SIMLESA Soil Manual

Simple protocols and resources for rapid field soil testing in Africa

Caspar W Roxburgh, Stuart Irvine-Brown, Ben Harms, Joseph X Eyre, and Daniel Rodriguez

The University of Queensland
Australia

Queensland Alliance for
Agriculture & Food Innovation

Queensland Government

CIMMYT
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SIMLESA
SUSTAINABLE INTENSIFICATION
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FOR FOOD SECURITY IN EASTERN AND
SOUTHERN AFRICA

Australian Government
Australian Centre for
International Agricultural Research

Author affiliations

Caspar W Roxburgh, Joseph X Eyre, Daniel Rodriguez

Queensland Alliance for Agriculture & Food Innovation (QAAFI), University of Queensland, St Lucia, Australia, 4072

Stuart Irvine-Brown

Queensland Department of Agriculture and Fisheries (DAF), Nambour, Australia, 4560

Ben Harms

Queensland Department of Science, Information Technology and Innovation (DSITI), Australia,

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1. Introduction

Soils are one of the main resources required for food production. Understanding soils can inform crop management, to achieve higher and more sustainable crop production, and ultimately higher farmers' profits. In Africa, these can lead to reduced levels of malnourishment and undernourishment.

Unfortunately, regular soil testing is uncommon. Schmidhalter (2005), showed that only 1% of agricultural soils globally are annually sampled for levels of nitrogen, the most widely limiting plant macronutrient. Soil testing is even less common in sub-Saharan Africa, where limited research infrastructure and human capacity reduces opportunities and increases costs of soil analysis.

Soil characterisation and interpretation can lead to a better informed agronomy management, crop choice. In sub-Saharan Africa, soils are particularly relevant given that many are naturally low in nutrients or have limited physio-chemical capacity that limits available soil water and nutrients (Bationo et al. 2012). Up until now, most soil analysis is performed by research institutions, that are limited in resources, and therefore coverage. This means that many sites have had few (if any) soil analyses performed. In addition, much of the soil analysis data available across Africa remains unavailable publicly, though recent efforts such as AfSIS - http://africasoils.net/ - have gone some way to rectifying this.

Some soil properties vary rather significantly spatially but also over time. Natural soil variability even within a single field can mean an analysis of regional soils offers little in valuable information for farmers trying to manage their own fields. There is, therefore, a gap between what conventional research methods can currently provide, and what practical and actionable knowledge is needed by smallholder farmers. To overcome this, we propose simple rapid field soil tests as a valuable resource, this manual provides a first insight on their use and value.

1.1. What does this manual offer?

This manual offers a scientifically-informed, low-tech approach for soil testing in remote areas, with specific tailoring to the Eastern and Southern African context. The analysis options included in this manual are limited to those that can be determined reliably using simple and rapid field methods. Here, rapid field analysis techniques were included only where peer-reviewed literature had demonstrated good agreement with traditional laboratory results (i.e. R2 values of 0.90 or more). All relevant studies demonstrating good reliability and precision of methods are cited in the document.

Our hope is that this manual may lead to improved understanding and appreciation of soil properties and management recommendations that are evidence-based. A number of rapid and affordable tests have been developed, though mostly, remain underutilised. This manual provides an open-access and scientifically robust instruction for using these techniques. We have also attempted to provide contacts for sourcing necessary low-tech equipment in Eastern and Southern Africa.

It should be noted that the techniques in this manual are not intended to replace traditional methods for soil sampling, sample storage and preparation and laboratory analysis. Traditional methods should be used wherever and whenever possible, and (in particular) are necessary for peer-reviewed scientific research. Having said that, there are many circumstances where this level of precision and accuracy is not a priority nor is it necessary. This manual provides some resources to help fill that gap in needs and resources.

1.2. How to use this manual?

This document provides simple, practical and achievable standardised methods for determining soil attributes in the field with limited resources and no laboratory facilities. It is intended for research and extension services, who may use the techniques to test farmers' fields, and provide rapid feedback on a number of valuable soil indicators. The introductory background information (Section 1) and the section on resources for equipment (Section 5) are suited to guiding team leaders organising the soil testing. Section 2 provides basic instruction on how to sample soils appropriately for the methods outlined in this manual. We recommend that team leaders study this section carefully and review it with officers before completing the sampling and analysis. It is important to note that unlike other soil manuals, this document does not provide full instruction on soil sampling, preparation and storage for laboratory analysis. If this is of interest, there are many existing resources covering that perspective (e.g. Klute et al. 1986; Bottomley et al. 1994; Sparks et al. 1996; Dane and Top 2002; SSSA 2008; Rayment and Lyons 2011).

Individual protocols (Section 3) are written with the intention that they will be taken to the field by extension officers to guide field testing. Each protocol in Section 3 includes: i) a brief description of the characteristic being measured, ii) clear and simple instructions on what is needed and how to complete the analysis, iii) simple steps for calculating the results (often with pre-programmed excel spreadsheets), and iv) a guide to interpreting the results to provide immediate feedback to farmers. Section 4 provides results from the SIMLESA project's soil analyses completed at five major research stations (in Ethiopia, Mozambique and Malawi) where long-term trials were conducted. These results are included simply as a useful reference for researchers. Finally, Section 5 includes resources for team managers on where to source necessary materials for the protocols in this book, as well as further reading materials on soil analysis.

1.3. What can we learn using rapid field techniques?

Within the scientific, peer-reviewed literature, a number of rapid and low-tech soil tests have been developed to the point of being able to accurately determining key soil characteristics.

. In this manual, we provide recommended methods for performing a site characterisation and determining and interpreting eight soil characteristics:

1. Site characterisation
2. Soil texture
3. Soil colour
4. Soil bulk density
5. Soil gravimetric water content
6. Soil pH
7. Electrical conductivity (EC)
8. Soil mineral nitrogen (nitrate)

The protocols are presented in order of complexity with the earlier protocols recommended to be completed first. Collectively, adoption of these protocols would be a big step toward a better understanding and characterisation of the soil at a particular location and the provision of valuable information to guide farmers in how to better manage their fields.

What can these soil properties tell us?

Soil texture can be used to estimate the water holding capacity of a soil (Hazelton and Murphy 2007), as well as its ability to hold nutrients such as potassium, calcium, mineral nitrogen (nitrate) which are more readily stored in higher clay content soils (USDA 1999). Soil bulk density provides an important physical measure of a soil's porosity (Hazelton and Murphy 2007), affecting water infiltration and rooting depth (USDA 1999). Soil bulk density is also an important component in calculating the total nutrient content of soils in kg ha-1 (Dalgliesh and Foale 1998). Soil gravimetric water content is crucial when calculating soil bulk density and its water capacity, as well as the mass content of soil nutrients (such as nitrogen).

Soil pH is an important factor that has the potential to affect crop growth and can often be relatively simple to overcome (particularly acidic soils) – Upjohn et al. (2002). Electrical conductivity provides a measure of soil salinity, which if high enough could disrupt plant uptake of soil water and nutrients (Hazelton and Murphy 2007). High soil salinity can be addressed through gypsum (CaSO4) application. Finally, soil mineral nitrogen is the primary form of plant-available soil nitrogen, and is mostly present in soils as nitrate-N due to rapid nitrification (Norton 2008). As one of the most important crop macronutrients, soil N is critical in determining the potential yield of a crop at the beginning of a season and whether the application of fertiliser is advisable.

Each of these soil attributes is discussed in greater detail in their relevant section.

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2. Getting your sampling right – the first step

2.1. Introduction to rapid testing

The purpose of analysing soil in relation to agriculture is to obtain an accurate indication of the attributes that influence crop or pasture productivity and identify soil factors that may be limiting yields. Given the vast distances to certified laboratories, as well as the large timeframes between field sampling and lab analysis, rapid field tests can provide an alternative and the opportunity to obtain valuable supplementary data. This is particularly so in countries where few accredited soil laboratories are present. Previous research has demonstrated that rapid low-tech tests may be useful surrogates for traditional laboratory analyses for a range of soil physical and chemical indicators.

