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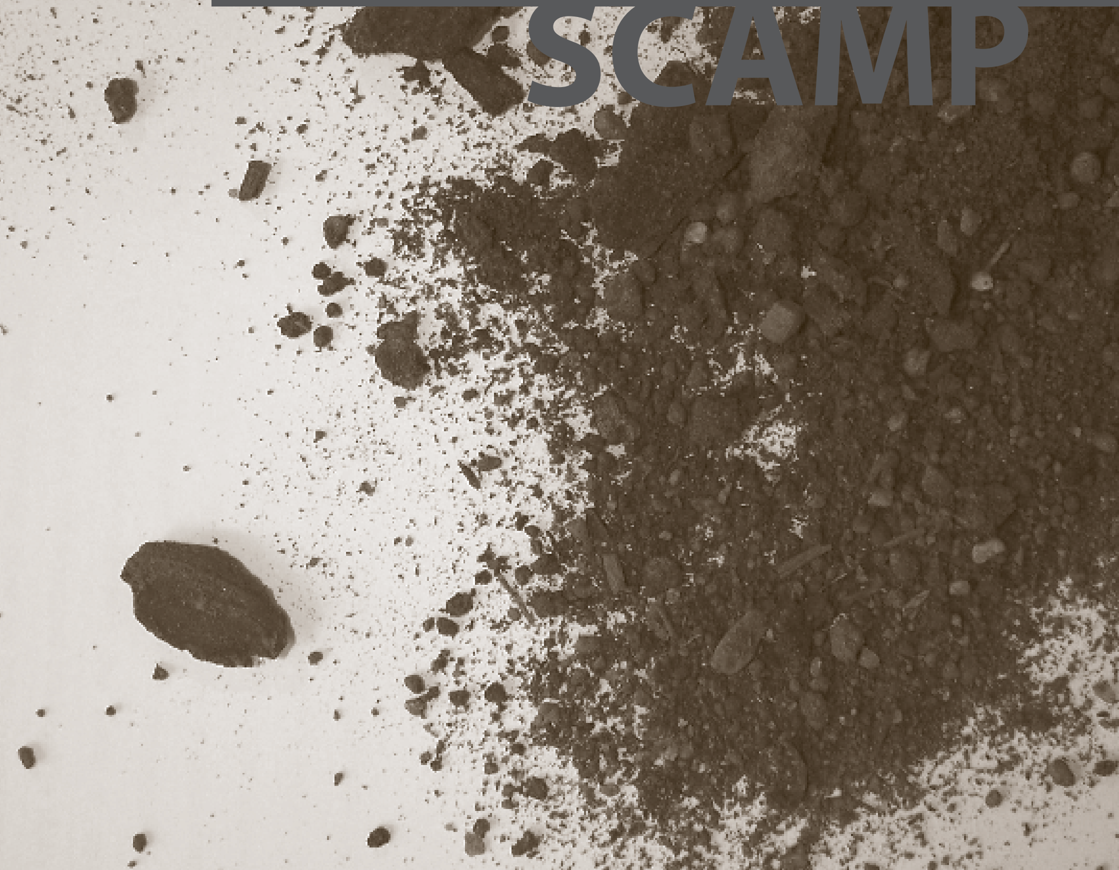
GUIDELINES FOR SUSTAINABLE MANAGEMENT OF TROPICAL UPLAND SOILS




Soil Constraints and Management Package (SCAMP)

GUIDELINES FOR SUSTAINABLE MANAGEMENT OF TROPICAL UPLAND SOILS

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Australian Centre for International Agricultural Research
2008

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Published by the Australian Centre for International Agricultural Research (ACIAR)
GPO Box 1571, Canberra ACT 2601, Australia
PHONE: 61 2 6217 0500 EMAIL: aciar@aciar.gov.au

Moody, P.W. and Cong, P.T. 2008. Soil Constraints and Management Package (SCAMP): guidelines for sustainable management of tropical upland soils. ACIAR Monograph No. 130, 86pp.

ISBN 978 1 921434 51 8 (print)
ISBN 978 1 921434 52 5 (online)

Technical editing by Biotext
Design by WhiteFox Communications
Printing by Goanna Print Canberra

FOREWORD

The aim of undertaking a soil survey is generally to provide an inventory of the soil resource as part of the terrestrial ecosystem. The survey usually characterises the pedological features of the soil profile (e.g. origins and characteristics) so that a taxonomic classification can be made. However, this classification is rarely interpreted in terms of how soil constraints might affect sustainable production of crops, forage or pastures, and how this information can provide guidance on managing these constraints.

This booklet describes a decision-support framework called the *Soil Constraints and Management Package* (SCAMP). This framework attempts to bridge the gap between taxonomic soil surveys and informed management strategies for sustainable production on upland soils in the tropics. Being simplistic yet comprehensive, it can be applied to any upland situation.

SCAMP was developed in the Australian Centre for International Agricultural Research (ACIAR)-funded project SMCN/2002/085: *Utilising basic soil data for the sustainable management of upland soils in Vietnam and Australia*. ACIAR hopes that this booklet will stimulate interest in sustainable soil management, particularly in the tropics, and provide the framework to organise soil data and observations to answer the questions that a landholder asks about soil data: 'What does it mean?' and 'What can I do about it?'

Peter Core
Chief Executive Officer
ACIAR

ACKNOWLEDGMENTS

We sincerely thank Dr Rod Lefroy, Dr Nguyen Cong Vinh, Dr Narong Chinabut, Dr Sathien Phimsarn and Mr Putu Wigena for their significant input into the prototype SCAMP at a workshop in March 2002 funded by The ATSE Crawford Fund, Australia.

CONTENTS

ABBREVIATIONS, ACRONYMS AND SHORTENED FORMS

Abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
AEC	anion exchange capacity
CEC	cation exchange capacity
EC	electrical conductivity
ECEC	effective cation exchange capacity
$\mathbf{EC_{se}}$	electrical conductivity of a saturation extract
FAO	Food and Agriculture Organization of the United Nations
FCC	fertility capability classification system
GIS	geographic information system
OC	organic carbon
PBI	phosphorus buffer index
pHBC	pH buffer capacity
Ps	sorbed phosphorus
SCAMP	*Soil Constraints and Management Package*
SOC	soil organic carbon
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture

Shortened forms used to describe soil attributes

Soil texture

C	clayey topsoil (i.e. clay or heavy clay texture; or >35% clay)
CR	clayey topsoil overlying rock (or other hard root-restricting layer that cannot be removed by tillage)
L	loamy topsoil (i.e. sandy loam, silty loam, loam or clay loam texture; or 20–35% clay)
LC	Loamy topsoil overlying clayey subsoil
LR	Loamy topsoil overlying rock (or other hard root-restricting layer that cannot be removed by tillage)
O	organic soils (i.e. >12% total organic carbon to a depth of 50 cm or more)
R	Rock or other hard root-restricting layer that cannot be removed by tillage

S	sandy topsoil (i.e. sand or loamy sand texture; or <20% clay)
SC	sandy topsoil overlying clayey subsoil
SL	sandy topsoil overlying loamy subsoil
SR	sandy topsoil overlying rock (or other hard root-restricting layer that cannot be removed by tillage)

Soil constraints

a	aluminium toxicity
a^{-}	aluminium toxicity constraint for extremely acid-sensitive crops
ar	acidification hazard
b	calcareous
comp	compaction layer
e	low nutrient retention
er	erosion hazard
g	prolonged waterlogging (as evidenced by gleying)
g^{-}	intermittent or seasonal waterlogging
geric	*geric* characteristic
gravelly	gravel rating
hs	hard-setting
i	high phosphorus-fixation
i^{-}	extremely low phosphorus-fixation
k	low potassium reserves
n	sodicity
n^{-}	marginal sodicity
om	low total organic carbon
s	salinity
s^{-}	marginal salinity
v	vertic properties

1 INTRODUCTION

As a component of the terrestrial ecosystem, soil fulfils many functions that are essential for sustaining plant growth. These functions, summarised in Table 1, comprise the criteria against which 'soil health' or 'soil quality' is assessed. Soils differ in their capacity to fulfil these functions; consequently, the productive potential of a soil is limited by its inherent constraints. Identifying and managing these constraints is fundamental to sustainable production systems.

The *Soil Constraints and Management Package* (SCAMP) is a framework and methodology that allow soil constraints to be identified systematically from basic soil attributes. Inferences are then drawn about how individual soils should be managed to maximise their productive potential.

TABLE 1 Soil attributes used in SCAMP to assess the ability of a soil to fulfil ecosystem functions

Soil function	Soil attribute used in SCAMP to assess ability of soil to fulfil the function
Partitioning of applied water into drainage and/or run-off	Permeability class, drainage class, infiltration rate
Storage of plant-available water	Texture
Supply of adequate oxygen to roots	Texture, permeability class, drainage class, compaction
Provision of favourable conditions for seedling establishment	Texture, structure, consistence, slaking and dispersion
Storage of nutrients essential to plant growth	Texture, colour, pH, organic carbon, cation exchange capacity
Supply of nutrients essential to plant growth	Texture, colour, pH, electrical conductivity, organic carbon, cation exchange capacity
Suppression of plant pathogens	Organic carbon, texture, cation exchange capacity
Immobilisation of contaminants	Texture, colour, pH, organic carbon, cation exchange capacity

SCAMP = *Soil Constraints and Management Package*

SCAMP is an adaptation of the fertility capability classification (FCC) of Sanchez et al. (1981, 2003). SCAMP:

- considers a wide range of basic soil attributes to determine constraints to productivity
- assesses the risk of off-site nutrient movement by identifying the pathways of water flow.

SCAMP can be applied at plot, farm or catchment scale; it can also be linked to a geographic information system to produce hazard and risk maps.

SCAMP has three levels of application, depending on the availability of data on key soil attributes (Table 2). Level 1 uses only observations made on the position of the soil in the landscape and observations and measurements made on a soil 'mini-pit' in the field. Level 2 uses field observations and some simple field measurements requiring minimal equipment. Level 3 uses a limited range of diagnostic laboratory analyses that can be determined using basic analytical instruments.

TABLE 2 Data collection methods used to determine soil attributes in each SCAMP application level

SCAMP application level	Soil attributes	Data collection methods
1	Slope, texture, colour, structure and consistence, dispersion class, permeability class, drainage class, erosion hazard, compaction	Observations on the position of the soil in the landscape, and observations and measurements made on a soil 'mini-pit' in the field
2	Field electrical conductivity (EC), field pH, infiltration rate	Field observations and some simple field measurements requiring minimal equipment
3	Cation exchange capacity, organic carbon, pH buffer capacity, phosphorus buffer capacity	A limited range of diagnostic laboratory analyses that can be determined using basic analytical instruments

SCAMP = *Soil Constraints and Management Package*

Soil management strategies that can be inferred from the SCAMP assessment become more comprehensive as the application level of SCAMP moves from Level 1 to Level 3. For example, properties and constraints to long-term productivity that can be inferred for a soil of sandy texture using a Level 1 application include:

- good infiltration
- low plant-available water capacity
- low cation exchange capacity
- a tendency to compact if fine sand.

To ensure this soil remains productive, management practices would need to include addition of organic matter, conservation of soil moisture and application of soluble fertilisers (in split applications and at low rates). This example illustrates how management strategies can be deduced from consideration of the basic soil attribute of texture.

Inferring soil management practices from soil attributes is the same principle on which the FCC (Sanchez et al. 1981) is based. Using the FCC, the following has been shown:

- Soils in one FCC unit may belong to different orders, suborders, great groups, subgroups or families in soil classification systems.
- The number of FCC units in a given area is much smaller than the number of soil classification units (e.g. orders, suborders, great groups, subgroups or families), thereby simplifying interpretations.
- Fertiliser recommendations based on FCC units are more profitable than generalised recommendations.

Applying SCAMP to upland soils is expected to deliver the same outcomes as the FCC, thus improving both the use of soil-survey data and the management of these soils.

This booklet, which is designed to be taken into the field, covers the following topics:

- the various soil attributes considered in SCAMP and what they mean in terms of soil functions (Section 2)
- the field and laboratory procedures required to describe a soil using the different application levels of SCAMP—depending on the resources available, the user can apply one or more levels, as appropriate (Section 3)
- the criteria used to assess a soil using SCAMP (Section 4)
- the implications and management of the soil attributes and constraints identified in the SCAMP assessment (Sections 5 and 6)
- the suitability of the soil for growing particular crops (Section 7).

2 BACKGROUND

2.1 Soil texture

Soil texture depends on the proportions of sand, silt and clay in a soil. Texture is important because it affects the soil's water-holding capacity, porosity and aeration, hydraulic conductivity, compactability, resistance to root penetration, nutrient-holding capacity [i.e. cation exchange capacity (CEC)] and resistance to acidification.

2.2 Soil colour

Topsoil and subsoil often have visually distinctive colours that can be used to infer the proportion of organic matter, the amount and oxidation state of soil iron oxides, and the degree of aeration of the soil.

2.3 Soil structure and consistence

Primary soil particles (clay, silt and sand-sized) bond together into larger sized aggregates (peds) that are separated by surfaces of weakness. The proportion of aggregation and the aggregate size affect a soil's water-holding capacity and aeration; for example, tightly packed, dense aggregates impede root penetration and drainage.

Soil structure describes the proportion and shape of the aggregates or peds. Soil consistence is a measure of the soil's strength and coherence. Consistence has major effects on pathways of water movement through or over the soil surface, ease of seedling emergence and depth of root penetration.

2.4 Soil slaking and dispersion

Slaking is the spontaneous disintegration of a soil aggregate when placed in water. Dispersion is a process similar to slaking but involves the release of clay-sized particles into the water during slaking, which causes the water to become cloudy. Slaking occurs when the forces holding the aggregate together are weak, and dispersion indicates that the soil is probably sodic (sodium rich). Both slaking and dispersion are signs that the soil will be susceptible to compaction and surface sealing.

2.5 Soil permeability and drainage

Permeability and drainage describe how water behaves in a soil (McDonald et al. 1990):

- *Permeability* refers to the potential of a soil to transmit water internally; it is related to the saturated hydraulic conductivity of the soil profile, and is therefore independent of the soil's position in the landscape.
- *Drainage* refers to the rate of removal of water from the soil profile, and is therefore determined by the position of the soil in the landscape.

2.6 Erosion hazard

Erosion is the movement of surface soil through the action of water or wind. Water erosion is the more common form of erosion in the tropics. Water erosion resulting in the relatively uniform removal of soil across a surface is called sheet erosion. When water concentrates in shallow flow lines and preferentially erodes soil from those lines, the result is rill erosion. When rills become increasingly deep through concentration of run-off, gully erosion occurs. All forms of erosion result in the preferential loss of nutrient-rich surface soil, and therefore cause a decline in soil fertility.

Erosion hazard ranks the risk of loss of surface soil through erosion.

