so each kg of N costs

R5 x (100/46) = R10.87 per kg N in urea.

Each ton of LAN costs R3 660. 1 ton = 1 000 kg.

One kg of LAN therefore costs

R3 660 ÷ 1 000

= R3.66 per kg of LAN.

LAN contains 28% N, so each kg of N costs

R3.66 x (100/28)

= R13.07 per kg N in LAN.

LAN is therefore the more expensive* N carrier per unit of N applied, but losses are less and more N might be taken up by the plant.

*at the costs used in this exercise

To apply straights or blends?

Mrs Smith needs to apply 100 kg N, 20 kg P and 150 kg K per ha to a field. Calculate how much fertiliser she should apply per ha, a) as 'straights' (urea, supers and potassium chloride) and, b) as a blend. Which would be the cheaper option?

a) Straights

Urea:

Urea has 46% N

100 kg/ha x (100/46)

= 217.4 kg urea per ha,

or (217.4 ÷ 50) = 4.3 bags,

rounded up to 5 bags/ha

Supers:

Supers has 10.5% P

20 kg/ha x (100/10.5)

= 190.5 kg supers per ha,

or (190.5 ÷ 50) = 3.8 bags,

rounded up to 4 bags/ha

Potassium chloride:

KCl has 50% K

150 kg/ha x (100/50)

= 300 kg KCl per ha,

or (300 ÷ 50) = 6 bags/ha

b) Blends

Mrs Smith has access to the following blends: 5:1:5 (46), 3:1:4 (45) and 6:1:8 (46). Which blend should she buy to apply 100 kg N, 20 kg P and 150 kg K per ha, and how much should she apply per ha?

<table>
<tr><th>5:1:5 (46)</th><th>3:1:4 (45)</th><th>6:1:8 (46)</th></tr>
<tr><td>This blend contains
N: 46 % x 5/(5+1+5) = 20.91 % N
P: 46 % x 1/(5+1+5) = 4.18 % P
K: 46 % x 5/(5+1+5) = 20.91 % K</td><td>This blend contains
N: 45 % x 3/(3+1+4) = 16.88 % N
P: 45 % x 1/(3+1+4) = 5.63 % P
K: 45 % x 4/(3+1+4) = 22.50 % K</td><td>This blend contains
N: 46 % x 6/(6+1+8) = 18.40 % N
P: 46 % x 1/(6+1+8) = 3.07 % P
K: 46 % x 8/(6+1+8) = 24.53 % K</td></tr>
<tr><td>So, 100 kg of the blend would contain 20.91 kg N, 4.18 kg P and 20.91 kg K</td><td>So, 100 kg of the blend would contain 16.88 kg N, 5.63 kg P and 22.5 kg K</td><td>So, 100 kg of the blend would contain 18.4 kg N, 3.07 kg P and 24.53 kg K</td></tr>
<tr><td colspan="3">After this, it's a case of experimenting with different rates of the blends until a suitable ratio of N:P:K is found. This is made easier if a simple spreadsheet is set up on your computer.</td></tr>
<tr><td>For example:
300 kg of this blend would contain three times the nutrients in 100 kg, i.e. 62.73 kg N, 12.54 kg P and 62.73 kg K.</td><td>For example:
300 kg of this blend would contain three times the nutrients in 100 kg, i.e. 50.64 kg N, 16.89 kg P and 67.5 kg K.</td><td>For example:
300 kg of this blend would contain three times the nutrients in 100 kg, i.e. 55.2 kg N, 9.21 kg P and 73.59 kg K.</td></tr>
<tr><td colspan="3">After having tried a number of different rates of these blends, the ones that come closest to 100:20:150 are:</td></tr>
<tr><td>500 kg of this product, containing 105 kg N, 21 kg P and 105 kg K.
N and P roughly correct; K is far too little.</td><td>650 kg of this product, containing 110 kg N, 37 kg P and 146 kg K.
Roughly correct for N and K; almost double the P that is needed.</td><td>600 kg of this product, containing 110 kg N, 18 kg P and 147 kg K.
P and K roughly correct; N slightly more than needed.</td></tr>
</table>

From this choice of blends, Mrs Smith should choose 600 kg/ha of 6:1:8 (46), because it gives the closest blend to 100 N: 20 P: 150 K. This translates to 12 bags per ha.

Note: It is almost impossible to find a blend that will give exactly the right amount of nutrients per hectare. Sometimes a 'top up' can be applied as a straight fertiliser; for example, if too little K is supplied in the blend, one can 'top up' the field with KCl.

Costs

*Assume that the fertiliser costs the following (per bag): **Urea** - R250, **Supers** - R200, **KCl** - R275 and **6:1:8 (46)** - R350.*

Therefore, applying straights would cost Mrs Smith:

Urea: 5 bags x R250/bag = R1 250/ha

Supers: 4 bags x R200/bag = R800/ha

KCl: 6 bags x R275/bag = R1 650/ha

Total straights: R3 700 per ha.

And applying the 6:1:8 (46) blend would cost her: 12 x R350/bag = R4 200 per ha.

It would therefore be cheaper for Mrs Smith to apply the straights (at these prices), but the added cost and effort of applying each fertiliser separately needs to be taken into account.

Fertiliser tables: How much nutrient in each fertiliser?

There are tables available to make fertiliser calculations easier. See Appendix I for tables listing a number of the more common fertilisers, their nutrient content and the amounts to apply.

Micronutrient application rates

Micronutrient deficiencies, determined by soil or leaf test or (less reliably) by visual symptoms (see Chapter 7), can usually be corrected by standard application rates of specific fertilisers. Table 8.2 lists the micronutrients more commonly required in sugarcane fields, and their application rates. Sulphur, although not a micronutrient, has been included because laboratories do not often provide application rates.

Fertiliser application: timing and placement

Once the correct fertiliser has been chosen, due consideration must be given the timing and placement of this fertiliser as this can have important effects on cane yield and nutrient use efficiency. Application of N, P and K will be discussed here while Ca and Mg were discussed in Chapter 6. Trace elements are often applied in small amounts in other fertilisers, and are otherwise only applied when a specific deficiency is suspected.

Nitrogen application

The timing of N fertilisation can have a major impact on the efficiency of use of N by the crop. Because N can be lost in numerous ways, it needs to be applied at just the right time to avoid losses by volatilisation (gaseous loss to the atmosphere), leaching (being washed out of the soil by heavy rainfall or irrigation) or denitrification (loss to the atmosphere under waterlogged conditions). It needs to be applied at a time when the plant roots are sufficiently developed to be able to use the N, but well in advance of harvest so that cane quality is not affected. On certain soils, high N losses make it preferable to apply the N in split applications, so that the roots have a greater chance of taking it up.

Once soil samples have been submitted for analysis and a fertiliser recommendation obtained, N needs to be applied according to the specifications in the laboratory report. FAS's N recommendations are based on the following criteria:

- the organic matter and clay levels in the topsoil
- the attainable yield (as specified on the soil sample submission form)
- residual N from cover crops.

Nitrogen should not be applied until growth commences. If moisture and temperature are not favourable, N should not be applied.

Plant cane

Less N is generally recommended for plant cane than ratoon cane, as some N is released from the soil during land preparation before planting. About one third of the recommended N should be applied in the furrow at planting; too much N in the furrow at planting could burn the cane setts. The remaining N should be topdressed later. For spring, summer and early autumn crops, the balance should be banded on the row 6 - 10 weeks after planting; while for late autumn and winter-planted crops, N should be banded on the row when the cane is knee height, though not later than early spring. Note that if the laboratory determines that volatilisation potential is moderate, topdressed urea should be broadcast, not banded.

Table 8.2. Sulphur and micronutrient application rates.

Deficient nutrient	Product to correct deficiency	Application rate and method
Sulphur (S)[1]	• Gypsum (15 - 18% S) • Ammonium sulphate (22 - 24% S) • Ammonium sulphate nitrate (ASN) (12.8% S)	Plant cane: • Apply 600 kg/ha gypsum in the furrow Ratoon cane: • Acid soils: 300 kg/ha gypsum as a top-dressing on every second ratoon, banded on the row • Neutral/alkaline soils: Application of N as ammonium sulphate or ASN on every second ratoon will supply adequate S.
Zinc (Zn)[2]	• Zinc sulphate (heptahydrate – 22% Zn) • Suitable zincated fertiliser blend (e.g. 2:3:4 (30) + 0.5% Zn)	Plant cane: • 10 kg/ha Zn in the furrow Ratoon cane: • If cane < 6 months, Zn may be applied as foliar spray of 1% zinc sulphate in 250 L/ha. • Otherwise, topdress 10 kg/ha Zn over the row after harvest.
Iron (Fe)[3]	• Ferrous sulphate (19 - 20% Fe)	Foliar Spray: • 1 - 1.5% solution ferrous sulphate foliar application at the rate of 300 - 400 L/ha. • Apply at 5 - 6 leaf stage.
Copper (Cu)[4]	• Copper sulphate (monohydrate (35% Cu) or pentahydrate (25% Cu)) • Copper chloride (47% Cu)	Foliar Spray: • 5 kg Cu per ha: - 14 kg/ha copper sulphate (monohydrate - 35% Cu) or - 20 kg/ha copper sulphate (pentahydrate - 25% Cu) or - 10 kg/ha copper chloride (47% Cu) • Mix with 300 - 400 L/ha water.

Deficient nutrient	Product to correct deficiency	Application rate and method
Manganese (Mn)	• Manganese chloride (17% Mn) • Manganese sulphate (23 - 28% Mn)	Topdress or furrow soil application: • 20 kg Mn per ha: - 118 kg/ha manganese chloride or - 74 kg/ha manganese sulphate Foliar spray: • 1 - 2 kg Mn per ha: - 4 - 8 kg/ha manganese sulphate in 400 L water
Molybdenum (Mo)[5]	• Agricultural lime, applied to soils with $pH_{(CaCl2)} < 4.8$, will make Mo more available • Sodium molybdate (39% Mo)	Topdress or furrow soil application: • 250 g Mo per ha at planting. - 640 g/ha sodium molybdate Foliar Spray: • 100 g Mo per ha - 0.25 kg/ha sodium molybdate - Mix with 200 - 300 L/ha water and apply with a knapsack.
Boron (B)[5]	• Solubor (20% B) • Boric acid (17% B) • Borax (11% B)	Topdress or furrow soil application: • 1 kg B per ha - 5 kg/ha Solubor or - 6 kg/ha boric acid or - 9 kg/ha Borax. Foliar Spray: • 0.4 kg B per ha - 2 kg/ha Solubor or boric acid - Mix with 200 - 300 L/ha water.

Note:

- It is essential that soil-applied micronutrients be applied *evenly* over the field. One way to achieve this is to bulk-up the micronutrients with small amounts of gypsum or lime before spreading.
- Foliar applications of nutrients often perform more effectively when applied with adjuvants such as wetters. Consult your chemical representative for advice on suitable products.

Ratoon cane

After harvest, there is a period when very little new root or shoot material is available for N uptake and storage. This period can be quite long in winter-harvested fields. Growers should be careful not to apply N too soon after harvesting: N left unused in the field is very prone to leaching, especially if heavy rainfall occurs during the period when root development is limited. Nitrogen should therefore be applied only after vigorous regrowth has commenced.

Box 8.2. Nutrient management to limit environmental risk

Unwise use of both organic and inorganic fertilisers can lead to environmental pollution. It is the duty of every grower, as custodian of agricultural land, to avoid pollution where possible.

Two of the biggest culprits for groundwater pollution are N and P.

Nitrogen is easily washed (leached) out of the soil. This occurs particularly in situations where the plant has been unable to take up the applied N, due to:

- over-application of N,
- surface runoff of the N before it can be washed into the soil, or
- application during periods when the plant is not growing rapidly enough to take up the N.

Just as N acts as a fertiliser for sugarcane crops, it also acts as a fertiliser in aquatic systems: when too much N is washed into a watercourse, it promotes an explosion of plant and algae growth, knocking the system out of balance. The plants and algae deplete the available oxygen supply – so-called ‘eutrophication’ – and in extreme cases, dead zones are created, where nothing can live. This has potentially devastating effects on commercial and non-commercial marine populations. Nitrogen pollution from sugarcane farming has been listed as one of the reasons for the degradation of the Great Barrier Reef off north-eastern Australia.

A less well known effect of excess N in waterways is that, once this N reaches the sea, the increased nutrient load in the water causes increased growth of marine algae. Although this activity sequesters or ‘locks up’ carbon dioxide from the atmosphere – a positive spinoff – the process produces nitrous oxide (N_20), a greenhouse gas far more potent than carbon dioxide.

Phosphorus is another culprit causing eutrophication or excessive nutrient load in water bodies. Over-applying P fertilisers should be avoided; keep in mind that ‘organic’ nutrient sources, such as poultry manure, are high in P, and their storage and use should be carefully managed. Over-supply of P in surface and ground waters can, in severe cases, lead to human deaths when blue-green algae (a form of cyanobacteria) gets out of hand. Although agriculture is not the only source of P pollution, it is a major culprit in causing the algal blooms that lead to increased water treatment costs, degraded fishing and boating activities, and depressed tourism activities and property values. Because P has traditionally been well supplied on commercial cane farms in South Africa, it is often not necessary to apply more P, especially for ratoon crops. Again, this highlights the importance of regular soil sampling to establish accurately the amount of each nutrient needed by the crop.

In addition, N applications should be split when N losses are likely, for example on sandy or waterlogged soils. Topdressing of lime can also have implications on N application, in particular where urea is the choice of N carrier. Urea should not be applied within the same season that lime has been topdressed; rather choose a different N carrier.

Situations where reduced N rates are recommended

Nitrogen rates should be reduced by 20 - 30 kg/ha where growth limiting factors can be identified. Examples include fields where:

- soils are very shallow
- high eldana numbers are a concern
- nematodes are a problem, but a nematicide is not used
- rainfall is comparatively low
- salinity/sodicity problems exist
- cane is to be harvested at a younger age than usual.

Situations where additional N is recommended

Where N application is followed by excessive rainfall, take a leaf sample to establish the need for extra N. This applies to both one- and two-year crops; some additional N may be required during the second summer of a two-year crop if heavy rainfall was experienced during the first year.

Phosphorus application

Phosphorus is immobile in most soils, and is not prone to gaseous losses. Its application is therefore easier to manage than N. However, since P is of paramount importance for root growth, all the recommended P for the plant crop should be applied in the furrow. This P is generally enough to cover the first ratoon as well. Greater amounts of P will be required on high P-fixing soils, which will be identified by the laboratory.

Potassium application

Like P, K is less subject to losses and soil movement than N. Up to 100 kg/ha K can be placed in the furrow at planting; the remainder should be broadcast and incorporated if tillage is being undertaken. In ratoon crops, all K is broadcast, and applications generally do not need to be split. Potassium recommendations are based on the amount of clay in the soil: generally, the more clay, the greater the K recommended. Irrigated soils with a very high ratio of (Ca + Mg) to K require higher rates of K. This is because high levels of Ca and Mg can limit the amount of K taken up by the plant during winter.

Inorganic fertiliser application methods

Fertiliser can be applied in a number of different ways, depending on the technology available, amount to be applied and area to cover. The most common application methods are discussed below.

Tractor-mounted fertiliser spreaders

These spreaders are commonly used where large areas need to be fertilised. They consist of a bin into which the fertiliser is poured, and a distribution point below the bin, which spreads the fertiliser in a swath behind the tractor (Figure 8.3). The distributor can be an oscillating type

Figure 8.3. A tractor-mounted fertiliser spreader.

(a moving outlet pipe) or a spinning disc. Applying fertiliser with these spreaders requires very careful calibration, as distribution and fertiliser rate depends on the speed of movement of the tractor. See Appendix II for calibration details.

Knapsack granule fertiliser applicator

Granular fertilisers are commonly applied on steep slopes using a knapsack applicator (Figure 8.4). This applicator has a pipe for fertiliser release and allows efficient banding of fertiliser in areas where steep slopes prohibit the use of machinery. The applicator has single or double row configuration, and can be adjusted to apply fertiliser in a broad swath (for broadcasting) rather than a band, if necessary. See Appendix II for calibration details.

Figure 8.4. A knapsack applicator.

Figure 8.5. A wheelbarrow applicator.

Wheelbarrow applicator

This applicator has a small fertiliser bin which distributes fertiliser in a band (Figure 8.5). Calibration of the applicator needs to consider row width, speed of travel and fertiliser type (see Appendix II for details). The slot below the bin can be widened or narrowed to increase or reduce the rate of fertiliser release.

Fertigation

Growers with drip irrigation have the option of applying their fertiliser through dripper lines. This practice is called 'fertigation'. If managed properly, fertigation can be a very efficient way of applying fertiliser, particularly N, which will infiltrate into the soil, rather than be left on the surface where it is prone to volatilisation. Fertigation also allows more split applications: N fertiliser can be applied in up to 10 splits for a winter-harvested crop (though not within two months of harvesting this crop), and 4 - 5 splits during the first five months after a summer harvest. Fertiliser is dissolved in water in a mixing tank before being sent through the irrigation system. It is important to know which types of fertiliser are suitable for use in fertigation – not all types are easily soluble in water – and how often fertiliser can be applied. Fertigation specialists should be contacted for further advice on suitable nutrient sources. Fertigation is not suitable for poorly drained or saline soils.

Injection of anhydrous ammonia

Anhydrous ammonia, a gaseous N carrier, can be injected into the soil. It can be an effective carrier, provided that the soil seals well after injection. Very clayey soils can therefore be problematic if clods prevent effective sealing; optimal water content of the soil during application is thus important. Contractors with the correct equipment and know-how should be used to apply this product. There is some evidence that anhydrous ammonia decreases the number of plant-parasitic nematodes in the soil;

Figure 8.6. Injection of anhydrous ammonia.

it has a fumigation effect which kills most soil microbes, but only within a very narrow strip on either side of the injection line.

Tin-and-string method

One of the oldest and most reliable ways of applying fertiliser is the tin-and-string method. This method can be used on both small and large areas, though availability of staff might make it prohibitive on large estates. In this method, a tin of a certain size is filled with fertiliser. A person then dribbles the fertiliser out over a certain distance – marked out by a length of string (Figure 8.7). The tin and length of string should be calibrated for each fertiliser type and rate. This method can be very effective over large areas when a group of 4 - 6 people, each

Figure 8.7. Tin-and-string method.

Figure 8.8. Aerial application of fertiliser.

with a tin, covers the length of one string at the same time. It is important to note that fertiliser should be applied evenly over the distance of the string. Any fertiliser left in the tin when the end of the string is reached should be spread evenly back over the entire length of the string. See Appendix II for details on how to calculate the length of string required for each tin and fertiliser type.

Appendix III contains calculations which have been done for numerous types of fertiliser and row spacing, showing the correct string length for a 500 ml tin.

Aerial application

When urea is applied aerially a fixed-wing aircraft is commonly used (Figure 8.8). This application method is surprisingly cost-effective, though evenness of application will depend on the skill of the contractor and prevailing weather conditions.

Organic amendments: use and application

Products added to the soil as alternative sources of nutrients and which are derived from living organisms are known as organic amendments. A number of these products are routinely used in the South African sugar industry. They vary in their rates of decomposition, which affect the ease with which nutrients are mineralised (released) for plant use. As mentioned in Chapter 5, the C:N ratio is a particularly important characteristic of organic matter that affects the rate of decomposition. Knowing the C:N ratio of organic amendments is very useful when deciding which organic amendment to use.

It is important to bear in mind that the same source of organic matter product may vary from batch to batch. For this reason, although the typical nutrient content of each of the organic amendments is described in this chapter, organic amendments should always be analysed prior to use to ensure that actual nutrient content of the product is known and thereby applied more accurately.

Table 8.3 lists some of the organic amendments used in the South African sugar industry, along with typical C:N ratios and N, P, K and moisture contents. Each of these will be discussed in the sections to follow.

Organic amendments are a valuable source of nutrients. In addition, they have a positive effect on the physical properties of the soil, and because they tend to be waste products they are generally cheaper than inorganic fertilisers. It is important to remember that organic amendments alone are not always able to satisfy the full nutrient requirements of a crop. For example, poultry manure supplies large amounts of N and P, but generally insufficient K for sugarcane production.

Table 8.3. Some of the organic amendments used in the SA sugar industry, along with their typical C:N ratios and N, P, K and moisture contents.