The idea behind rapid field testing is to overcome not only the challenge in scientific infrastructure (both physical and human) but also to provide more efficient and affordable soil testing options that can be applied more widely than traditional methods. The principles regarding soil sampling to capture the inherent diversity of farmers' soils remains identical to those when sampling for traditional laboratory analysis. What follows is a very brief overview of how to approach soil sampling in the field. This is followed by a series of protocols for determining the following attributes using rapid in-field tests:

1. Site characterisation
2. Soil texture
3. Soil colour
4. Soil bulk density
5. Soil gravimetric water content
6. pH
7. Electrical conductivity (EC)
8. Soil mineral nitrogen (nitrate and nitrite)

2.2. Initial site characterisation

When conducting any kind of field evaluation, it is important that a basic site characterisation takes place before any sampling or analysis. Initial site description must include information about the overall position of the site in the landscape along with a range of other factors that relate to the soil and its management. Collecting this basic information will be extremely valuable in the future, especially if field experimentation will take place. These factors will also help determine if the site selected is representative of the wider region. This protocol outlines some important steps that all researchers or extension officers should complete before doing any soil sampling and analysis. It is largely based on the protocols of USDA (1999), as well as the work by Dalgliesh and Foale (2005).

2.2.1. Materials (What will I need?)

A printed copy of the 'Site Characterisation Input Sheet' - see Appendix 1 or find it online at https://cloudstor.aarnet.edu.au/plus/index.php/s/EjR58WERJOundFp

A smartphone with an altimeter app installed on it (see notes in 'Site Characterisation Input Sheet' in Appendix 1 for details)

A notebook for recording any additional observations,

2.2.2. Method (What do I do?)

The following information should be recorded immediately when arriving at a field for soil testing. Record the information using a printed 'Site Characterisation Input Sheet' (provided in this manual and online) or input directly into the web-based application. If using the printed input data sheet, you will need to enter your data into the corresponding excel characterisation datasheet after the field visit. This excel sheet is available online at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/EE6XdvOzENpHWcQ

When arriving at the field, record the following information in the input sheet:

1. Describer's name, affiliation and contract details (phone and email)
2. Date – day/month/year
3. Obtain a GPS reference for the site (i.e. latitude and longitude measurements). This can be completed using:
   - A smartphone with 3G or stronger connection (suitable for many areas)
   - A dedicated satellite GPS recording device (more suited to areas with no connectivity – see Section 5 for information on where to purchase this device)
4. Record the village name, county (or administrative post), district, and province or state
5. Record the farmer's name and phone number
6. Climate – A description of recent weather is needed to provide context for the results of any analysis that is to take place. This should include asking the farmer about any recent rainfall, any notable events such as a heatwave or frost.
7. Write down any information about the type of landform – e.g. is the field on a Floodplain, Terrace, Hill slope, or Valley?
8. Measure the elevation (m) and calculate an estimated slope gradient (%) of the field. This can be completed using most smartphones – see input sheet in Appendix 1 for details)
9. Describe the surface uniformity of the field, noting any soil colour changes, areas of gravel or rocks,
10. If the field is on a hillside, note the site aspect (e.g. North-West facing).
11. Write down any observations on the soil's capacity for drainage – look for signs of flooding and / or ponding; ask the farmer if there is water ponding during heavy rains.
12. Examine the soil surface to estimate the percentage of cover (use guide in the input sheet in Appendix 1)
13. Make a note of any potential signs of erosion (cause by water, wind, or landslide) and the type of erosion (rill, gully, sheet) – see instruction notes in the input sheet found in Appendix 1.
14. Record the type of and state of surrounding vegetation (trees / shrubs / pasture / crops).
15. Take photographs of the site and any distinguishing features of the soil or crop plants that will complement the site description (e.g. areas of ponding, areas where soil colour or type appear to change, etc.).

2.2.3. How to interpret the results, and What this means for the farmer?

Details of interpreting aspects of a site characterisation are available in the Site Characterisation Input Sheet available in Appendix 1.

Further reading:

The FAO's guidelines for soil description (4th edition)

http://www.fao.org/docrep/019/a0541e/a0541e.pdf

References

FAO (2006) Guidelines for soil description (4th Edition). (Food and Agriculture Organization of the United Nations: Rome) Available at http://www.fao.org/3/a-a0541e.pdf [Accessed 1 September 2017].

USDA (1999) Soil quality test kit guide. United States Department of Agriculture. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf [Accessed 3 August 2017]

2.3. Principles of soil sampling

As stated earlier, this manual is not supposed to replace instruction on best practice when sampling soils. However, this manual would be far less valuable without including some basic information on soil sampling procedures.

2.3.1. Considering spatial variability

The main factor to consider when sampling soil for analysis is that soils are remarkably variable. Two soil samples taken immediately side by side can give differing results that each suggest the need for distinct management practices. This means that sampling and sub-sampling can be a major source of error when testing soils. A study by Hunt et al. (1991) comparing error from various sources when comparing two methods of soil N analysis found that the majority of error in nitrogen testing (57% of cumulative error) was the result of variability between individual soil samples. In other words, poor sampling will generally lead to poor results.

The main methods controlling variability when sampling are as follows:

1. Take many soil samples
2. Avoid taking samples from areas that might not properly represent the rest of the field
3. Make composite samples (i.e. multiple samples mixed together) to provide more representation within each analysis sample
4. Take soil samples in a field along a transect at regular intervals to avoid human bias

Sample variability can be controlled by using a strategic approach when sampling (Figure 1). This means deliberately avoiding areas of a field that may give a particularly different result (e.g. an area that had a different crop in the previous season, an area where an old cattle kraal used to be located).

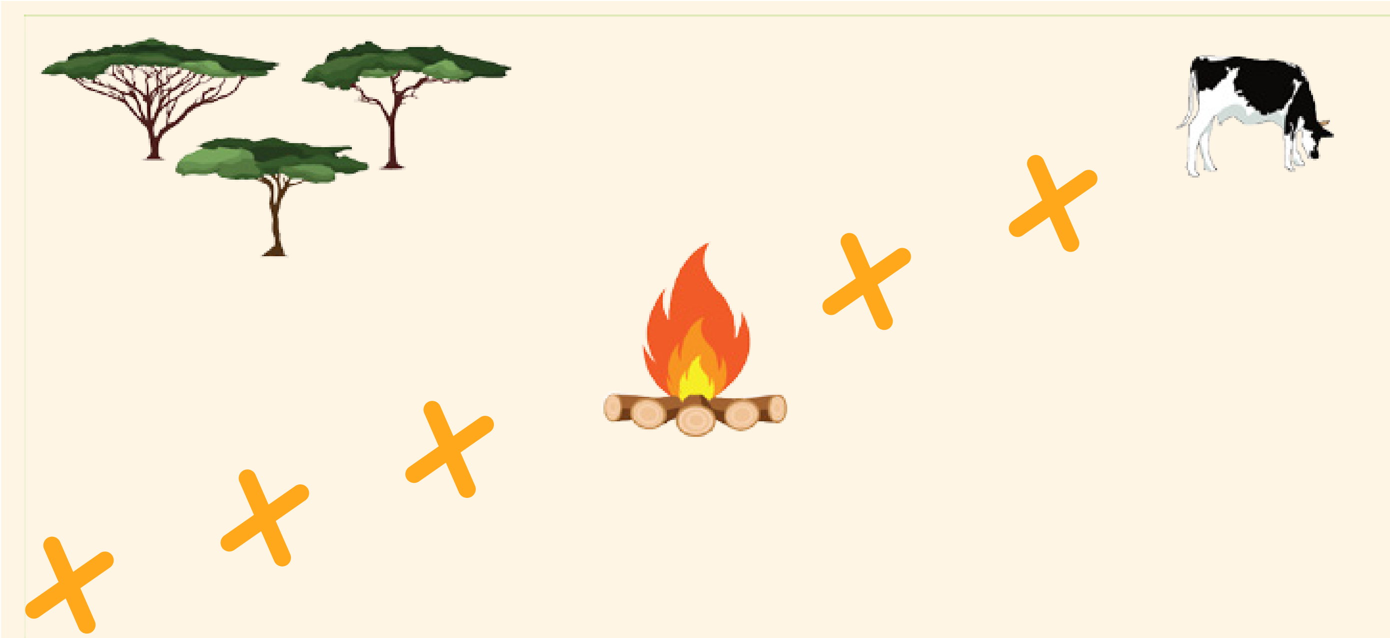

Figure 1: A diagram of a field with areas that will not be representative of normal soil characteristics and therefore should be avoided while sampling. Previous burning, nearby trees and areas where livestock are could all impact soil fertility results. X symbols represent points where soil samples can be strategically taken.