2.7 Compaction

Soil compaction causes an increase in soil bulk density, with a reduction in the air-filled porosity of the compacted layer and its ability to transmit water. Soil compaction is the result of cultivation or animal and machinery traffic when the soil is wet enough to be in a plastic state and therefore able to be compressed. The soil moisture content at which the soil becomes plastic is known as its plastic limit (Section 2.11). A compaction layer in the soil results in perched watertables, thus causing soil waterlogging during wet periods. When the soil is dry, the compaction layer is a physical barrier to root penetration, restricting rooting depth and thereby limiting water and nutrient availability to the crop.

2.8 Soil pH

Soil pH_{water} measures the molar activity (concentration) of hydrogen ions in the soil solution. It is a negative logarithmic scale, so a decrease of 1 pH unit increases the hydrogen ion concentration tenfold. At pH 7 (neutrality), the activity of hydrogen ions is equivalent to the activity of hydroxyl ions; at pH < 7, hydrogen ions predominate and the soil is acidic; at pH > 7, hydroxyl ions predominate and the soil is alkaline. Soil pH has large effects on the availability of many nutrients and is symptomatic of toxic amounts of certain elements, such as aluminium (Al) and manganese (Mn).

Soil pH can be measured easily in the field (refer to Section 3.2.1 below). In the laboratory, soil pH can be measured at different soil:solution ratios (e.g. 1:1, 1:2.5, 1:5) and in different salt solutions (e.g. water, 0.01 M $CaCl_2$, 1 M KCl). Varying either of these conditions will change the pH reading obtained. As the soil:solution ratio changes from 1:1 to 1:5 in water, pH increases. As salt concentration increases, pH generally decreases. For example, the relationship between pH(1:1) and pH(1:5) in water for 29 Acrisols and Ferralsols (Phan Thi Cong, unpublished data) was:

$$pH_{w(1:5)} = 1.09\ pH_{w(1:1)} - 0.10\ (r = 0.94).$$

2.9 Electrical conductivity

Electrical conductivity (EC) is a measure of the salt concentration in the soil solution—as salt concentration increases, so does EC. A high EC has an adverse effect on plant growth, mainly due to osmotic effects that severely restrict the ability of plant roots to take up water.

EC depends on the soil:solution ratio and decreases as the ratio increases (because of a dilution effect) unless a sparingly soluble solid phase is present (e.g. gypsum). The presence of gypsum tends to maintain the EC as the soil:solution ratio increases. Most work relating decreased crop yield to increasing EC measures EC of a saturation extract (EC_{se}) of the soil (where the soil:solution ratio is generally < 1:1). This measurement can be made in the field using a portable EC meter to measure the conductivity of a soil paste as described in Section 3.2.2 below. However, the routine measurement of EC in the laboratory is generally carried out at a soil:solution ratio of 1:5. The relationship between EC_{se} and $EC_{1:5}$ depends on the clay content of the soil. Table 13 gives an approximate conversion of EC_{se} to $EC_{1:5}$.

2.10 Infiltration rate

Infiltration rate determines how quickly rainfall or irrigation water moves into the soil. A low infiltration rate means that rainfall or irrigation water will either pond on the soil surface (if it is flat) or move off-site as run-off (if it is sloping). A high infiltration rate indicates that much of the rainfall or irrigation water will enter the soil and may result in drainage.

2.11 Plastic limit

The plastic limit is the soil water content at which the soil becomes 'plastic'; that is, capable of being deformed when external force is applied. When soil is deformed and thus compacted, porosity and pore size decrease; this prevents root penetration when the soil is dry. If soil is cultivated when it is wetter than its plastic limit, the soil smears instead of fracturing, and a plough pan or compaction layer forms. If the soil is cultivated when it is drier than its plastic limit, the plough or hoe can fracture the soil to produce a desirable seedbed.

2.12 Organic carbon

Soil organic carbon (SOC) is critical for maintaining the chemical, physical and biological health of soil. In soils that contain predominantly 'variable' charged clay minerals (such as most acidic upland soils), SOC is a key determinant of CEC, which increases as SOC increases. SOC is generally highly correlated with total nitrogen (N). Therefore, the amount of N mineralisation (i.e. conversion of organic N compounds to ammonium-N) increases as SOC increases. Soil micro-organisms require a carbon source for energy. Thus, increasing SOC is generally associated with increasing microbial activity in the soil, which increases the rate of release of nutrients from the soil organic matter and helps the soil to suppress plant pathogens. By helping to bind soil particles into aggregates, SOC assists in keeping the aggregates stable. Stable aggregates are necessary to maintain soil porosity and therefore water infiltration and adequate aeration; stable aggregates also resist compaction caused by ploughing and vehicle and animal traffic.

SOC is commonly determined by several laboratory methods. It is necessary to know the analytical method used to interpret SOC values. Combustion analysers raise the soil sample to a temperature of about 1,300 °C and all organic carbon (OC), including any charcoal or carbonate that may be present, is oxidised. However, the Walkley and Black (1934) method for determining SOC relies on the heat generated from the dilution of concentrated sulfuric acid to assist the dichromate in oxidising OC, so not all of the SOC is oxidised. SOC determined by the Walkley and Black method is thus generally lower than that determined by combustion. As a rough approximation, Walkley and Black OC comprises about 74% of total SOC, although this percentage varies from soil type to soil type.

Recently, permanganate-oxidisable OC has been used as a measure of 'labile' or active SOC (Blair et al. 1995). SOC oxidised by 33 mM potassium permanganate is highly correlated with many key soil properties (Moody et al. 1997). Determination of both total SOC and Walkley–Black SOC requires laboratory facilities; however, Weil et al. (2003) developed a procedure for measuring permanganate-oxidisable SOC in the field, and this has been modified for use in SCAMP (see Section 3.3.1 below).

2.13 pH buffer capacity

Soil acidification (when soil pH decreases progressively over time) is a natural process in humid areas. However, this process is accelerated by agricultural production systems where one or more of the following occur:

- product is removed from the production site
- soil organic matter levels increase (e.g. under pastures)
- ammonium-based fertilisers are used in excess of crop N requirements.

As soil becomes more acidic, nutrient availability to plants decreases and the possibility of toxicities (Al and/or Mn) to plant growth increases. Plant productivity declines and the range of crops that can be grown decreases because only acid-tolerant species can be used. Soil microbial diversity decreases and fungi become dominant. Off-site effects of soil acidification include increased erosion and sediment movement due to decreased surface cover, and nitrate pollution of groundwater if excessive rates of ammonium-based fertiliser are applied.

The rate of soil acidification (i.e. the rate of decline of soil pH with time) depends on the acid input of the current land use and the pH buffer capacity (pHBC) of the soil (i.e. the amount of acid [H^+] input required to decrease soil pH by 1 unit). Heavy-textured soils such as Vertisols have a high pHBC and require a large H^+ input to cause a pH decrease, whereas light-textured soils such as Acrisols have a low pHBC. These latter soils will suffer a large decrease in soil pH if used for an agricultural system with a high acidification rate.

pHBC is generally determined in the laboratory by measuring soil pH after an appropriate incubation period (e.g. 7 days) of moist soil with a range of additions of acid (as HCl) and alkali (as NaOH) (Aitken and Moody 1994). The pHBC is calculated as the inverse slope of the relationship between H^+ or OH^- added (*x*-axis) and soil pH (*y*-axis). Alternatively, pHBC can be estimated from SOC and clay using a pedotransfer function (see Section 3.3.2 below).

2.14 Phosphorus buffer capacity

In upland soils, phosphorus (P) deficiency is a common limitation to productivity, and application of P fertilisers is often necessary. Iron (Fe) and Al oxyhydroxides strongly adsorb (i.e. 'fix') P, making it unavailable for crop uptake. Therefore, in soils that contain large amounts of these oxyhydroxides (e.g. Ferralsols), more P fertiliser must be applied to meet crop requirements than in soils containing lesser amounts of oxyhydroxides. The relationship between P in solution and sorbed P (*Ps*) is called 'P buffer capacity'. Soils that have a high P buffer capacity (i.e. high P-fixing soils) have larger amounts of *Ps* in equilibrium with a particular solution P concentration than do soils that have a low P buffer capacity.

P buffer capacity can be measured by adding graded amounts of P to a soil and measuring the resultant solution P concentrations after an equilibration period. The *Ps* is then plotted against the solution P concentration to give a P sorption curve. The P buffer capacity is the slope of the P sorption curve. A more convenient way to measure P buffer capacity is to calculate a P buffer index (PBI) from a single addition of P, as outlined in Section 3.3.3 below.

2.15 Cation exchange capacity

CEC refers to the number of negative charges capable of holding cations by electrostatic forces per unit weight of soil. It is made up of 'permanent' charges (due to isomorphous replacement in the clay mineral lattice) and 'variable' charges (due to Fe and Al oxyhydroxides and organic groups). The size and sign (either negative or positive) of the variable charges depend on soil pH and the ionic strength (measured as electrical conductivity) of the soil solution. In acidic soils, the Fe and Al oxyhydroxides carry a net positive charge (i.e. there is an anion exchange capacity, or AEC, rather than a CEC), whereas organic groups carry a net negative charge. In a surface soil containing an appreciable amount of organic matter as well as Fe and

Al oxyhydroxides, the overall result is a negative charge (i.e. CEC), whereas in the subsoil where organic matter levels are low, a net positive charge (i.e. AEC) might occur. This is often the case in Ferralsols.

The determination of CEC using extracting solutions buffered at pH 7.0, 8.2 or 8.5 is not appropriate for soils that contain appreciable amounts of variable charge surfaces—as most upland soils do. This is because negative charges are generated on the variable charge surfaces due to the high (buffered) pH of the extracting solution. These charges do not exist in the soil at field pH. Because of the effect of pH on the CEC of soils with variable charge, the most appropriate way to determine CEC of acidic soils is to sum the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and the exchangeable acidity (Al^{3+} + H^{+}).

The 'CEC to clay ratio' is calculated as [effective cation exchange capacity (ECEC) ($cmol_c$/kg)/clay (%)]. When used for subsoil samples (to remove the effect of organic matter on the ratio), it is a useful index for indicating the clay mineralogy of a soil. Ratios of less than 0.2 are associated with 1:1 type clays (e.g. kaolinite) and Fe and Al oxyhydroxides, which exhibit variable charge characteristics; ratios of greater than 0.8 indicate the presence of 2:1 type clays (e.g. smectites), which are predominantly permanently charged. If the CEC to clay ratio indicates that variable charge materials predominate, then this has implications for liming and fertiliser management (see Section 5.3.4 below).

3 METHODS AND PROCEDURES

3.1 Application Level 1

Application Level 1 of SCAMP involves recording site information, and digging a mini-pit to observe the following characteristics of the topsoil (plough-layer) (0–20 cm) and subsoil (20–50 cm): texture, colour, structure, moist consistence, dispersion class, compaction and gravel rating. The permeability class, drainage class and erosion hazard are decided from site and mini-pit observations.

3.1.1 Site data

On the SCAMP field sheet (Appendix 1), record the following site information: date, site name, province, district, commune, village, hamlet, farmer's name, latitude, longitude, altitude, slope, surrounding landform, site position in the landscape, current land use, soil surface condition and any signs of erosion.

3.1.2 Mini-pit

Use a spade or hoe to dig a mini-pit that is 40 cm wide, about 60 cm long and 50 cm deep. Prepare one face by carefully 'picking' at it with a pointed knife to expose the structure.

On the SCAMP field sheet record the following information for depths of 0–10 cm, 10–20 cm, 20–30 cm and 30–50 cm:

- soil texture (Section 3.1.3)
- soil colour (including presence and colour of mottles) (Section 3.1.4)
- structure and consistence (Section 3.1.5)
  (note: split a depth interval if it is evident that a change in colour, texture, structure or consistence occurs within that depth interval)
- presence of roots and visible pores
- dispersion class (Section 3.1.6)
- gravel rating (Table 11)

Assess and record the permeability and drainage classes (Section 3.1.7) and erosion hazard (Section 3.1.8). Determine whether a compaction layer is present (Section 3.1.9) and, if so, record its depth. Record the occurrence of vertic properties (Table 11).

3.1.3 Soil texture

To determine soil texture in the field, take about a spoonful of soil in one hand and add water, drop by drop, while working the soil until it reaches a sticky consistency. Roll the soil into a ball and determine the texture by reference to Table 3 and Figure 1. Alternatively, squeeze the wetted soil between thumb and forefinger to form a flat ribbon. Determine the texture based on the length of the ribbon that can be formed without breaking (Table 3).

TABLE 3 Soil characteristics indicative of soil texture

Soil texture	Description[a]	Relevant diagram in Figure 1	Length of soil ribbon (mm)[b]
Sand	The soil stays loose and separated, and can only be accumulated in the form of a pyramid.	A	< 15
Sandy loam	The soil contains enough silt and clay to become sticky and can be made into the shape of a fragile ball.	B	15–25
Silty loam	Similar to the sandy loam, but the soil can be shaped by rolling it into a small, short cylinder. Soil has a 'silky' feel.	C	25
Loam	Contains almost the same amount of sand, silt and clay. Can be rolled into a 15 cm long (approximately) cylinder that breaks when bent.	D	25
Clay loam	Similar to loam, although the cylinder can be bent into a U shape (without forcing it) and does not break.	E	40–50
Fine clay	The soil cylinder can be made into the shape of a circle but shows some cracks.	F	50–75
Heavy clay	The soil cylinder can be shaped into a circle without showing any cracks.	G	> 75

Sources: [a] EUROCONSULT (1989) [b] McDonald et al. (1990)

If laboratory analyses of dispersed particle sizes are available, then a 'texture triangle' (Figure 2) can be used to convert the percentages of sand, silt and clay into a texture.