Organic amendment	C:N	N (%)	P (%)	K (%)	Moisture (%)
Bagasse	40:1 to 50:1	0.34	0.27	0.21	>50
Compost	15:1 to 20:1	0.66	0.09	0.55	±55
Condensed molasses stillage (CMS)	26:1 to 45:1	1.0	0.16	5.5	±45
Filtercake	20:1 to 30:1	1 to 2	0.5 to 2.5	0.2 to 0.3	±50
Flyash	20:1 to 150:1	0.1	0.1	0.8	20 to 75
Green manure (legume)	10:1 to 20:1	1.6 to 2.9	0.25	1 to 3	35 to 70
Kraal (farm-yard) manure	17:1	2.4	0.86	1.5	±14
Molasses	30:1 to 60:1	0.65	0.12	2.77	±75
Pith	131:1 to 300:1	0.35	-	0.07	±40
Poultry litter	10:1 to 14:1	3.3	1.6	1.8	20
Poultry manure	6:1 to 15:1	2.5	1.5	1.6	40
Sawdust	>200:1	0.32	0.11	0.14	<20
Sugarcane tops	66:1	0.79	0.18	1.10	60
Sugarcane trash	60:1 to 120:1	0.19	0.11	0.59	15
Vinasse	15:1 to 30:1	0.2	0.09	1.15	85 to 95

Manures and compost

Raw manures (poultry and animal manures) can be excellent sources of N and P and organic matter. There are, however, differences between manures obtained from different sources. In general, poultry manure tends to have higher concentrations of N and P compared to farmyard manure.

Two main types of poultry manure exist – poultry litter and battery manure. Poultry litter comes from broilers which have bedding material (e.g. sawdust). The bedding material (or litter) absorbs the droppings, drying them out a little, and prevents loss of nutrients. In addition, it is easier to handle than battery manure. Battery manure is derived from egg-laying hens that are kept in cages which have no litter. The manure tends to be wet and lumpy and difficult to handle and spread. Nutrient losses occur more easily from battery manure than from chicken litter.

Animal manures are similar to poultry manures in that their nutrient contents vary depending on diet. In addition, all manures (animal and poultry) differ depending on the length of storage time and the manner in which they are stored.

Supplying manures to meet N requirements often results in an over-application of P. This is because manures often contain similar amounts of N and P, but crops require much more N than P. It is therefore recommended that manures be applied at the rate that satisfies the P requirement and not the N requirement of the crop. Over-application of P results in P build-up in the soil, and is thus a potential environmental hazard (see Box 8.2). In addition, manures should not be applied near sensitive areas. Sensitive areas are defined as those close to surface and subsurface water sources and residential and public areas.

Manures contain readily available nitrogen which is easily lost to the atmosphere via volatilisation. For this reason, manures should ideally be incorporated into the soil to maximise nitrogen efficiency.

Figure 8.9 illustrates nitrogen losses from different incorporation methods. In the first instance, poultry manure is broadcast and left on the soil surface, in the second it is applied to the surface and incorporated less than 12 hours later, and in the third instance the manure is applied to the soil surface and incorporated less than four days later[6].

The graph shows that incorporating the poultry manure results in less nitrogen loss than broadcasting it. The sooner the nitrogen is incorporated into the soil, the lower the nitrogen loss. Alternatively, it can be applied in the furrow at planting. In ratoon crops, incorporation of the product in the interrow is the best practice; if this is not practical, banding on the row or interrow is preferable to broadcasting over the whole area.

Applying **composted manures** is another option. Composts have some advantages over applying raw manures:

- the nutrients are supplied in a more stable form, allowing less volatilisation and leaching of N,
- the weight and volume of the original product is reduced,
- odours are less offensive, and
- the presence of pathogens and weeds is lowered.

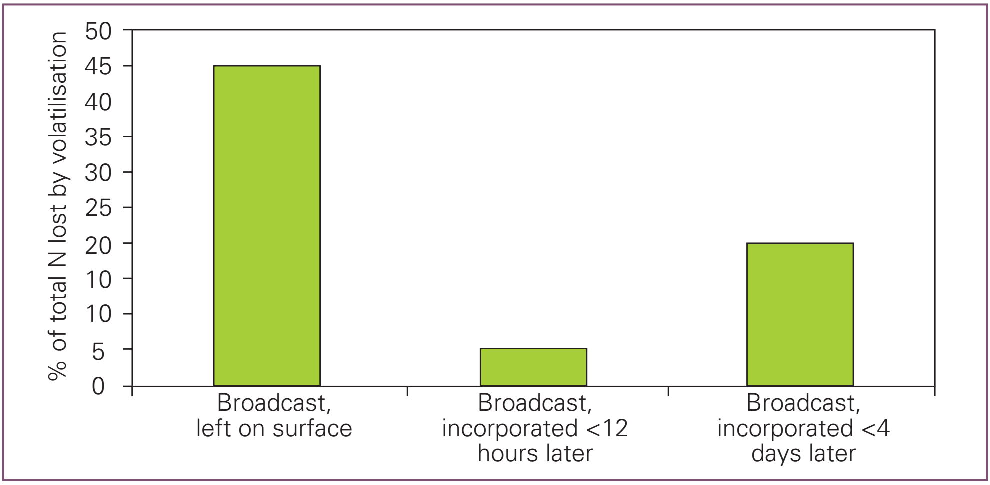


Figure 8.9. Nitrogen losses from poultry manure through volatilisation when left on the surface compared with incorporation[6].

The properties of manures are compared with the properties of composted manure in Table 8.4.

Green manures and cover crops

The practice of growing green crops to improve soil conditions is referred to as 'green manuring'. In the sugar industry, this practice is particularly important to break the sugarcane monoculture and improve overall soil health. Cover crops are crops grown to protect the soil with a living mulch during fallow periods. The terms 'cover crops' and 'green manures' are often used interchangeably.

Green manures have a wide range of properties, and different species can have the following benefits to the soil:

- Breaking pest and disease cycles
- Weed control
- Nematode control

Table 8.4. Properties of raw and composted manures[7].

Raw manure	Composted manure
High availability of nutrients: N, P, K	Low availability of nutrients, especially N
Heterogeneous	Homogeneous
High volume	Low volume
Very biologically active	Biologically stable
Strong odour	Non-offensive odour
Wet	Moist to dry
May contain weed seeds and pathogens	Weed seeds and pathogens killed

- Addition of nitrogen
- Increasing microbial populations
- Increasing organic matter levels
- Protecting the soil surface during fallow periods.

Green manures are generally hardy crops, and do not require a lot of management. Details of crop choice, planting methods and management guidelines can be found in SASRI's Green Manuring manual[8].

Legume green manures 'fix' nitrogen directly from the atmosphere. When these plants decompose, much of this N becomes available to the subsequent cane crop. Nitrogen fertiliser can thus be reduced when this biological N is taken into account. The amount of N available from a legume depends on the species grown, the biomass produced and the percentage of N found in the plant tissues. Not all of the N fixed by legumes becomes available to the cane crop; on average, around 40 - 60% of the total legume N is available. Table 8.5 gives some examples of the amount of N that can become available to a cane crop after various legumes.

Since release of the N from green manures is not immediate, some fertiliser N (typically 40 - 50 kg/ha N) should be applied soon after planting the cane to ensure continuous N supply. Plant N supply should thereafter be monitored by leaf sampling.

Table 8.5. Average nitrogen availability of various green manure crops.

Crop	Dry matter yield (t/ha)	% N*	N availability (kg/ha)**
Sunn hemp (*Crotalaria juncea*)	2 m tall: 9 t/ha	2.5	Total N = 225 kg/ha; assume 110 kg/ha available in the first season.
	1.5 m tall: 4 - 6 t/ha	2.5	Total N = 100 - 150 kg/ha; assume 50 - 75 kg/ha available in the first season.
Cowpeas (*Vigna unguiculata*)	0.6 m tall: 1 - 3 t/ha	2.2	Total N = 22 - 66 kg/ha; assume 10 - 30 kg/ha available in the first season.
Soybeans (*Glycine max*)	Dryland: 3 - 4 t/ha	2 - 2.5	Total N = 60 - 100 kg/ha; assume 30 - 50 kg/ha available in the first season.
	Irrigated: up to 10 t/ha	2 - 3	Total N = 200 - 300 kg/ha; assume 100 - 150 kg/ha available in the first season.
Velvet beans (*Mucuna deeringiana*)	5 - 8 t/ha	2.3	Total N = 115 - 180 kg/ha; assume 55 - 90 kg/ha available in the first season.

*as % of above-ground dry matter

**assuming 50% availability of N to the subsequent crop

Sugarcane tops and trash

Surveys of the South African sugar industry have shown that about 90% of all sugarcane fields are burnt. Industry extremes are the irrigated regions, which burn almost 100% of all fields, and the northern parts of KwaZulu-Natal, near Empangeni, where less than 30% of fields are burnt. Valuable organic matter is lost to the atmosphere during burning.

When sugarcane is trashed at harvest, essentially two organic soil amendments remain on the soil. Firstly, there is the dead sugarcane trash which has a high C:N ratio, but does not have many nutrients which are immediately available to the growing crop. It does however create a blanket over the soil which can help prevent water loss via evapotranspiration (see Chapter 2), maintain a more stable environment for microbial life (Chapter 4) and protect the soil against erosion (Figure 8.10). The other product is the green sugarcane tops, which contain more water and nutrients, and which release nutrients to the crop more rapidly.

Filtercake

Filtercake, a by-product of sugar production, is a mixture of sugar juice, starch, wax, gums and pectins. The composition of the filtercake will vary according to the amount of soil and extraneous material in the cane that is delivered to the mill, the variety, the nature of the milling and clarification process and whether flyash is incorporated.

Originally filtercake was used as a source of P, but more recent research has shown that a crop can benefit from its nitrogen content, and the calcium content can help to overcome calcium deficiencies. In addition, humic acids re-

Figure 8.10. A blanket of sugarcane tops and trash preserves soil moisture and prevents erosion. Green sugarcane tops also release nutrients to the new crop.

Figure 8.11. In addition to providing N, P and Ca, filtercake also improves the physical condition of the soil.

leased from the organic matter in filtercake can help ameliorate Al toxicity.

The N:P:K ratio of filtercake is hardly ever ideally suited to sugarcane production, and as a result, it is usually balanced with inorganic fertilisers. Filtercake generally has 1 - 2% N, 0.5 - 2.5% P and 0.2 - 0.3% K. The application rate of filtercake is dependent on soil type and slope position.

In addition to its nutritional benefits, filtercake improves the physical conditions of the soil by increasing the aggregate stability and infiltration of water. Moisture holding capacity, improved cation exchange capacity, lower soil bulk density and increased rooting depth are also benefits of using filtercake.

Filtercake is typically applied at a rate of 20 - 50 t/ha, with rates of up to 150 t/ha for longer-lasting effects. Care should be taken not to apply the higher rate in areas prone to eldana infestation.

Flyash

Flyash is the residue left in the boilers after bagasse has been burnt to generate steam in the sugarcane factory. It usually contains nutrients such as potassium, calcium, magnesium, sulphur and silicon. Flyash contains very little nitrogen (Table 8.5); however, it contains an appreciable amount of silicon (7 - 18%), calcium (1.5%) and potassium (0.8%) and is therefore of most value as a low-grade source of these nutrients. In addition to this, flyash has a pH that ranges from 7.4 to 9.2.

In freely draining soils, about 200 t/ha of flyash can be applied. Studies have shown that up to 100 t/ha can be applied to sandy soils. If flyash is to be added at planting, only soils with the following characteristics should be considered:

- Freely drained soils
- Electrical conductivity (in a saturated paste) below 200 mS/m because flyash EC may be very high
- Sodium adsorption ratio below 4
- Soils with low available silicon reserves and low pH will receive particular benefit from flyash.

Care should be taken when applying flyash because it may contain certain heavy metals (see Box 8.3). Over-application of coal-derived flyash may contaminate soils and pollute the environment. Flyash should therefore be analysed before application.

Molasses, vinasse and condensed molasses stillage (CMS)

Molasses, vinasse and condensed molasses stillage (CMS) are liquid by-products of sugar and ethanol production. Molasses is a thick, syrupy by-product produced when sugarcane or sugar beet is processed to make sugar. Molasses is used to make alcohol and a residual by-product of this process is called vinasse. Concentrating vinasse produces CMS.

Molasses, vinasse and CMS contain a variety of nutrients including N, P, Ca, Mg and S, but are of most value as a source of K. CMS has a formulation of roughly 7:1:37 in terms of N:P:K. In order to balance the product, commercial suppliers fortify it to supply additional N and P.

Box 8.3. Heavy metals

Heavy metals are widely known to be dangerous soil pollutants, affecting both human and animal health. In agriculture, the most commonly referred to heavy metals include cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), mercury (Hg), arsenic (As), zinc (Zn) and chromium (Cr). In the South African sugar industry, the most important potential sources of heavy metals include animal manure (pig slurry can contain high levels of copper) and sewerage sludge. Most commercial fertiliser products are certified to be free of heavy metals, but for alternative nutrient sources, the onus should be on the supplier to test, and provide certification for, their products.

It is important to remember that all of these products have relatively low pH values and are corrosive. Implements used to apply these products to fields should therefore be resistant to corrosion (Figure 8.11). In addition, molasses is sticky and viscous, and thus difficult to apply. The viscosity of vinasse and CMS is not a problem, and they can be applied with conventional spraying equipment.

Care should be taken when applying these products – overuse is harmful to the environment, especially if they contaminate water sources.

Bagasse

Bagasse is the fibre left over after the juice has been extracted from sugarcane stalks. It is not a good source of nutrients, but is excellent for restoring and maintaining physical properties of the soil. Soils that benefit most from using it are those with low organic mat-

Figure 8.11. Accumulation of potassium chloride from vinasse on the pipework of a vinasse reservoir (left). Vinasse pumphouse with stainless steel piping to minimise the effects of corrosion on maintenance (right).

ter levels (less than 2%), sandy soils and degraded soils. Adding bagasse to soils is likely to cause N immobilisation (see Chapter 5) resulting in nitrogen deficiencies. Bagasse should be thoroughly mixed into the soil to accelerate organic matter decomposition thereby reducing the duration of nitrogen deficiency (see Table 8.5 for bagasse C:N ratio).

Wood shavings and pith

Wood shavings and pith have very high C:N ratios because they contain high lignin contents and therefore decompose very slowly. These products are poor at supplying nutrients to the soil and are therefore usually added to the soil to improve the physical properties, especially when soils are sandy, low in organic matter or degraded[9].

The danger of using these products, however, is that, because of their high C:N ratio, they usually immobilise nitrogen added to the soil as mineral fertiliser, resulting in nitrogen deficiencies in crops despite having applied recommended quantities of N. Recommendations are therefore to add additional nitrogen to the soil to aid decomposition. In addition, the amendments should be thoroughly mixed into the soil.

In certain cases, sawdust is used as a bedding material for broilers, and under these circumstances the litter (sawdust) absorbs the droppings, reducing loss of nutrients. When the sawdust is mixed into the chicken manure, the additional nitrogen from the manure helps to overcome the nitrogen immobilisation effect of the sawdust's high C:N ratio.

Sewerage sludge

Sewerage sludge is an organic amendment. Although it has beneficial soil effects (nutrient supplier, soil conditioner), sewerage sludge from some municipalities might contain harmful substances (heavy metals and human pathogens) and should therefore be used with caution. In addition, there is a potential of strong odour and the ability to attract disease carriers.

Use of sewerage sludge is strictly regulated. Sewerage sludge producers need to have the sewerage sludge classified in terms of the micro-organisms, stability class and pollution hazard, for which there are strict guidelines, to ensure that each of these is within acceptable limits. In addition, continuous monitoring of the product needs to take place. Sewerage sludge users need to comply with the relevant legislation and guidelines.

Alternative growth stimulants

In recent years a number of alternative growth stimulants have entered the market. Examples of such products include:

- Solutions of organic acids and compost teas.
- Various extracts of micro-organisms, seaweed, fish, animal or vegetable products.

Although many of these products may have some merit based on sound principles, the application rate of the product is often too low and the cost too high to make any major difference to the crop, compared to the actual requirement.

It is important that growers are aware of such products. If, however, a product appears to show merit, a simple on-farm trial should be used to establish the efficacy of the product (see Chapter 9).

SUMMARY

1. Inorganic fertilisers are supplied as straights (supplying one of the three major nutrients – N, P or K), or compounds and blends (supplying two or three of these nutrients). It is important to be able to conduct calculations to establish the amount of each nutrient in a specific blend, the amount of fertiliser (straights, compounds and blends) to be applied to a field and the cost of the individual nutrient in a straight fertiliser.

2. Micronutrient deficiencies can be determined by soil or leaf test or (less reliably) by visual symptoms, and can usually be corrected by standard application rates of specific fertilisers.

3. Correct timing and placement of nutrients is crucial. N is the most difficult nutrient to apply correctly. Its application depends on the season, soil type and moisture status of the soil. In the plant crop, all P fertiliser should be applied directly into the furrow; at ratooning, it is surface-applied. Up to 100 kg K/ha can be applied in the furrow at planting; the rest of the K requirement should be topdressed, and all ratoon K is topdressed.

4. Fertiliser can be applied in a number of different ways, depending on the technology available, amount to be applied and area to cover. These include tractor-mounted spreaders, knapsack granule fertiliser applicators, wheelbarrow-type applicators, fertigation, injection of anhydrous ammonia, the ‘tin and string’ method and aerial application.

5. While organic amendments are a valuable source of nutrients, their nutrient content usually does not meet sugarcane requirements. All products should be analysed prior to use, and it is important to know the C:N ratio of the amendment.

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Chapter 9

DIAGNOSIS OF NUTRITIONAL PROBLEMS

Diagnosis of Nutritional Problems

It is difficult, and risky, to estimate crop nutrient requirements without a knowledge of the current nutrient status of the crop and nutrient reserves in the soil. While visual symptoms (see Chapter 7) can give some indication of nutrient deficiencies, analysis of leaf and soil samples takes the guesswork out of nutrient management. This chapter provides practical guidelines on the diagnosis of nutritional problems. Particular attention is given to the correct procedures for taking leaf and soil samples.

Soil sampling

Soil sampling is done for a number of reasons, and each objective will require a slightly different sampling method in order for the best results to be obtained. In this chapter the sampling for fertiliser and other amendment recommendations is presented. Other types of soil sampling are presented in the following chapters:

- Chapter 11: Opening a pit to familiarise yourself with the soil
- Chapter 11: Sampling for soil health assessment
- Chapter 10: Sampling for soil salinity/sodicity assessment.

Sampling for fertiliser and other amendment recommendations

Soil testing is the only way to establish the nutrient levels in the soil, as well as to predict the amounts of fertiliser and lime that are required before the crop is planted. This allows maximum efficiency in the use of fertiliser and lime, so that sufficient, but not excess, nutrients are applied.

When should soils be sampled?

Soil samples can be taken at any time during the year. Samples should be taken from every replant field, and ratoon crops should be sampled after every second crop. Collect the samples in good time so that they can be analysed and fertiliser purchased and applied before replanting (or ratooning). Where fields are to be replanted, soil samples should ideally be taken after the second-to-last ratoon crop has been harvested. This allows sufficient time to plan and buy fertiliser and lime.

Sampling procedure

For routine topsoil analyses and fertiliser recommendations, samples should be collected using a Beater auger (Table 9.1). Use of this auger ensures that a constant sampling depth is maintained (20 cm for sugarcane; 15 cm for most other crops) and allows for easy collection of a large number of subsamples. The recommended sampling procedure follows.

Table 9.1. Topsoil sampling procedure.

	When sampling, avoid any obviously different patches of soil (e.g. anthills, old roads, filtercake, lime or fertiliser dumps, etc.). If the field consists of two distinctly different soil types, or only parts of the field have received large amounts of, for example, filtercake, a separate sample should be submitted from each section.
	Because a very small amount of soil is analysed in the lab, it is vital that the sample submitted should be a good representation of the 'average' conditions across the field. For this reason, at least 30 - 40 subsamples should be collected from each field. The subsamples should be taken in a zigzag pattern across the field. For ratoon crops, eight interrow subsamples should be collected for every one sample on the row.
	Secure a sampling bag onto the top of the Beater auger bit.
	Push the bit into the soil as far as it will go; this will ensure the correct depth of sampling. In hard or dry soils, press down on the auger with your foot to ensure that it is fully inserted to the correct depth.

	Remove the bit from the ground. Turn the auger upside down and knock the bit with your hand or a stick until all the soil falls into the bag.
	Continue to the next position in the field, and repeat the process. The sampling bag will naturally fold over, so that collected soil is not lost after sampling.
	Once the correct number of subsamples has been taken, they should be mixed thoroughly in the bag.
	Completely fill the laboratory sample box with this mixed soil, and discard any soil that is left over in the sampling bag. Enter required details correctly on the box before sending samples through to the laboratory for analysis.

Sampling to depth (subsoil sampling)

If subsoil acidity problems or any other subsoil nutritional problems are suspected, sampling to depth should be undertaken before each replanting event. In this case, soils should be sampled with a Dutch (screw type) auger (Figure 9.1), marked off at 20 cm intervals. Ideally, samples should be taken to a depth of 80 to 100 cm, in increments of 20 cm (i.e. 0 - 20, 20 - 40, 40 - 60, 60 - 80 and 80 - 100 cm). Keep the samples from each depth interval in separate bags.