Most of the time, soil samples are mixed together into composite samples (also known as 'bulking'). For example, if only five samples can be tested from one field, take 15 samples and mix three together for each test (Figure 2). This will lead to each sample capturing the diversity of a wider area of soil than if a single sample had been tested. Obviously, creating composite samples will lead to more soil in each bulked sample, so taking a sub-sample of each composite after proper mixing is important. This is typically done by 'quartering' (Figure 3).

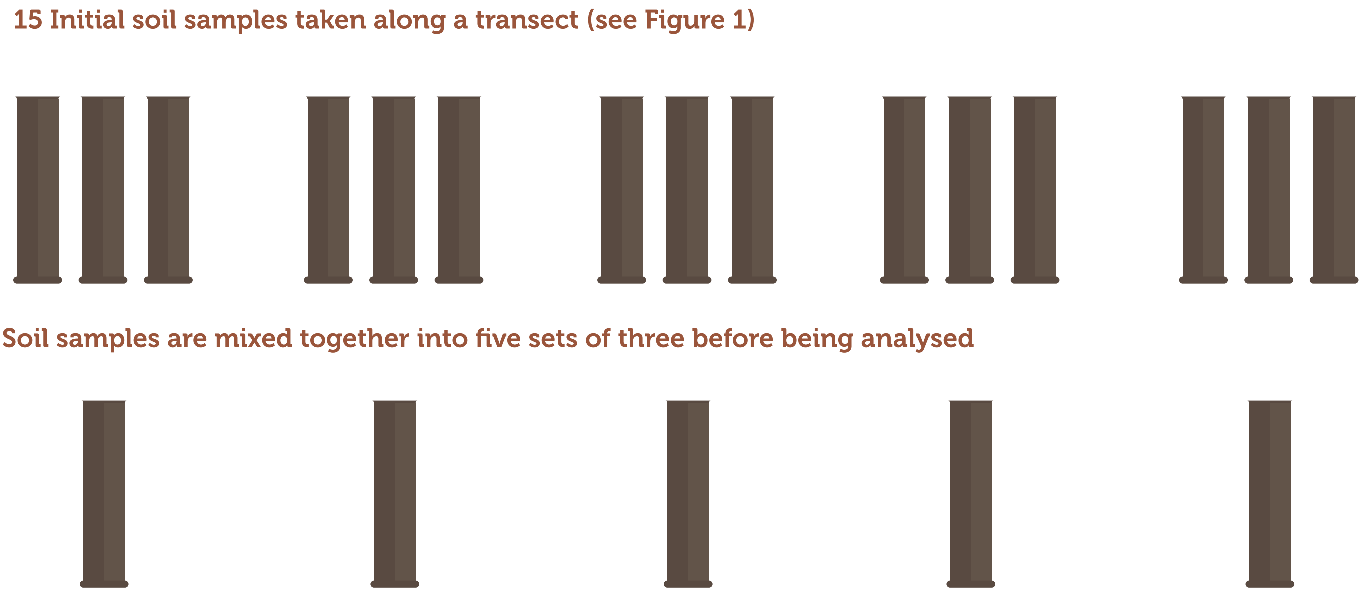

Figure 2: Diagram illustrating how to composite soil samples to increase the representation of samples being analysed

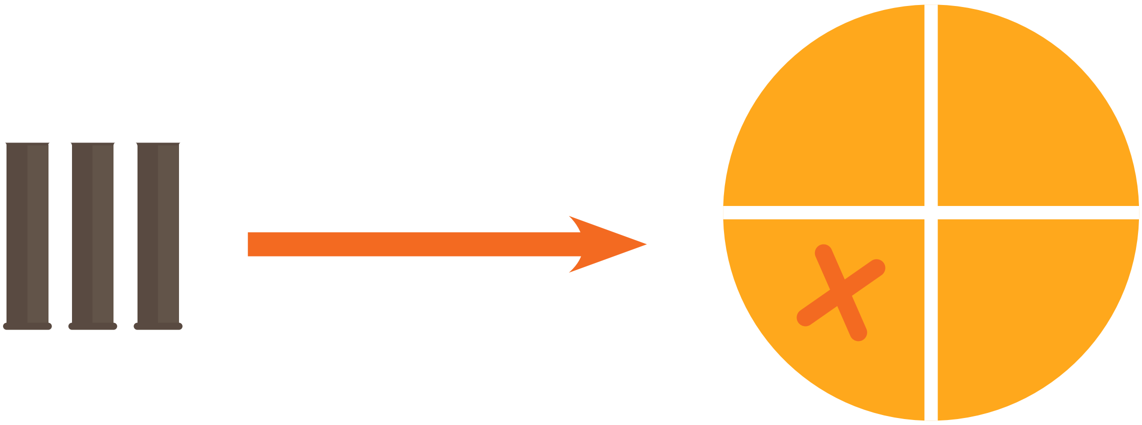

Figure 3: After sampling a field for soil and combining several individual samples into composites (i.e. bulking), you will need to take a sub-sample of the composite. First, make sure that you have mixed the samples together very carefully. Then, a simple technique for sub-sampling is to lay the soil out flat in a circle and divide the soil into quarters. Take one quarter as your sample that will be used for the rapid in-field analysis. In the diagram above the blue X indicates the quarter being used as the sub-sample.

Finally, most soil scientists recommend using a transect of a field to sample (i.e. walking in a straight line from one corner to another), stopping at regular intervals along the transect (Figure 4). This removes potential human bias in selecting sites for sampling.

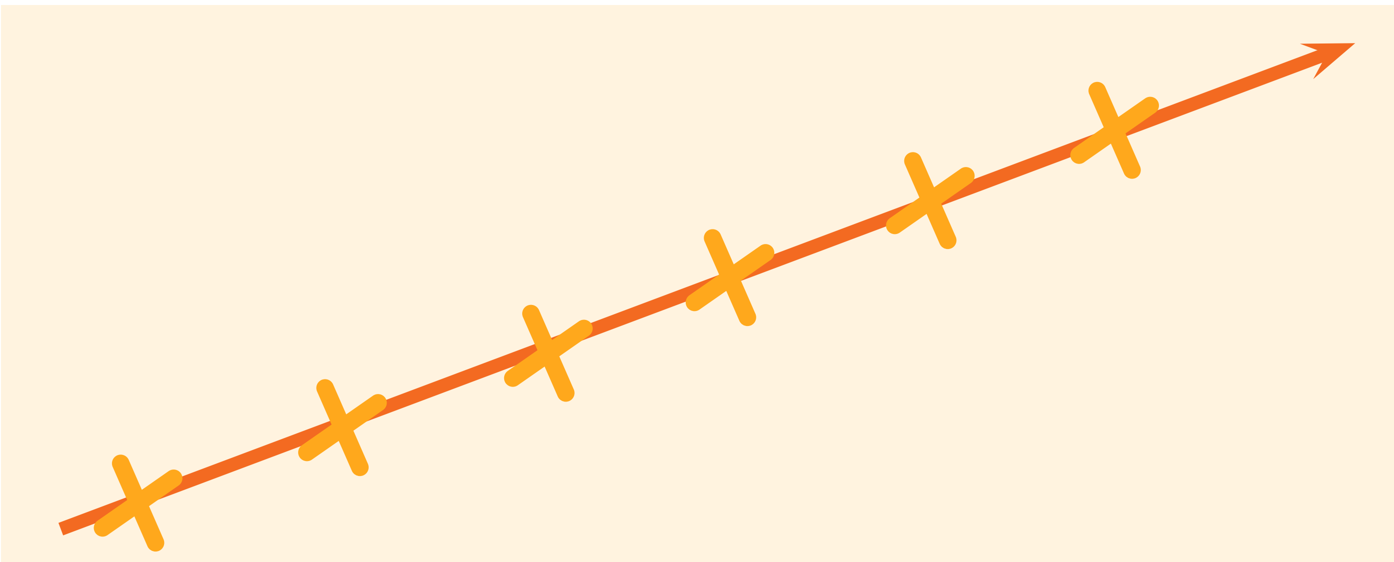

Figure 4: Example of a transect approach to soil sampling in a field. The X symbols represent points where samples are taken.