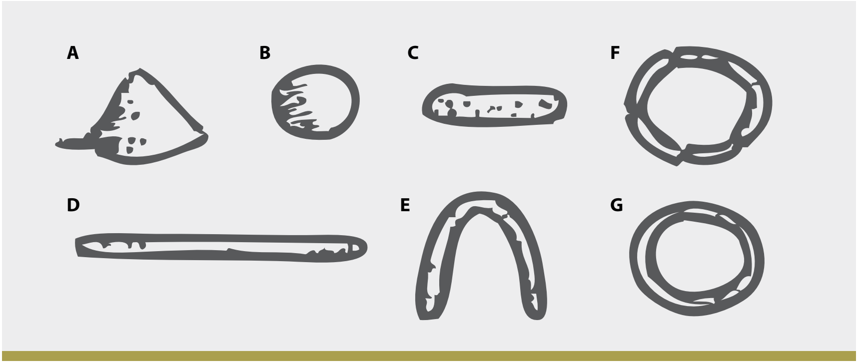

FIGURE 1 Determination of texture by the behaviour of soil at sticky consistency (Source: EUROCONSULT 1989). A: sand; B: sandy loam; C: silty loam; D: loam; E: clay loam; F: fine clay; G: heavy clay

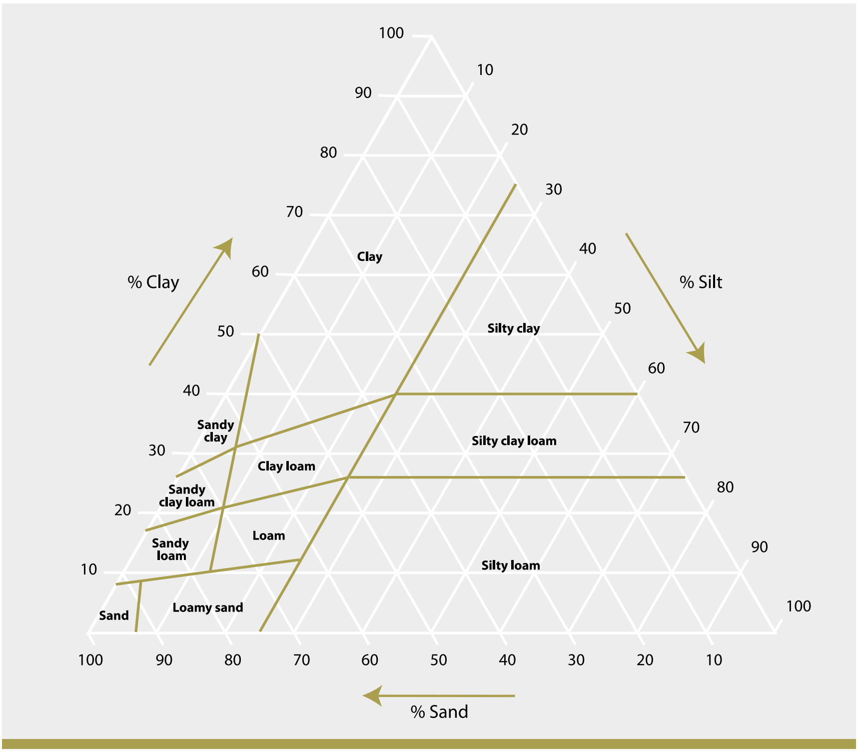

FIGURE 2 The texture triangle relating particle size distribution to field texture (Source: McDonald et al. 1990)

3.1.4 Soil colour

Formal soil classification systems use detailed descriptions of colour based on Munsell colour charts. Examples of such systems are the United States Department of Agriculture (USDA) Soil Taxonomy and the Food and Agriculture Organization of the United Nations / United Nations Educational, Scientific and Cultural Organization (FAO/UNESCO) system. SCAMP uses a simple list of soil colours; these are listed in Table 4, which also shows the relevant Munsell hue, value and chroma for each colour.

Determine the soil colour with reference to Table 4.

TABLE 4 Soil characteristics associated with soil colour

Soil colour	Typical Munsell hue/value/ chroma	Soil types and characteristics
Black	5YR/< 3/1–2 7.5YR/< 3/1–2 10YR/< 3/1–2	Peat or organic soils—high in organic matter Vertisols Soils derived from limestone under reduced conditions
White, pale or bleached	–/8/< 4	Sandy soils
Red	10R/–/6–8 2.5YR/–/6–8	Well-drained soils with high content of iron oxides
Yellow or yellow–brown	7.5YR/> 6/> 6 10YR/> 6/> 6 2.5Y/> 6/> 3 5Y/> 6/> 2	Imperfectly drained to moderately well-drained soils with high content of iron oxides
Brown	2.5YR/< 7/3–4 5YR/< 6/3–4 7.5YR/< 6/3–4 10YR/< 6/3–8 2.5Y/< 5/2–6	Moderate soil organic matter levels, and some iron oxides
Gleyed, grey or blue–grey	Gley charts or Colour charts –/3–7/1	Near permanent waterlogging; anaerobic (reduced) conditions
Mottles	Orange, yellow, red	Intermittent waterlogging; intermittent anaerobic (reduced) conditions

R = red; Y = yellow; YR = yellow–red

3.1.5 Soil structure and consistence

Use a shovel or trowel to obtain a 10 cm × 10 cm × 10 cm block of undisturbed soil that is slightly moist. Gently break the soil apart by hand. If the soil is structured it will separate into structural units (peds or aggregates). If the soil has no structure (i.e. 'massive'—see below), then the shear lines between 'clods' will be jagged and there will be no identifiable aggregates.

In the SCAMP field sheet (Appendix 1) note the degree of aggregate development, the shape of the aggregates and the presence of macropores (holes visible without the need for magnification).

Describe the proportion of aggregate development as one of the following:

- massive—coherent material that lacks distinct aggregates (Figure 3G)
- single grained—loose, structureless material that comprises individual grains (Figure 3F)
- weak—less than one-third of soil material is in aggregates
- moderate—one-third to two-thirds of soil material is in aggregates
- strong—more than two-thirds of soil material is in aggregates.

Describe the shape of the aggregates as granular, blocky, prismatic, columnar or platy (Figure 3).

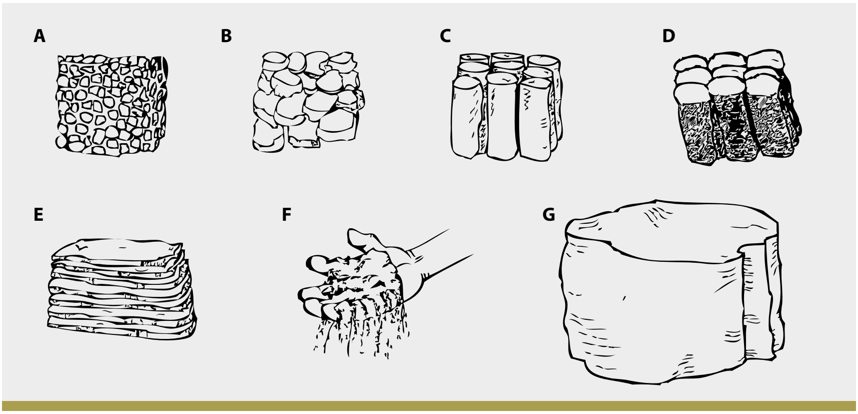

FIGURE 3 Aggregate shapes used to describe soil structure (Source: NASA 2004). A: Granular (soil resembles cookie granules generally less than 0.5 cm in diameter; commonly found in surface horizons where roots have been growing); B: Blocky (soil in irregular blocks that are generally 1.5–5.0 cm in diameter); C: Prismatic (vertical columns of soil that might be several centimetres long; usually found in lower horizons); D: Columnar (vertical columns of soil that have a 'cap' at the top; commonly found in sodic subsoils); E: Platy (thin, flat plates of soil that lie horizontally; usually found in compacted soil); F: Single grained (soil broken into individual particles that do not stick together; always accompanies a loose consistence; commonly found in sandy soils); G: Massive (soil with no visible structure, hard to break apart and appearing in very large clods).

To determine moist consistence of the soil, take a small block of moist soil (squirt water onto the soil block if necessary), hold it between thumb and forefinger if possible, and squeeze until the soil falls apart or crumbles. Describe the moist consistence as loose, friable, firm or extremely firm, by reference to Figure 4.

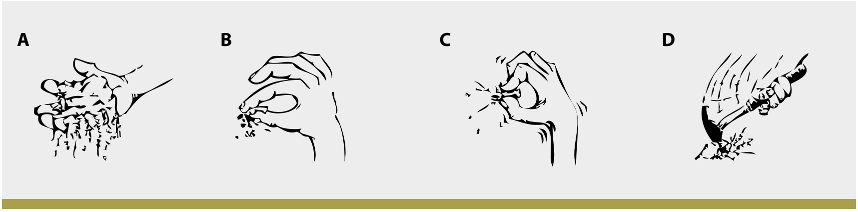

FIGURE 4 Description of moist consistence depends on the force necessary to crumble a soil aggregate (Source: NASA 2004). A: Loose; B: Friable; C: Firm; D: Extremely firm.

3.1.6 Soil slaking and dispersion

To assess the slaking and dispersion characteristics of a soil, place two to three dry, pea-sized aggregates in a dish or jar of distilled water (or rainwater if distilled water is not available; use the local irrigation water if the site is irrigated). After 5 minutes, observe the aggregates, rate their appearance according to Figure 5 and record the dispersion class in the SCAMP field sheet (Appendix 1).

Take another couple of aggregates and add water, drop by drop, while working the soil until it reaches a sticky consistency. Mould the aggregate into a ball shape and place in the dish of water. Rate the appearance of the re-moulded aggregate after five minutes according to Figure 5.

3.1.7 Soil permeability and drainage

By reference to Table 5, use the soil's texture, structure and presence of pores, or its dispersion ratings, to determine its permeability class. However, if the infiltration rate of the soil is measured (i.e. Application Level 2), refer to Table 8 to assign a permeability class.

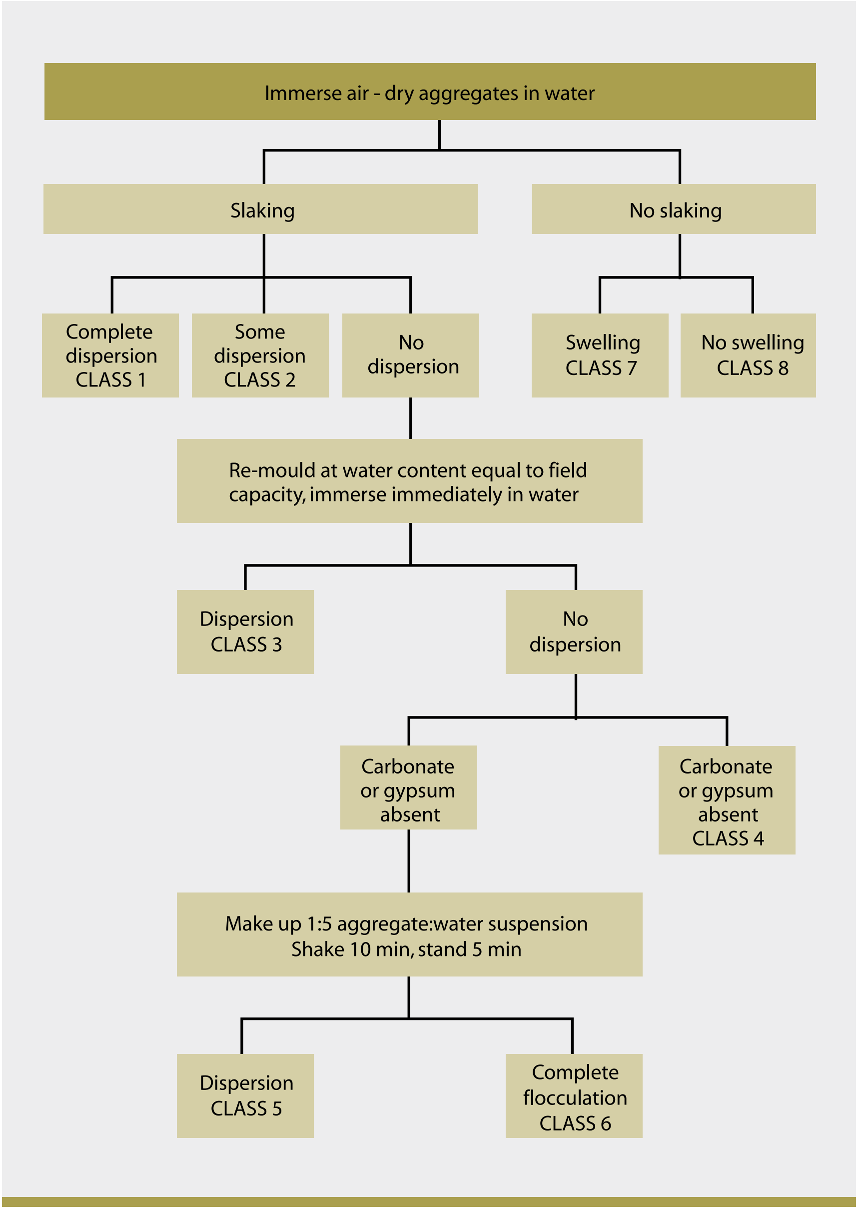

FIGURE 5 Criteria used to determine Emerson (1967) dispersion classes

TABLE 5 Typical saturated hydraulic conductivities (K_s) and permeability classes associated with various soil textures and soil structures

Class	Soil permeability (as time for soil profile to wet up to field capacity)	Description
1—very slowly permeable (K_s < 0.2 mm/hour)	Months	Generally clay or silty clay loam with coarse structure and absence of visible pores; or dispersion class 1 (see Figure 5)
2—slowly permeable (K_s 0.2–2.0 mm/hour)	Weeks	Generally clay or silty clay loam with few visible pores and massive, weak or moderate structure; or dispersion class 2 (see Figure 5)
3—moderately permeable (K_s 2.0–20 mm/hour)	Days	Generally clay texture with massive, moderate or strong structure; pores clearly visible
4—highly permeable (K_s > 20 mm/hour)	Hours	Sandy or loamy texture, although clayey, sesquioxidic soils with moderate-strong fine structure, may be highly permeable; large and connecting pores are clearly visible

To determine the soil's drainage class, refer to Table 6 and assign a class based on the depth to the watertable, the period that a watertable is present, soil colour and texture, and the presence and colour of mottles or gleying. If a compaction layer is present, assign the soil lower classes of permeability and drainage than the classes suggested by other soil properties.

TABLE 6 Soil drainage classes derived from soil drainage characteristics, colour and texture

(A) DRAINAGE CLASS BASED ON THE DURATION OF WATERLOGGING OR TIME TO DRAIN

Class	Description
1—very poorly drained	Watertable remains at or near surface most of the year. Strong gleying and accumulation of surface organic matter are common features.
2—poorly drained	All horizons remain wet for several months. Some gleying. Seasonal ponding and a perched watertable are common features.
3—imperfectly drained	Some horizons are wet for periods of several weeks. Some horizons may be mottled or have orange linings on root channels.
4—moderately well drained	Some horizons may remain wet for as long as 1 week after addition of water. Soils are usually loamy to clayey in texture.
5—well drained	Some horizons may remain wet for several days after addition of water. Soils are usually loams.
6—rapidly drained	No horizon is normally wet for more than several hours after addition of water. Soils are usually sandy.

TABLE 6 Continued

(B) DRAINAGE CLASS BASED ON COLOUR AND SCAMP TEXTURE TYPE

Colour	Mini-pit appearance	SCAMP texture type in topsoil		
		Sandy (*S*)	Loamy (*L*)	Clayey (*C*)
Black	No mottles	6	4	4
	Mottles or gleying	–	3	3
Red	No mottles	6	6 (fine structure: 5)	5 (strong structure: 6)
	Mottles or gleying	5	4	4
Brown	No mottles	6	4	4
or yellow	Mottles or gleying	5	3	3
Grey	No mottles	4	4	4
	Mottles or gleying	3	3	2

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3.1.8 Erosion hazard

Determine the erosion hazard by considering the slope and observed erosion, referring to Table 7.