Take three to four subsamples (borings) from random positions across the field. The subsamples for each depth interval must be placed into the appropriate sampling bag (e.g. all 0 - 20 cm subsamples will be combined into one bag).

Mix the soil in each sample bag thoroughly and transfer into sample boxes. The sampling depth should be clearly marked on the sample box. Thus there will be up to five sample boxes, each containing a composite sample from a certain soil depth.

Fill in all the necessary details on the sample box, as well as on the soil sample submission form.

Interpreting soil data

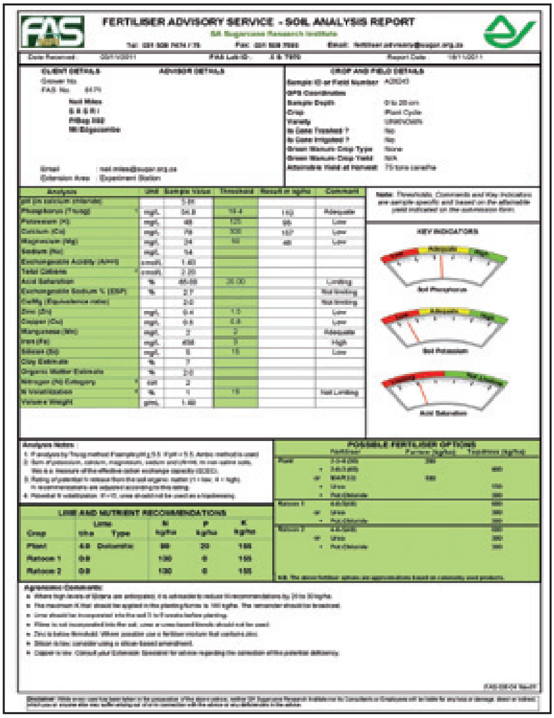
Different laboratories often use different analytical methods, and each will have its own distinctive way of reporting the results. Laboratories will also calculate nutrient and lime requirements using different norms.

Soils entering a laboratory are routinely oven-dried and then ground to pass through a 1 or 2 mm sieve. They are then measured out (by weight or volume), and sent for the various analytical tests.

Figure 9.1. Dutch or screw-in auger, used for sampling to depth when subsoil acidity is suspected. The auger should be marked at 20 cm intervals to facilitate depth monitoring of subsamples.

The results of these tests are shown on the report form, which is sent to the grower (Figure 9.2). On this report form, the threshold values for the various nutrients are usually shown, and sometimes a comment is given, to indicate whether the soil is low, medium or high in a specific nutrient. Based on these nutrient levels and the results of many field trials, lime and fertiliser recommendations are provided, and some laboratories further give suggestions on the types of fertiliser that can be applied.

As a result of different methods of analysis and recommendation, it is difficult to provide a 'generic' explanation for the interpretation of soil test data. However, some common themes are dealt with in more detail below.



FERTILISER ADVISORY SERVICE - SOIL ANALYSIS REPORT

Figure 9.2. A typical laboratory report showing results for various analyses.

Units

Laboratories analyse soils either on a *weight* basis (e.g. 5 g of soil, weighed out for the analysis) or *volume* basis (e.g. 5 ml of soil, scooped with a calibrated 'spoon'). Soils can differ markedly in density (weight per unit volume). For example, one cubic metre of clay soil may weigh 900 kg (900 kg/m^3, or 0.9 g/ml), whereas the same volume of sandy soil may weigh 1 400 kg (1 400 kg/m^3, or 1.4 g/ml). Since a grower is fertilising a fixed volume of soil rather than a mass of soil, analysis on a volume basis provides a more accurate indication of nutrient reserves.

Nutrients will be reported per unit volume (e.g. mg/L – as opposed to ppm) on your soils report if the volume method was used.

Some of the units used in soils reports include the following:

- parts per million (ppm: approximates to mg/L)
- milligrams per litre (mg/L: approximates to ppm)
- milli-equivalents per 100 g (meq/100g: equivalent value to cmol$_c$/L, or cmol(+)/L)
- centimoles charge per litre (cmol$_c$/L: equivalent value to meq/100g)
- kilograms per hectare (kg/ha).

pH

Soil pH is used to describe the degree of acidity or alkalinity of a soil. In most laboratories, an electrode is inserted into a suspension of soil and a specific medium. Three media are commonly used for the measurement of pH in soil:

- Water (pH_w, $pH(H_20)$ or pH(w))
- Potassium chloride:
  1 *M* KCl (pH_{KCl} or pH(KCl))
- Calcium chloride:
  0.01 *M* $CaCl_2$ (pH_{CaCl2} or $pH(CaCl_2)$).

Research has shown that pH measurements undertaken in calcium chloride ($CaCl_2$) or potassium chloride (KCl) are more reliable than water measurements. Strictly speaking, pH values measured in the different media cannot be directly compared. However, some rules of thumb can be applied to compare the different pH values obtained (Table 9.2). Internationally, measurement of pH in diluted $CaCl_2$ is the most widely accepted procedure, as this approximates most closely to the composition of the soil solution.

Soil acidity and acid saturation

Soil acidity – as evidenced by low pH values – can be problematic for a number of reasons (see Chapter 6). Soil test reports may list the following measures which relate to soil acidity:

- *Soil pH:* for sugarcane, a soil $pH(CaCl_2)$ value < 4.5 can also be associated with a danger of aluminium toxicity.
- *Exchangeable acidity:* aluminium (Al^{+++}) and hydrogen (H^+) ions are two of the main culprits limiting growth at low pH values. Exchangeable acidity is thus a measure of the amount of these ions in the soil (i.e. Al + H expressed in $cmol_c/L$).
- *Acid saturation percentage:* this is another index of soil acidity and the damage it can cause to roots. Acid saturation percentage (expressed in $cmol_c/L$) =

$$\frac{(Al + H)}{(Al+H)+Ca+Mg+K+Na} \times 100$$

Laboratories usually recommend lime applications to neutralise excessive acidity. The actual amount of lime recommended varies widely with crop species and sometimes even from one variety to another within a species.

Table 9.2. General 'rules of thumb' which can be used to convert pH values obtained in the different media.

To convert pH measured in…	… to pH measured in…	…do the following	For example
Water	KCl	- 1	pH (w) 5.0 → ~ pH (KCl) 4.0
Water	$CaCl_2$	- 0.75	pH (w) 5.0 → ~ pH ($CaCl_2$) 4.25
KCl	Water	+ 1	pH (KCl) 4.0 → ~ pH (w) 5.0
KCl	$CaCl_2$	+ 0.25	pH (KCl) 4.0 → ~ pH ($CaCl_2$) 4.25
$CaCl_2$	Water	+ 0.75	pH ($CaCl_2$) 4.5 → ~ pH (w) 5.25
$CaCl_2$	KCl	- 0.25	pH ($CaCl_2$) 4.5 → ~ pH (KCl) 4.25

Soil P measurements

There are a number of different tests used to measure the amount of plant-available P in soil. The most commonly used tests in South African laboratories are the Bray 1, Ambic, Truog and Olsen tests (Table 9.3).

These tests give different results, depending on the extractants used and the soil P pool targeted, and different tests work better under different conditions. It is important that the correct test is chosen for the specific soil conditions, if results are to be meaningful. The tests used in the South African sugar industry are the Truog and resin methods.

Phosphorus fertiliser recommendations are made when the soil P value falls below the threshold (shown in the laboratory soil report). Threshold values are determined using data from long-term field trials. Although laboratories differ in their approach, the amount of P needed to bring the soil test value up to this threshold can be calculated using models developed by Johnston and others[6]. The amount of P required to raise a soil test is dependent on clay content, type of clay and depth of incorporation. For example, a sandy soil (< 10% clay) with a soil P test showing 8 units below the soil P threshold (Truog method), would require (8 x 2.99) = 23.92 kg of P fertiliser per hectare to raise this soil to the P threshold level.

Total cations

Some laboratories provide a value for total cations. This is the sum of the major positively charged ions on the soil: potassium, calcium, magnesium, aluminium and hydrogen (and sometimes sodium). In non-saline soils, this is a measure of the effective cation exchange capacity (ECEC), and is measured in centimoles charge per kg soil (cmol_c/kg soil, or cmol_+/kg soil) (see Chapter 3).

Exchangeable sodium

Sodium can be problematic in soils when in excess. The degree to which the soil is saturated with sodium can be calculated by the formula:

- Exchangeable Sodium % (ESP) =

$$\frac{\text{exchangeable sodium}}{\text{cation exchange capacity}} \times 100$$

A high ESP value indicates that sodicity is a limiting factor in the soil (see Chapter 10).

Table 9.3. Some of the more commonly used P extraction methods in South Africa.

P analysis method	Extractant used	Suited to
Truog[1]	Dilute acid	Acid soils
Ambic 2[2]	Mixed alkaline extractant	All soils
Bray 1[3]	Mixed weak acid	Acid soils
Olsen[4]	Alkaline extractant	All soils
Resin[5]	Resin strips	All soils

Nitrogen release

There is currently no reliable test for total available soil N since N is present in so many forms in the soil. Fertiliser recommendations are therefore based on a prediction of N release from the soil.

All soils release a certain amount of N to the crop each year. Nitrogen is released or 'mineralised' from the organic matter (OM) in the soil. Soils with higher OM contents release more N per year than low OM soils; high OM soils therefore require less N fertiliser to be applied in order for the crop to grow well. Clay content plays a role here too, as higher clay soils tend to stabilise and protect the soil OM, maintaining the OM pool for longer periods than in sandier soils.

Different laboratories take this natural N release into account in different ways when calculating N fertiliser recommendations. At SASRI's Fertiliser Advisory Service (FAS), soils have been grouped into four different categories, based on their organic matter and clay content:

- Category 1: <2% organic matter
- Category 2: 2 - 4% organic matter, < 35% clay
- Category 3: 2 - 4% organic matter, ≥ 35% clay
- Category 4: >4% organic matter.

These are referred to as 'N category' in the soil test report. Based on numerous laboratory and field trials, the amount of N released from the various N categories has been determined. Fertiliser recommendations are then based on supplementing amounts of N released from the soil. Countries differ in their approach; the Australian sugar industry, for example, bases N recommendations on six N categories.

Nitrogen volatilisation

FAS measures the extent to which urea nitrogen is likely to volatilise (be lost to the atmosphere in a gaseous form) for different soil types. Based on the results of this measurement, different N management strategies and sources are suggested:

- N volatilisation test <5%: low volatilisation potential. Use either urea or another carrier (such as LAN).
- N volatilisation test 5 - 15%: moderate volatilisation potential. Use a different N carrier, or split and broadcast your urea.
- N volatilisation test >15%: high volatilisation potential. Use an alternative N carrier (e.g. LAN) – not urea.

How are fertiliser recommendations calculated?

The amounts of nutrients needed for crop growth are generally based on a soil threshold level for each nutrient. Threshold levels are based on measured responses in field trials involving increasing increments of a particular nutrient.

The threshold (or critical) level for a particular nutrient is the point beyond which no further yield advantage will be achieved by adding more of that nutrient (Figure 9.3). Applying fertiliser above this threshold value would be a waste of money and a potential hazard to the environment.

Threshold levels often vary according to soil clay percentage and the levels

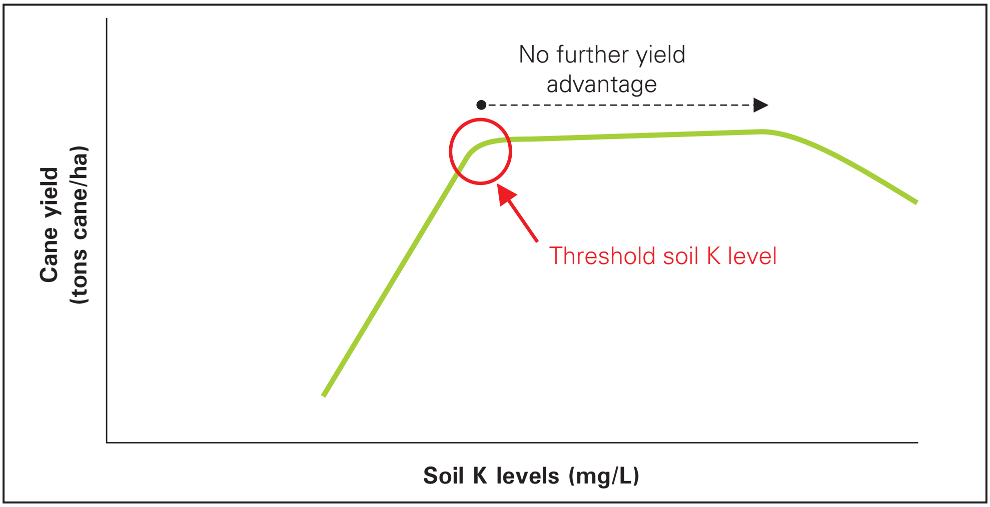


Figure 9.3. Example of the type of graph used to determine fertiliser rates: Cane yield vs soil potassium levels.

of other nutrients in the soil. Fertiliser rates are calculated to ensure that growers apply the right amount of nutrient to reach that threshold soil nutrient value.

Once the amount of each nutrient required has been determined, fertiliser rates can be calculated using the methods described in Chapter 8.

Box 9.1. The 'ideal' soil?

Considerable attention has been given to the concept of an 'ideal' or 'balanced' soil. This work, first formalised by Bear and co-workers[6,7] and later expanded upon by Albrecht[8,9,10], proposed that the cations Ca, Mg, K and H should occupy fixed percentages of the soil's exchange complex (active surface area). This formed the basis of the 'Basic Cation Saturation Ratio' (BCSR) recommendation system. An 'ideal' or 'balanced' soil was said to contain 65% Ca, 10% Mg and 5% K.

Although many consultants still tout these ratios as being ideal for crop growth, research has repeatedly shown that there is no 'ideal' basic cation saturation ratio or range; optimum soil fertility can be maintained across a range of cationic ratios. In fact, continued promotion of the 'ideal' soil or BCSR concept is likely to "result in the inefficient use of resources in agriculture..."[11].

Emphasis should rather be placed on providing sufficient – but not excessive – levels of each basic cation, rather than trying to achieve a 'balanced' ratio which does not exist[12].

Leaf sampling

Leaf sampling should be a routine part of crop management. It can be used to establish how effectively nutrients from the soil are being taken up, whether they are present in the crop in the correct balance, and whether there are any problems that need to be addressed. Leaf nitrogen measures are particularly useful, due to the difficulty in measuring plant-available soil nitrogen. If samples are taken early enough in the season, corrective doses of N fertiliser can be applied based on the leaf sample results, otherwise, nutrient amounts can be corrected for the following crop.

Leaf sampling requirements

Before taking a leaf sample, the following considerations must be kept in mind:

- The crop should have been growing vigorously during the three weeks prior to sampling.
- The crop must not be water-stressed prior to sampling.
- At least four weeks should have passed since the last fertiliser top-dressing.
- The crop should be the correct age, and sampled during the correct month, depending on the area (Table 9.4). This will enable the analytical results to be interpreted more reliably.
- If the field consists of areas of good and poor growth, a separate sample should be taken from each portion, even if the field has been fertilised as one unit.

Once these conditions have been satisfied, the leaf sample can be collected.

Interpreting leaf data

In sugarcane leaves, macronutrients are reported as a percentage, and micronutrients in parts per million (ppm).

There are two commonly accepted methods of evaluating leaf data:

- The *critical nutrient concentration* (CNC) approach is the most widely accepted method for interpreting plant nutrient concentration data. This is based on crop yield vs nutrient concentration (e.g. Figure 9.4). The turning point between the deficient and adequate zones indi-

Table 9.4. Cane age and leaf sampling period for the different regions.

Area	Crop age	Sampling period
Northern irrigated	3 - 5 months	October - April
Coastal lowlands	4 - 7 months	November - March
Midlands	4 - 9 months	December - March
Other African countries	3 - 5 months	October - April

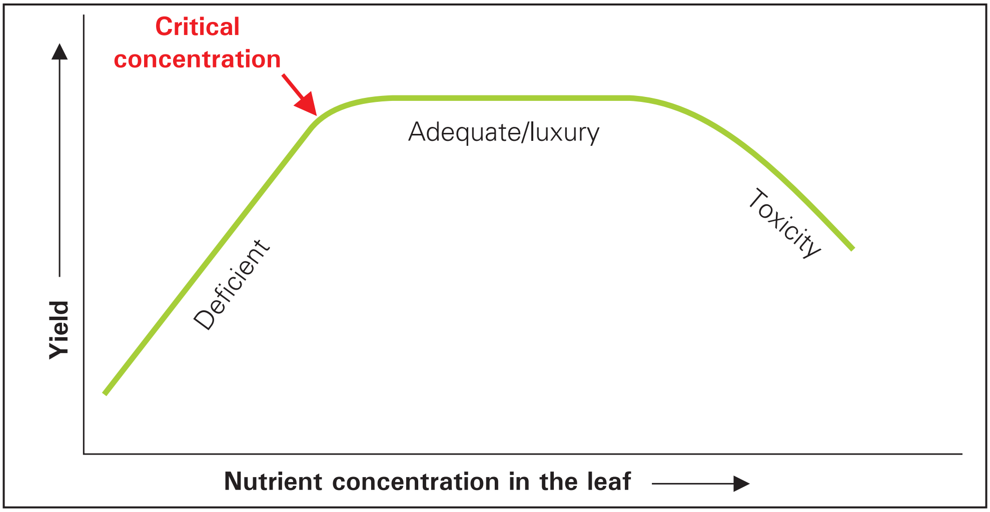


Figure 9.4. Typical relationship between leaf nutrient concentration and yield, showing the 'critical' concentration[13].

Table 9.5. Leaf sampling procedure.

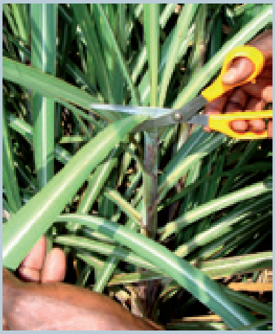
	Select leaves from stalks of average height, but not from young shoots. The leaf selected for sampling should be the third one from the top. The first leaf that is at least halfway unrolled is counted as number one. If the spindle is not yet halfway unrolled then ignore it, and start counting from the next leaf. The third (sampled) leaf is usually the first leaf with a visible dewlap or 'collar' where the leaf blade and sheath meet. Cut the third leaf off at the base, and proceed to take the next sample.
	Collect about 40 leaves in this way from across the field, following a zigzag pattern.
	Holding the leaves in a bundle, chop off the tops and bottom, leaving a central portion roughly 30 cm long.
	As soon as possible after collecting the samples, strip out the midrib from this portion; this is easily done by tearing. Discard the midrib.
	Bundle the leaf blades together and tie them up with a leaf sample label. Fill in all the details on this label, as well as on the leaf sample submission form. Be careful not to contaminate the leaf samples by contact with fertiliser or used fertiliser bags. Leaf samples should not be kept for long periods in an airtight bag or container, in case they start to go mouldy.

Table 9.6. Example of the sample value and critical ranges for nitrogen as shown on a leaf report.

Nutrient	Unit	Sample value	Leaf criteria				Comment on sample value
			Low	Sufficient	High	Excess	
Nitrogen (N)	%	1.93	< 1.6	1.6 - 2.0	2.0 - 2.8	> 2.8	Sufficient

cates the critical level for the nutrient in question. The critical level is therefore the concentration below which supplies of the nutrient begin to limit growth. Interpreting leaf samples with the CNC method simply involves comparing the sample nutrient concentrations with established critical values. Where the sample concentration is less than the critical value for the nutrient in question, a deficiency is indicated.

- The *Diagnosis and Recommendation Integrated System (DRIS)* technique is based on nutrient ratios, and is used to identify imbalances, deficiencies and excesses in nutrient levels in crops, and rank them in order of importance.

Leaf sample reports present the sample value (in % or ppm) of the nutrient in question – i.e. the value obtained when testing that specific leaf sample. Using the CNC approach, the ranges for interpretive purposes for the different nutrients may be shown. An example for nitrogen is given in Table 9.6.

Some leaf sample reports may represent the nutrient levels graphically. An example is given below (Figure 9.5). Nutrients falling within the 'sufficient' band on the graph are assumed to be adequate for good growth. In this example, P, K and Si are deficient.