2.3.2. How to take samples?

Once the sampling strategy (i.e. number of samples, composites, transect, etc) has been developed, the next step is to take individual samples correctly. The first point to make here is that soil samples are broken into different depths. Different sources of instruction will suggest different sampling depth intervals. For example, AfSIS recommends two depths (0-20 cm and 20-50 cm) are taken for basic diagnostics in research trials (Table 1). For measuring soil fertility, it is important to capture the amount of mobile nutrients to the depth that plant roots will grow to. This may be up to 180 cm deep in the case of maize, though for smaller crops it is much shallower. This will provide the best picture of how much nutrients are available for the plant to capture during a season. Having said that, it can be extremely difficult to take deep soil samples without mechanised hydraulic sample corers. If these are unavailable, a tailor made manual hammer can be extremely valuable to get deep soil samples. The type of soil will also determine the ease with which sampling can occur. Sampling after rain while soils are wet can drastically improve the ease of sampling. Despite the importance of deeper sampling, taking shallow samples for rapid analysis can still be valuable, but it is important to remember that shallow soil (i.e. the top 15 cm) under conservation agriculture practices can have much higher fertility than deeper soils so sampling should always go to at least 50 cm.

Table 1: Recommended soil sample depth intervals from various sources in Africa

Recommending body	Soil depth intervals
AfSIS diagnostic trials	0-20 cm, 20-50 cm
AfSIS soil profiles database	0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm, 100-200 cm
SIMLESA soil recommendations	0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm

Figure 5a & b – Residue removed and a soil sample taken from within a CA trial plot. / Measuring out on-farm CA plot trial site with GPS reference being taken in the background for later use with spatial data analysis methods.

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3. Simple field protocols for soil analysis

3.1. Soil texture

Soil texture can tell us a lot of valuable information which can help determine which crops to grow and how to grow them. Texture largely affects water movement and nutrient retention in soil. Texture can also influence a soil's vulnerability to erosion. The clay content of soil holds most of its water and nutrients, however, soils with high clay content are prone to water logging – this is an important consideration in high rainfall environments of sub-humid and humid regions.

Laboratory analysis of soil texture requires a hydrometer and at least 24 hours. Luckily, soil texture can be rapidly assessed using a simple hand method with nothing but soil and water. This method is relatively reliable providing the person making the assessment has good experience with the method. The hand method involves taking a handful of soil, wetting it with water, noting changes as it is worked into a ball and then squeezed between your thumb and forefinger. The following protocol was taken from Dalgliesh and Foale (2005) which itself was adapted from Chapman and Murphy (1991).

Materials (What will I need?)

Water (to wet the soil) – rainwater or tap water in a bottle will be fine but it must not contain any dirt

Soil samples (see section 2.2 for instructions on how to take soil samples)

A sieve of 2 mm (in case there is gravel in the soil)

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
   - Enter the unique field code from the Site Characterisation in the 'Soil Texture Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Take enough soil to fit into the palm of your hand. Remove any large stones, twigs or stubble
6. Moisten the soil with water, a little at a time, and knead until the ball of soil just fails to stick to your fingers. Add more water to get it to this sticky point (this is the soil's drained upper limit).
7. Work the soil in this manner for one to two minutes, noting its behaviour (see Table 2). Inspect the sample to see if sand is visible. If not, it may still be felt or heard as you work the sample in your hand
   a. A soil with a high proportion of:
      - Sand: will feel gritty
      - Silt: will feel silky
      - Clay: will feel silky and plastic when wet
8. Press and slide the ball out between the thumb and forefinger to form a ribbon. Note the length of self-supporting ribbon that can be formed in the 'Soil Texture Input Sheet' (see Table 2)
9. Use Table 2 to classify the soil
   a. Remember that soil texture can change as you go down the soil profile and this variation is described by the following terms:
      - Uniform: the texture is the same throughout the profile
      - Duplex: The texture changes significantly at a certain depth; there is often about 150mm of loam over a dense clay subsoil (these are also called texture-contrast soils)
      - Gradational: the texture changes gradually down the profile. Many soils vary from a loamy surface to a clay loam and then to clay.

Table 2: Guide to determining soil texture based on a) whether it will form a ball; b) how many centimetres that ball can be made into a ribbon; and c) the feel, appearance and durability of the wet soil in the hand. Adapted from Dalgliesh and Foale (2005).

Ball	Ribbon (cm)	Feel	Texture
Will not form a ball	nil	Single grains of sand stick to fingers	Sand (S)
Ball just holds together, fragile	~0.5	Feels very sandy, visible sand grains	Loamy sand (LS)
Can be handled	1.5 to 2.5	Sandy, slight stickiness	Coarse sandy loam (CSL), Fine sandy loam (FSL)
Ball holds together	2.5	Spongy, smooth, not gritty or silky	Loam (L)
Ball holds together	2.5	Slightly spongy, fine sand can be felt	Loamy fine sand (LFS)
Ball holds together	2.5	Very smooth to silky	Silt loam (SL)
Ball holds together strongly	2.5-4	Sandy to touch, medium sand grains visible	Sandy clay loam (SCL)
Ball holds together	4-5	Plastic, smooth to manipulate	Clay loam (CL)
Ball holds together strongly	5-7.5	Plastic, smooth, slight resistance to shearing (breaking when squeezed) between thumb and forefinger	Light clay (LC)
Ball holds together strongly	>7.5	Plastic, smooth, handles like plasticine, can be moulded into rods without fracture, moderate shearing resistance	Medium clay (MC)
Ball holds together strongly	>7.5	Plastic and smooth, handles like stiff plasticine, can be moulded into rods without fracture, very firm shearing resistance	Heavy clay (HC)

How to interpret the results and What does this mean for the farmer?

Once you have completed the texture test and have estimated which texture type the soil is, you can make some general comments to the farmer on what this kind of soil means for their management. Table 3 (below) indicates soil textures and some general attributes.

Table 3: Estimated water holding capacity, infiltration/erosion and bulk density implications for different soil textures (Queensland Government 2011; Hazelton and Murphy 2007; USDA 2014).

Texture	Estimated water stored per 10 cm of soil depth (mm)*	Infiltration (low = higher erosion risk)	Ideal bulk density (see protocol 3.3)
Sand	4	Very rapid	< 1.60
Loamy sand	4	Very rapid	< 1.60
Fine sandy loam	5	Very rapid	< 1.40
Loam	6-7	Moderately rapid to rapid	< 1.40
Loamy fine sand	6-7	Moderately rapid to rapid	< 1.60
Silt loam	6-7	Moderately rapid to rapid	< 1.40
Sandy clay loam	6-7	Very slow to slow	< 1.10
Clay loam	8	Extremely slow to moderate	< 1.10
Light clay	10	Very slow to moderate	< 1.10
Medium clay	10-12	Very slow to moderate	< 1.10
Heavy clay	12	Extremely slow to moderate	< 1.10

*Using the above table, it's possible to estimate the total water storage capacity of the soil from field texture. Simply sum the water storage capacity for each layer/horizon of soil to the required depth. Please note that this will be a crude estimate. The water storage capacity is also strongly influenced by soil structure (with better structured soils holding more water). Also note that fine sandy soils will hold more water than coarse sands.

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3.2. Soil colour

Soil colour can be an approximation of several important soil properties, including organic matter content, and drainage characteristics. Soil colour is mainly due to the presence of iron oxides and organic matter. Organic matter consists of darkly coloured compounds, which tend to mask the colours of iron oxides. The presence of manganese oxides also darkens the soil. In a few soils, the colour is derived directly form the parent material. Red indicates iron compounds in their oxidised form, which reflects good drainage and aeration. In yellow soils, the iron oxides are present in reduced form, which indicates restricted drainage and less aeration, at least at certain times of the year. Similarly, grey often indicates impeded drainage. Bleached (near white or white) horizons as in bleached A2 horizons are indicative of seasonal saturation and intense leaching of organic matter. Strong mottling usually indicates serious problems with soil wetness.