TABLE 7 Erosion hazard determined by the slope and pattern of observed erosion

Erosion hazard	Criteria
1—low	No evidence of erosion; or slope < 2%; or slope < 1% if *n* constraint present
2—moderate	Evidence of soil accumulation along fencelines due to sheet erosion; or evidence of some rills; or slope 2–5%; or slope 1–2% if *n* constraint present
3—high	Rills common; or exposure of some roots; or slope 5–10%; or slope 2–5% if *n* constraint present
4—very high	Evidence of extensive rill or gully erosion; or slope 10–15%; or slope 5–10% if *n* constraint present
5—extreme	Evidence of severe rill and gully erosion; or slope > 15%; or slope 10–15% if *n* constraint present

3.1.9 Compaction

Examine the mini-pit for evidence of the following (the presence of any of these factors indicates compaction):

- platy structure
- impeded root growth ('right angle' appearance of roots at the top of the compaction layer)

- extremely firm consistence compared with soil above and below the layer
- increased penetrometer resistance compared with soil above and below the layer.

If any of these criteria are encountered, record the depth of their first appearance on the SCAMP field sheet.

3.1.10 Gravel

Assign a gravel rating to each depth based on the criteria in Table 11.

3.1.11 Vertic properties

Record the presence of vertic properties based on the criteria in Table 11.

3.2 Application Level 2

Application Level 2 of SCAMP uses some simple equipment to supplement observations made in Level 1. The requirements are a handheld pH meter (a 'pH pen'), a handheld electrical conductivity (EC) meter (an 'EC pen') and a piece of plastic drainpipe for infiltration measurements. This equipment allows measurements of soil pH, salinity and infiltration rate to be made, thus increasing the information available for making decisions on sustainable soil management practices.

3.2.1 Soil pH

Before measuring soil pH, check that the pH meter has been calibrated against buffer standards of pH 4.0 and pH 6.0 or pH 7.0. If you are unsure how to calibrate the meter, check the instrument's instruction manual.

In the field, measure the pH_{water} and the pH_{KCl}, as follows:

- pH_{water}—Prepare a soil paste by stirring deionised water into some soil in a tube to form a smooth paste. Carefully insert the electrode bulb into the paste and wait for the pH reading to become steady. Record the pH_{water} on the SCAMP field sheet. Alternatively, determine field pH by mixing soil and a universal indicator solution into a paste on a flat plate, then use the colour of the indicator solution to determine soil pH.
- pH_{KCl}—In the laboratory, prepare 1 M KCl by dissolving 74.55 g of KCl in deionised water and making up to 1 L in a volumetric flask. Then proceed as for pH_{water}, but use the 1 M KCl as the solution for making the soil paste. Record the pH_{KCl} on the SCAMP field sheet.

3.2.2 Electrical conductivity

Before measuring EC in the field, check that the EC meter has been calibrated against a standard salt solution at a known temperature. In the field, prepare a soil paste by stirring deionised water into some soil in a tube to form a smooth paste. Carefully insert the EC probe into the paste and wait for the EC reading to become steady. Record the reading (in dS/m) in the row labelled 'Field EC (saturated paste)' in the SCAMP field sheet.

3.2.3 Infiltration rate

To measure infiltration rate, use a plastic drainpipe of 10 cm diameter, cut into 10 cm lengths. Bevel one edge of each section of pipe so that it can be inserted easily into the soil. Select a level area and carefully brush away any loose surface litter. If vegetation is present, clip it close to the soil surface and remove the clippings. Place a section of pipe on the soil surface and push it a few millimetres into the soil to form a seal between the pipe and the soil surface. Drape a piece of plastic sheeting on the soil surface inside the pipe to protect the surface from disturbance when water is applied. Add 400 mL of water to the pipe (this volume is equivalent to applying 50 mm of water) and quickly remove the plastic sheeting to allow the water to infiltrate into the soil. In the SCAMP field sheet, record the time taken for the water to disappear from the ring. Table 8 allows the conversion of the infiltration time to permeability class.

TABLE 8 Hydraulic conductivity and permeability class derived from the rate of three-dimensional flow from a section of circular pipe

Time for 400 mL (50 mm) of water to disappear from a section of pipe of 10 cm diameter	Infiltration rate	Hydraulic conductivity (mm/hour)	Equivalent permeability class (Table 5)
< 10 minutes	High	> 36	4
> 10 minutes, < 2 hours	Moderate	> 3.6	3
> 2 hours	Low	< 3.6	1, 2

Source: F. Cook (pers. comm.)

3.2.4 Plastic limit

To assess whether a soil is wetter or drier than its plastic limit, collect some soil (about the size of a golf ball) from at least 10 cm below the proposed depth of cultivation. Roll the soil between the palms of the hands and attempt to form a rod or cylinder about 50 mm long and 4 mm thick. If cracks appear in the cylinder, the soil is drier than its plastic limit and is therefore suitable for cultivation. If the cylinder stays intact, then the soil is wetter than its plastic limit, and cultivation will cause compaction. This information is not recorded in the SCAMP field sheet because it is dependent on the moisture status of the soil at the time of sampling. However, this technique is very useful for assessing the readiness of the soil for cultivation.

3.3 Application Level 3

Application Level 3 of SCAMP involves quantitative measurements of soil organic carbon (SOC), exchangeable cations and the ability to fix phosphorus (P). SOC can be measured in the field using a portable spectrophotometer. The other measurements need to be made in a laboratory, which must have a spectrophotometer suitable for determining P colorimetrically, and either an atomic absorption spectrometer or a flame photometer for determination of exchangeable cations. This basic laboratory equipment also allows determination of extractable P.

Where data are available relating crop yield to extractable P or exchangeable calcium (Ca), magnesium (Mg) or potassium (K), these measurements can be used to determine fertiliser requirements. However, this application is outside the scope of SCAMP.

3.3.1 Soil organic carbon (permanganate-oxidation method)

Different strengths of potassium permanganate have been used to determine the part of SOC that can be oxidised relatively easily (Loginow et al. 1987; Blair et al. 1995). The easily oxidisable fraction correlates with a wide range of important soil properties (e.g. Moody et al. 1997). Unlike 'total' (or near 'total') SOC—determined, for example, using the Walkley–Black or combustion analyser method—permanganate-oxidisable SOC can be determined in the field. The field method is described below and is a modification of that proposed by Weil et al. (2003).

Sample preparation

Using a trowel or shovel, take 0–10-cm soil samples from several positions in the field being sampled and mix the samples together in a bucket. Break any soil clods apart by hand. Take a subsample of the bulk soil and pass it through a 2-mm sieve. If the soil is wet, allow a subsample to dry in the sun before sieving.

Equipment

The following equipment is required:

- 50-mL graduated disposable plastic centrifuge tubes (internal diameter 30 mm)
- plastic test tube racks
- 5-mL standard teaspoon (equivalent to 5 g ± 0.5 g soil)
- 550-nm wavelength pocket colorimeter (for field use) or a laboratory spectrophotometer
- 1-mL graduated pipette
- 25-mL dispenser or measuring cylinder
- one funnel and washed glass wool.

Reagents

The following reagents are needed (reagents should be analytical grade):

- 0.1 M $CaCl_2.2H_2O$
- 33 mM $KMnO_4$.

Preparation of reagents

0.1 M $CaCl_2$

Weigh 1.47 g $CaCl_2.2H_2O$ into a volumetric flask and dilute to 100 mL with deionised H_2O.

33 mM $KMnO_4$

Weigh 5.21 g $KMnO_4$ into a small beaker and stir until dissolved (a hot plate can be used, but it should be no hotter than 60 °C). Filter the solution through a funnel containing a plug of washed glass wool and dilute to 1 L in a volumetric flask. Store the solution in an amber glass bottle or in a dark place.

Preparation of standard solutions

Prepare five standard solutions, as shown in Table 9.

TABLE 9 Preparation of standard solutions of $KMnO_4$

Standard number	Vol of H_2O (mL)	Vol of 33 mM $KMnO_4$ (mL)	Concentration of standard (mM)
1	20	5	6.6
2	15	10	13.2
3	10	15	19.8
4	5	20	26.4
5	0	25	33.0

Add 1 mL of 0.1 M $CaCl_2$ to each standard solution and mix well.

Add 1 mL of each standard solution to a set of labelled 50 mL plastic tubes and add deionised H_2O to the 50 mL mark. Cap and shake by hand. Prepare these secondary standard solutions on the day of use and take to the field.

Procedure

To determine SOC:

- » place a level teaspoon of dry, sieved soil (equivalent to 5 g soil) into a 50–mL plastic centrifuge tube
- » add 25 mL of 33 mM $KMnO_4$ solution, then add 1 mL of 0.1 M $CaCl_2$ solution to assist flocculation of soil particles
- » cap the tube and shake the solution by hand for two minutes (note: timing is critical)
- » leave the solution to stand for five minutes (note: timing is critical)
- » at the end of the five minutes, take 1 mL of the supernatant using a pipette and dilute in a plastic centrifuge tube to the 50 mL mark with deionised H_2O
- » zero the colorimeter (or spectrophotometer) with water and measure the absorbances of all standard solutions and samples at a wavelength of 550 nm (note: if the absorbance of any sample is less than 0.4, repeat the extraction using 2.5 g of soil instead of 5 g of soil)
- » plot the results as mM $KMnO_4$ (*x*-axis) versus absorbance (*y*-axis) and either draw a straight line through the points or fit a regression line to the relationship.

Calculations

From the standard graph, calculate the concentration of $KMnO_4$ (mM*)* left in the samples after the oxidation period (note: it is assumed that 1 mmol MnO_4^- is consumed—reduced from Mn^{7+} to Mn^{2+}—in the oxidation of 0.75 mmol or 9 mg of carbon) using the following equation:

$$C(g/kg) = \frac{(Mo - M_1) \times 26 \times 9}{1000 \times 5}$$

where:

- » Mo = initial concentration of $KMnO_4$ (33 mM)
- » M_1 = concentration of $KMnO_4$ (mM) after oxidation (calculated from standard calibration curve)

- final volume of $KMnO_4$ solution = 26 mL
- weight of soil = 5 g

Calculate SOC and record the value and rating (see Table 10) in the SCAMP data record sheet.

TABLE 10 Soil organic carbon rating determined from 33 mM permanganate-oxidisable carbon content (g/kg) using the field method for soils of various textures

Soil organic carbon rating	Soil texture (SCAMP texture type)			
	Sand (S)	Sandy loam (L)	Loam (L)	Clay loam/Clay (C)
1	< 0.10	< 0.14	< 0.18	< 0.24
2	0.10–0.20	0.14–0.28	0.18–0.36	0.24–0.40
3	> 0.20	> 0.28	> 0.36	> 0.40

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3.3.2 pH buffer capacity

An estimate of the pH buffer capacity (pHBC) can be obtained from topsoil (0–10 cm) data using the following pedotransfer function (Aitken et al. 1990) where SOC is the uncorrected Walkley–Black SOC concentration:

$$\text{pHBC (g CaCO}_3\text{/kg soil.pH unit)} = [0.955 \times \text{SOC\%} + 0.011 \times \text{clay\%}] \times 1.2$$

Calculate pHBC and record in the SCAMP data record sheet.

Many agricultural systems have acid-addition rates of about 2 kmol H^+/ha.year (e.g. Moody and Aitken 1997). Based on the weight of soil being 10^6 kg in a hectare of 0–10 cm soil at a bulk density of 1.0 Mg/m^3, it will take 10, 20 and 40 years for soil pH to decrease by 1 unit in soils with pHBCs of 20, 40 and 80 $mmol_c$/kg soil.pH unit, respectively (equivalent to 1, 2 and 4 g $CaCO_3$/kg soil.pH unit, respectively). Therefore, these values for pHBC can be rated as low, moderate and high for comparative purposes.

3.3.3 Phosphorus buffer capacity

A convenient way to measure P buffer capacity of the topsoil (0–10 cm) is to calculate a P buffer index (PBI) from a single addition of P, as described below.

Calculation of PBI

The PBI, developed by Burkitt et al. (2002), correlates strongly with the P buffer capacity; it is adapted from Method 9I1 in Rayment and Higginson (1992). Briefly, soil is equilibrated with 0.01 M $CaCl_2$ containing 100 mg P/L as potassium dihydrogen phosphate (KH_2PO_4). A 1:10 soil to solution ratio is used (e.g. 2 g [sieved to < 2 mm] soil in 20 mL of equilibrating solution). Approximately 0.25% (v/v) chloroform is added to the equilibrating solution to reduce microbial activity (in the case of 20 mL equilibrating solution, this corresponds to 50 µL). The suspension is shaken end over end (14 revolutions per minute, or rpm) for 17 hours at 25 °C, then centrifuged at 3,000 rpm (relative centrifugal force = 2,096 *g*). The concentration of P in the supernatant is measured by the colorimetric method of Murphy and Riley (1962). Because of the large initial addition of P, the supernatant may need to be diluted by up to a factor of 100 for soils that do not sorb much P.

The amount of P sorbed (*Ps*) by the soil (in mg P/kg) is calculated as the difference between the initial amount of P added (1,000 mg P/kg at the specified soil:solution ratio of 1:10) and the amount of P left in the equilibrating solution (mg P/kg). The latter is calculated by multiplying the final solution P concentration (*c*, in mg P/L) by 10 (because the soil:solution ratio is 1:10).

PBI is derived from the Freundlich equation, which is used to linearise the relationship between total P sorbed and final solution P concentration (i.e. the P sorption curve). Total P sorbed by the soil is calculated as the amount of sorbed P already present in the soil plus the amount of newly sorbed P from the P addition. Previously sorbed P is estimated as the content of Colwell-extractable P (Colwell 1963) or the Olsen-extractable P (Olsen et al. 1954) in the soil. The total P sorbed for use in calculating PBI is therefore the sum of Colwell-P or Olsen-P and *Ps*.

PBI is calculated according to either of the following equations:

$$\text{PBI}_{+\text{ColP}} = [Ps\ (\text{mg P/kg}) + \text{Colwell P (mg/kg)}]\ /\ c\ (\text{mg P/L})^{0.41}$$

$$\text{PBI}_{+\text{OlsP}} = [Ps\ (\text{mg P/kg}) + 4.59 \times \text{Olsen P (mg/kg)}]\ /\ c\ (\text{mg P/L})^{0.41}$$

Calculate PBI and record in the SCAMP data record sheet.

3.3.4 Cation exchange capacity

The most appropriate way to determine the cation exchange capacity (CEC) of acidic soils is to sum the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and the exchangeable acidity ($Al^{3+} + H^{+}$), determined as follows:

- the exchangeable cations are extracted by one of the following:
  - 1 M NH_4Cl (adjusted to pH 7.0, but not buffered) (Method 15A1 in Rayment and Higginson 1992)
  - 1 M ammonium acetate at pH 7.0 (Method 15D3 in Rayment and Higginson 1992)
- the exchangeable acidity is extracted by 1 M KCl (Method 15G1 in Rayment and Higginson 1992).

The sum of the exchangeable cations and the exchangeable acidity is termed the effective cation exchange capacity (ECEC), and it is a good measure of the CEC of the soil at its field pH. Record ECEC in the SCAMP data record sheet.