The ranges, or leaf criteria, may differ depending on the crop age and season of

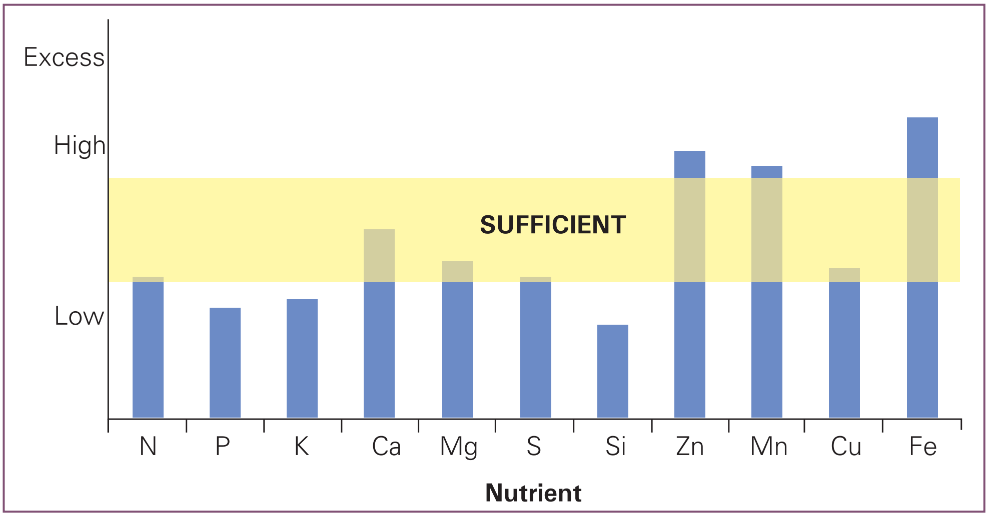


Figure 9.5. Example of a graph used to illustrate leaf nutrient sufficiency in a leaf sampling report. Those nutrients with bars falling within the 'sufficient' zone are considered to be adequate for good crop growth.

harvesting. Different countries also often use different ranges, depending on research findings. Because leaf nutrient concentrations differ over the season and the age of the crop, the laboratory assumes that sampling has taken place at the correct time and age.

Leaf reports usually do not suggest rates of fertiliser to correct any deficiencies or imbalances found; top-up fertiliser amounts should be discussed with an advisor.

The importance of record-keeping

Records of past soil and leaf samples are extremely important. Mistakes or inaccuracies in sampling or testing are inevitable, and if past records from the same field are available for comparison, these irregularities will be seen in context.

Simple on-farm observation trials

While there is no substitute for scientifically designed and conducted trials, simple on-farm observational trials may assist the farmer to compare products or product rates.

If a nutrient deficiency is suspected or if it is necessary to observe how a product performs under certain conditions, then observation trials could provide useful information.

Often, farmers will buy enough product for a few hectares, treat one field and leave another untreated, and then compare the responses, sometimes even comparing responses of a particular field this year to that achieved last year. Unfortunately, such an approach will not help a grower to draw any valid conclusions, and is a waste of resources.

Basic guidelines for the establishment of observation trials

- Choose a place in a field where the soil and cane growth is uniform.
- Keep it simple; compare a maximum of three treatments, i.e. your standard treatment plus two variations.
- Either rectangular ‘plots’ or long ‘strips’ can be used (Figure 9.6) for the trial layout.
- A control, or standard treatment, is vital in order to measure any improvements over standard practice. For example, if you wish to test whether your field is deficient in molybdenum, be sure to include some plots or strips where no molybdenum is applied: this will provide your ‘baseline’ with which to compare the other treatments.
- Repeat treatments at least 3 times – i.e. if there are 2 treatments, repeat them each 3 times in different plots or strips: 2 x 3 = 6 plots or strips in total (Figure 9.6). This allows you to obtain an average for each treatment, in case there is variation in the field.
- Start the trial at least 5 m inside the field to overcome any end effects in the cane growth[14].
- Each plot or strip must be at least five rows wide and a minimum of 10 m long (Figure 9.6).
- Distinguish your treated and untreated rows with some visible marking (Figure 9.7). A sketch or map of the trial will also help.
- Apply all the treatments on the same day.

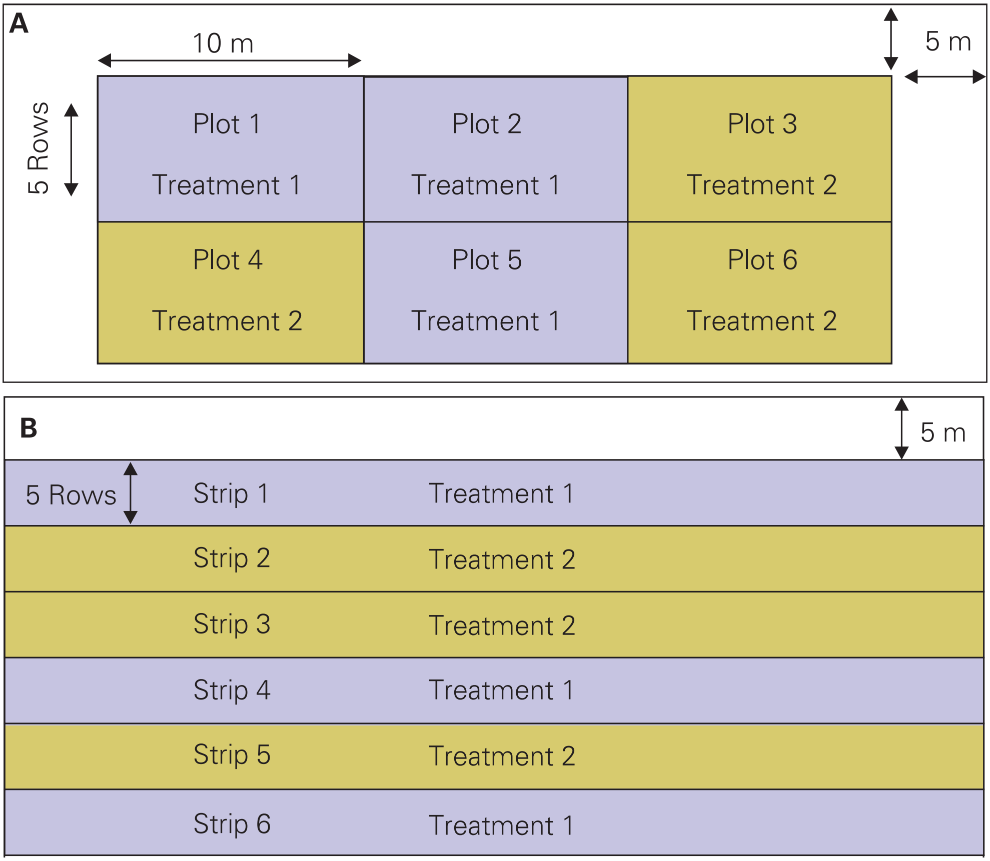


Figure 9.6. Example of the field layout of a simple on-farm trial. Note: each treatment should be repeated 3 times, randomly throughout the field. Trials can be prepared in plots (A) or strips (B). If using a strip layout, each strip should be at least 5 rows wide, and can continue for the length of the field.

Figure 9.7. Example of plot marking with plastic pegs in an on-farm trial.

- Explain to your staff, and foreman, where the field is and what special precautions to take, if any.

- Monitor the trial for visible differences in crop vigour, colour, and stalk height and numbers.

- It must be emphasised again that these are general guidelines. The procedures for setting up trials will vary according to the product being tested (i.e. ripeners, herbicides, fungicides, etc). Extension Specialists will be able to assist with comprehensive procedures for these different products.

Nutrient sufficiency trials

Some farmers may be concerned that they are applying a specific nutrient or product – for example, N or poultry manure – at too low a rate. A recommendation would be to apply a standard rate of the nutrient to the entire field, and a higher rate to two or three cordoned off strips of the field. Each strip should be at least 5 rows wide, and run for the length of the field (Figure 9.6B). If improved growth is apparent in these strips, a top-up dressing of the nutrient can be applied to the rest of the field. Note that this is not an accurate test of the product, but rather a rough indicator of nutrient sufficiency.

Table 9.7. Calculating the amount of extra nutrient to apply to the test strips in the field, using urea as an example.

Urea	Standard field application rate	120 kg/ha N
	Test strip application rate	160 kg/ha N
	Size of test strips (ha)	5 m x 100 m = 500 m^2 Or (500 m^2/10 000 m^2) = 0.05 ha.
	Calculation	160 kg/ha – 120 kg/ha = 40 kg/ha N extra to apply to the test strips. 30 kg/ha x 0.05 ha =2 kg N to each test strip.
	Amount to apply to each strip	2 kg N x (100/46) *- urea contains 46% N* = 4.3 kg *extra* urea to each test strip.*

*Note: Assume that the *whole field* (including the strips) has already received the standard rate. The urea example can be adapted to other nutrients, products and test strip sizes.

SUMMARY

- An efficient nutrient management programme requires routine analyses of soil and leaf samples.
- Soil testing is the only way to establish the nutrient levels in the soil, as well as to predict the amount of fertiliser and lime that is required by the crop.
- If subsoil acidity is suspected, sampling to depth should be conducted before each replanting event.
- Leaf sampling should be used to establish how effectively nutrients from the soil are being taken up, whether they are present in the crop in the correct balance, and whether there are any problems that need to be addressed.
- The amount of nutrients needed for a crop are generally based on a soil threshold level for each nutrient. The threshold levels represent the point beyond which no further yield advantage will be achieved by adding more of that particular nutrient.
- Simple on-farm observational trials may assist a farmer to compare fact against sales-talk.

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Chapter 10

SOIL SALINITY AND SODICITY

Soil Salinity and Sodicity

Introduction

Salinity and sodicity problems usually occur in semi-arid and arid regions of the world where potential evapotranspiration from the soil far exceeds precipitation, thus allowing salts to accumulate in the soil. In agriculture, areas with salinity/sodicity problems usually have the following characteristics[1]:

- A seasonal water supply which leads to over-irrigation during some periods of the year and under-irrigation during others
- Drainage systems which are inadequate or non-existent
- A relatively flat topography such as a valley bottom or alluvial fan
- A high concentration of salts in the soil either derived from the parent material or from build-up over the years, and
- A fluctuating water table.

The main types of salts that lead to salinity/sodicity problems occur naturally in the soil. Examples are sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), calcium sulphate ($CaSO_4$), magnesium sulphate ($MgSO_4$)[1] and potassium chloride (KCl). In instances where there are high concentrations of calcium (Ca), magnesium (Mg) and sometimes potassium (K), the soil is said to be saline.

Saline soils are problematic because they retard the uptake of soil water by crops due to high osmotic potentials (think of trying to grow crops using sea water). Crops growing in saline soils can therefore show symptoms of water stress despite the presence of adequate

Figure 10.1. Measurement of soil salinity undertaken in a laboratory.

water. Sodic soils contain excessive concentrations of sodium (Na) and are a concern because this causes clay dispersion (breaking up of soil aggregates), followed by clay particles moving into soil pores and creating blockages that impede the infiltration of water and air into the soil.

In addition to the salt cations (Ca, Mg, K and Na) being problematic, the salt anions, chloride (Cl) and sulphates (SO_4), if present in large quantities, can also have negative effects on sugarcane growth. For example, the presence of high concentrations of chlorides can inhibit the uptake of nitrogen and phosphorus by sugarcane.

Development of saline and sodic soils

Salinity and sodicity may arise from two sources:

1. Highly soluble salts from parent material dissolving into soil water.
2. Irrigation with water containing high salt concentrations.

Salts present in the soil can originate from the weathering of parent material. The salts become dissolved in water (irrigation or rain) and are then transported to salt-accumulating areas – usually areas that have lower elevations (e.g. alluvial fans, valley bottoms, etc.). The water accumulates in the lower-lying areas by running off over the soil surface or in the subsurface soil layers as seepage. Eventually the water will be lost via evaporation, leaving the salts behind to accumulate in the soil and create saline or sodic conditions[2].

In agriculture, in particular where crops are irrigated, the development of saline and/or sodic conditions can be exacerbated where over-irrigation occurs, where poor quality water is used and/or where there is insufficient drainage. In instances where soils are naturally high in salts and over-irrigation occurs, the

Figure 10.2. Excessive salt build-up from a leaking irrigation pipe.

irrigation water can leach the salts into the underlying water table or carry them in the runoff water to the valley bottom (as illustrated in Figure 10.3). The lack of a good drainage system allows the water table to rise towards the surface of the soil where it (and the water accumulated from runoff) can evaporate, leaving the precipitated salts behind.

In some instances, the water carrying the dissolved salts can be washed into rivers and other water sources, thus increasing the salt concentration of these systems which, in many instances, are used for irrigation. Under these circumstances, soils previously considered non-saline or non-sodic can develop salinity or sodicity problems when prolonged use of this poor quality water occurs.

Danger areas for salinity and/or sodicity problems are therefore valley bottoms and low-lying areas, duplex soils and where there is irrigation with inadequate drainage.

Measuring and interpreting salinity and sodicity in soils

To assess a salinity or sodicity problem in soils, it is recommended that soil samples be taken for laboratory analysis. This should be done to depth to assist in identifying the source and extent of the problem and in developing a reclamation strategy.

Samples should ideally be taken with a Dutch (screw-in) auger, marked off at 30 cm depth increments, in the following manner:

- In instances where there are patches of suspected salinity/sodicity in a field: the suspected patches (with poor crop growth) must be sampled separately from areas with better crop growth. Take three to four core samples from the suspected salt-affected patches, and three to four cores from the non-affected areas. Sample at three depths (0 - 30, 30 - 60 and 60 - 90 cm).
- At each sampling site, place the 0 - 30 cm soil into one bag, the 30 - 60 cm sample into another bag and 60 - 90 cm into a third bag. Move on to the next sample site, and place the same depths into these bags.
- When three to four sampling sites have been combined, mix the samples thoroughly and submit them to the laboratory. There will thus be three boxes

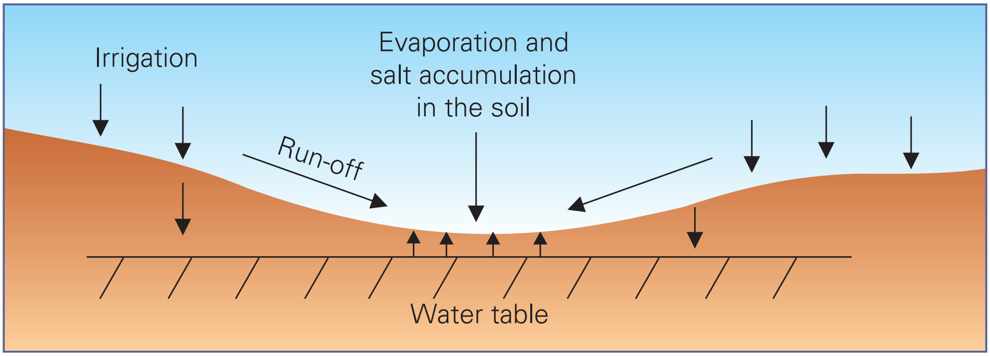

Figure 10.3. The transportation and accumulation of salts and the subsequent development of saline or sodic conditions.

(for the three depths) from the well-growing areas and three boxes for the poor growing areas. Remember to fill in the label on the sampling box, as well as the sample submission form.

- If the area is irrigated, a sample of the irrigation water should be sent to the lab along with the soil samples. (See next page for water sampling guidelines.)

The laboratory will measure electrical conductivity to test for salinity and determine the sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP) to assess for any sodicity problems.

The electrical conductivity (EC) of soil is measured using an electrical conductivity meter, usually in a saturated paste extract, and recorded in milli-siemens per metre (mS/m). The sodium adsorption ratio is essentially the ratio of sodium to calcium plus magnesium ions in the soil. It is determined by measuring the concentrations of sodium, calcium and magnesium from a saturated paste extract and inserting the values into the equation (see Box 10.1), while exchangeable sodium percentage is the percentage of total cations present in the soil up by sodium (see Box 10.1).

Interpreting salinity and/or sodicity in soil

For interpretive purposes, the electrical conductivity, sodium adsorption ratio or exchangeable sodium percentage and pH are all taken into account because sometimes soils are in transition between salinity and sodicity (saline-sodic soils). Under these circumstances, the high concentration of sodium (that would normally cause clay dispersion) is counteracted by the high concentrations of calcium and magnesium. The net result might be weaker aggregates. If, however, the calcium and magnesium salts are leached out, dispersion of the soil particles will take place rapidly[2].

Soils can thus be categorised as normal (without salinity or sodicity problems), saline, saline-sodic or sodic, based on chemical characteristics described in Table 10.1.

Box 10.1. Calculating sodicity

Sodium Adsorption Ratio (SAR) is calculated using the following equation. This is, however, usually calculated by the laboratory to which the samples are submitted and analysis reports will report the SAR value:

$$\text{SAR} = \frac{[\text{Na (meq/L)}]}{\sqrt{\dfrac{0.5\,[\text{Ca (meq/L)}] + 0.5\,[\text{Mg (meq/L)}]}{2}}}$$

Exchangeable sodium percentage (ESP) is calculated using the following equation. As with SAR, the laboratory will report the ESP value in the analysis report:

$$\text{ESP} = \frac{\text{Exchangeable sodium (cmol}_c\text{/kg)}}{\text{Cation exchange capacity (cmol}_c\text{/kg)}} \times 100$$

To convert an SAR value to ESP, use the following equation (suitable for the range 39 - 110 ml/L)[3]:

$$\text{ESP} = \frac{100\,(0.01475\ \text{SAR} - 0.0126)}{0.01475\ \text{SAR} + 0.9874}$$

Table 10.1. Categories and properties of saline and sodic soils.

Type	Electrical conductivity* (mS/m)	SAR** (ESP)	Dominant cation(s)	pH (water)	Effect on soil structure
Normal	< 400	< 6 (< 7)	None	< 8.5	None
Saline	> 400	< 6 (< 7)	Mainly Ca and Mg	< 8.5	None (osmotic interference of plant uptake of water)
Saline-sodic	> 400	> 6 (> 7)	Ca, Mg and Na	< 8.5	Early stages of dispersion
Sodic	< 400	> 6 (> 7)	Mainly Na	> 8.5	Severe dispersion and possible Na toxicity

* Electrical conductivity (EC) givens an indication of the total cation concentration.

** This value is dependent on soil type and expresses Na relative to the total cation concentration. In soils that are more resistant to clay dispersion this value will be higher (see Table 10.3).

Interpreting salinity results

Different crops have different tolerance levels for salinity problems. Table 10.2 shows general soil salinity categories for sugarcane and how they are likely to affect the sugarcane crop. This can help with interpreting the electrical conductivity results received from the laboratory.

Interpreting sodicity results

When dealing with sodicity problems it is important to know and understand the soil type and related structure because different soils will vary in their susceptibility to clay dispersion. For this reason, soils of the South African sugar industry have been assigned critical sodium adsorption ratios and exchangeable sodium percentage values (Table 10.3) based largely on the content and type of clay present in the soil. When the SAR (or ESP) determined by the laboratory is greater than the critical value into which that soil is grouped, the soil will be considered sodic.

Measuring and interpreting irrigation water salinity and sodicity

If irrigation water salinity or sodicity issues are suspected, it is important that a sample of the water is submitted to the laboratory for analysis. Samples should be collected using the following steps:

- Use a clean bottle and rinse it several times with the irrigation water before taking a sample.
- If the sample is collected from an irrigation dam or river, do not collect the sample from the edge of the dam/river; collect it a few metres in from

Table 10.2. Threshold values, categories and the effect on sugarcane growth.

EC_e (mS/m)*	Categorisation	Effect on sugarcane crop
0 - 200	Non-saline	None
200 - 400	Slightly saline	Slight
400 - 600	Moderately saline	50% decrease in crop yield
> 600	Highly saline	Stools are killed

*EC_e = electrical conductivity measured in a saturated paste

Table 10.3. Critical SAR and ESP values of different soils for sugarcane production.

Critical SAR 6 (Critical ESP 7)	Critical SAR 10 (Critical ESP 12)	Critical SAR 15 (Critical ESP 17)
Generally poorly drained, highly dispersed grey soils. Usually sandy alluvial soils.	Mainly slow draining black, swelling clays. Usually clayey alluvial soils.	Mainly well-drained, non-dispersive soils, usually in upland positions.

the edge, if possible. Similarly, do not collect water from the water surface; collect the sample from about 0.3 m below the surface.

- Label the bottle clearly.
- Fill in the laboratory water sample submission form.

Interpreting the salinity and/or sodicity in water

The laboratory will assess the salinity/ sodicity hazard of the irrigation water by assessing the criteria listed in Table 10.4.

Once the effective electrical conductivity and the adjusted sodium adsorption

Table 10.4. Criteria for assessing salinity and/or sodicity problems in water.