Soil colour is objectively assessed using a Munsell soil colour chart. However, a simple method of noting the broad soil colour can still tell us something about the soil properties listed earlier. It is recommended that soil colour be assessed in the middle of the day and in direct sunlight (FAO 2006). Where no single colour is dominant, the colour is said to be mottled (FAO 2006). This simple method of assessing and interpreting soil colour was adapted from Moody and Cong (2008).

Materials (What will I need?)

The 'Soil Colour input sheet' (see Appendix 1)

A medium-sized shovel (recommended for checking deeper layers)

A Munsell colour chart (recommended if available to help interpret soil colour – not essential)

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
   a. Enter the unique field code from the Site Characterisation in the 'Soil Colour Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. (Recommended) Take the shovel and dig a mini soil pit 40 cm wide, 60 cm long, and 50 cm deep.
6. Examine the soil surface layer (0-20 cm) inside the mini soil pit. Use the guide in Table 4 to select a colour that most closely matches what you see.
7. Repeat step 6 for the subsoil layer (20-50 cm).
8. Note your observations in the 'Soil Colour Input Sheet'

Table 4: Main soil colour groups, corresponding Munsell chart details, and their characteristics. Adapted from Moody and Cong (2008).

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 Soils derived from limestone under reduced conditions
White, pale or bleached Red	-/8/<4 10R/-/6-8 2.5YR/-/6-8	Sandy soils 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 2.5YR/<5/2-6	Moderate soil organic matter levels, and some iron oxides
Greyed, 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

How to interpret the results, and What does this mean for the farmer?

The list of major soil colours and their properties are given in Table 4 (above). Use the column on the right to talk with the farmer about their soil. **Key factors** to discuss are whether the soil is high in **organic matter, sandy,** and **prone to waterlogging.** In addition, a further guide to estimating organic matter content of soil based on colour (for wet and dry soil) is available in Table 5 (below). Soils with more organic matter will tend to be higher in fertility and have good structure - therefore they should be able to support good crop growth and higher yields. Soils that are sandy will tend to have lower capacity to hold soil moisture, meaning they are less suited to production unless rainfall is high and regular. Sandy soils are also more prone to compaction and are higher in bulk density (see protocol 3.3 for details). Soils with low drainage will become waterlogged during high rainfall events. Waterlogging can damage crops and lead to loss of yield.

Table 5: Estimated values of organic matter content of soils based on their apparent soil colour when wet and dry. Table adapted from Schlichting et al. (1995) via FAO (2006). S = Sand / L = Loam / Si = Silt / C = Clay

Colour	Munsell Value		Moist soil			Dry soil	
		S	LS, SL, L	SiL, Si SiCL, CL, SCL, SC, SiC, C	S	LS, SL, L	SiL, Si, SiCL, CL, SCL, SC, SiC, C
Light grey	7				< 0.3	< 0.5	< 0.6
Light grey	6.5				0.3-0.6	0.5-0.8	0.6-1.2
Grey	6				0.6-1	0.8-1.2	1.2-2
Grey	5.5			< 0.3	1-1.5	1.2-2	2-3
Grey	5	< 0.3	< 0.4	0.3-0.6	1.5-2	2-4	3-4
Dark grey	4.5	0.3-0.6	0.4-0.6	0.6-0.9	2-3	4-6	4-6
Dark grey	4	0.6-0.9	0.6-1	0.9-1.5	3-5	6-9	6-9
Black grey	3.5	0.9-1.5	1-2	1.5-3	5-8	9-15	6-15
Black grey	3	1.5-3	2-4	3-5	5-12	> 15	> 15
Black	2.5	3-6	> 4	> 5	>12		
Black	2	> 6					

References

FAO (2006) Guidelines for soil description (4th Edition). (Food and Agriculture Organization of the United Nations: Rome) Available at http://www.fao.org/3/a-a0541e.pdf [Accessed 1 September 2017].

Moody P, Cong PT (2008) Soil constraints and management package (SCAMP): guidelines for sustainable management of tropical upland soils. ACIAR Monograph No. 130. (Australian Centre for International Agricultural Research: Canberra). Available at: http://aciar.gov.au/publication/mn130 [Accessed 14 August 2017].

3.3. Soil bulk density

Soil bulk density is an extremely important soil characteristic. It reflects the level of soil compaction and has important implications for root growth, water infiltration, the calculation of soil nutrient content, and fertilisation requirements. Bulk density is traditionally measured using a wide metal ring being carefully driven into the soil and removed to calculate the dry mass of a known unit area. While this method does not in itself require a laboratory, in some locations this specific type of soil ring might not be readily sourced. In these cases, a more low-tech device such as a hand-held soil sampling tube can be used instead (Schmidhalter 2005). A comparison of these two approached by Schmidhalter (2005) found no significant difference between their results.

Soil bulk density is an indirect measure of the total pore space which is also affected by texture and structure. The bulk density of fine textured mineral soils usually ranges from about 1.0 to 1.5 g/cm3, and that of sandy soils from 1.3 to 1.7 g/cm3. The bulk density of organic soils is usually much less than that of mineral soils and may be as low as 0.4 g/cm3. Bulk density and total pore space are readily altered by tillage operations.

The following protocol was developed mostly by drawing on the work of Dalgliesh and Foale (1998), USDA (1999) and Schidhalter (2005). The CSIRO guide to physical soil measurement and interpretation recommends measuring 3-5 replicates for bulk density (McKenzie et al. 2002).

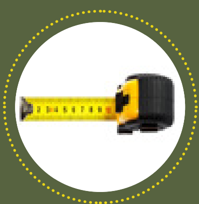
Materials (What will I need?)


Knife


Solar powered field scale (0.1 g precision)

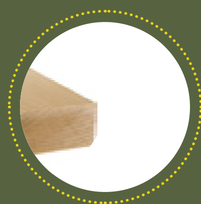

Small shovel


Metal soil sampling cylinder (50-100 mm length, 1.6 mm gauge wall, and 75-100 mm in diameter with both ends open)


Measuring tape


Hand held Sledge hammer


Small pocket calculator or smartphone


Wooden block


Water strong paper bag (Traditional Method only)

Bulk density input sheet (See Appendix 1 or print online version at https://cloudstor.aarnet.edu.au/plus/index.php/s/gbH230EhL0Ltbul)

Method (What do I do?)

Enter all data records into the Soil Bulk Density Input Sheet (See Appendix 1) and once you have completed the sampling, record the data into excel using the 'Bulk Density Data Input' excel file available at https://cloudstor.aarnet.edu.au/plus/index.php/s/nvIowYcmWUa03wP.

1. Make sure you have completed a site characterisation (see protocol 2.2).
   a. Enter the unique field code from the Site Characterisation in the 'Bulk Density Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Measure the length of the sample cylinder being used (Figure 6) and record it in the 'Bulk Density Input Sheet' (mm)
6. Measure the diameter of the sample cylinder being used (Figure 6) record it in the 'Bulk Density Input Sheet' (mm)
7. Weigh the sample cylinder using the field scale and record the weight in the 'Bulk Density Input Sheet'
8. Clear soil surface of the sample area (i.e. clearing any crop residue)
9. Place the soil sampling cylinder on the soil with the open ends on the soil and facing up to the sky
10. Place the wooden block on top of the soil sampling cylinder
11. Use the sledge hammer to carefully hammer in the sampling cylinder into the soil until approximately 3 cm remain above the soil surface – take extra care to avoid hammering the cylinder completely into the soil as this will lead to soil compaction and inaccurate bulk density calculations
12. Before removing the soil cylinder, use the measuring tape to measure the distance from the top of the cylinder to the soil surface. Do this in at least three separate places and record the results of each measurement to get an accurate result.
13. Use the small shovel to dig out the metal sampling cylinder. Take extra care not to hit the ring itself and make sure you remove extra soil underneath the cylinder.
14. Once the cylinder is removed from the soil, use the knife to remove all soil from outside the ring and to carefully cut off extra soil at the bottom of the ring.
15. Once all the soil outside of the sample cylinder is removed, place it on the field scale and record the weight on the 'Bulk Density Input Sheet'
16. At this stage, the gravimetric water content is all that is needed to calculate final bulk density. There are two options to calculate the gravimetric water content of the sample:
    a. Traditional method:
       i. Place the soil cylinder in the wet-strength paper bag
       ii. Weigh the soil cylinder in the wet-strength bag
       iii. Dry the cylinder using an over at 105° C for 48 hours
    iv. After drying record the dry weight
    b. Rapid method: If the traditional method is not possible, the gravimetric water content can be calculated using the known volume of the cylinder and assuming a particle density of 2.65 g / cm3. This method is included in a separate protocol in this section (Protocol 3.4).
17. Enter all the data recorded during sampling into the 'Bulk Density Data Sheet' excel file available online at: https://cloudstor.aarnet.edu.au/plus/index.php/s/nvIowYcmWUa03wP
18. It is recommended that 3-5 bulk density samples are taken per field at each depth interval (McKenzie et al. 2008).