4 ASSESSMENT OF SOIL ATTRIBUTES AND CONSTRAINTS

To facilitate the easy transfer of information about soil properties and constraints, *Soil Constraints and Management Package* (SCAMP) uses a notation system consisting of a series of abbreviated words or individual letters to describe the soil. The first attribute used in the SCAMP notation is the texture type (in capital letters) of the topsoil and subsoil. This is followed by the lower-case letters or abbreviations of the constraints that have been identified for that soil. Where a rating can be given to a constraint (e.g. the erosion hazard, *er*, has five classes), the rating is given in parentheses after the constraint [e.g. *er (low)*]. For inventory purposes, constraints are grouped under the general headings of drainage constraints, soil pH and acidity constraints, cation constraints, clay fraction constraints, landscape constraints and soil structural constraints. The criteria that need to be met for individual soil attributes and constraints are described in Table 11 and associated Tables 12 to 15.

Examples of the SCAMP notation for different soil types (FAO/UNESCO soil classification system) include the following:

- Many Ferralsols belong to the unit *C a i er(low)*—that is, clayey, aluminium toxic, high phosphorus fixation, low erosion hazard.
- Many Vertisols are *C v b er(low)*—that is, clayey, vertic, calcareous, low erosion hazard.
- A young Fluvisol with no constraints is simply classified as *L er(low)*—that is, loamy, low erosion hazard.
- An Acrisol of loamy texture on a sloping site, with gleying and a compaction layer, is classified as *L g er(high) comp*.

More constraints can be defined if the analytical data of Level 3 SCAMP are available for the site.

TABLE 11 Soil characteristics used to derive individual soil attributes and constraints

Attribute/constraint	Classification	Characteristics
Texture type—soil Use either the texture of the topsoil (0–20 cm) or the plough-layer (whichever is the shallower).	*S* = sandy topsoils	» sand or loamy sand texture; or » < 20% clay
	L = loamy topsoils	» sandy loam, silty loam, loam, or clay loam texture; or » 20–35% clay
	C = clayey topsoils	» clay or heavy clay texture; or » > 35% clay
	O = organic soils	» > 12% total organic C to a depth of 50 cm or more
Texture type—subsoil Use the subsoil texture type only if, within 50 cm, there is a marked textural change from the topsoil, or if a hard root-restricting layer is encountered.	*SL* = sandy topsoil overlying loamy subsoil	
	SC = sandy topsoil overlying clayey subsoil	
	LC = loamy topsoil overlying clayey subsoil	
	SR, LR or *CR* = sandy, loamy or clayey topsoil overlying rock or other hard root-restricting layer that cannot be removed by tillage	
Drainage constraints	*g* = prolonged waterlogging	» gleying or grey mottles within 50 cm of the surface; or » soil saturated with water either naturally or with irrigation for > 200 days/year; or » drainage class 1 (see Table 6)
	g^- = intermittent or seasonal waterlogging	» orange, yellow or red mottles within 50 cm of the surface; or » soil saturated with water for > 60 days in most years; or » drainage class 2 (see Table 6)

TABLE 11 Continued

Attribute/constraint	Classification	Characteristics
Soil pH and acidity constraints	*a* = Al toxicity	» field pH_{water} or pH (1:1 water) < 5.0; or » pH (1:5 water) < 5.2 within 50 cm, except in organic soils, where pH must be < 4.7
	a^{-} = Al toxicity constraint for extremely acid-sensitive crops	» 10–60% Al saturation within top 50 cm of soil
	ar = acidification hazard: low, moderate or high based on pHBC value (note: pHBC is calculated from the equation in Section 3.3.2)	» < 1 g $CaCO_3$/kg soil.pH unit —high acidification hazard » 1–2 g $CaCO_3$/kg soil.pH unit—moderate acidification hazard » 2–4 g $CaCO_3$/kg soil.pH unit—low acidification hazard
	b = calcareous	» free $CaCO_3$ within the surface 50 cm (effervescence with HCl); or » field pH_{water} 8.0–8.5; or » pH(1:5 water) = 8.2
Cation constraints	*e* = low nutrient retention	» ECEC < 4 $cmol_c$/kg soil by Σ(Ca, Mg, Na, K) + KCl-extractable acidity (Al^{3+}+ H^{+}) in plough layer or surface 20 cm, whichever is shallower; or » refer to Table 12; or » CEC < 7 $cmol_c$/kg soil at buffered pH 7; or » CEC < 10 $cmol_c$/kg soil at buffered pH 8.2
	s = salinity	» ≥ 4 dS/m of electrical conductivity of saturated soil paste measured in the field (EC_{se}) within 50 cm of the soil surface. Refer to Table 13 for equivalent laboratory $EC_{1:5}$ values
	s^{-} = marginal salinity	» 2–4 dS/m field EC_{se} within 50 cm of the soil surface (note: refer to Table 13 for equivalent $EC_{1:5}$ values)
	n = sodicity	» ≥ 15% Na-saturation of ECEC within the surface 50 cm
	n^{-} = marginal sodicity	» 6–15% Na-saturation of ECEC within the surface 50 cm; or » Emerson (1967) dispersion class 1, 2 or 3 (see Figure 5)

TABLE 11 Continued

Attribute/constraint	Classification	Characteristics
	k = low K reserves	» exchangeable K < 0.20 $cmol_c$ /kg soil within the surface 50 cm; or » K saturation < 2% of Σ(Ca, Mg, Na, K) if Σ < 10 $cmol_c$ /kg soil within the surface 50 cm
Clay fraction constraints	*i* = high P-fixation	» 'high' or 'very high' category in Table 14; or » hues of 7.5YR or redder and granular structure
	i^- = extremely low P-fixation	» 'extremely low' category in Table 14
	v = vertic properties	» severe topsoil shrinking and swelling; or » very sticky plastic clay; or » > 35% clay and 'CEC to clay ratio' [ECEC /clay (%)] > 0.8 indicating the presence of 2:1 clay minerals
	om = low total organic C	» rating 1 in Table 10
	geric = *geric* characteristic	» delta pH (pH_{KCl}–pH_{water}) is zero or positive. » When delta pH is positive, the soil has a net positive charge on the variable charge surfaces, indicating a very limited ability to hold cations such as Ca^{2+}, Mg^{2+} and K^+. When delta pH is zero, the soil has no net charge on the variable charge surfaces and CEC depends on the amount of permanent charge (which is generally very low in soils with this property)
Landscape constraints	*gravel* = gravel rating	» 1 (gravelly) denotes 35–60% of pebbles (2–75 mm) by volume; » 2 (very gravelly): 61–90% of pebbles by volume; » 3 (gravel land): > 90% gravel by volume
	er = erosion hazard rating	» 1 (low) » 2 (moderate) » 3 (high) » 4 (very high) » 5 (extreme) » (note: erosion hazard rating based on Table 7)

TABLE 11 Continued

Attribute/constraint	Classification	Characteristics
Soil structural constraints	*hs* = hard-setting	» Emerson (1967) dispersion class 1, 2 or 3 (see Figure 5); or » extremely firm consistence of the topsoil; or » see Table 15
	comp = compaction layer	» platy structure; or » impeded root growth ('right angle' appearance of roots at the top of the compaction layer); or » extremely firm consistence compared to soil above and below the layer; or » increased penetrometer resistance compared to soil above and below the layer

CEC = cation exchange capacity; ECEC = effective cation exchange capacity; EC_{se} = electrical conductivity of a saturation extract; pHBC = pH buffer capacity; YR = yellow–red in Munsell colour system

TABLE 12 Identifying the low-ECEC constraint (*e*) from SCAMP texture type and soil organic carbon rating

Soil organic carbon rating[a]	Sandy (*S*)	Loamy (*L*)	Clayey(*C*)
1	*e*	*e*	*e*
2	*e*	*e*	–
3	*e*	–	–

ECEC = effective cation exchange capacity; SCAMP = *Soil Constraints and Management Package*
a Refer to Table 10 for soil organic carbon ratings

TABLE 13 Soil salinity criteria as EC_{se} and the equivalent $EC_{1:5}$ determined from soil clay content and SCAMP texture type

EC_{se} (dS/m)	Corresponding $EC_{1:5}$ (dS/m) based on % clay content			
	10–20 (Sandy, *S*)	20–40 (Loamy, *L*)	40–60 (Clayey , *C*)	60–80 (Clayey, *C*)
2.0	0.16	0.20	0.23	0.31
4.0	0.30	0.40	0.50	0.62

EC_{se} = electrical conductivity of a saturation extract; SCAMP = *Soil Constraints and Management Package* Source: Shaw (1999)

TABLE 14 Phosphorus buffer index ranges used to classify phosphorus buffer capacity

Phosphorus buffer capacity	Phosphorus buffer index (PBI)
Extremely low	< 15
Very, very low	15–35
Very low	36–70
Low	71–140
Moderate	141–280
High	281–840
Very high	> 840

TABLE 15 The potential for hard-setting (*hs*) based on the field texture or SCAMP texture type and the ECEC:clay ratio

ECEC/Clay ratio	Sand (*S*)	Loamy sand (*S*)	Sandy loam (*L*)	Sandy clay loam (*L*)	Sandy clay (*C*)	Clay (*C*)
< 0.2	–	*hs*	*hs*	*hs*	*hs*	–
0.2–0.8	–	*hs*	*hs*	*hs*	–	–
> 0.8	–	–	*hs*	*hs*	–	–

SCAMP = *Soil Constraints and Management Package* ; ECEC = effective cation exchange capacity
Source: Mullins et al. (1990)

5 IMPLICATIONS AND MANAGEMENT OF SOIL ATTRIBUTES

5.1 Application Level 1 attributes

5.1.1 Soil texture

Implications

Table 16 shows the implications of field texture for root growth, compaction and plant-available water. Table 17 indicates the physical and hydraulic properties of soil that can be inferred from pedotransfer functions developed from soil property databases (Saxton et al. 1986). However, these values are only indicative, because the properties can vary widely within a particular *Soil Constraints and Management Package* (SCAMP) texture type.

Management

Table 16 indicates management practices for tillage, nutrients and erosion control for soils of different SCAMP texture types.

TABLE 16 Soil characteristics associated with soil texture type and their management implications

SCAMP texture type	Characteristics	Management
S (sandy topsoil)	High rate of infiltration; low plant-available water-holding capacity; seedling wilt can occur because of a rapidly drying soil surface; minimal resistance to root growth; limited ability to supply nutrients; excessive leaching of nutrients, particularly nitrate, potassium and sulphate.	Monitor crops for nutrient deficiencies; maintain surface cover or roughness to reduce risk of wind erosion; apply soluble fertilisers in split applications.
L (loamy topsoil)	Medium infiltration rate; moderate plant-available water-holding capacity; root growth not restricted; moderately to highly susceptible to compaction[a]; fine sandy loam and silty loam textures can be highly susceptible to water erosion and may be hard-setting.	Only till when soil is drier than its plastic limit; take appropriate erosion control measures; maintain surface cover.

TABLE 16 Continued

SCAMP texture type	Characteristics	Management
C (clayey topsoil)	Low infiltration rates; moderate-high plant-available water-holding capacity; root growth frequently restricted; moderately to highly susceptible to mechanical compaction[a]; some restriction on water movement leading to periodic waterlogging or, on sloping sites, potential for high run-off; difficult to till. Note: when *i* constraint is present (i.e. soil is *Ci*) the soil has high infiltration rates and low plant-available water-holding capacity.	To prevent compaction, only till when soil is drier than its plastic limit; maintain surface cover. If soil is *C i*, then it is easy to till.
O (organic soils)	Artificial drainage may be needed and subsidence will occur; possible micronutrient deficiencies (copper, molybdenum, boron, zinc and manganese); may have high rates of nitrogen mineralisation.	Artificial drainage may be required, or crop row will require mounding; foliar sprays should be used to correct micronutrient deficiencies; may need to apply high levels of herbicide.
SC (sandy topsoil over clayey subsoil), *LC* (loamy topsoil over clayey subsoil), *SR* (sandy topsoil on rock), *LR* (loamy topsoil on rock) *CR* (clayey topsoil on rock)	Susceptible to severe soil degradation if erosion reduces the depth of the topsoil or exposes undesirable subsoil (e.g. sodic); if positioned low in the landscape, may experience periodic waterlogging due to perched watertables; in *SC* soils in particular, the root system will be restricted to topsoil resulting in water stress during dry periods and possible nutrient deficiencies due to the limited rooting depth.	Give high priority to erosion control using methods described in Section 5.1.5.

[a] For further information on soil compaction, refer to McGarry (1993)

TABLE 17 Indicative values for some key physical and hydraulic properties for soils of different textures

Texture (equivalent SCAMP texture type)	Field capacity (cm^3 water/ cm^3 soil)	Bulk density (Mg/m^3)	Saturation (cm^3 water/ cm^3 soil)	Saturated hydraulic conductivity (mm/hour)	Plant-available water (cm^3 water/ cm^3 soil)
Sand (*S*)	0.12	1.72	0.35	8.84	0.07
Sandy loam (*L*)	0.21	1.50	0.43	1.33	0.10
Loam (*L*)	0.26	1.41	0.47	0.87	0.14
Silty loam (*L*)	0.29	1.41	0.47	1.87	0.18
Clay loam (*L*)	0.33	1.31	0.51	0.27	0.14
Clay (*C*)	0.44	1.23	0.54	0.16	0.13

SCAMP = *Soil Constraints and Management Package* Source: Saxton et al. (1986)

5.1.2 Soil colour

Implications

Soil colour can be used to infer the relative amount of soil organic matter, the amount and oxidation state of soil iron oxides, and the degree of aeration of the soil; all of which have management implications (Table 18). For example, sandy soils, as indicated by a white colour, have characteristically low cation exchange capacity (CEC), and it can therefore be inferred that they will be inherently infertile, with possible leaching losses of nitrate, potassium (K) and sulfate (Table 18).

TABLE 18 Soil characteristics associated with soil colour and their management implications

Soil colour	Soil types and characteristics	Implications
Black	Peat/soils high in organic matter	Anaerobic conditions; drainage problems; low pH; high denitrification risk
	Vertisols	Workability; tillage problems; Zn deficiency
	Soils derived from limestone under reduced conditions	Deficiencies of P, Fe, Zn; drainage problems
White/pale/ bleached	Sandy soils	Nutrient deficiencies; leaching of nitrate, potassium, sulfate; low plant-available water
Red	Well-drained soils with high content of iron oxides	High P fixation; possible Al (and Mn?) toxicities; low plant-available water
Yellow/yellow brown	Imperfectly drained to moderately well-drained soils with high content of iron oxides	Moderate P fixation; possible Mn toxicity; low plant-available water; compaction
Brown	Moderate soil organic matter levels and some iron oxides	Low to moderate P fixation; low to moderate plant-available water
Gleyed/grey/ blue grey	Near permanent waterlogging; anaerobic (reduced) conditions	Drainage problems; high denitrification risk; methane emission hazard
Mottles	Intermittent waterlogging; intermittent anaerobic (reduced) conditions	Intermittent drainage problems; denitrification risk when waterlogged; methane emission hazard when waterlogged

Management
Implications associated with various soil colours (Table 18) include:

- » impeded drainage
- » high risk of denitrification
- » leaching of nutrients
- » low quantities of plant-available water.