Parameter	Explanation
Electrical conductivity (EC)	Gives an indication of the total amount of dissolved salts in the irrigation water.
Effective electrical conductivity (EEC)	Calculated by determining the electrical conductivity of the irrigation water and then adjusting it by taking the diluting effect of rainfall into account.
Sodium adsorption ratio (SAR)	Calculates the ratio of sodium relative to calcium and magnesium ions.
Adjusted sodium adsorption ratio (ASAR)	Bicarbonate in water will react with the available Ca to form insoluble calcium-bicarbonate which will precipitate out of solution leaving the Na and Mg behind. In terms of the sodium adsorption ratio definition above, the Ca and Mg amount has decreased relative to Na and the SAR value will be higher. It is therefore important to take the bicarbonate load of water into account when it is assessed for SAR. If the pH of water is higher than 8.0, it is an indication that bicarbonate might be present in significant quantities and the lab will automatically determine its concentration in the water sample.
pH	If the pH of water is higher than 8.0 it is an indication that bicarbonate might be present in significant quantities and the lab will automatically determine its concentration in the water sample.

ratio have been calculated, irrigators can use Figure 10.4 to determine the class of water: Good (Class A), Moderate to poor (Class B), Poor (Class C) or Very poor (Class D). Based on this, they can then use Table 10.5 to determine the suitability of the water for irrigation and make appropriate management decisions.

River water quality

Water pumped from rivers or boreholes for irrigation should also be regularly checked for quality. Fertiliser applied in excess to fields can end up in underground water reservoirs or in rivers. The problem is smaller in fast flowing rivers which dilutes the fertiliser salts

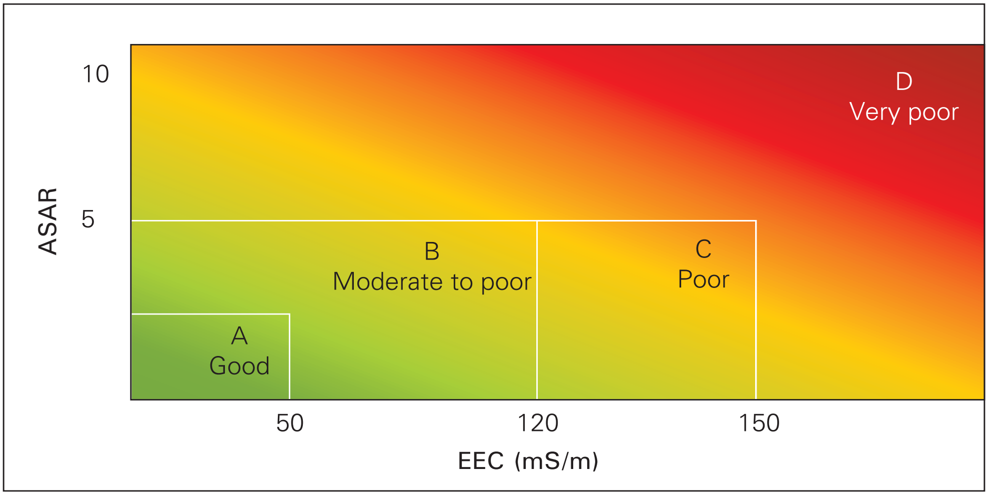

Figure 10.4. Using the Adjusted Sodium Adsorption Ratio (ASAR) and the Effective Electrical Conductivity (EEC) to assess irrigation water quality.

Table 10.5. Suitability classes for irrigation water.

Suitability class	Suitability for use
Class A	Suitable for use on all soils *except* those naturally containing high salt concentrations (derived from parent material) and a restrictive layer that prevents free percolation of water, unless drainage is installed.
Class B	Suitable for irrigation on freely draining soils. In instances where Class B water has to be used on soils with restricted drainage, ensure that sufficient drainage is installed.
Class C	Suitable for irrigation on freely draining soils provided better quality water is not available. It is important to note that using Class C water for irrigation can affect normal crop growth. Short term salt build-up in the soil is likely to occur particularly during drought periods, but the situation should improve after good rainfall. Particular care should be taken to avoid waterlogging.
Class D	Unsuitable for irrigation under normal conditions.

many times. All rivers normally flow more slowy in winter, and it is then that the concentration of salts is at its highest. Irrigators must therefore know the amount of salts they are applying to their fields in order to manage this effectively (i.e. by diluting this water with another source that is known to be of a better quality).

Salinity and sodicity management

Because salinity and sodicity problems tend to develop in irrigated areas (see *Development of saline and sodic soils* discussed earlier), irrigation management practices are often used to address the problem. This sometimes involves irrigating the crop frequently with good quality irrigation water and occasionally leaching the salts from the profile. In many instances, this can take place passively during high rainfall events or when the crop is over-irrigated. All management procedures ultimately aim to maintain salinity and sodicity below levels that affect sugarcane production negatively. Some preventive strategies are listed below.

Ensure adequate drainage

Adequate drainage is especially important on sites that are naturally poorly drained (e.g. a duplex soil). The installation of an artificial subsurface drainage system is necessary where natural drainage is inadequate.

Drainage installation is done by laying perforated pipes at pre-determined intervals throughout the field. Spacing largely depends on how quickly water moves through the soil profile, soil conductivity, drain depth and maximum water table height above the drains. It is essential that the subsurface drainage water is managed appropriately. When installing drainage, an expert should be consulted.

It is important to remember that in South Africa it is illegal to install drains in certain areas (e.g. swamps, wetlands or watercourses). More information can be obtained from the relevant government department.

Avoid poor quality irrigation water

Where possible, avoid the use of poor quality irrigation water. If this cannot be done, the water must be reclaimed as discussed on page 137.

Regular monitoring

It is important to take water samples from the irrigation source twice a year and have them analysed in order to monitor the salinity/sodicity status of the water. This is necessary because water quality varies within and between seasons. Samples should also be taken whenever a salinity/sodicity problem is suspected.

Salt leaching

Occasionally, leaching is done to prevent any salt build-up in the root zone. The water applied in excess is referred to as the leaching requirement (LR) and is determined by the crop's tolerance to salinity as well as the salinity of the irrigation water. The leaching requirement can be estimated as follows[4]:

- Establish the threshold value for the crop (340 mS/m for sugarcane)
- Determine the salinity of the irrigation water, and
- Use Figure 10.5 to determine the leaching requirement (see Box 10.2).

Reclamation of saline and sodic soils

The reclamation of saline and sodic soils is an expensive and challenging operation. For this reason, an attitude of 'prevention is better than cure' should always be adopted. As mentioned in the previous section, it is essential to have soil and irrigation water tested regularly so that soils which do not have salinity/sodicity problems do not become problematic in time. Table 10.6 contains some of the mitigative procedures commonly used to reclaim saline/sodic soils.

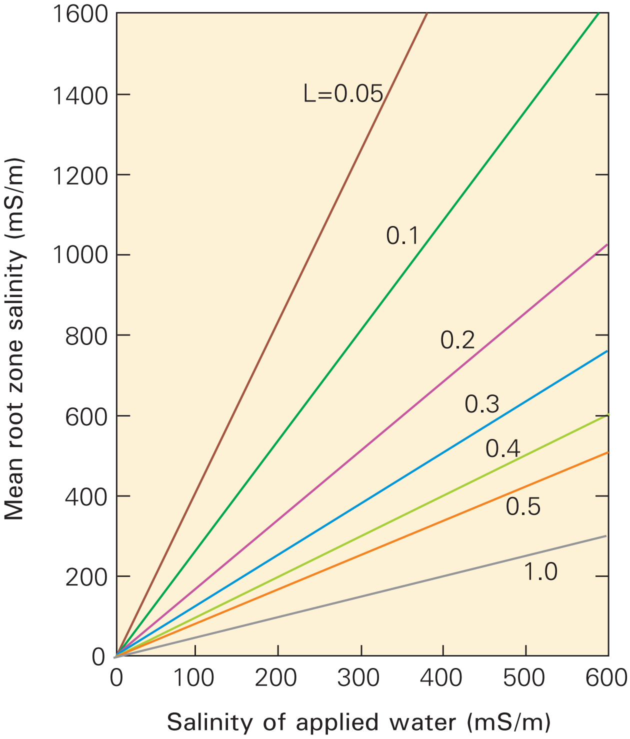

Figure 10.5. Salinity tolerance of sugarcane in relation to water salinity[5].

Box 10.2. Leaching requirement

What is the leaching requirement for sugarcane irrigated with water with a salinity of 200 mS/m and a leaching fraction of 36%?

Using Figure 10.5 plot sugarcane's salinity tolerance (340 mS/m) on the Y-axis and the irrigation water salinity (200 mS/m) on the X-axis the leaching fraction is about 0.28 or 28%. If this value is greater than the leaching fraction (LF) which is water that is applied in excess to remove excess salts from the root zone, additional irrigation will have to be applied and is calculated as follows[4]:

$$AW = \frac{\text{ET or SWD}}{1 - \frac{LF}{100}}$$

AW = Applied water (assumes no runoff)

ET = Evapotranspiration

SWD = Soil water depletion

LF = Leaching fraction

Reclamation of saline and sodic water

To reduce salinity or sodicity in irrigation water, the water must be 'treated' at the source. The most common method of reducing the problem would be to dilute the saline/sodic water with water of better quality. This is cost effective provided that a water source of better quality is in close proximity to the saline/sodic water.

Table 10.6. Some reclamation procedures for saline and sodic soils.

Soil category	Reclamation procedure
Saline and saline-sodic	• Ensure that there is adequate drainage. • Apply sufficient amounts of water to leach excess salts from the soil.
Sodic	• Ensure that there is adequate drainage. • Incorporate large amounts of organic matter to prevent dispersed soil from recompacting. • Apply gypsum in amounts recommended by a laboratory or a consultant. • Sodium ions must be replaced by calcium or magnesium to improve soil structure. • Apply amounts of quality water as specified by a consultant to leach excess salts from the soil.

SUMMARY

- Soil salinity and sodicity issues can lead to a drastic decline in crop production levels. History shows that large areas of land have had to be abandoned as a result of salt build-up in soils. Irrigation cannot be sustainable without salt management.

- The first step in identifying salinity or sodicity problems in soils or irrigation water is to take samples according to prescribed procedures.

- Management of salinity and sodicity issues involves avoiding over-irrigation of fields, ensuring sufficient drainage and using good quality water for irrigation purposes. Occasional leaching, which should be done in a carefully calculated manner, can help to prevent a build-up of salts.

- Off-site environmental impacts of adding large amounts of salts to our fresh water systems should also be considered. Wherever possible, drainage water should be treated before discharging into fresh water bodies.

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Chapter 11

SOIL HEALTH ASSESSMENTS

Soil Health Assessments

Improper management of soils can lead to damaging changes in soil function, which in turn can lead to yield decline. Factors which have the potential to diminish soil health need to be identified and sustainable management practices introduced to reverse these processes. Conducting a soil health assessment is an essential exercise for those involved in agriculture. This assessment will help to review the condition of a soil and can be useful for monitoring trends over time. For example, to determine the impact of soil management practices on sustainability, indicators which are sensitve to changes, such as organic matter content, microbial activity or the abundance of earthworms, may be used.

A soil health assessment can also serve as a diagnostic tool. Problem areas in a field can be compared to normal areas. Depending on the nature of the problem, selected indicators can be used to confirm specific problems, such as soil penetration resistance to confirm the presence of a compacted soil layer and pH to confirm soil acidification.

These indicators are interpreted within the context of the inherent properties of the soil in question For example, a soil organic matter content of 1% may be considered high for a sandy soil whilst it is low for a clay soil. As another example, plant available water of 100 mm in a sandy soil may indicate that the soil water content is at field capacity (full). The same 100 mm in a clayey soil may indicate a water content of only 60% of field capacity.

Figure 11.1. A large number of earthworms is a good indicator of a healthy soil.

Establishing the framework

All soil health assessments start by establishing the inherent properties of the soil. This provides the baseline for interpreting soil health indicators.

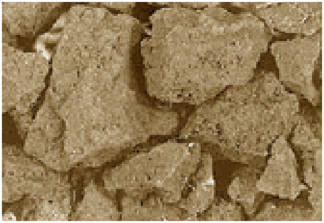
Field assessment

Field assessment methods should involve robust indicators that are cost effective. Their big advantage is that they can be conducted in fields by the farmer. However, due to the subjective nature of many of the indicators, they have their limitations, and should complement (and not replace) a detailed laboratory analysis. For example, the clay content of a soil in the field can be estimated by means of the sausage test (see Chapter 1) but only a laboratory analysis will provide an exact value. A field assessment should involve the following steps:

1. Collecting site information

Walk-in information: topography (slope steepness), aspect (slope direction), plant cover, homogeneity, presence of stones, ant hills, etc.

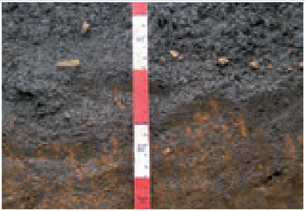
History: for how long has a certain management practice been applied, which fertilisers, organic amendments, herbicides, etc. have been applied?

Colour	Texture	Structure
		
What is the colour of the topsoil?: • black (indicating high organic matter or dark clays), • red (well drained), • dark brown (possibility of high organic matter) or • grey (sandy, with low organic matter).	How much clay is in the topsoil? • Perform the sausage test (see Chapter 1). Also note whether the sand is coarse or fine, when rubbing it between your fingers.	Is your soil structure granular, crumbly or blocky? When you break off a clod of the soil, are the individual particles held together strongly? This might indicate that the clay content is fairly high and that tillage might be challenging as it will have to be performed at a narrow soil water content range.

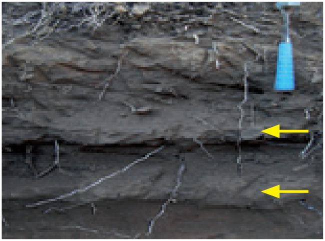
For a more thorough analysis, you need to look at the deeper soil layers and the whole soil profile. A representative spot in the field should be chosen for opening a pit.

2. Opening a profile pit

Dig the pit large enough to enable you to examine and take samples while in it. The pit should be at least 1.0 m wide, 1.0 m long and 1.2 m deep on a deep soil. On a shallow soil, you must enter the root layer (C horizon). Armed with a knife or geologist's pick and a bottle of water, climb into the pit and look for the features described below.



Soil depth: How deep is the soil? Are the roots distributed to depth or are they restricted to shallower depths? Note whether any restrictive layer (such as rock, water table, sudden change in clay content or a compacted layer) is limiting root growth.



Compacted layers: Chip or prod gently down the soil profile, from top to bottom. Is there a layer where the soil becomes more difficult to chip? This could indicate a higher clay content (do the sausage test to confirm) or a compacted layer.

Rooting: How deep did the roots penetrate the soil? Are they dense and white to brownish in colour, with many roots hairs (healthy) or shallow, gnarled and blackened (unhealthy)? Sugarcane roots need at least 50 cm of soil depth, though ideally they prefer a much deeper profile.

3. Assessing field uniformity

It is important to obtain an idea of the soil uniformity of each field. This will assist with better and more effective management. To describe a soil, open a pit and record the following information for each layer:

- colour, texture and structure
- depth of the layer
- depth from the surface to any restricting layers.

If, during this procedure, areas are noticed that exhibit significant differences in soil compared to what was observed in the original pit(s), consider opening an additional pit(s) to describe the new soil.

It is not always practical to dig a soil pit within each suspected soil form. The use of a screw-type auger (see Chapter 10) is therefore essential to confirm soil changes, which should be recorded on field maps. Also record the depth of restricting layers preventing further penetration of the auger.

Should the field happen to be bare, it is the ideal opportunity to use soil surface colour variations to act as a guide to possible soil form changes. Be sure not to sample on (or too near) the colour change, as these areas are in transition, and hence difficult to identify. The number of auger holes per field will differ greatly depending on the uniformity of the soil: an area with a variable soil will require one hole per hectare, whereas a more uniform area might need fewer holes. However, there should be at least one hole per five hectares. Draw a map of the approximate boundaries between soils. This will be useful in determining field boundaries and areas from which soil and leaf samples will be taken.

The information on soil texture (sand/silt/clay) and on soil form (soil depth, soil layers) provides the farmer with knowledge on basic soil properties, which are important for management decisions. A basic example is given in Table 11.1.

For more detailed information, especially on the soil nutrient status, soil samples should be taken from the topsoil (0 - 20 cm) and various subsoil layers for a chemical laboratory analysis (see Chapter 9).

Table 11.1. Soil texture and soil property relation

	Shallow, sandy soil	Deep, clay soil
Fertility/yield potential	Low	High
SOM-status	Low	High
Nutrient requirement	High (but nutrients are at risk of being leached out)	Low (but nutrient fixation might limit availability)
Mineralisation capacity	Low	High
Plant available water storage capacity	Low	High
Workability	Easy	Difficult
Erosion risk	High	Low

4. *Assessment of soil chemical properties in the field*

Some analytical methods for a quantitative determination of available nutrients have been simplified and can be carried out with little effort using basic equipment in the field. Colorimetric (colour changing) test methods are used for most of these tests and the final colour is compared against laminated colour charts. Test strips for measuring pH (Figure 11.2) are commonly used. Also widely used are test strips for measuring nitrate and ammonium in soil water or a prepared soil extract (Figure 11.2). The results from test strips are highly reproducible with the use of a hand-held reflectometer (a device to interpret colour), but accuracy is limited. Although more expensive, pocket meters generally allow for better accuracy (i.e. pH and electrical conductivity (EC), (Figure 11.2) but is still not nearly as accurate as the equipment used in laboratories. These quick field assessments only give the user an indication of the field condition and should always be backed up by an assessment conducted in a credible laboratory. A cursory search for 'field test kits' on the internet will yield much information on soil constituents that can be quantified *in situ*.

Box 11.1. Soil test kits

There are diverse soil test kits available on the market comprising various compilations of simple soil tests. Before purchasing one or the other it is strongly recommended to get expert advice on the value of the product first.

Assessment of soil health

Comprehensive field and laboratory approach

Due to the complexity of soils it is not possible to find a single key indicator for evaluating the performance of soils. Several integrated approaches for soil health assessment have been developed[1,2,3,4]. They differ in the chosen indicators but the basic concept is the same: by linking selected indicators for physical, chemical and biological proper-

Figure 11.2. pH test strips, Nitrate test strips and pH and EC pocket meter.

Soil biology	Erosion	Crop condition/ Plant health
		
Is there evidence of earthworms (tunnels or actual earthworms) in the soil? A large number of earthworms (2 - 5 in a spade of topsoil) is a good indicator of a healthy soil. (See Chapter 5 for more details on soil biology.)	Best to observe after heavy rain. Is there evidence that topsoil has been transported downslope by surface runoff? Have gullies started developing?	Does the crop show vigorous growth or does it look stressed? Are the plants often affected by diseases?
Soil compaction	**Soil salinity**	**Soil pollution**
		
Does water stand in the cane rows after rainfall (low infiltration) Did you use heavy machinery in wet fields?	Does the crop look stressed even after good rain or irrigation?	Do you have emitters in your neighbourhood which could cause an input of hazardous substances?

ties the components and interactions of a soil system are viewed together. However first simple field observations and observations of the surrounding environment can help to identify soil problems.