How to interpret the results, and What does this mean for the farmer?

Soil bulk density (on its own can) be used to provide clear advice to farmers. Firstly, the ideal bulk density will depend on the texture of the soil (see Table 3 and 6). Bulk density will naturally increase with soil depth and a general rule is that bulk density values above 1.6 g/cm3 typically restrict plant root growth. The USDA provides useful guidelines on which bulk density values will restrict root growth for different soils (USDA 2014).

Table 6: Values of bulk density which will affect root growth for different soil textures. Bulk density values above those listed as 'critical' will severely restrict plant root growth. Adapted from USDA (1999).

Soil texture	Ideal bulk density	Bulk density that may affect root growth	Critical Bulk Density
	------------------------------(g/cm3)------------------------------		
Sands, loamy sands	< 1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams, loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.30	1.60	> 1.75
Silt loams, silty clay loams	< 1.40	1.55	> 1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	< 1.10	1.49	> 1.58
Clays	< 1.10	1.39	> 1.47
(> 45% clay)			

For soils with bulk density greater than critical values (Table 6), it can be beneficial to grow crops with thicker taproots that can penetrate denser soil (Materechera et al. 1991; 1992). This means recommending farmers grow crops such as safflower, beans or cowpea. If the farmer wishes to grow cereals for staple food supply, maize and sorghum will cope better in high bulk density soils than wheat or barley. If the subsoil layer (i.e. below 50 cm deep) is severely compacted, all cereal crops will struggle to grow through the soil and will have restricted access to subsoil water. In these situations, another option is for the farmer to grow a perennial crop which may be able to penetrate deeper layers over time (VRO 2009).

Other management practices that affect soil bulk density relate to tillage and residue management. Research in maize cropping has shown that conservation agriculture management (i.e. zero tillage, increased residues and crop rotations) can have variable effects on bulk density. These effects range from no changes (Logsdon and Karlen 2004), increases (Dam et al. 2005) or decreases in bulk density (Thierfelder et al. 2012; 2015). Bulk density decreases in shallow soil under CA due to the accumulation of organic matter at these depths (Thierfelder et al. 2012).

References

Dalgliesh N, Foale M (1998) Soil Matters: monitoring soil water and nutrients in dryland farming. Agricultural Production Systems Research Unit. (Cranbrook Press: Toowoomba). Available at https://www.apsim.info/Portals/0/APSoil/Soil%20matters.pdf. [Accessed 1 September 2017].

Dam RF, Mehdi BB, Burgess MSE, Madramootoo CA, Mehuys GR, Callum IR (2005) Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. Soil and Tillage Research 84, 41-53.

Logsdon SD, Karlen DL (2004) Bulk density as a soil quality indicator during conversion to no-tillage. Soil and Tillage Research 78, 143-149.

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McKenzie N, Coughlan K, Cresswell H (2002) Soil physical measurement and interpretation for land evaluation. (CSIRO Publishing: Collingwood). Available at http://www.publish.csiro.au/book/3147/.

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3.4. Estimating gravimetric water content

Gravimetric water content is typically measured through drying soil samples in an oven (105°C for 48 hours), a microwave (30-40 minutes on high power), or in the sun (2 days) (Dalgliesh and Foale 1998). While these drying techniques are not exactly 'high tech', they have several drawbacks. Firstly, they cannot typically be performed in the field, and therefore require additional time especially when drying locations are far from the field. A second issue is that when testing many soil samples, large storage areas are needed and these are not always available. However, Schimdhalter (2005) showed that an estimate of gravimetric water content can be calculated without drying soils through using an assumed soil particle density of 2.65 g / cm^3.

This estimation method allows for gravimetric water content to be calculated very quickly, allowing other soil parameters (e.g. Bulk Density- see protocol 3.3) to be calculated rapidly and feedback to be given to farmers immediately.

Background

The theory of this protocol is based on two equations. This first equation represents the standard method for calculating gravimetric water content based on the difference between the wet and dry weights of soil:

$$GWC=(W_i - W_d) / W_d$$

Where GWC is the gravimetric water content (in g / g), Wi¬ ¬is the initial weight of the soil sample, and Wd¬ is the dry weight of the soil sample. The dry weight of the soil sample can be calculated using this following equation:

$$W_d = PDS \times \frac{(W_i - W_w)}{(PDS - PDW)}$$

Where W_d is the dry weight of the soil sample, Wi is the initial weight of the soil sample, Ww is the weight of water in the sample, PDS is the particle density of the soil sample (assumed to be 2.65 g / cm3), and PDW is the particle density of water (assumed to be 1 g / cm3).

In other words, if we record the field-moist weight of the soil sample in a known volume (e.g. soil sample core volume), and then add a known volume of water, we can use these two calculations to estimate gravimetric water content.

Materials (What do I need?)

Note that this protocol is not needed to estimate gravimetric water content when testing for soil nitrate via the protocol in this manual. The required measurements are taken during that procedure in Protocol 3.7.2.

'Soil Gravimetric Water Input Sheet' – see appendix 1

Bucket or plastic tub for mixing the bulked soil samples

Timer (regular phone stopwatch will do)

A soil sample (see section 2 for details on principals of soil sampling)

A 500 ml graduated measuring cylinder with lid (see Section 5 for list of suppliers)

1.5 l bottle of water

Field balance (to 0.1 g accuracy)

A small teaspoon

A measuring cup with ml markings

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
   a. Enter the unique field code from the Site Characterisation in the 'Soil Gravimetric Water Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Take a representative soil sample (see section 2.3) and mix it together in the bucket/tub
   a. You will need at least 100 ml of soil for each sample being tested
   b. You will need to test each sample analysed for other attributes that requires gravimetric water content – e.g. Bulk Density
6. Measure the height of the graduated measuring cylinder and record it on the 'Soil Gravimetric Water Input Sheet'
7. Measure the diameter of the graduated measuring cylinder and record it on the 'Soil Gravimetric Water Input Sheet'
8. Weigh the graduated measuring cylinder (with the lid on) using the field balance and record weight to the closest 1g on the 'Soil Gravimetric Water Input Sheet'
9. Add 250 mL of water to the cylinder and weigh (with lid) – record the weight to the nearest 1 g in the 'Soil Gravimetric Water Input Sheet'
10. Add 100 mL of soil into the cylinder (use the teaspoon) and record the weight (with lid on) to the nearest 1 g in the 'Soil Gravimetric Water Input Sheet'
11. Make sure the cylinder is properly sealed, start the timer for 3 minutes and then shake the mixture until the timer is done.
12. Record the final volume of the soil-water solution (mL) in the cylinder on the 'Soil Gravimetric Water Input Sheet'
    a. The solution should have reduced in volume after shaking due to trapped air in the soil releasing.
13. Wash the soil and water out from the cylinder before reusing
14. Perform steps 9-13 for all soil samples that require testing for gravimetric water content
    a. NOTE: each sample measured for bulk density (Protocol 3.3) will need its gravimetric water content estimated separately.
15. Once all samples have been tested, enter the recorded data for each sample into a separate row in the 'Soil Gravimetric Water Content Data Input' excel file. This will automatically calculate the final estimate of soil gravimetric water content using the equations outlined in the beginning of this protocol.
    a. The excel file is available at: https://cloudstor.aarnet.edu.au/plus/index.php/s/rA76zpP0P2CTwfn

References

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3.5. Soil pH

Soil pH is a measure of the acidity or alkalinity of the soil. High or low pH values can indicate a soil status that disrupts the uptake of soil nutrients by plants. The pH range normally found in soils varies from 3 to 9. Various categories of soil pH may be arbitrarily described as follows:

- Strongly acid (pH < 5.0)
- Moderately to slightly acid (5.0-6.5)
- Neutral (6.5-7.5)
- Moderately alkaline (7.5-8.5), and
- Strongly alkaline (> 8.5)

The significance of soil pH lies in its influence on:

- Availability of soil nutrients,
- Solubility of toxic nutrient elements in the soil (which can be a problem in strongly acid soils)
- Physical breakdown of root cells,
- CEC in soils whose colloids (clay/humus) are pH-dependent, and
- Soil biological activity.