Management options for minimising the impacts of these issues on productivity include (respectively):

- » mounding of crop rows and construction of drainage channels to remove excess water
- » improved drainage by mounding of crop rows and split nitrogen (N) fertiliser applications to reduce soil nitrate concentrations
- » split fertiliser applications and increasing soil CEC by retaining crop residues and including green manures in the crop rotation
- » increasing the plant-available water content of the soil by retaining crop residues and including green manures in the crop rotation.

5.1.3 Soil structure and consistence

Implications
The shape and arrangement of soil aggregates, and the strength and coherence of the soil, have major effects on the pathway of water movement (run-off or drainage), the ease of root penetration into the soil, rooting depth and seedling emergence. Tables 19 and 20 indicate the inferences that can be drawn from structure and consistence, respectively.

Management
The management options for dealing with the constraints imposed by soil structure are presented in Table 19. The main implications of strong or rigid soil consistence are restricted water flow and restricted root growth; appropriate management options such as growing rotation crops with strong penetrating roots are indicated in Table 20.

TABLE 19 Implications and management options associated with soil structure

Structure	Implications	Management
Moderate to strong and fine (< 20 mm diameter), granular	Good drainage and aeration	» Use minimum tillage and controlled traffic
Coarse (> 20 mm diameter), blocky, prismatic or columnar	Poor drainage and aeration	» Grow rotation crops (including a pasture phase) with strong penetrating roots to produce macropores and dry the soil » Apply gypsum or lime if the poor structure is associated with sodicity » Use mechanical ripping
Massive structure in clay loam and clay soils	Poor drainage and aeration	» Manage as for coarse, blocky, prismatic or columnar structure
Massive structure in clay loam and clay soils with numerous visible macropores	Good drainage and aeration	» Use minimum tillage and controlled traffic
Massive structure in sands and loams	Good drainage	» Use minimum tillage and controlled traffic
Single-grained	Good drainage but highly erodible	» Increase soil organic matter by retaining crop residues and growing green-manure crops » Maintain surface cover
Platy structure	Compacted soil	» Grow rotation crops (including a pasture phase) with strong penetrating roots to dry the soil and produce macropores » Apply gypsum or lime if the poor structure is associated with sodicity » Use mechanical ripping

TABLE 20 Description of moist soil consistence and its implications for management

Soil consistence	Description	Implications
Loose, weak	Soil block (25–30 mm axis) crumbles under slight force applied between thumb and forefinger (0–20 Newtons)	» No restrictions to root growth » Slight restrictions to water flow
Firm	Soil block crumbles under moderate to strong applied force (20–80 Newtons)	» Water flow may sometimes be restricted, contributing to periodic waterlogging
Strong to rigid	Soil block cannot be crumbled (80–800 newtons)	» Root growth is restricted » Water flow may be restricted

Source: Fitzpatrick et al. (1999)

5.1.4 Permeability and drainage

Qualitative permeability and drainage classes can be combined to identify the major pathway of movement of rainfall or irrigation water when it contacts the soil surface. Figure 6, which is based on expert opinion, illustrates this, and Table 21 allocates the major water pathway against the various permeability and drainage classes.

TABLE 21 The major pathways of water movement associated with different permeability and drainage classes

Permeability class	Drainage class					
	1	2	3	4	5	6
1	R/P	R/P	R/P	R/P	R/P	D + R/P
2	R/P	R/P	R/P	D + R/P	D + R/P	D + R/P
3	R/P	R/P	R/P	D + R/P	D	D
4	R/P	R/P	D + R/P	D + R/P	D	D

D = drainage; R/P = run-off or ponding, depending on slope

Implications

Where the major water movement pathway is:

- drainage (e.g. permeability class 4, drainage class 5–6)—soils may lose nutrients such as nitrate-N by leaching, resulting in accelerated soil acidification and groundwater pollution. If effective cation exchange capacity (ECEC) is low (*e* constraint), K may also leach.
- run-off (e.g. permeability class 1–4, drainage class 1–2)—soils may be susceptible to erosion; off-site sediment movement causes infrastructure damage (e.g. siltation of drains, roads and water storages) and degrades the quality of surface water.
- ponding (e.g. permeability class 1–4, drainage class 1–2)—soils have a high potential for denitrification if soil organic carbon (SOC) levels are moderate to high, and nitrate is present.

Management

Drainage: To reduce the risk of leaching losses of nutrients, apply N and K fertilisers in split applications in accord with crop demand.

Run-off: To minimise erosive loss of soil where run-off is a major pathway of water movement, apply soil conservation practices appropriate to the slope of the land; maintain soil surface cover by retaining crop residues, growing cover crops or applying mulches.

Ponding: To minimise denitrification risk, mound crop rows to improve drainage in the root zone and split N fertiliser application to reduce the concentration of nitrate present in the soil.

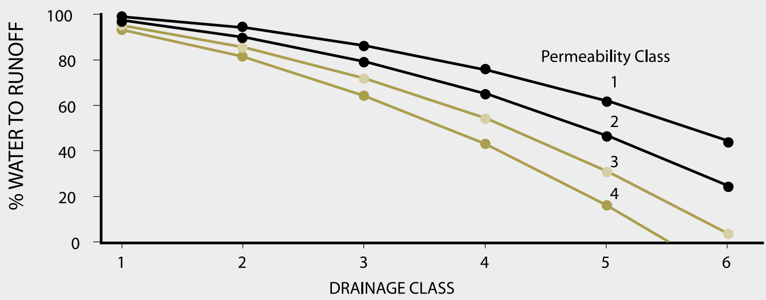

FIGURE 6 Percentage water to run-off for combinations of permeability and drainage classes (Source: Queensland Department of Natural Resources and Mines 2004)

5.1.5 Erosion hazard

Implications

Erosion hazard ranks the risk of loss of surface soil through erosion. The hazard is based on a consideration of slope and observed erosion (refer to Table 7) and has categories ranging from 1 (low) to 5 (extreme).

Management

- Erosion hazard 1: No special soil conservation practices are required.
- Erosion hazard 2: Protect the soil surface by stubble retention, minimal tillage and contour cropping. These practices reduce the ability of water to cause erosion by slowing the speed of run-off water.
- Erosion hazard 3: Protect the soil surface by stubble retention, minimal tillage and contour cropping, and construct soil conservation structures such as contour banks or hedgerows.
- Erosion hazard 4: If soils with this erosion hazard are cropped, a pasture phase must be the major component of the cropping system to limit soil loss.
- Erosion hazard 5: Soils should not be cropped and should be maintained under continuous pasture.

5.2 Application Level 2 attributes

5.2.1 Soil pH

Implications

Using pH_{water}, soils can be broadly classified into acidity or alkalinity classes, as shown in Table 22.

TABLE 22 Soil pH classes based on soil pH in water

	pH_{water}						
	< 4.6	4.6–5.5	5.6–6.5	6.6–7.5	7.6–8.5	8.6–9.1	> 9.1
Class	Extremely acidic	Strongly acidic	Acidic	Neutral	Alkaline	Strongly alkaline	Extremely alkaline

Table 23 describes the implications of soil pH as it affects nutrient availability, elemental toxicities and soil microbial activity.

TABLE 23 Implications of the six diagnostic soil pH ranges and management strategies for maintaining productivity

Diagnostic range (soil pH_{water})	Implications	Management
< 4.6	» Soil pH values markedly less than 4: – will be found in peat and acid sulfate soils – may occur in extremely weathered mineral soils of low fertility – may occur in soils of low pH buffer capacity subjected to highly acidifying agricultural practices, such as high application rates of ammonium-based N fertilisers, removal of large amounts of harvested product or mineralisation of nitrate from decomposing leguminous plant residues. » Al or Mn toxicity is probable. » Deficiencies of Mo (because of decreased availability at low pH) and Ca, Mg, and K (due to leaching losses) can occur. » Activity of some soil micro-organisms (especially nitrifiers) is reduced.	To return to a productive state, these soils will require large amounts of lime. Farming systems that use highly acid-tolerant species may be used where application of liming materials is not practical. Addition of organic materials to mineral soils may help to ameliorate soil acidity.

TABLE 23 Continued

Diagnostic range (soil pH_{water})	Implications	Management
4.6–5.5	» This pH range denotes significant soil acidification, which can be due to natural processes or to the long-term use of intensive agricultural practices (see above). » Al or Mn toxicity is probable. » Deficiencies of Mo and Ca, Mg, and K can occur, for the reasons given above. » Activity of some soil micro-organisms (especially nitrifiers) is reduced.	Amelioration of soils in this pH range is often necessary if productive yields are to be maintained, and is often economically viable. Use of acid-tolerant species and addition of organic material as outlined above may be employed.
5.6–6.5	» At this pH range, optimum growth can be obtained for many acid-tolerant cultivars, providing that adequate amounts of N and P are available. » Mn toxicity may still limit yield in waterlogged soils with high reducible Mn contents.	Amelioration of these soils is economically viable; liming strategies should be determined according to the crops being grown.
6.6–7.5	» This pH range is optimal for the growth of most plant species. » Mn toxicity may limit yield in waterlogged soils with high reducible Mn contents.	Soils are likely to be productive, providing there are no nutrient deficiencies (e.g. P, N, Zn, Mo) or salinity effects.
7.6–8.5	» This pH range is regarded as alkaline. » Zn, Fe and Mn become less available as the pH increases, whereas Mo becomes more available.	Micronutrient deficiencies may be present, particularly where acidic soils have been over-limed.
> 8.6	» At this pH range, soils are strongly alkaline and dominated by Na, Ca and Mg carbonates. » Deficiencies of micronutrients (e.g. Cu, Zn, Fe, Mn), K or P can occur. » B toxicity can exist. » The soil is likely to have a very poor nutritional and structural status.	Only alkaline-tolerant plants will survive, and micronutrients may be required. If soil EC_{se} exceeds 1.9 dS/m, then the soil may be saline and groundwater will need to be lowered. If EC_{se} is less than 0.95 dS/m, then the soil is sodic and will require acidifying; legumes and gypsum may be effective at reducing exchangeable Na.

EC_{se} = electrical conductivity of a saturation extract
Source: Slattery et al. (1999)

In summary, strongly acidic soils can have the following characteristics:

- aluminium and/or manganese toxicity
- phosphorus (P) deficiency
- calcium and/or magnesium deficiency
- reduced N mineralisation because of restricted microbial activity
- reduced molybdenum and boron availability.

Strongly alkaline soils can have the following characteristics:

- surface sealing and crusting problems due to excessive sodium
- reduced availability of iron, manganese, zinc, P and copper
- reduced microbial activity and reduction in fungal population.

Management

Crops differ in their tolerance to acidity, and a short-term management option in low input systems is to grow crops tolerant of high aluminium (Al) saturation. High Al saturation is a common consequence of low soil pH, and Table 24 gives an assessment of the Al tolerance of several important crops. This management strategy is not sustainable in the long term because soil acidification will continue unamended and crop options will become increasingly more limited.

Low soil pH is countered by applying liming materials such as agricultural lime (calcium carbonate), dolomite (magnesium carbonate plus calcium carbonate), or other materials that have a liming effect on the soil. The efficiency of these materials for neutralising acidity depends on their neutralising value (relative to pure calcium carbonate, which has a value of 100) and their particle size—the finer the material, the more rapidly it reacts with the soil.

Organic materials such as plant residues can have a liming effect because they produce alkaline products as they decompose or are burned. The amount of alkalinity produced depends on the content of basic cations such as calcium, magnesium, sodium and K relative to anions such as sulfate, nitrate and phosphate. The potential for an organic material to produce alkalinity is measured by its 'ash alkalinity' and is determined by ashing the material, dissolving the residues in acid, and then back-titrating the acid with alkali. Leguminous residues generally have higher ash alkalinity than grass residues.

TABLE 24 Tolerance of upland crops to aluminium (Al) saturation (exchangeable Al as a percentage of ECEC)

Crop	Latin name	Al saturation[a]		
		Low (0–40%)	Mod. (40–70%)	High (> 70%)
Maize	*Zea mays*	✔	✔	✕
Mungbean	*Vigna radiata*	✔	✕	✕
Sorghum	*Sorghum bicolor*	✔	✔	✕
Groundnut	*Arachis hypogea*	✔	✔	✕
Cowpea	*Vigna unguiculata*	✔	✔	✔
Soybean	*Glycine max*	✔	✕	✕
Upland rice	*Oryza sativa*	✔	✔	✔
Cassava	*Manihot esculenta*	✔	✔	✔
Brachiaria	*Brachiaria* spp.	✔	✔	✔
Setaria	*Setaria* spp.	✔	✔	✕
Mucuna	*Mucuna cochinchinensis*	✔	✔	✔
Gliricidia	*Gliricidia sepium*	✔	✕	✕
Flemingia	*Flemingia congesta*	✔	✔	✔
Calliandra	*Calliandra calothyrsus*	✔	✔	✔
Leucaena	*Leucaena* spp.	✔	✕	✕
Sugarcane	*Saccharum* spp.	✔	✔	✔
Rubber	*Hevea brasiliensis*	✔	✔	✔
Oil palm	*Elaeis guineensis*	✔	✔	✔

ECEC = effective cation exchange capacity; Mod. = moderate
[a] '✔' indicates tolerance; '✕' indicates lack of tolerance
Source: Dierolf et al. (2001)

As some plant materials decompose, they produce organic acids that have the ability to complex toxic soil aluminium, rendering it harmless to the growth of plant roots.

Lime requirement

Soil acidity is most often corrected by the addition of liming materials. However, soils differ in the amount of alkalinity required to raise the soil pH by 1 unit (defined as the soil's pH buffer capacity or pHBC), and a calibrated lime-requirement soil test [e.g. Mehlich (1976) buffer method] should be used to calculate the amount of lime required to raise the soil pH to a desired target value. A soil pH_{water} of 5.5 is considered to be an appropriate target pH that is economic. The following equation is based on extensive field data of Aitken et al. (1995) and indicates, for a particular Mehlich buffer soil pH value, the amount of good quality agricultural lime (typically with a neutralising value of 95 and a fineness of 80% < 0.125 mm) required to raise the pH_{water} of the surface 10 cm of soil to a target value of 5.5 ($LR_{5.5}$), assuming a bulk density of 1 Mg/m^3:

$$LR_{5.5}\,(\text{tonnes/ha}) = 67.109 - 19.77\,pH_{Mehlich} + 1.455\,pH_{Mehlich}{}^{2}\ (r^2 = 0.76)$$

Where such a calibrated lime-requirement test is not available, Table 25 gives a guide to the amounts of good quality agricultural lime (typically with a neutralising value of 95 and a fineness of 80% < 0.125 mm) required to correct soil acidity.