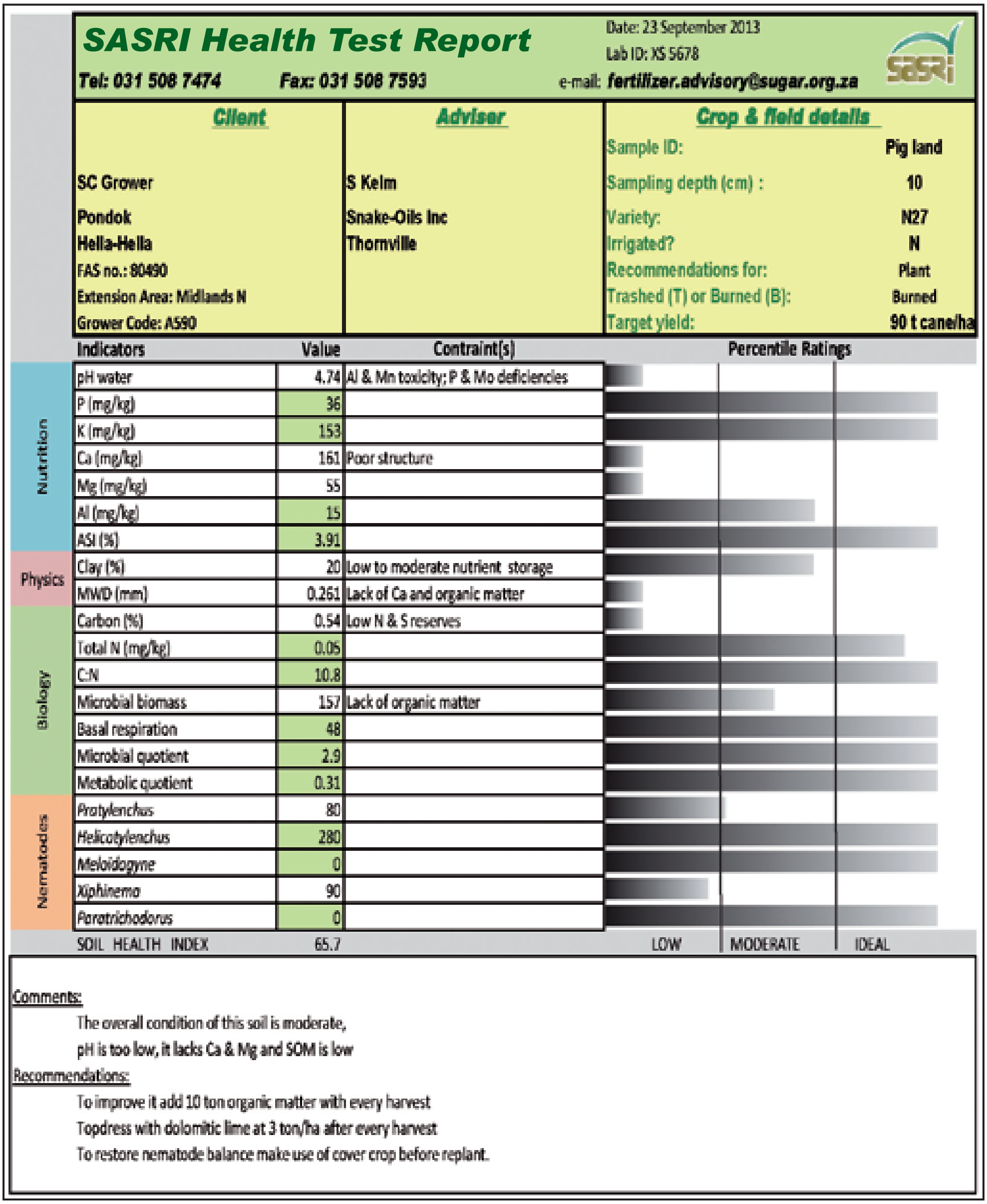
A number of soil health assessment guides for in-field observations have been developed using a scorecard system, where each of the observed parameters are categorised as poor, medium or good. One example of an indicator scorecard table is shown in Table 11.2.

Most of the field assessment indicators are of a qualitative nature and are based on observations. The more specific the purpose of the assessment is (e.g. diagnosis of specific soil problems) the more the number of quantitative measurables that need to be involved, and a laboratory assessment will be necessary.

Table 11.2. Indicator table developed by farmers for in-field observations.

Indicator	Poor	Medium	Good	My rating		
				Poor	Med	Good
Earthworms	0 - 1 worms in a spade of topsoil, no casts or holes.	2 - 10 worms in a spade of topsoil, few casts and holes.	10+ worms, lots of casts and holes, birds behind tillage.			
Organic matter – colour	Topsoil color similar to subsoil colour (excluding humic soils).	Surface colour slightly different to subsoil colour.	Topsoil clearly darker than subsoil.			
Compaction	5 mm steel rod bends when inserting, not easy to sample with Beater auger.	Have to push hard with steel rod.	Steel rod goes in easily.			
Soil tilth/ structure	No evidence of structure, not easy to sample with Beater auger.	Somewhat cloddy.	Soil crumbles well, gives way when walked upon.			
Erosion	Large gullies, visible evidence of sediment loss, thin or no topsoil.	Few gullies up to 5 cm deep colored water from runoff.	No gullies, clear runoff water.			
Water holding capacity	Plant stresses even if the soil is wet.	Water is depleted after a week.	Holds water for a long period of time without puddling.			
Drainage/ infiltration	Water lies for a long time, evaporates more than drains.	Water lies for short period of time, eventually drains.	No ponding, no runoff; soil drains easily following irrigation or light rainfall.			
Crop condition	Problem growing throughout season, poor or uneven growth, yellow or purple color.	Fair growth, spots in field different, medium green color.	Normal healthy dark green, excellent growth all season, across field.			
pH via test strips	Hard to correct.	Easily rectified.	Proper pH for crop.			
Nutrient holding capacity	Soil tests dropping with more fertiliser applied than used by the crop.	Little change or slow trend.	Soil tests trending up in relation to fertiliser applied and crop harvested.			

A comprehensive assessment of soil health includes a wide range of chemical, physical and biological parameters determined in the laboratory and in the field. Suitable indicators for a soil health assessment of sugarcane soils have been selected and standards for their interpretation have been developed[4]. As a result of this work, a package for a soil health assessment is now available from SASRI which summarises the results of the comprehensive list of parameters into a soil health index. An example of a soil health test report is shown in Figure 11.3. This comprehensive route is recommended where degradation of the



SASRI Health Test Report

Date: 23 September 2013
Lab ID: XS 5678

Tel: 031 508 7474 Fax: 031 508 7593 e-mail: fertilizer.advisory@sugar.org.za

Client	Advisor	Crop & field details	
		Sample ID:	Pig land
SC Grower	S Kelm	Sampling depth (cm) :	10
Pondok	Snake-Oils Inc	Variety:	N27
Hella-Hella	Thornville	Irrigated?	N
FAS no.: 80490		Recommendations for:	Plant
Extension Area: Midlands N		Trashed (T) or Burned (B):	Burned
Grower Code: A590		Target yield:	90 t cane/ha

	Indicators	Value	Contraint(s)
Nutrition	pH water	4.74	Al & Mn toxicity; P & Mo deficiencies
	P (mg/kg)	36	
	K (mg/kg)	153	
	Ca (mg/kg)	161	Poor structure
	Mg (mg/kg)	55	
	Al (mg/kg)	15	
	ASI (%)	3.91	
Physics	Clay (%)	20	Low to moderate nutrient storage
	MWD (mm)	0.261	Lack of Ca and organic matter
Biology	Carbon (%)	0.54	Low N & S reserves
	Total N (mg/kg)	0.05	
	C:N	10.8	
	Microbial biomass	157	Lack of organic matter
	Basal respiration	48	
	Microbial quotient	2.9	
	Metabolic quotient	0.31	
Nematodes	*Pratylenchus*	80	
	Helicotylenchus	280	
	Meloidogyne	0	
	Xiphinema	90	
	Paratrichodorus	0	
	SOIL HEALTH INDEX	65.7	

Comments:

The overall condition of this soil is moderate,
pH is too low, it lacks Ca & Mg and SOM is low

Recommendations:

To improve it add 10 ton organic matter with every harvest
Topdress with dolomitic lime at 3 ton/ha after every harvest
To restore nematode balance make use of cover crop before replant.

Figure 11.3. An example of the SASRI soil health test report.

soil quality and yield decline are obvious, but the cause of the problem cannot be diagnosed.

Long term maintenance of soil fertility

Maintaining your soils' fertility involves a long-term strategy, with many facets. The most important points to consider are the following:

- Wherever possible, aim to increase – or at least maintain – soil organic matter levels (see Chapter 5). Organic amendments, reduced tillage, long fallows with break crops and green cane harvesting are some of the measures that can be employed.
- Protect your soil life by implementing conservation agricultural measures (diversification via crop rotations, keeping soil covered through mulching and trashing).
- Get to know your soils; then monitor them, and manage soil fertility according to soil type. Keep an eye out for soil acidity (dryland) or salinity/sodicity (irrigated regions) with regular subsoil sampling (see Chapters 9 and 10).
- Apply fertiliser and lime/gypsum according to soil analysis and laboratory recommendations (Chapter 9).
- Employ erosion prevention measures as per your land use plan.
- Avoid compaction by timing field operations carefully. Do not use heavy machinery in wet fields.
- Guard against stool damage by matching wheel and row spacing, and managing infield traffic and loading operations (Chapter 1).

Box 11.2 SUSFARMS®

SuSFarMS® is a self-assessment guide for farmers to test their compliance with a list of legal regulations and their agronomic and social sustainability. Contact the SASRI library for a copy.

The sustainability of your farming operation can be tracked – by you and others – using a self-assessment guide such as SUSFARMS®. Regular audits will allow you to benchmark your operation against the most desirable management practices; aim to increase your score and compliance each time. SUSFARMS® is designed to encourage sustainable sugarcane production through the implementation of better management practices (BMPs). The SUSFARMS® system is a tool which takes into account relevant local and international legislation and BMPs developed by the sugar industry. A list of criteria, against which cane growers are scored, is used as a progress tracker by the growers themselves or by extension specialists, and the status of the farm determined[5].

Suggested management solutions to soil health problems

common soil-related problems that limit sugarcane yield are soil acidification, salinity and sodicity, nutritional imbalances, shortage of soil organic matter with reduced biological activity, compaction and stool damage, reduced infiltration, runoff and erosion. Use Table 11.3 to determine the possible causes of these problems, and to formulate mitigation strategies.

Table 11.3. Common problems in sugarcane soils, their indicators, possible causes and suggested solutions (adapted from USDA 2001).

Indicators	Possible causes	Suggestions to improve soil quality
Compaction		
High bulk density (lab test). High penetration resistance. Low porosity (lab test). Poor root distribution.	Working wet soil. Excess traffic. Heavy machinery. Repeated tillage at same depth. Poor aggregation. Low organic matter.	Avoid working wet soil. Reduce traffic/tillage operations. Use controlled traffic patterns. Avoid using heavy machinery. Rip to alleviate compaction. Till when soil is not excessively wet or dry. Add organic residues/manures. Diversify cropping system (i.e. make use of green manures). Adopt conservation tillage practices.
Crusting		
Poor infiltration; increased runoff. Evidence of crusting at the soil surface. Low aggregate stability (lab test). Slake test results poor (lab test).	Excess sodium. Low soil organic matter. Low residue cover.	Increase organic residues. Chisel plough to break up crust. Use cover crops. For sodium problem - see 'Sodicity' in Chapter 10.
Poor drainage		
Low infiltration rate; increased runoff and erosion. Slow water flow through the soil.	Plough pan. High water table. Poor soil structure.	Rip subsoil to break up plough pan. Install drainage system. Add organic matter.

Indicators	Possible causes	Suggestions to improve soil quality
Poor soil biological activity		
Absence of (or few) earthworms. Pitfall trapping numbers low.	Low soil organic matter. Lack of surface cover. Excess pesticides. Excessive tillage. Poor aeration. Excessive soil acidity/salinity/sodicity. Monocropping.	Increase organic residues. Use conservation tillage. Use crop rotations. Use cover crops. Manage soil acidity/salinity/sodicity. Avoid overuse of pesticides.
Salinity		
Water stress symptoms despite sufficient water supply. Observe white salt deposits. High electrical conductivity (lab test).	Water seepage from higher areas. Poor quality irrigation water. Shallow water table. Poor drainage.	Leach excess salts. Irrigate to manage water table. Manage water quality. Improve drainage. Grow salt tolerant break crops.
Sodicity		
Soil crusting. High pH (lab test). High SAR (lab test). Poor soil structure.	Water seepage from higher areas. Shallow water table. Unsuitable or poor quality irrigation water. Poor drainage.	Apply gypsum according to lab recommendations, then leach with irrigation water. Manage irrigation water quality and scheduling. Improve drainage.
Erosion		
Evidence of soil wash or movement, gullies. Shallow topsoil. Poor aggregate stability.	Surface crust. Lack of cover and residue. Low organic matter. Plough pan or compacted layer. Tillage on steep slopes. Tillage of entire hill slope.	Reduce tillage. Use organic residues. Use cover crops during fallows. Increase surface residue. Use correct contour intervals. Practice strip cropping.

Indicators	Possible causes	Suggestions to improve soil quality
Poor infiltration		
Increased runoff. Poor aggregate stability. Ponding.	Compaction. Surface crusting. Plough pan. Poor soil structure/aggregation. Excess sodium.	Add organic residue. Diversify crop rotation. For sodium problem, see ‘Sodicity’ in Chapter 10. Subsoil or rip when soil is not excessively wet or dry.
Low organic matter/residue		
Low organic carbon (lab test). Low percent residues returned.	Excess tillage. Residue burned off. Low residue crops. Too much bare fallow. Insufficient additions of crop residue.	Diversify or increase crop rotations. Add animal manure. Use cover crops. Use high residue crops. Reduce tillage.
Poor root development		
Aluminium toxicity. Root disease. Sensitivity to water stress. Stubby roots. Poor plant growth. Poor root distribution. Lodging.	Nematodes. Plough pan. Subsoil acidity. Over-application of herbicides. Poor liming practices. Poor drainage and/or over-irrigation High frequency, low application rates of irrigation.	Ensure proper drainage. Alleviate compacted layers. Manage soil acidity. Irrigation scheduling. Calibrate herbicide applications. Control soil pests.
Large clods following tillage		
Large clods following tillage.	Low organic matter and lack of surface residue. Tillage when the soil is excessively wet or dry. Compaction.	Avoid tillage when excessively wet or dry. Increase organic residues. Use cover crops.

SUMMARY

- Soil health assessments are essential to identify and reverse any improper management practices which contribute to soil damage and yield decline.
- The indicators used in a soil health assessment are usually interpreted within the context of the inherent properties of that soil (soil quality).
- A field assessment is the most appropriate and easiest way for an initial soil quality assessment. The more specific the purpose of the assessment (e.g. diagnosis of specific soil problems), the more the number of quantitative measurables that need to be involved. A credible laboratory assessment will also be necessary.
- A comprehensive soil health analysis involves chemical, physical and biological soil parameters. This is recommended where degradation of soil quality together with declining yields cannot be attributed to a specific soil problem.

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APPENDICES, GLOSSARY & INDEX

Appendix I

Quantities of N, P and K per unit of fertiliser

				50			100			200			300		
	Mixture		%	N	P	K	N	P	K	N	P	K	N	P	K
1	0	1	36	9.0	0.0	9.0	18.0	0.0	18.0	36.0	0.0	36.0	54.0	0.0	54.0
1	0	1	48	12.0	0.0	12.0	24.0	0.0	24.0	48.0	0.0	48.0	72.0	0.0	72.0
1	0	2	39	6.5	0.0	13.0	13.0	0.0	26.0	26.0	0.0	52.0	39.0	0.0	78.0
1	0	2	48	8.0	0.0	16.0	16.0	0.0	32.0	32.0	0.0	64.0	48.0	0.0	96.0
1	0	3	49	6.1	0.0	18.4	12.3	0.0	36.8	24.5	0.0	73.5	36.8	0.0	110.3
2	0	3	38	7.6	0.0	11.4	15.2	0.0	22.8	30.4	0.0	45.6	45.6	0.0	68.4
2	0	3	48	9.6	0.0	14.4	19.2	0.0	28.8	38.4	0.0	57.6	57.6	0.0	86.4
2	0	5	49	7.0	0.0	17.5	14.0	0.0	35.0	28.0	0.0	70.0	42.0	0.0	105.0
2	3	2	22	3.1	4.7	3.1	6.3	9.4	6.3	12.6	18.9	12.6	18.9	28.3	18.9
2	3	2	30	4.3	6.4	4.3	8.6	12.9	8.6	17.1	25.7	17.1	25.7	38.6	25.7
2	3	4	24	2.7	4.0	5.3	5.3	8.0	10.7	10.7	16.0	21.3	16.0	24.0	32.0
2	3	4	30	3.3	5.0	6.7	6.7	10.0	13.3	13.3	20.0	26.7	20.0	30.0	40.0
2	3	4	40	4.4	6.7	8.9	8.9	13.3	17.8	17.8	26.7	35.6	26.7	40.0	53.3
3	0	5	38	7.1	0.0	11.9	14.3	0.0	23.8	28.5	0.0	47.5	42.8	0.0	71.3
3	1	0	40	15.0	5.0	0.0	30.0	10.0	0.0	60.0	20.0	0.0	90.0	30.0	0.0
3	1	1	30	9.0	3.0	3.0	18.0	6.0	6.0	36.0	12.0	12.0	54.0	18.0	18.0
3	1	4	37	6.9	2.3	9.3	13.9	4.6	18.5	27.8	9.3	37.0	41.6	13.9	55.5
3	1	4	45	8.4	2.8	11.3	16.9	5.6	22.5	33.8	11.3	45.0	50.6	16.9	67.5
3	1	5	38	6.3	2.1	10.6	12.7	4.2	21.1	25.3	8.4	42.2	38.0	12.7	63.3
3	1	5	45	7.5	2.5	12.5	15.0	5.0	25.0	30.0	10.0	50.0	45.0	15.0	75.0
4	0	5	38	8.4	0.0	10.6	16.9	0.0	21.1	33.8	0.0	42.2	50.7	0.0	63.3
4	0	5	48	10.7	0.0	13.3	21.3	0.0	26.7	42.7	0.0	53.3	64.0	0.0	80.0
4	0	9	48	7.4	0.0	16.6	14.8	0.0	33.2	29.5	0.0	66.5	44.3	0.0	99.7
4	1	0	42	16.8	4.2	0.0	33.6	8.4	0.0	67.2	16.8	0.0	100.8	25.2	0.0
4	1	1	42	14.0	3.5	3.5	28.0	7.0	7.0	56.0	14.0	14.0	84.0	21.0	21.0
4	1	5	46	9.2	2.3	11.5	18.4	4.6	23.0	36.8	9.2	46.0	55.2	13.8	69.0
4	1	6	38	6.9	1.7	10.4	13.8	3.5	20.7	27.6	6.9	41.5	41.5	10.4	62.2
4	1	6	47	8.5	2.1	12.8	17.1	4.3	25.6	34.2	8.5	51.3	51.3	12.8	76.9
4	1	12	46	5.4	1.4	16.2	10.8	2.7	32.5	21.6	5.4	64.9	32.5	8.1	97.4
4	1	12	47	5.5	1.4	16.6	11.1	2.8	33.2	22.1	5.5	66.4	33.2	8.3	99.5

4	1	15	47	4.7	1.2	17.6	9.4	2.4	35.3	18.8	4.7	70.5	28.2	7.1	105.8
4	3	4	40	7.3	5.5	7.3	14.5	10.9	14.5	29.1	21.8	29.1	43.6	32.7	43.6
5	0	3	33	10.3	0.0	6.2	20.6	0.0	12.4	41.3	0.0	24.8	61.9	0.0	37.1
5	1	5	36	8.2	1.6	8.2	16.4	3.3	16.4	32.7	6.5	32.7	49.1	9.8	49.1
5	1	5	46	10.5	2.1	10.5	20.9	4.2	20.9	41.8	8.4	41.8	62.7	12.5	62.7
5	1	7	45	8.7	1.7	12.1	17.3	3.5	24.2	34.6	6.9	48.5	51.9	10.4	72.7
6	0	5	35	9.5	0.0	8.0	19.1	0.0	15.9	38.2	0.0	31.8	57.3	0.0	47.7
6	1	0	42	18.0	3.0	0.0	36.0	6.0	0.0	72.0	12.0	0.0	108.0	18.0	0.0
6	1	0	43	18.4	3.1	0.0	36.9	6.1	0.0	73.7	12.3	0.0	110.6	18.4	0.0
6	1	6	38	8.8	1.5	8.8	17.5	2.9	17.5	35.1	5.8	35.1	52.6	8.8	52.6
6	1	6	46	10.6	1.8	10.6	21.2	3.5	21.2	42.5	7.1	42.5	63.7	10.6	63.7
6	1	7	47	10.1	1.7	11.8	20.1	3.4	23.5	40.3	6.7	47.0	60.4	10.1	70.5
6	1	8	37	7.4	1.2	9.9	14.8	2.5	19.7	29.6	4.9	39.5	44.4	7.4	59.2
6	1	8	46	9.2	1.5	12.3	18.4	3.1	24.5	36.8	6.1	49.1	55.2	9.2	73.6
6	1	9	38	7.1	1.2	10.7	14.3	2.4	21.4	28.5	4.8	42.8	42.8	7.1	64.1
7	1	6	46	11.5	1.6	9.9	23.0	3.3	19.7	46.0	6.6	39.4	69.0	9.9	59.1
7	1	9	47	9.7	1.4	12.4	19.4	2.8	24.9	38.7	5.5	49.8	58.1	8.3	74.6
8	0	5	47	14.5	0.0	9.0	28.9	0.0	18.1	57.8	0.0	36.2	86.8	0.0	54.2
8	0	7	47	12.5	0.0	11.0	25.1	0.0	21.9	50.1	0.0	43.9	75.2	0.0	65.8
8	1	0	44	19.6	2.4	0.0	39.1	4.9	0.0	78.2	9.8	0.0	117.3	14.7	0.0
8	1	7	35	8.8	1.1	7.7	17.5	2.2	15.3	35.0	4.4	30.6	52.5	6.6	45.9
8	1	7	47	11.8	1.5	10.3	23.5	2.9	20.6	47.0	5.9	41.1	70.5	8.8	61.7
8	1	10	47	9.9	1.2	12.4	19.8	2.5	24.7	39.6	4.9	49.5	59.4	7.4	74.2
18	20	0	35	8.3	9.2	0.0	16.6	18.4	0.0	33.2	36.8	0.0	49.7	55.3	0.0
MAP			33	5.5	11.0	0.0	11.0	22.0	0.0	22.0	44.0	0.0	33.0	66.0	0.0
Amm supers			16	1.9	6.1	0.0	3.8	12.2	0.0	7.6	24.4	0.0	11.4	36.6	0.0
Superphosphate			10.5	0.0	5.3	0.0	0.0	10.5	0.0	0.0	21.0	0.0	0.0	31.5	0.0
Urea			46	23.0	0.0	0.0	46.0	0.0	0.0	92.0	0.0	0.0	138.0	0.0	0.0
Ammonium sulphate			21	10.5	0.0	0.0	21.0	0.0	0.0	42.0	0.0	0.0	63.0	0.0	0.0
LAN			28	14.0	0.0	0.0	28.0	0.0	0.0	56.0	0.0	0.0	84.0	0.0	0.0
ASN			27	13.5	0.0	0.0	27.0	0.0	0.0	54.0	0.0	0.0	81.0	0.0	0.0
UAN (Urea-Amm. nitrate)			32	16.0	0.0	0.0	32.0	0.0	0.0	64.0	0.0	0.0	96.0	0.0	0.0
Anhyd Ammonia			82	41.0	0.0	0.0	82.0	0.0	0.0	164.0	0.0	0.0	246.0	0.0	0.0
KCl			50	0.0	0.0	25.0	0.0	0.0	50.0	0.0	0.0	100.0	0.0	0.0	150.0
Pot sulphate			40	0.0	0.0	20.0	0.0	0.0	40.0	0.0	0.0	80.0	0.0	0.0	120.0
Pot nitrate			51	6.5	0.0	19.0	13.0	0.0	38.0	26.0	0.0	76.0	39.0	0.0	114.0