At high pH values, availability of phosphorous (P), and most micronutrients tends to decrease. The exceptions are boron (B) and Molybdenum (Mo) which do not decrease at high pH. Soils of Eastern and Southern Africa (including those for on-station and on-farm trial sites for SIMLESA) will have a wide range of pH values and therefore a wide range of nutrient availabilities. Cropping soils should ideally have pH values between 6.0 and 8.0 as this provides the greatest availability of nutrients from the soil profile. Generally hot humid climates tend towards forming acidic soils due to the higher rainfall in these areas (Juo and Franzluebbers 2003). In addition, some farm management practices can decrease soil pH over time (i.e. acidify the soils). For instance, applying large amounts of nitrogen fertilisers or high levels of organic matter can lead to acidification of soils (Upjohn et al. 2005). Conversely, soils of drier areas such as the semi-arid tropics are generally alkaline (i.e. above pH 7.0) due to lack of rainfall and as a result of the presence of Calcium carbonate (Juo and Franzluebbers 2003). Calcium carbonate will visibly effervesce (fizz) when a few drops of strong acids (such as vinegar) are added to the soil.

For testing pH, the most common procedure uses a pH meter to measure a solution of soil and deionized water or a 1M CaCl2 solution. However, low-tech options such as field test kits are available and provide robust results that correlate well with laboratory methods as long the reagents used (Universal indicator solution and Barium Sulphate powder) are within date and not regularly exposed to extremes of temperature (>40°C).

In this manual, we describe methods for using a) field test kits to test field moist soil, b) a soil pH meter, and c) a test for strong acidity or alkalinity without specialised equipment. Field test kits are typically available for purchase from nurseries, while pH meters can be purchased online. Finally, the simple test uses items commonly found at supermarkets. A list of providers for the specialised equipment (e.g. pH meters) in each SIMLESA country is provided in Section 5.

3.5.1. Testing pH with a field test kit

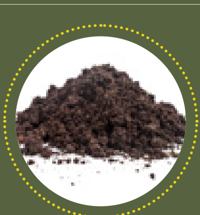
Materials (What do I need?)

Flat white surface for soil testing (e.g. white tile, white dinner plate, etc)

Timer (a mobile phone will do)

Mixing bucket or tub (any large container will do)

The 'Soil pH Input Sheet' (see Appendix 1)



A soil sample (see section 2.3 for details)

A teaspoon

Bottle of water

One of the following:

Colorimetric field test kit (see Section 5 for list of suppliers)	Soil pH meter or 'pH and EC meter' + Whatman filter paper (see Section 5 for list of suppliers)	An alternative method without need for either test kit is provided but not recommended

Method (What do I do?)

The exact method will depend on the type of test kit you are using. Therefore, you will need to follow the instructions provided in the manual.

1. Make sure you have completed a site characterisation (see protocol 2.2).
   - Enter the unique field code from the Site Characterisation in the 'Soil pH Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Take a representative soil sample (see section 2.3) and mix it together in the bucket/tub
   a. You will need at least one handful of soil for each sample being tested
   b. We recommend bulking 5-15 cores into each composite sample for testing to ensure a representative sample (see section 2 for details).
   c. Test to 180 cm depth (if possible) separating as recommended in Table 1, Section 2.3.2
6. Take a handful of soil from the sample bucked/tub and place it on the white surface (i.e. tile or plate)
7. Open the test kit and follow the instruction provided
8. Compare the results to the indicator colours provided and note the pH value you estimate in the 'Soil pH Input Sheet – test kit'

Sample method for test kits

1. Take a representative field moist soil sample of the depth to be examined. (Approximately ¼ the size of your palm). Break up the aggregates between finger and thumb and place on mix plate.
2. Place 4-5 drops of Phenol-thiolate (universal indicator) on the soil sample. Mix soil with indicator to obtain good contact with total soil sample. (Beware it stains!)
3. Sprinkle enough barium sulphate over where universal indicator has wet the soil sample and observe colour change occurring. Stop sprinkling once a sufficient colour reaction has occurred.
4. Match the colour appearing on the soil sample with the pH calibrated colour card. This is an approximate guide but gives instant detectable results (to 0.5 pH range) to quickly assess soil pH.

Technical remark – ensure mix plate is cleaned well with DI water after each pH measurement. Not suitable for people who are colour blind.

3.5.2. Method for use with pH meter or pH and EC meter

- Soil pH meters are specialised equipment for rapidly testing soil acidity/alkalinity.
- They are increasingly affordable and can often be purchased as a dual pH and EC meter (see protocol 3.6). With this in mind, we provide a second protocol for testing soil pH using a pH meter instead of a pH test kit.
- If your team is planning on doing many pH tests it will be cheaper in the long run to purchase a pH meter (rather than test kits).

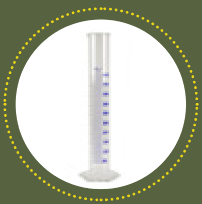
Materials (What do I need?)

Small stapler

1.5 L Deionized water

Pair of scissors

A teaspoon



500 mL Graduated cylinder with lid – see Section 5 for listed suppliers

Whatman filter paper (No.1) – see Section 5 for listed suppliers

Mixing bucket or tub (any large container will do)

Soil 'pH meter' or 'pH and EC meter' – see Section 5 for listed suppliers

Timer (a mobile phone will do)

A soil sample (see section 2.3 for details)

Standard calibration solutions

The 'Soil pH Input Sheet – pH meter' (see Appendix 1)

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
   a. Enter the unique field code from the Site Characterisation in the 'Soil pH Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Take a representative soil sample (see section 2.3) and mix it together in the bucket/tub
   a. You will need at least 50 mL of soil for each sample being tested
   b. We recommend bulking 5-15 cores into each composite sample for testing to ensure a representative sample (see section 2 for details).
   c. Test to 180 cm depth (if possible) separating as recommended in Table 1, Section 2.3.2
6. Weigh the measuring/mixing cylinder (lid on) and record in the 'Soil pH Input Sheet'
7. Add 250 mL of water to the cylinder, weigh the cylinder with water (lid on) and record in the 'Soil pH Input Sheet'
8. Add 50 mL of the soil sample (until the volume of soil and water in the cylinder reaches 300 mL).
9. Weight the soil-water mixture in the cylinder (with lid on) and record the weight in the 'Soil pH Input Sheet'
10. Mix the solution well in an 'end over end' fashion for a minimum of 3 minutes per sample (use timer).
11. Take out a piece of the Whatman filter paper and cut a radial line (i.e. from edge of the circle to the centre point)
12. Curl the filter paper into a cone shape and staple together near the edge of the paper

13. Place filter paper in the solution pointed side in first and allow to stand for 3 minutes while you calibrate the pH meter.
14. Prepare timer for 30 seconds
15. Put the pH meter in the soil-water suspension that has filtered through the paper (about 3 cm deep).
16. Take the reading after 30 seconds with one decimal or upon the pH meter settling for more than 3 seconds, which-ever is first.
17. Record the pH value in the 'Soil pH Input Sheet'
18. Remove the pH meter from the suspension, and rinse the glass electrode tip thoroughly with DI water in a separate beaker/cup,
    - Carefully dry excess water off by dabbing with a tissue before resting the pH meter or taking another measurement.

a) 

b) 

Figure 7: Images of a) Whatman filter paper being rolled into a cone shape (Step 12) and b) being placed in a soil-water shaken extract (Step 13). Adapted from USDA (1999).