TABLE 25 Lime requirement for various upland crops based on soil pH in water and the level of aluminium (Al) saturation

pH in water	Aluminium saturation (%)	Approximate lime requirement to reach 10–20% Al saturation (e.g. for soybean, mungbean)	Approximate lime requirement to reach 30–40% Al saturation (e.g. for maize, groundnut)
4.0–4.9	70–30	1–4 tonnes lime/hectare	1–3 tonnes lime/hectare
5.0–5.5	30–0	0–4 tonnes lime/hectare	0–0.5 tonnes lime/hectare
> 5.5	0	0 tonnes lime/hectare	0 tonnes lime/hectare

Source: Dierolf et al. (2001)

5.2.2 Electrical conductivity

Implications

Plants differ in their ability to tolerate salt, and the implications of salinity on productivity will depend on the crop being grown. Table 26 indicates the electrical conductivity (EC) values corresponding to the salinity tolerance classes of Maas and Hoffman (1977).

TABLE 26 Salt tolerance of crops grouped according to soil salinity criteria measured as EC_{se} or the equivalent $EC_{1:5}$ for different soil clay contents and field textures

Plant salt-tolerance grouping[a]	EC_{se} range (dS/m)[b]	Corresponding $EC_{1:5}$ based on soil clay content (dS/m)[c]				Soil salinity rating
		10–20% clay (loamy sand, sandy loam)	20–40% clay (loam, clay loam)	40–60% clay (clay)	60–80% clay (heavy clay)	
Sensitive crops	< 0.95	< 0.07	< 0.09	< 0.12	< 0.15	Very low
Moderately sensitive crops	0.95–1.9	0.07–0.15	0.09–0.19	0.12–0.24	0.15–0.3	Low
Moderately tolerant corps	1.9–4.5	0.15–0.34	0.19–0.45	0.24–0.56	0.3–0.7	Medium
Tolerant crops	4.5–7.7	0.34–0.63	0.45–0.76	0.56–0.96	0.7–1.18	High
Very tolerant crops	7.7–12.2	0.63–0.93	0.76–1.21	0.96–1.53	1.18–1.87	Very high
Generally too saline for crops	> 12.2	> 0.93	> 1.21	> 1.53	> 1.87	Extreme

EC_{se} = electrical conductivity of a saturation extract
[a] Maas and Hoffman (1977) [b] Corresponds to a 10% yield reduction [c] Shaw (1999)

Management

The management of saline soils depends on lowering the watertable, attempting to leach excess salts from the root zone, and selecting crops appropriate to the salinity status of the soil.

5.2.3 Dispersion

Implications

Spontaneous slaking or dispersion of soil aggregates in water indicates poor aggregate stability. The implications of spontaneous dispersion, based on the Emerson (1967) dispersion classes (refer to Section 3.1.6 above) are indicated in Table 27.

Management

Options for managing various degrees of aggregate dispersion are given in Table 27.

TABLE 27 Implications and management responses for soils of different Emerson dispersion classes

Dispersion class[a]	Implications	Management
1–2	» Soil will spontaneously disperse because of high sodium saturation or low EC. » Typically low in organic carbon. » Soil will crust, compact and erode easily.	» Add gypsum to displace exchangeable Na and to maintain soil solution EC. » Maintain soil cover with crop residues, mulches or cover crops.
3	» Soil will disperse after moulding at field capacity; moulding simulates tillage or machinery traffic. » Typically low in organic carbon. » Soil will compact if tilled or trafficked when wetter than its plastic limit, and will hard-set when dry.	» Restrict cultivation and traffic if soil is wetter than plastic limit. » Use surface mulching to retain soil moisture so that hard-setting does not occur.
4–8	» Stable aggregates. » Excellent soil condition.	

EC = electrical conductivity [a] Emerson (1967)

5.2.4 Infiltration rate

Implications

When rainfall intensity or the rate of application of irrigation water exceeds the hydraulic conductivity of a soil, surplus water either moves off site as run-off (if the site is sloping) or ponds (if the slope is < 1%). Run-off can erode surface soil and is likely to do so if the soil surface is not protected by vegetation or plant stubble. Off-site sediment movement affects water quality and causes problems with drainage infrastructure. In the case of soils with high hydraulic conductivity (such as sands), rainfall or irrigation water will move through the soil and may reach depths that exceed the rooting depth of crops grown in the soil. This deep drainage will cause loss of soluble nutrients such as nitrate-N by leaching, with harmful effects on the quality of groundwater. If a compaction layer is present, it will act as a barrier to water movement through the profile and will reduce the infiltration rate once the wetting front reaches the compacted zone.

Management

Management of soils with low infiltration rates involves minimising the erosion risk of run-off water as described in Section 5.1.5 above. In contrast, drainage is the main pathway of water movement in soils of high infiltration rate and Section 5.1.4 above describes management options for reducing nutrient losses by leaching.

5.3 Application Level 3 attributes

5.3.1 Soil organic carbon

Implications

Depending on temperature, soil moisture and the soil clay minerals present, SOC is protected from oxidation (decomposition) to a greater or lesser extent. Therefore, although it is not possible to define an optimum level of SOC, Table 28 gives general ratings for total SOC. In a particular environment, such as the tropics, SOC levels are determined by the amount of biomass recycling in the system, and tend to decrease in the following order: forest > improved pasture > unimproved pasture > crops with residue retained > crops with stubble removed or burnt.

TABLE 28 Soil organic carbon status determined from total organic carbon contents in soils of various textures

Soil organic carbon status (SCAMP texture type)	(%C)			
	Sand (*S*)	Sandy loam (*S*)	Loam (*L*)	Clay loam/clay (*C*)
Low	< 0.5	< 0.7	< 0.9	< 1.2
Moderate	0.5–1.0	0.7–1.4	0.9–1.8	1.2–2.0
High	> 1.0	> 1.4	> 1.8	> 2.0

SCAMP = *Soil Constraints and Management Package*
Source: Baldock and Skjemstad (1999)

Table 10 indicates approximate values for permanganate-oxidisable SOC determined by the field method (Section 3.3.1) that correspond to the total SOC contents in Table 28.

In some situations, it has been possible to define a SOC 'sustainability index' for a particular soil type by considering the soil property or properties that are most limiting to sustainable production in that cropping system. For the Ferralsols of Australia, infiltration rate is the key determinant of sustainability in rain-fed cropping systems, and the concentration of 33 mM permanganate-oxidisable SOC required for 'no run-off' from a 30-minute rainfall event has been suggested as a suitable sustainability index for these soils (Bell et al. 1999). In general, however, it is not possible to define ageneralised 'critical' SOC level below which the soil ecosystem does not function. To take this into account, SCAMP does not rate SOC status as 'low', 'moderate' or 'high'; rather, it assigns it a rating of 1–3 on the basis of Table 10 in Section 3.3.1.

Management

Because of the role of SOC in many important soil properties, maintain or increase SOC levels whenever possible. This can be achieved by:

- mulching and incorporating green-manure crops (e.g. legumes or forage grasses) into the topsoil
- retaining all crop residues (e.g. maize or rice straw) in the field where the crop has grown
- not burning crop residues; burning causes the loss of C as carbon dioxide gas and exposes the soil surface to erosion
- controlling erosion; erosion is particularly detrimental to SOC because of the off-site movement of topsoil, which is richer in SOC than subsoil
- using minimum or zero-tillage farming systems to reduce the loss of SOC from cultivation
- using strip and alley cropping; these cropping systems allow the application of plant residues from the strip or alley crop to the inter-row area
- applying organic materials (such as animal manure, composted municipal waste, sewage sludge and locally available industrial organic wastes) obtained from off site.

5.3.2 pH buffer capacity

Implications

Soils with a low pHBC will acidify quickly under agricultural systems with a high acid-addition rate. If soil acidification is allowed to proceed without amelioration, the subsoil as well as the topsoil will become acidified. Because the alkalising effect of lime is limited mainly to the soil in which it is incorporated, subsoil acidification is difficult and costly to correct.

Management

- Both surface and subsoil (bottom of rooting depth) pH need to be monitored frequently so that a regular liming program can be implemented to maintain soil pH at levels required for optimum crop growth.

- It is critical to obtain an accurate lime requirement for soils from a calibrated lime-requirement soil test (e.g. using a buffer pH method such as the Mehlich method—see Section 5.2.1). In soils of low pHBC, application of 'blanket rates' of agricultural lime (e.g. 1 tonne/hectare) may cause such a large increase in soil pH ('overliming') that micronutrient deficiencies are induced.

5.3.3 Phosphorus buffer capacity

Implications

The P buffer index (PBI) is a convenient measure of the P-fixing ability (P buffer capacity) of a soil. This property affects the interpretation of extractable soil P values and has implications for P fertiliser management.

The critical values of soil P tests that correlate with the quantity of sorbed P in a soil such as the Colwell (1963) method increase as the P-fixing ability of a soil increases. PBI can be used to adjust 'critical' soil P test levels to allow for this effect (Moody 2007). PBI is also positively correlated with the amount of added fertiliser P required to raise extractable soil P status (Burkitt et al. 2001).

Besides these specific interpretations of PBI, the index is also useful for identifying:

- extremely low sorbing soils where P may be lost by leaching, and therefore may pose a threat to groundwater quality (Table 14)
- highly sorbing soils where large amounts of P will be required to correct a deficiency (Table 14).

Management

Soils with extremely low P buffer capacity (such as acidic sands) will pose a risk to water quality if too much fertiliser P is applied. Use citrate-soluble P sources (e.g. reactive rock phosphate) on such soils rather than water-soluble forms (e.g. superphosphate).

P fertiliser management for soils of high to very-high P buffer capacity depends on:

- reducing contact between soil and fertiliser if water-soluble P sources are used; this can be achieved by placing the fertiliser in concentrated bands below and to the side of crop seeds, so that emerging roots contact the fertiliser early in crop development—placing the fertiliser in concentrated bands rather than dispersing the applied P through the soil reduces the chance for P fixation

- using citrate-soluble P sources in acidic soils rather than water-soluble sources.

Supplementing applied inorganic P fertiliser with organic materials (e.g. plant residues) that contain P is an important management strategy for soils of both low and high P buffer capacity.

5.3.4 Cation exchange capacity

Implications

A low ECEC (< 4 $cmol_c$/kg) means that there are few sites for holding cations, and applying high rates of a cation such as K^+ in fertiliser increases the likelihood of losses due to leaching. The ECEC of materials with variable charge—such as organic matter and Fe and Al oxyhydroxide surfaces—depends on pH and ionic strength (EC) of the soil solution. As pH or EC decreases, so does ECEC; soil acidification will reduce ECEC in soils with variable charge, resulting in possible cation loss in run-off or leaching.

Management

- Increase soil pH by liming; the resultant increase in ECEC is a benefit of lime application to variable-charge soils that is often not recognised.
- Increase SOC by management options indicated in Section 5.3.1.

6 IMPLICATIONS AND MANAGEMENT OF SOIL CONSTRAINTS

This section describes the implications of each type of soil constraint, and discusses management options for dealing with the constraint.

6.1 Drainage constraints

6.1.1 Intermittent or seasonal waterlogging (g^-)

Implications

- It may not be possible to till, plant and undertake other practices in a timely manner.
- Denitrification can occur during periods when the watertable is high and nitrogen (N) carryover may be poor.

Management

- Artificial drainage may be necessary for the production of crops sensitive to wetness.
- Where artificial drainage is impractical, mounding of crop rows will improve drainage.
- To minimise denitrification risk, mound crop rows to improve drainage in the root zone and split N fertiliser application to reduce the concentration of nitrate present in the soil at any particular time.

6.1.2 Prolonged waterlogging (*g*)

Implications

- Crops sensitive to wetness cannot be grown without drainage.
- It may not be possible to till, plant and undertake other practices in a timely manner.
- Denitrification can occur and N carryover may be poor.

Management

- Artificial drainage is necessary. This may be impractical if the soils occupy low-lying areas or basins with a restricted outlet. In this situation, mounding of crop rows will improve drainage in the root zone.
- To minimise denitrification risk, mound crop rows to improve drainage in the root zone and split N fertiliser application to reduce the concentration of nitrate present in the soil.

6.2 Soil pH and acidity constraints

6.2.1 Aluminium toxicity (*a*, *a*⁻)

Implications

- Plants sensitive to aluminium (Al) toxicity will be affected unless lime is applied.
- Extraction of soil water below depth of lime incorporation will be restricted.
- Al presence reduces uptake of calcium (Ca) and magnesium (Mg) and may induce deficiencies of these nutrients.
- Manganese (Mn) toxicity may occur on some of these soils.

Management

- Deep incorporation of lime during initial liming operations is suggested if the area is subject to short-term drought periods that can significantly reduce yield. After a few years, the effects of liming will probably reach more deeply into the soil profile and subsequent liming operations may not need to include deep incorporation.
- The application of agricultural lime can lower available Mg levels due to co-precipitation with Al. If soil Mg status is considered to be marginal, use dolomitic limestone or dolomite to correct soil pH.

6.2.2 Calcareous (*b*)

Implications

- Potential deficiency of certain micronutrients, principally copper, zinc, iron and Mn.
- The presence of carbonate in the soil encourages ammonia volatilisation.
- If the soil has formed from serpentine, chlorite schist, or other ultrabasic rock, Mg levels normally exceed Ca levels and can create Ca:Mg imbalances that may result in undesirable soil structure.

Management

- Avoid applying rock phosphate and other water-insoluble phosphates.
- Use foliar applications as the most efficient means to correct micronutrient deficiencies.
- Gypsum application may be required if undesirable soil structure is present.
- The use of highly acidifying fertilisers such as elemental sulfur or ammonium sulfate is recommended.
- Minimise ammonia volatilisation by incorporating ammonium or urea fertilisers into the plough layer and by irrigating after fertilisation.

6.3 Cation constraints

6.3.1 Low nutrient retention (*e*)

Implications

- Inability to retain potassium (K), Ca and Mg against leaching.

Management

- Use split applications of N, K, Ca and Mg fertilisers.
- Avoid overliming by using a lime requirement soil test to determine lime requirements (refer to Section 5.2.1 above).
- Analyse soil or crop tissue frequently to monitor nutrient availability.
- Investigate the use of slow-release fertilisers.

6.3.2 Salinity (*s, s*⁻)

Implications

- Reduced productivity due to the osmotic effects of soluble salts on crop growth.

Management

- Requires drainage and special management for salt-sensitive crops.
- Use salt-tolerant species and cultivars.

6.3.3 Sodicity (*n, n*⁻)

Implications

- Soil dispersion and puddling.
- Poor infiltration and poor aeration.
- If sodium (Na) level is high in the plough layer, there is an increased probability of surface crust formation.

Management

- Where crusting is a problem, maintain moisture at the soil surface during germination and seedling emergence to soften crusts and improve the stand.
- Plant seed in the furrow or side of the mound to avoid the area of salt build-up that occurs on the top of the mound.
- If leaching of Na is impractical, grow Na-tolerant crops.
- To minimise capital investment, Na can be removed over a period of several years by adding a portion of the total gypsum required and by initially growing Na-tolerant crops, later shifting to less Na-tolerant crops.

6.3.4 *Geric* characteristic (*geric*)

Implications

- Soils with little net surface charge have a very limited capacity to retain nutrient cations (e.g. Ca and K)
- In highly weathered soils, the net surface charge may be positive, indicating an ability to hold anions such as nitrate and sulfate, but not cations.