Appendix I (continued)

Quantities of N, P and K per unit of fertiliser

				400			500			600			700		
Mixture			%	N	P	K	N	P	K	N	P	K	N	P	K
1	0	1	36	72.0	0.0	72.0	90.0	0.0	90.0	108.0	0.0	108.0	126.0	0.0	126.0
1	0	1	48	96.0	0.0	96.0	120.0	0.0	120.0	144.0	0.0	144.0	168.0	0.0	168.0
1	0	2	39	52.0	0.0	104.0	65.0	0.0	130.0	78.0	0.0	156.0	91.0	0.0	182.0
1	0	2	48	64.0	0.0	128.0	80.0	0.0	160.0	96.0	0.0	192.0	112.0	0.0	224.0
1	0	3	49	49.0	0.0	147.0	61.3	0.0	183.8	73.5	0.0	220.5	85.8	0.0	257.3
2	0	3	38	60.8	0.0	91.2	76.0	0.0	114.0	91.2	0.0	136.8	106.4	0.0	159.6
2	0	3	48	76.8	0.0	115.2	96.0	0.0	144.0	115.2	0.0	172.8	134.4	0.0	201.6
2	0	5	49	56.0	0.0	140.0	70.0	0.0	175.0	84.0	0.0	210.0	98.0	0.0	245.0
2	3	2	22	25.1	37.7	25.1	31.4	47.1	31.4	37.7	56.6	37.7	44.0	66.0	44.0
2	3	2	30	34.3	51.4	34.3	42.9	64.3	42.9	51.4	77.1	51.4	60.0	90.0	60.0
2	3	4	24	21.3	32.0	42.7	26.7	40.0	53.3	32.0	48.0	64.0	37.3	56.0	74.7
2	3	4	30	26.7	40.0	53.3	33.3	50.0	66.7	40.0	60.0	80.0	46.7	70.0	93.3
2	3	4	40	35.6	53.3	71.1	44.4	66.7	88.9	53.3	80.0	106.7	62.2	93.3	124.4
3	0	5	38	57.0	0.0	95.0	71.3	0.0	118.8	85.5	0.0	142.5	99.8	0.0	166.3
3	1	0	40	120.0	40.0	0.0	150.0	50.0	0.0	180.0	60.0	0.0	210.0	70.0	0.0
3	1	1	30	72.0	24.0	24.0	90.0	30.0	30.0	108.0	36.0	36.0	126.0	42.0	42.0
3	1	4	37	55.5	18.5	74.0	69.4	23.1	92.5	83.3	27.8	111.0	97.1	32.4	129.5
3	1	4	45	67.5	22.5	90.0	84.4	28.1	112.5	101.3	33.8	135.0	118.1	39.4	157.5
3	1	5	38	50.7	16.9	84.4	63.3	21.1	105.6	76.0	25.3	126.7	88.7	29.6	147.8
3	1	5	45	60.0	20.0	100.0	75.0	25.0	125.0	90.0	30.0	150.0	105.0	35.0	175.0
4	0	5	38	67.6	0.0	84.4	84.4	0.0	105.6	101.3	0.0	126.7	118.2	0.0	147.8
4	0	5	48	85.3	0.0	106.7	106.7	0.0	133.3	128.0	0.0	160.0	149.3	0.0	186.7
4	0	9	48	59.1	0.0	132.9	73.8	0.0	166.2	88.6	0.0	199.4	103.4	0.0	232.6
4	1	0	42	134.4	33.6	0.0	168.0	42.0	0.0	201.6	50.4	0.0	235.2	58.8	0.0
4	1	1	42	112.0	28.0	28.0	140.0	35.0	35.0	168.0	42.0	42.0	196.0	49.0	49.0
4	1	5	46	73.6	18.4	92.0	92.0	23.0	115.0	110.4	27.6	138.0	128.8	32.2	161.0
4	1	6	38	55.3	13.8	82.9	69.1	17.3	103.6	82.9	20.7	124.4	96.7	24.2	145.1
4	1	6	47	68.4	17.1	102.5	85.5	21.4	128.2	102.5	25.6	153.8	119.6	29.9	179.5
4	1	12	46	43.3	10.8	129.9	54.1	13.5	162.4	64.9	16.2	194.8	75.8	18.9	227.3
4	1	12	47	44.2	11.1	132.7	55.3	13.8	165.9	66.4	16.6	199.1	77.4	19.4	232.2

4	1	15	47	37.6	9.4	141.0	47.0	11.8	176.3	56.4	14.1	211.5	65.8	16.5	246.8
4	3	4	40	58.2	43.6	58.2	72.7	54.5	72.7	87.3	65.5	87.3	101.8	76.4	101.8
5	0	3	33	82.5	0.0	49.5	103.1	0.0	61.9	123.8	0.0	74.3	144.4	0.0	86.6
5	1	5	36	65.5	13.1	65.5	81.8	16.4	81.8	98.2	19.6	98.2	114.5	22.9	114.5
5	1	5	46	83.6	16.7	83.6	104.5	20.9	104.5	125.5	25.1	125.5	146.4	29.3	146.4
5	1	7	45	69.2	13.8	96.9	86.5	17.3	121.2	103.8	20.8	145.4	121.2	24.2	169.6
6	0	5	35	76.4	0.0	63.6	95.5	0.0	79.5	114.5	0.0	95.5	133.6	0.0	111.4
6	1	0	42	144.0	24.0	0.0	180.0	30.0	0.0	216.0	36.0	0.0	252.0	42.0	0.0
6	1	0	43	147.4	24.6	0.0	184.3	30.7	0.0	221.1	36.9	0.0	258.0	43.0	0.0
6	1	6	38	70.2	11.7	70.2	87.7	14.6	87.7	105.2	17.5	105.2	122.8	20.5	122.8
6	1	6	46	84.9	14.2	84.9	106.2	17.7	106.2	127.4	21.2	127.4	148.6	24.8	148.6
6	1	7	47	80.6	13.4	94.0	100.7	16.8	117.5	120.9	20.1	141.0	141.0	23.5	164.5
6	1	8	37	59.2	9.9	78.9	74.0	12.3	98.7	88.8	14.8	118.4	103.6	17.3	138.1
6	1	8	46	73.6	12.3	98.1	92.0	15.3	122.7	110.4	18.4	147.2	128.8	21.5	171.7
6	1	9	38	57.0	9.5	85.5	71.3	11.9	106.9	85.5	14.3	128.3	99.8	16.6	149.6
7	1	6	46	92.0	13.1	78.9	115.0	16.4	98.6	138.0	19.7	118.3	161.0	23.0	138.0
7	1	9	47	77.4	11.1	99.5	96.8	13.8	124.4	116.1	16.6	149.3	135.5	19.4	174.2
8	0	5	47	115.7	0.0	72.3	144.6	0.0	90.4	173.5	0.0	108.5	202.5	0.0	126.5
8	0	7	47	100.3	0.0	87.7	125.3	0.0	109.7	150.4	0.0	131.6	175.5	0.0	153.5
8	1	0	44	156.4	19.6	0.0	195.6	24.4	0.0	234.7	29.3	0.0	273.8	34.2	0.0
8	1	7	35	70.0	8.8	61.3	87.5	10.9	76.6	105.0	13.1	91.9	122.5	15.3	107.2
8	1	7	47	94.0	11.8	82.3	117.5	14.7	102.8	141.0	17.6	123.4	164.5	20.6	143.9
8	1	10	47	79.2	9.9	98.9	98.9	12.4	123.7	118.7	14.8	148.4	138.5	17.3	173.2
18	20	0	35	66.3	73.7	0.0	82.9	92.1	0.0	99.5	110.5	0.0	116.1	128.9	0.0
MAP			33	44.0	88.0	0.0	55.0	110.0	0.0	66.0	132.0	0.0	77.0	154.0	0.0
Amm supers			16	15.2	48.8	0.0	19.0	61.0	0.0	22.8	73.2	0.0	26.6	85.4	0.0
Superphosphate			10.5	0.0	42.0	0.0	0.0	52.5	0.0	0.0	63.0	0.0	0.0	73.5	0.0
Urea			46	184.0	0.0	0.0	230.0	0.0	0.0	276.0	0.0	0.0	322.0	0.0	0.0
Ammonium sulphate			21	84.0	0.0	0.0	105.0	0.0	0.0	126.0	0.0	0.0	147.0	0.0	0.0
LAN			28	112.0	0.0	0.0	140.0	0.0	0.0	168.0	0.0	0.0	196.0	0.0	0.0
ASN			27	108.0	0.0	0.0	135.0	0.0	0.0	162.0	0.0	0.0	189.0	0.0	0.0
UAN (Urea-Amm. nitrate)			32	128.0	0.0	0.0	160.0	0.0	0.0	192.0	0.0	0.0	224.0	0.0	0.0
Anhyd Ammonia			82	328.0	0.0	0.0	410.0	0.0	0.0	492.0	0.0	0.0	574.0	0.0	0.0
KCl			50	0.0	0.0	200.0	0.0	0.0	250.0	0.0	0.0	300.0	0.0	0.0	350.0
Pot sulphate			40	0.0	0.0	160.0	0.0	0.0	200.0	0.0	0.0	240.0	0.0	0.0	280.0
Pot nitrate			51	52.0	0.0	152.0	65.0	0.0	190.0	78.0	0.0	228.0	91.0	0.0	266.0

Appendix I (continued)

Quantities of N, P and K per unit of fertiliser

				800			900			1000		
Mixture			%	N	P	K	N	P	K	N	P	K
1	0	1	36	144.0	0.0	144.0	162.0	0.0	162.0	180.0	0.0	180.0
1	0	1	48	192.0	0.0	192.0	216.0	0.0	216.0	240.0	0.0	240.0
1	0	2	39	104.0	0.0	208.0	117.0	0.0	234.0	130.0	0.0	260.0
1	0	2	48	128.0	0.0	256.0	144.0	0.0	288.0	160.0	0.0	320.0
1	0	3	49	98.0	0.0	294.0	110.3	0.0	330.8	122.5	0.0	367.5
2	0	3	38	121.6	0.0	182.4	136.8	0.0	205.2	152.0	0.0	228.0
2	0	3	48	153.6	0.0	230.4	172.8	0.0	259.2	192.0	0.0	288.0
2	0	5	49	112.0	0.0	280.0	126.0	0.0	315.0	140.0	0.0	350.0
2	3	2	22	50.3	75.4	50.3	56.6	84.9	56.6	62.9	94.3	62.9
2	3	2	30	68.6	102.9	68.6	77.1	115.7	77.1	85.7	128.6	85.7
2	3	4	24	42.7	64.0	85.3	48.0	72.0	96.0	53.3	80.0	106.7
2	3	4	30	53.3	80.0	106.7	60.0	90.0	120.0	66.7	100.0	133.3
2	3	4	40	71.1	106.7	142.2	80.0	120.0	160.0	88.9	133.3	177.8
3	0	5	38	114.0	0.0	190.0	128.3	0.0	213.8	142.5	0.0	237.5
3	1	0	40	240.0	80.0	0.0	270.0	90.0	0.0	300.0	100.0	0.0
3	1	1	30	144.0	48.0	48.0	162.0	54.0	54.0	180.0	60.0	60.0
3	1	4	37	111.0	37.0	148.0	124.9	41.6	166.5	138.8	46.3	185.0
3	1	4	45	135.0	45.0	180.0	151.9	50.6	202.5	168.8	56.3	225.0
3	1	5	38	101.3	33.8	168.9	114.0	38.0	190.0	126.7	42.2	211.1
3	1	5	45	120.0	40.0	200.0	135.0	45.0	225.0	150.0	50.0	250.0
4	0	5	38	135.1	0.0	168.9	152.0	0.0	190.0	168.9	0.0	211.1
4	0	5	48	170.7	0.0	213.3	192.0	0.0	240.0	213.3	0.0	266.7
4	0	9	48	118.2	0.0	265.8	132.9	0.0	299.1	147.7	0.0	332.3
4	1	0	42	268.8	67.2	0.0	302.4	75.6	0.0	336.0	84.0	0.0
4	1	1	42	224.0	56.0	56.0	252.0	63.0	63.0	280.0	70.0	70.0
4	1	5	46	147.2	36.8	184.0	165.6	41.4	207.0	184.0	46.0	230.0
4	1	6	38	110.5	27.6	165.8	124.4	31.1	186.5	138.2	34.5	207.3
4	1	6	47	136.7	34.2	205.1	153.8	38.5	230.7	170.9	42.7	256.4
4	1	12	46	86.6	21.6	259.8	97.4	24.4	292.2	108.2	27.1	324.7
4	1	12	47	88.5	22.1	265.4	99.5	24.9	298.6	110.6	27.6	331.8

4	1	15	47	75.2	18.8	282.0	84.6	21.2	317.3	94.0	23.5	352.5
4	3	4	40	116.4	87.3	116.4	130.9	98.2	130.9	145.5	109.1	145.5
5	0	3	33	165.0	0.0	99.0	185.6	0.0	111.4	206.3	0.0	123.8
5	1	5	36	130.9	26.2	130.9	147.3	29.5	147.3	163.6	32.7	163.6
5	1	5	46	167.3	33.5	167.3	188.2	37.6	188.2	209.1	41.8	209.1
5	1	7	45	138.5	27.7	193.8	155.8	31.2	218.1	173.1	34.6	242.3
6	0	5	35	152.7	0.0	127.3	171.8	0.0	143.2	190.9	0.0	159.1
6	1	0	42	288.0	48.0	0.0	324.0	54.0	0.0	360.0	60.0	0.0
6	1	0	43	294.9	49.1	0.0	331.7	55.3	0.0	368.6	61.4	0.0
6	1	6	38	140.3	23.4	140.3	157.8	26.3	157.8	175.4	29.2	175.4
6	1	6	46	169.8	28.3	169.8	191.1	31.8	191.1	212.3	35.4	212.3
6	1	7	47	161.1	26.9	188.0	181.3	30.2	211.5	201.4	33.6	235.0
6	1	8	37	118.4	19.7	157.9	133.2	22.2	177.6	148.0	24.7	197.3
6	1	8	46	147.2	24.5	196.3	165.6	27.6	220.8	184.0	30.7	245.3
6	1	9	38	114.0	19.0	171.0	128.3	21.4	192.4	142.5	23.8	213.8
7	1	6	46	184.0	26.3	157.7	207.0	29.6	177.4	230.0	32.9	197.1
7	1	9	47	154.8	22.1	199.1	174.2	24.9	223.9	193.5	27.6	248.8
8	0	5	47	231.4	0.0	144.6	260.3	0.0	162.7	289.2	0.0	180.8
8	0	7	47	200.5	0.0	175.5	225.6	0.0	197.4	250.7	0.0	219.3
8	1	0	44	312.9	39.1	0.0	352.0	44.0	0.0	391.1	48.9	0.0
8	1	7	35	140.0	17.5	122.5	157.5	19.7	137.8	175.0	21.9	153.1
8	1	7	47	188.0	23.5	164.5	211.5	26.4	185.1	235.0	29.4	205.6
8	1	10	47	158.3	19.8	197.9	178.1	22.3	222.6	197.9	24.7	247.4
18	20	0	35	132.6	147.4	0.0	149.2	165.8	0.0	165.8	184.2	0.0
MAP			33	88.0	176.0	0.0	99.0	198.0	0.0	110.0	220.0	0.0
Amm supers			16	30.4	97.6	0.0	34.2	109.8	0.0	38.0	122.0	0.0
Superphosphate			10.5	0.0	84.0	0.0	0.0	94.5	0.0	0.0	105.0	0.0
Urea			46	368.0	0.0	0.0	414.0	0.0	0.0	460.0	0.0	0.0
Ammonium sulphate			21	168.0	0.0	0.0	189.0	0.0	0.0	210.0	0.0	0.0
LAN			28	224.0	0.0	0.0	252.0	0.0	0.0	280.0	0.0	0.0
ASN			27	216.0	0.0	0.0	243.0	0.0	0.0	270.0	0.0	0.0
UAN (Urea-Amm. nitrate)			32	256.0	0.0	0.0	288.0	0.0	0.0	320.0	0.0	0.0
Anhyd Ammonia			82	656.0	0.0	0.0	738.0	0.0	0.0	820.0	0.0	0.0
KCl			50	0.0	0.0	400.0	0.0	0.0	450.0	0.0	0.0	500.0
Pot sulphate			40	0.0	0.0	320.0	0.0	0.0	360.0	0.0	0.0	400.0
Pot nitrate			51	104.0	0.0	304.0	117.0	0.0	342.0	130.0	0.0	380.0

Appendix II

Calibration of inorganic fertiliser application

Tractor-mounted fertiliser spreaders

Spreading fertiliser with these spreaders requires careful calibration, as distribution and fertiliser rate depend on the speed of movement of the tractor as well as the swath width. In order to calibrate the spreader, the fertiliser in question needs to be placed into the bin, and the fertiliser emanating from the spreader needs to be collected and weighed. It is often best to obtain model-specific assistance from the manufacturer of the spreader. Specific calibration methods will be outlined in the user manuals that accompany the spreader.

Knapsack granule fertiliser applicator

Knapsack applicators often have single or double row configuration, and can be adjusted to apply fertiliser in a broad swath (for broadcasting) rather than a band, if necessary.

Calibration example

Mr Bhengu wants to apply 300 kg/ha urea using a knapsack applicator. How should he calibrate the knapsack applicator?

Step A: Mark out 50 m (a = 50 m).

Step B: Fill the knapsack with urea. Measure the time it takes to walk the 50 m, carrying the full knapsack. Measure this three times and take an average (b = 55 seconds). Note that, where the knapsack operator has to walk on steep slopes, this time should be increased by 10%.

Step C: Attach a bag or hold a plastic jug under the knapsack outlet tube, to collect the fertiliser. Weigh the amount of fertiliser that was released in the time it took to walk 50 m (in this example, 55 seconds). Measure three times and take an average (c = 1.9 kg).

Step D: Record row width (d = 0.9 m).

Step E: Calculate the amount of fertiliser released per ha at the current nozzle width. Calculations will be done on a per hectare basis, i.e. 10 000 m^2.

c = 1.9 kg fertiliser released in 50 m, so

1.9 kg ÷ 50 m = 0.038 kg fertiliser released per metre.

There are 10 000 m^2 in 1 ha, and with 0.9 m row spacing (d), there are

10 000 m^2 ÷ 0.9 m = 11 111.1 m of row per ha.

0.038 kg fertiliser per metre x 11 111.1 m/ha of row =

422.2 kg fertiliser being released (per hectare), at the current nozzle width.

Step F: If necessary, loosen the slide of the nozzle to adjust the nozzle width. Repeat Steps C and E. Repeat until the correct amount is obtained. In this example, because he requires 300 kg/ha, Mr Bhengu needs to make the nozzle narrower to allow less urea to flow out of the knapsack. He should continue to conduct this calibration until 300 kg/ha is obtained.

Once the correct aperture has been found, fasten the slide at this calibrated position. Make a note of this position for future reference.