Management

- Fertiliser management will need to use small frequent applications of nutrients in accord with crop demands.
- Liming the surface soil to pH_{water} 5.5 will increase the ability of the soil to retain cations by increasing net negative charge [i.e. cation exchange capacity (CEC)].
- Add organic materials, such as green-manure crops, to increase CEC.

6.3.5 Low K reserves (*k*)

Implications

- K fertiliser may be required frequently.
- Potential K–Mg–Ca imbalances.

Management

- Fertiliser K rates may be low with the first couple of crops grown on newly cleared land but rates will need to increase with time and are higher than on soils that do not have a *k* constraint.
- Monitor soil K levels frequently.

6.4 Clay fraction constraints

6.4.1 High phosphorus-fixation capacity (*i*)

Implications

- Applied phosphorus (P) is 'fixed' in the soil and made relatively unavailable to the current crop.

Management

- If funding is available, large initial broadcast and incorporated applications of citrate-soluble P fertiliser such as reactive phosphate rock will provide residual benefit for several years and provide long-term monetary savings if P fertiliser costs rise due to inflation. In subsequent years, only annual maintenance applications should be required. Initial rates range from 5 to 10 kg P/ha for each 1% of clay.
- P fertilisation in minimum input cropping systems should aim to use minimal rates of water-soluble P fertiliser applied in bands or pockets and to grow low P-demand crops.
- Banding P fertiliser applications reduces fertiliser–soil contact and will therefore decrease the loss of P availability by fixation. However, fertiliser placement will concentrate roots around the band, and this may reduce root proliferation and crop yield in areas that have short-term droughts. To avoid this, use an initial, reduced-rate, broadcast application accompanying a banded application to encourage a more uniform root distribution.
- Test soil P levels periodically. Reduce P applications with time as the soil P fixation capacity is satisfied.

6.4.2 Extremely low phosphorus-fixation capacity (i^-)

Implications

- Application of water-soluble P fertilisers will result in the movement of P into the subsoil, causing possible pollution of groundwater or lateral movement into surface water.

Management

- Use citrate-soluble forms of P fertiliser (e.g. reactive rock phosphate) as P sources to prevent high soil solution P concentrations.
- Grow crops with a low demand for P.

6.4.3 Vertic properties (*v*)

Implications

- Clayey textured topsoil has shrink-and-swell properties.
- Tillage is difficult when the soil is too dry or too moist.

Management

- To avoid compaction, ensure that the moisture content of the soil is just below the plastic limit when cultivating.
- To enable the soil to self-repair from compaction, allow the soil to undergo several wetting–drying cycles.

6.4.4 Low organic carbon content (*om* rating = 1)

Implications

- See Section 2.12 above.

Management

- Mulch and incorporate 'green-manure' crops such as legumes or forage grasses into the topsoil.
- Retain all crop residues as surface cover in the field where the crop has grown.
- Do not burn crop residues.
- Use minimum or zero tillage farming systems in association with strip or alley cropping.
- Apply organic materials (e.g. animal manure, composted municipal waste, sewage sludge, and locally available industrial organic wastes) obtained from off site.

6.5 Landscape constraints

6.5.1 Gravel (*gravelly*)

Implications

- Gravel causes serious interference with tillage and restricts the range of crops that can be grown.

Management

- Table 29 indicates management strategies for different levels of gravel.

TABLE 29 Description of gravel rating and its implications for management

Rating	Description	Management
Gravelly	» The surface layer contains enough pebbles to interfere seriously with tillage. » The types of crops that can be grown are restricted, the precision of planting and of fertiliser placement is reduced, and young plants are frequently buried during tillage. » Plant-available water content is reduced.	Add organic residues to increase soil volume and to improve the organic matter status of the soil.
Very gravelly	» The surface contains so many pebbles that tillage is often impractical, although not necessarily impossible. » Plant-available water content is reduced.	Use appropriate planting techniques (e.g. individual sowing holes for each plant). Plant suitable crops such as pineapple.
Gravel land	» Very compact, tillage is not possible. » Plant-available water content is reduced.	Do not use; not suitable for cropping.

6.52 Erosion hazard (*er*)

Implications

- Soil erosion causes a loss of plant nutrients and organic matter and can lead to soil structural problems.

Management

- Undertake appropriate erosion control involving: maintenance of surface cover; reducing traffic and tillage; using permanent beds; using soil conservation structures such as contour banks; and using cropping system layouts such as hedgerows and alley cropping.

6.6 Soil structural constraints

6.6.1 Hard-setting (*hs*)

Implications

- Hard-setting surfaces have a low infiltration rate.
- Poor crop germination and establishment is associated with hard-setting surfaces.
- Hard-setting soils impede root growth.

Management

- Use surface mulch to maintain soil surface moisture.
- Limit tillage and machinery traffic.
- Avoid tillage and machinery traffic when soil is wetter than its plastic limit.

6.6.2 Compaction layer (*comp*)

Implications

- Compaction layers restrict root growth and therefore limit rooting depth.

Management

- To remove the compaction layer, cultivate the soil when it is drier than its plastic limit.
- Grow tap-rooted crops to penetrate the compaction layer.
- Maintain the soil in a moist condition by, for example, surface mulching to reduce the retardation of root growth by the compaction layer.

7 SOIL SUITABILITY FOR SPECIFIC CROPS

7.1 Introduction

The *Soil Constraints and Management Package* (SCAMP) identifies general soil constraints (e.g. drainage, permeability, acidity and hard-setting) to crop productivity. However, crops vary in their tolerance to these constraints. Hence, whereas a particular soil attribute or constraint might be a major limitation to the productivity of one crop, it may pose only a minor limitation to another crop. The Food and Agriculture Organization of the United Nations (FAO 1976) framework for land evaluation uses five classes to categorise the suitability of a specific soil or landscape unit for growing a particular crop. Once a suitability class is assigned to a soil or landscape unit for growing a particular crop, suitability tables or maps (if the soil or landscape data are spatially referenced) can be constructed. To facilitate the use of SCAMP for this application, individual soil attributes and constraints have been rated according to their effects on the sustainable production of several important upland crops.

7.2 Methods

For each of the selected upland crops, four of the five classes used by the FAO (1976) framework for land suitability evaluation have been applied to individual soil attributes and constraints identified in the SCAMP assessment. Table 30 describes the criteria used to allocate a suitability class.

TABLE 30 Soil suitability classified according to the potential for sustainable production.

Suitability class	Criterion	Description
1	Highly suitable	Soil is suitable for sustainable production of the crop without amelioration.
2	Moderately suitable	Soil is suitable for sustainable production of the crop with minor amelioration (e.g. liming, mounding to improve local drainage).
3	Marginally suitable	Soil is only suitable for sustainable production of the crop with major amelioration (e.g. large-scale drainage works).
4	Currently not suitable	Soil is not suitable for sustainable production of the crop.

Source: FAO (1976)

Once suitability classes have been applied to individual soil attributes and constraints, the overall suitability (class 1–4) of a soil type for growing a particular crop is given as the suitability class of the most limiting attribute or constraint (i.e. the highest score recorded across all attributes and constraints). For example, if one soil attribute is rated as '4' (i.e. currently not suitable) and all other attributes and constraints have been rated as suitable, then the overall soil suitability is rated as '4'. The ratings are not permanent but can be reassessed if innovative management strategies are developed to reduce the impact of the most limiting constraint on sustainable production.

7.3 Soil suitability for specific crops

Several of the soil constraints identified in SCAMP have effects on crop productivity, irrespective of the crop grown. These constraints are:

- low cation exchange capacity (*e*)
- high phosphorus (P) fixation (*i*)
- extremely low P fixation (i^-)
- potassium deficiency (*k*)
- low organic carbon (*om* rating 1)
- hard-setting characteristics (*hs*)
- compaction layers (*comp*)
- gravel (*gravelly*).

However, the relative effects of some of the other soil attributes and constraints on crop productivity vary according to the particular crop because of differences in the ability of the crop to tolerate the constraint. Tabulation of these differences has been undertaken for the following upland crops: paddy rice, maize, peanut, soybean, cassava, sugarcane, cashew, vegetables, watermelon, dragon fruit, coconut, banana and citrus. Ratings are based on collation of information in Williams (1975), Landon (1984), Page (1984), Schaffer and Andersen (1994), Robinson (1996) and Dierolf et al. (2001). Table 31 presents suitability ratings of each soil attribute and constraint identified in the SCAMP assessment, assessed against the requirements of specific crops.

The following general comments can be made about the 'ameliorative measures' that may need to be undertaken for suitability class 2 or 3 to

TABLE 31 The suitability class[a] of specific soil attributes and constraints for various upland crops.

	SCAMP descriptor	Paddy rice	Maize	Peanut	Soybean	Cassava	Sugarcane	Cashew	Vegetables	Watermelon	Dragon fruit	Coconut	Banana	Citrus
SCAMP texture type	*S*	4	2	2	2	2	2	1	2	2	2	1	2	2
	L	1	1	1	1	1	1	2	1	1	1	1	1	1
	C	1	1	3	2	2	1	3	1	1	1	2	1	2
	O	4	3	3	3	2	3	4	3	3	4	3	3	4
Drainage rating (*g*)	1	2	4	4	4	4	4	4	4	4	4	4	4	4
	2	1	4	3	3	3	3	4	4	4	4	3	4	4
	3	3	3	3	2	3	2	3	3	3	3	2	3	3
	4	4	1	2	1	2	1	2	1	1	2	1	2	2
	5	4	1	1	1	1	1	1	1	1	1	1	1	1
	6	4	1	1	1	1	1	1	2	1	1	1	1	1
Slope (%)	0–2	1	1	1	1	1	1	1	1	1	1	1	1	1
	2–5	2	1	1	1	1	1	1	1	1	1	1	1	1
	5–10	3	2	2	2	2	2	1	2	2	2	2	2	2
	> 10	4	3	3–4	3	3	2	2	3	3	3	2	3	2
Soil pH	a^-	1	2	1	2	1	1	2	2	2	2	2	2	2
	a	2	3	2	3	2	2	3	3	3	3	3	3	3
Salinity	s^-	2	3	3	3	3	2	3	2	2	2	2	2	2
	s	3	4	4	4	4	4	4	4	3	3	3	4	3
Drought tolerance		L	L	M	L	H	L	H	L–M	M	H	L	L	M
Main nutrient/ water uptake zone (cm)		< 50	80–100	50–100	50–100	> 100	> 100	> 100	30–60	> 100	> 100	50–75	50–75	> 100
Nutrient needs (element required)		High N	High N, K	Ca[b]		Tolerates low fertility	High N		High N, P, K		Tolerates low fertility		High N, K	High N, K

S = sandy; *L* = loamy; *C* = clayey; *O* = organic; ***a*** = aluminium (Al) toxicity; **a**$^-$ = Al toxicity constraint for extremely acid-sensitive crops; **H** = high; **L** = low; M = moderate; ***s*** = salinity; ***s***$^-$ = marginal salinity; SCAMP = *Soil Constraints and Management Package*

[a] See Table 30 [b] Needed in pegging zone

modify specific soil attributes or constraints to meet the requirements of particular crops:

7.3.1 Texture

S: Because of the low inherent plant-available water content of sandy soils, irrigation will be required for crops of low drought tolerance.

For crops with high nutrient demands, the low effective cation exchange capacity of sandy soils requires nutrients to be applied in split applications at rates in accord with crop demand.

C: Root crops are not suited to clayey soils because of harvesting difficulties.

Clayey soils are unsuitable for crops that do not tolerate prolonged soil wetness; the low permeability of clayey soils causes them to remain wet for a longer period than soils of lighter texture.

O: These soils generally occur in low-lying parts of the landscape and often have a very shallow watertable. They are therefore unsuitable for crops that cannot tolerate waterlogged conditions. Raised beds and large-scale drainage is necessary for establishing better drainage conditions.

7.3.2 Drainage

Soils with imperfect or poor drainage are unsuitable for crops that cannot tolerate waterlogged conditions. Raised beds and large-scale drainage works must be undertaken if such crops are to be grown.

7.3.3 Acidity

a: Soils with this constraint are unsuitable for crops with a low or moderate tolerance to aluminium (Al) and/or manganese toxicity unless a comprehensive liming program is undertaken.

a^-: These soils require a liming program if they are being used to grow crops of low tolerance to Al toxicity.

7.3.4 Salinity

s: Soils with this constraint are unsuitable for growing crops of low salinity tolerance, and will require ameliorative leaching for crops of moderate salinity tolerance. If sodicity is also present (*n* or n^- constraint), application of gypsum will be needed to prevent soil dispersion during the leaching process.

s^-: Soils with this constraint will require an effective leaching regime to be established to remove soluble salts from the root zone of salt-sensitive crops. If sodicity is also present (*n* or n^- constraint), application of gypsum will be needed to prevent soil dispersion during the leaching process.

7.3.5 Main nutrient/water uptake zone

Crops with a comparatively shallow active rooting depth will not be as sensitive as deeper-rooted crops to constraints such as a compaction layer (*comp*) or a root-restricting horizon (*R*).

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APPENDIX 1:

SCAMP FIELD AND LABORATORY DATA RECORD SHEETS FOR APPLICATION LEVELS 1–3

SCAMP FIELD SHEET

Date:		
Site name:		
Province:	District:	Commune:
Village:	Hamlet:	Farmer:
Latitude:	Longitude:	Altitude:
Slope:	Landform[a]:	Landscape position[b]:
Current land use[c]:	Surface condition[d]:	Evidence of erosion:

[a] the landscape in which the site occurs; e.g. flood plain, undulating, steeply incised

[b] where the site is positioned; e.g. on a ridge top, mid-slope, foot-slope or alluvial flat

[c] current cropping, pasture or plantation system

[d] describes the surface cover; e.g. standing plant stubble, plant residue, plant sward or bare; and whether the surface is tilled or untilled

MINI-PIT OBSERVATIONS: APPLICATION LEVEL 1 SCAMP

	0–10 cm	10–20 cm	20–30 cm	30–50 cm
Texture				
Colour				
Structure Aggregate development (massive, single-grained, weak, moderate, strong) Shape (granular, blocky, prismatic, columnar, platy)				
Moist soil consistence (loose, friable, firm, extremely firm)				
Presence and colour of mottles?				
Compaction layer? Depth?				
Visible pores? Roots?				
Dispersion class				
Gravel rating				
Permeability class				
Drainage class				
Erosion hazard rating				
Vertic properties? (yes *or* no)				

MINI-PIT OBSERVATIONS: APPLICATION LEVEL 2 SCAMP

	0–10 cm	10–20 cm	20–30 cm	30–50 cm
Field pH (saturated paste): pH_{water} pH_{KCl}				
Field EC (saturated paste) (dS/m)				
Infiltration time: Permeability class				

LABORATORY MEASUREMENTS: APPLICATION LEVEL 3 SCAMP

	0–10 cm	10–20 cm	20–30 cm	30–50 cm
Organic C (g/kg): *om* rating				
pH buffer capacity (g $CaCO_3$/ kg soil. pH unit): *ar* rating				
P buffer index: *i* rating				
Effective cation exchange capacity ($cmol_c$/kg): *e* rating				

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