Wheelbarrow applicator

Calibration of this applicator needs to consider row width, speed of travel and fertiliser type. The slot below the bin can be widened or narrowed to increase or reduce the rate of fertiliser release.

Calibration example:

Assuming Mr Hlongwa needs to apply 550 kg/ha 2:3:4 (46) fertiliser to his field, how should he go about calibrating his wheelbarrow applicator?

Step A: Mark out 50 m (a = 50 m).

Step B: Measure the time it takes to walk the 50 m, pushing the applicator; measure this 3 times and take an average (b = 50 seconds).

Step C: Attach a bag under the spreader, to collect the fertiliser. Weigh the amount of fertiliser that was released in the time it took to walk 50 m (in this example, 50 seconds). Measure 3 times and take an average (c = 2.6 kg).

Step D: Record row width (d = 1.2 m).

Step E: Calculate the amount of fertiliser released per ha at the current slot width. Calculations will be done on a per hectare basis, i.e. 10 000 m^2.

c = 2.6 kg fertiliser released in 50 m, so

2.6 ÷ 50 = 0.052 kg fertiliser released per metre.

There are 10 000 m^2 in 1 ha, and with 1.2 m row spacing (d), there are

10 000 m^2 ÷ 1.2 m = 8 333.3 m of row per ha.

0.052 kg fert per metre x 8 333.3 m/ha of row =

433.3 kg fertiliser being released (per hectare), at the current slot width.

Step F: If necessary, change slot width and repeat Steps C and E. Repeat until the correct amount is obtained. In this example, because he requires 550 kg/ha, Mr Hlongwa needs to open the slot wider to allow more fertiliser to flow out of the bin. He should continue to conduct this calibration until 550 kg/ha is obtained.

Tin-and-string method

Calibration for the tin-and-string method involves calculating the distance (using a length of string) over which a tin of fertiliser should be applied.

Calibration example:

Mr Smith has a supply of empty 500 ml tins which he will use to apply fertiliser. He wants to apply 300 kg/ha of 4:1:0 (42). How long should each string be to apply the correct amount?

Step A: Measure the mass of the empty 500 ml container (a = 42 g).

Step B: Measure the mass of the 500 ml container, filled with 4:1:0 (42) fertiliser (b = 340 g).

Step C: Measure the row spacing (c = 1.2 m).

Step D: Do the calculations:

1) Mass of fertiliser = b – a = 340 g – 42 g = 298 g per tin

2) There are 10 000 m^2 in 1 ha, and with 1.2 m row spacing (c), there are

10 000 m^2 ÷ 1.2 m = 8 333.3 m of row per ha.

3) 300 kg of fertiliser spread over 8 333.3 m of row

= 300 kg ÷ 8 333.3

= 0.036 kg/m, or 36 g/m.

4) If 36 g needs to be applied per metre, how many metres will 298 g (in each tin) cover?

298 g ÷ 36 g/m = 8.28 m.

Therefore each string should be 8.28 m long, i.e. each tin will cover 8.28 m of row.

Note: Appendix III contains calculations which have been done for numerous types of fertiliser and row spacing, showing the correct string length for a 500 ml tin.

Appendix III

Hand application of fertiliser using an oil tin (500 ml)

Fertilisers are grouped according to their bulk density. Some examples are shown in the following table.

Bulk density group	A	B	C	D	E
Fertiliser	Urea 1:0:1 (47) 1:0:1 (37)	4:1:0 (30) 5:1:5 (45) 5:1:5 (42) 5:1:5 (38) 4:1:1 (33) 4:1:1 (30)	2:3:2 (22) Zn 2:3:4 (30) Zn 3:2:1 (25) Zn	Amm. Supers 16 Saaifos 16 LAN Amm. Sulphate	Amm. Supers + Zn Saaifos 16 + Zn KCl Supers 11.3%

The approximate length of row in meters (at different row spacings) that should be covered in applying 500 ml of fertiliser at different rates

Row spacing		0.91 m					1.00 m					1.07 m				
Bulk density group		A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Fertiliser rate (kg/ha)	100	53.0	57.0	65.0	69.0	73.0	49.0	52.0	59.0	63.0	66.0	46.0	49.0	55.0	49.0	62.0
	200	27.0	28.0	32.0	34.0	36.0	24.0	26.0	30.0	32.0	33.0	23.0	24.0	28.0	30.0	31.0
	300	18.0	19.0	22.0	23.0	24.0	16.0	17.0	20.0	21.0	22.0	15.0	16.0	18.0	20.0	21.0
	400	13.0	14.0	16.0	17.0	18.0	12.0	13.0	15.0	16.0	17.0	11.0	12.0	14.0	15.0	16.0
	500	11.0	11.5	13.0	14.0	14.5	10.0	10.5	12.0	13.0	13.5	9.0	10.0	11.0	12.0	12.5
	600	9.0	9.5	11.0	11.5	12.0	8.0	8.5	10	10.5	11.0	7.5	8.0	9.0	10.0	10.5
	700	7.5	8.0	9.0	10.0	10.5	7.0	7.5	8.5	7.5	9.5	6.5	7.0	8.0	8.5	8.5
	800	6.5	7.0	8.0	8.5	9.5	6.0	6.5	7.5	8.0	8.0	5.5	6.5	6.0	7.5	8.0
	900	6.0	6.5	7.0	7.5	7.5	6.0	6.0	6.5	7.0	7.5	5.0	5.5	6.0	6.5	7.0
	1000	5.5	6.0	6.5	7.0	7.5	5.0	5.5	6.0	6.5	7.0	4.5	5.0	5.5	6.0	6.5

Appendix III (continued)

Hand application of fertiliser using an oil tin (500 ml)

Fertilisers are grouped according to their bulk density. Some examples are shown in the following table.

Bulk density group	A	B	C	D	E
Fertiliser	Urea 1:0:1 (47) 1:0:1 (37)	4:1:0 (30) 5:1:5 (45) 5:1:5 (42) 5:1:5 (38) 4:1:1 (33) 4:1:1 (30)	2:3:2 (22) Zn 2:3:4 (30) Zn 3:2:1 (25) Zn	Amm. Supers 16 Saaifos 16 LAN Amm. Sulphate	Amm. Supers +Zn Saaifos 16 + Zn KCl Supers 11.3%

The approximate length of row in meters (at different row spacings) that should be covered in applying 500 ml of fertiliser at different rates

Row spacing		1.22 m					1.37 m					1.52 m				
Bulk density group		A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Fertiliser rate (kg/ha)	100	40.0	42.0	49.0	52.0	54.0	36.0	38.0	43.0	46.0	48.0	32.0	34.0	39.0	41.0	44.0
	200	20.0	21.0	21.0	26.0	27.0	18.0	19.0	22.0	24.0	24.0	16.0	17.0	19.0	21.0	22.0
	300	13.0	14.0	16.0	17.0	18.0	12.0	13.0	14.0	15.0	16.0	11.0	11.5	13.0	14.0	14.5
	400	10.0	11.0	12.0	13.0	14.0	9.5	9.5	11.0	11.5	12.0	8.0	8.5	10.0	10.5	11.0
	500	8.0	8.5	10.0	10.5	11.0	7.5	7.5	8.5	9.0	9.5	6.5	7.0	8.0	8.5	9.0
	600	6.5	7.0	8.0	8.5	9.0	6.0	6.5	7.0	7.5	8.0	6.5	5.0	6.5	7.0	7.5
	700	5.5	6.0	7.0	7.5	8.0	5.0	5.5	6.0	6.5	7.0	4.5	5.0	5.5	6.0	6.5
	800	5.0	5.5	6.0	6.5	7.0	4.5	5.0	5.5	6.0	6.5	4.0	4.0	5.0	5.5	6.0
	900	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	3.5	3.5	4.0	4.5	4.5	5.5
	1000	4.0	4.5	5.0	5.5	6.0	3.5	4.0	4.5	5.0	3.0	3.0	3.5	4.0	4.0	4.5

Glossary

Absorption: The incorporation of one substance into another (e.g. the uptake of nutrients and water by plant roots; absorption of radiation by a black surface).

Acid saturation: The amount of acidity (as hydrogen and aluminium) relative to the base cations (K, Na, Ca and Mg) that is adsorped on the surface of soil silt and clay particles.

Actinomycetes: Microbes which do not belong to fungi or bacteria. In terms of numbers, they are the second largest group in the soil (after bacteria). They are thermophile decomposers, meaning that they can decompose organic matter under warm to hot conditions (e.g. during the composting process).

Adsorption: The attraction of substances (ions, compounds) to the surface of a solid.

Albedo: The portion of radiation (sunlight) that is reflected from a surface. More is reflected from a white than a black surface.

Alluvial: Deposit of soil that was carried by water from an upland position. Usually in layers of various particle coarseness which is a factor of the speed of the water. Layers consisting of coarse material would have been carried by fast flowing waters.

Aspect: The direction towards which a slope is facing.

Available water capacity (AWC): This is the soil water content between field capacity and permanent wilting point. Often also referred to as *plant available water*.

Auger: A tool for boring into the soil in order to obtain a soil sample. (see also: screw-type auger, Beater auger)

Bagasse: The residue that remains after the juice is removed from the sugarcane stalk.

Banded: The placement of fertiliser in a band as opposed broadcasting.

Beater auger ('bicycle auger'): A soil auger used in the South African sugarcane industry to take topsoil samples for fertiliser advice. Developed by Dr BE Beater. See picture in Chapter 6. (see also: auger, screw-type auger).

Biochar: A term coined by New Zealander, Peter Read, in 2005. It is the combination of two words *bio* and *char* (from charcoal) and used to describe the black carbon-like material first found in soils of the Amazon. Portuguese settlers dubbed it '*terra preta*' meaning *black earth*.

Broadcasting: The distribution of a substance (i.e. fertiliser) over a wide surface area. The opposite of band placement.

Bulk Density: The mass of soil in a known volume (i.e. kg/m^3).

Chlorosis: Pale or yellow coloured sugarcane leaves caused by a lack of chlorophyll and often found in young cane growing on soils with a high pH (see picture in Chapter 7).

CMS: One of the by-products from the manufacturing of sugar is molasses. Distilleries use molasses to extract the alcohol, and a by-product from this process is vinasse which contains up to 95% water and is regarded as a useful source of potassium fertiliser. To reduce the transport cost vinasse is concentrated by evaporating the water to about 45%. This product is then called *concentrated molasses stillage* or CMS in short.

Conduction: This is the length (L) of flow of a substance over a known area (A) with a certain resistance (R) or Conduction = L/RA. The inverse of *conductance* is *resistance*.

Critical Nutrient Concentration: The critical nutrient concentration is the nutrient concentration in the plant below which the nutrient is deficient in terms of the growth requirements of the crop.

Deep drainage: This is when applied irrigation or rain water moves through the soil to a depth where the majority of the roots cannot reach it.

Denitrification: The reduction of nitrate (NO^{3-}) or nitrite (NO^{2-}) to gaseous nitrogen (N_2 or NO_x).

Desertification: A type of land degradation in which a relatively dry land region becomes increasingly arid, typically losing its bodies of water as well as its vegetation and wildlife.

Diagnosis and Recommendation Integrated System (DRIS): A system of interpreting leaf nutrient concentrations based largely on ratios.

Duplex soils: Soils with a permeable topsoil which changes abruptly to a very slowly permeable subsoil horizon which is not a hardpan.

Dutch auger: A screw-in type auger which is used for sampling soil to depth.

Effective rooting depth (ERD): the depth of soil that plant roots can readily penetrate to access water and nutrients. Can be limited by the presence of a physical (rocky, sandy or clayey) or chemical (alkaline, acidic) layer.

Electrical conductivity: A measure of the concentration of salts in the soil solution, as determined by the ability of a saturated paste extract to conduct electric current. Measured in millisiemens/m (mS/m).

Electrostatic force: The forces of attraction or repulsion between oppositely-charged or like charged particles or ions.

Eluviation: The removal of soil material or nutrients from a part or the whole of the soil profile by percolating water.

Evapotranspiration: The sum of the water lost from the soil by evaporation from the soil surface and by transpiration from the plant.

Exchangeable sodium (ESP): The percentage of the cation exchange capacity that is occupied by sodium. To calculate this, ion concentrations are expressed on an equivalents basis.

Fertigation: The application of plant nutrients using soluble fertilisers through an irrigation system, usually drip or sprinkler.

Fertiliser-blend: A mechanical mixture of different granular fertilisers.

Fertiliser-compound: Fertilisers made up of chemicals containing more than one nutrient in their formulation. Examples are di-ammonium phosphate and potassium nitrate.

Fertiliser-straight: Fertiliser products containing only one primary plant nutrient element. Examples are potassium chloride and ammonium nitrate.

Field capacity (FC): The percentage of water remaining in a freely draining soil after drainage has just stopped. Field capacity is thus the maximum amount of water a soil can hold against gravitational force.

Filtercake: The organic precipitate - removed by filtration - in the course of extracting the sugar from sugarcane in the milling process. In addition to varying moisture content, it contains plant nutrients in low concentrations, and is widely used as a soil amendment.

Filter Function: Soil acts as a filter to protect the quality of water and air by degrading of toxic compounds or excess nutrients.

Flyash: The ash remaining following the burning of bagasse to fire the boilers in sugar mills.

Free drainage: Water that moves out of a soil layer or soil profile under the influence of gravity. It comprises the fraction of water that is held between the field capacity and saturation limits.

Freely available water (FAW): This refers to the amount of water held between field capacity and stress point. It is the amount of soil water that can be extracted by the plant without experiencing any noticeable degree of water stress.

Green manures: A crop grown with the specific purpose of improving soil health and/or nutrient reserves.

Hardpan: A hard soil layer (usually in the subsoil) which develops through the cementation of carbonates, sesquioxides or silica. It limits infiltration of water and root elongation.

Horizons: A horizontal layer of soil developed through soil-forming processes. It differs from layers above or below it in terms of physical or chemical properties.

Hygroscopic water: This is the water that is held tightly by adhesion to soil particles. It is not available for plant use, and can be driven off only by heating.

Infiltration: Downward entry of water into the soil.

Leaching: The removal of soluble materials from the soil profile by percolating water.

Luxury uptake: In the case of over-supply of nutrients, plants may take up more than is actually required by the crop.

Macronutrients: This refers to nutrients which are taken up by the plants in large amounts.

Metabolic activity: Metabolic activity involves the transformation of energy and matter in each living organism, two life essential elements.

Micronutrients: Nutrients which are required by the plants in small quantities only, but are essential for plant health and growth.

Mineralisation: The conversion of decomposed organic matter into organic compounds.

Molasses: A viscous by-product of the refining of sugarcane, grapes or sugar beets in to sugar.

Mycorrhiza: Fungi which live in the root zone (rhizosphere) of the plants in a cooperative relationship (transferring nutrients, protecting agains pathogens)

Non-point source pollution: Pollution which cannot be attributed to a specific source or emitter. It comes from many diffuse sources: chemicals form agriculture, forestry, residential areas or sediments from construction sites and mining operations moving through the landscape by leaching or runoff.

Osmotic potentials: The potential of water molecules to move between regions of differing concentrations across a water-permeable membrane.

Parent material: The underlying geological material (generally bedrock) on which soil horizons form.

Peat soils: Soils formed mainly in wetland areas where high water tables or flooding conditions restrict the oxygen supply to the soil. In peat soils the decomposition/decay of organic matter is slowed down due to limiting oxygen.

Permanent wilting point (PWP): The minimal point of soil moisture required by the plant not to wilt. Green plants which remain wilted at dawn are indicative of permanent wilting point having been reached and shows that the plant is unable to extract water from the profile.

Permeability: This is a measure of the ability of soils to allow water to pass through it.

pH: The pH measures the hydrogen ion concentration. Solutions with a pH less than 7 are acidic and above 7 are alkaline.

Porosity: The ratio of the volume of soil pores to the total volume of soil.

Profile: The combination of soil layers (horizons) in a sequence from surface down represents a soil profile.

Ratoon chlorosis: A condition caused by iron deficiency induced by high soil alkalinity.

Resilience: The ability of an ecosystem to return to its original state after being disturbed.

Runoff: This is the flow of water (from rain, irrigation, snow melt or other sources) over land. It can cause dislocation of soil sediments (erosion).

Salinity: The amount of salts in the soil. Salts are product of a neutralisation reaction between acids and bases.

Salt anions/ salt cations: salts are composed of related numbers of anions (negative charged ions: Cl, SO4), and cations (positive charged ions: Ca, Mg K, Na) so that the product is of neutral electrical charge.

Saturated paste extract (saturation extract): The soil solution obtained from a soil at its saturation point.

Saturation (SAT): The water level in the soil where all the pores are filled with water and no air is present.

Screw-type auger (also Dutch auger, depth auger): An auger with a long shaft, driven into the ground with a twisting motion, used for the collection of subsoil samples (see also: auger, Beater auger).

Seepage: Gradual loss of water from a water body or soil. Seepage can occur when water is lost from dams, canals or reservoirs, or else when water escapes or emerges from the soil along a line or surface (as opposed to a spring, where water emerges from one localised spot).

Slag: A non-metallic byproduct obtained during the smelting of metallic ores. Sometimes used as a fertiliser or liming source.

Sodicity: soil condition in which soil has a low salt content but relatively high sodium content. The sodium causes clay particles to disperse and pore spaces to become blocked, resulting in poor water and air movement within the soil and thus poor plant uptake of water. Soil pH(water) is usually > 8.5; Sodium Adsorption Ratio > 6, Exchangeable Sodium Percentage > 7 and electrical conductivity < 400 mS/m in a sodic soil.

Sodium Adsorption Ratio: The ratio between soluble sodium and calcium plus magnesium. Used as an aid to classify soils as sodic or otherwise.

Soil health: The ability of a soil to meet its range of ecosystem functions as appropriate to its environment. In sugarcane agriculture, the term 'soil health' is used to assess the ability of a soil to sustain crop productivity, by providing a hospitable environment for beneficial soil organisms, resisting degradation and facilitating appropriate cycling of nutrients, air and water, both now and in the future. The health of a soil can be markedly affected by its management.

Soil organic matter: The living material, decomposing remains or wastes of plants, animals, insects or organisms. It consists of complex organic compounds, and contains substantial amounts of carbon (50 - 60%), as well as oxygen (30 - 40%), hydrogen (5%), nitrogen (4%), sulphur (1%) and other nutrients.

Stress point (SP): The soil water content where the plant is unable to satisfy the atmospheric demand for water, resulting in a short period of water stress during the hottest part of the day.

Sustainability: The capacity to endure. In agricultural terms, sustainability refers to the potential for long-term maintenance of viable production, by adopting management practices that are environmentally, economically and socially appropriate. These are referred to as the 'three pillars' of sustainability.

Symbiotic relationship: A close, prolonged association or relationship between two or more different organisms of different species that may benefit each member.

Thermal (heat) conductivity: Properties which govern the rate at which heat is conducted (moves) through the soil.

Total available water (TAW): The amount of water (in mm) that is effectively available to a crop, when both available water capacity (AWC) and effective rooting depth (ERD) are taken into account. TAW = AWC x ERD.

Transpiration: The process by which water is carried through plants from the roots to the leaves, where it evaporates and is released into the atmosphere.

Turgor: The state of turgidity or rigidity (fullness) of a cell or tissue, due to high water content.

Vinasse: One of the by-products from the manufacturing of sugar is molasses. Distilleries produce ethanol (alcohol) from the molasses, and vinasse is a by-product of this process. Vinasse contains up to 95% water and is sometimes used by farmers as a source of potassium. Vinasse can be concentrated (by evaporation) to form *concentrated molasses stillage* (CMS).

Volatilisation: Loss of nitrogen, from soil-applied ammonium fertilisers and urea, to the atmosphere in the form of ammonia gas.

Water holding capacity: Also called the 'saturation water content'. The amount of water that a specific soil is able to hold, defined as the ratio of the mass of water to the dry mass of the soil, when that soil is completely saturated with water.

Water table: Water can be stored underground in a saturated zone or layer of soil or parent material. This water is called 'groundwater', and the upper surface of the groundwater is termed the water table.

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Understanding & Managing SOILS in the South African Sugar Industry

Human survival is dependent on healthy, productive soils to supply the food needs of a rapidly increasing world population. Correct management of agricultural crops and the soils upon which they are grown is vital in order to prevent degradation and to ensure sustainability.

Sugarcane production imposes unique stresses on the soil. Monocropping and the removal of large amounts of crop material from the land at harvest, often after burning away crop residues, impact on soil health in various ways. Fortunately, there are several practices that farmers can implement to optimise both soil health and productivity.

This book has been written to serve as a reference guide for students and farmers. It starts by providing a basic understanding of the physical, chemical and biological properties of soils, and then goes on to describe some of the important practices which serve to conserve soil health and thereby promote sustainable agriculture.

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