Technical Remarks

- Make sure that the pH meter is calibrated effectively using the appropriate buffer solutions.
- Recommendation is for SIMLESA soil samples pH to be measured in a 1:5 (soil:water) suspension. For other purposes and knowledge of methodology, pH can be measured using either a 1:1 or 1:2.5 solution with water or using a salt solution as mentioned, or even in a saturated soil paste if needed. Yet values will differ with methods used across sites. When reporting always use the standard 1:5 (soil/water) first.
- The main advantage of the measurement of soil pH in salt solution is the tendency to eliminate interference from suspension effects and from variable salt contents, such as fertiliser residues.
- Air-dry soils may be stored several months in closed containers without affecting the pH measurement.
- Soil at pH $\leq$4.0 means presence of sulphides and pH $\geq$ 8.5 have significant quantities of Na.
- The determination of pH of field moist samples can present two limitations: taking a representative sample is difficult especially as soil moisture content varies; and biological activity can affect pH due to N mineralisation during storage of soils in their natural field moist state.
- Presence of clay may slow the pH meter electrode response. To avoid this, thoroughly clean electrode between samples.
- Suspended colloids influence pH through the junction potential effect. In the presence if negatively charged colloids (e.g., clay particles or organic matter), pH measured in the suspension will usually be lower than measurement in the supernatant liquid. This is the suspension effect. Therefore, place the pH meter the same distance above the surface of the soil for each reading to maintain uniformity in pH reading and be consistent with timing and temperature.

3.5.3. Alternative simple method (if no pH kits/meters available)

A rudimentary method of testing can be performed if no pH kit is available. This will not give you a pH value but just an indication of whether the soil is acidic, alkaline or neutral.

Materials (What do I need?)

'Soil pH Data Sheet'


1 litre water


Baking soda (1/2 cup)


Testing container (e.g. bucket)


White vinegar (500 ml)

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
   a. Enter the unique field code from the Site Characterisation in the 'Soil pH Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Take a representative soil sample (see section 2.3) and mix it together in the bucket/tub
   a. You will need at least 1 teaspoon of soil for each sample being tested
   b. We recommend bulking 5-15 cores into each composite sample for testing to ensure a representative sample (see section 2 for details).
   c. Test to 180cm depth (if possible) separating as recommended in Table 1, Section 2.3.2
6. Using the teaspoon, take a scoop of the mixed soil and place it into the testing container
7. Add ½ cup of vinegar to the soil
8. Record whether or not the soil begins to effervesce (fizz and bubble) in the 'Soil pH Input Sheet'
9. If the soil did not effervesce, clean the container and add another teaspoon of soil to it
10. Add ½ cup of water to the soil or until it becomes muddy
11. Add ½ cup of baking soda to the muddy wet soil
12. Note whether or not the soil begins to effervesce after adding the baking powder

How to interpret results, and What does this mean for the farmer?

What is a good pH value?

As stated earlier, pH values between 5.5 and 8 are considered acceptable for plant growth, with values between 6-7 considered optimal. Outside of these values, the ability of plants to take up nutrients from the soil will be constrained. You can use Table 7 (below) to make a quick interpretation of soil pH readings. Some plants, including maize, cowpea, pigeon pea and coffee are able to be cultivated successfully on more acidic (pH < 6.5) soils (Juo and Franzluebbers, 2003). For most others, soil acidity will restrict plant growth. Table 8 lists common crops and vegetables grown in Africa and their optimal pH ranges.

Table 7: A guide to soil conditions associated with various soil pH readings. Adapted from Estefan et al. (2013).

Soil pH	Indications	Associated conditions
<5.5	Soil is deficient in Ca and/or Mg and should be limed	Poor crop growth due to low cation exchange capacity and possible aluminium toxicity and expected P deficiency
5.5-6.5	Soil is lime-free and should be closely monitored to detect acidifying trends	Satisfactory for most crops
6.5-7.5	Ideal range for most crops	Soil cation exchange capacity is near 100% base saturation
7.5-8.4	Free lime exists in soil	Usually excellent filtration and percolation of water due to high Ca content on clays. P and micronutrients are less available
>8.4	Invariably indicates sodic soil*	Poor physical conditions of soil. Water infiltration and percolation are slow. Possible root deterioration.

* but not all sodic soils are alkaline

Table 8: Optimal pH ranges of different crop species commonly grown in Eastern and Southern Africa. Adapted from Hazelton and Murphy (2007).

Crop type	Crop	ECe value causing 50% yield loss
Legumes	Beans	5.5-6.5
	Cowpea (forage)	5.5-7
	Soybean	5.5-7
Grain crops	Maize	5.5-7
	Rice	5-6.5
	Sorghum	5.5-7
	Wheat	5.5-7
	Barley	6.25-7.75
Oil seed crops	Sunflower	5.5-6
Vegetable crops	Onion	6-6.5
	Carrot	5.5-7
	Lettuce	6-7
	Potatoes	5-5.5
	Cabbage	5.5-7
	Spinach	6-7
	Tomato	5.5-6.75

What if my pH is high?

For most soils in the semi-arid tropics, pH value will tend to be more alkaline (i.e. with pH above 8) due to lower rainfall (Juo and Franzluebbers 2003). If the pH value of the tested soil is above 8, it can begin to lower the availability of key nutrients in the soil - e.g. calcium, magnesium, iron, manganese, copper and zinc (DPI NSW 2002). Soil pH can be lowered by adding organic materials such as crop residues.

What if my pH is low?

For fields that have a pH value below 5.5 in the shallow (i.e. 0-60 cm) soil, it is recommended that the farmer apply lime to the soil to increase the pH (Upjohn et al. 2002). For subsoil acidity, subsoil liming or surface application of gypsum can help to increase pH, reduce Al and increase Ca2+ concentration (Juo and Franzluebbers 2003). Lime should be ground up finely before being added to soils and care should be taken to only apply what is needed (see Table 9). In tropical regions, lime is less readily available and most major crops have some tolerance for acidic soils meaning lime application should aim to raise pH to 5.3-5.5 (Juo and Franzluebbers 2003). Studies on acid soils in Western Kenya have shown that 4 to 6 t ha-1 of lime increased soil pH from approximately 5.5 to between 6 and 6.5 over two seasons, depending on soil type, application rate and method (Kiplagat et al. 2014). Broadcast applications of lime (Figure 8) were most effective, though this requires more labour than spot-application making it more expensive (Kiplagat et al. 2014). The total cost of lime application in Western Kenya was KSh 4707 per hectare for broadcast and KSh 2624 for banding.

Some cities will have lime available for purchase at nurseries though for more rural areas lime can be found in the form of a lime wash (also known as whitewash) used as white paint or coating when building houses. Look for it at stores selling construction supplies. Another option for increasing pH is through chicken manure.

Table 7: A guide to soil conditions associated with various soil pH readings. Adapted from Estefan et al. (2013).

Lime required (t / ha) to lift pH of surface soil to 5.2				
Soil test pH level	4	4.3	4.7	5.2 (to 5.5)
CEC = 1**	1.6	0.8	0.3	0.2
CEC = 5**	4.7	2.5	1.1	0.7
CEC = 10**	8.7	4.6	2.8	1.3
CEC = 15**	12.5	6.7	2.8	1.9

* assumes lime 95% purity or above.

** amount varies with soil cation exchange capacity (range given from 1 – 15)

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The remaining soil tests detailed in this section will require specialised equipment, but are still able to be performed without a dedicated soil laboratory. For these protocols, team leaders will need to consult Section 5 and ensure they have the necessary equipment prior to completing the analysis.

3.6. Electrical conductivity and soil salinity

Electrical conductivity (EC) is the measure of a soil's salinity (or more specifically the salts in the soil solution). All soils contain some salts, which are essential for plant growth. However, excess salts will hinder plant growth by affecting the soil-water balance. Soils containing excess salts occur naturally in arid or semi-arid areas where reduced rainfall allows accumulation of the salts in the profile. Soils can also accumulate salts in the profile as a result of management practices (e.g. involving heavy use of fertiliser). It is largely a concern in irrigated areas and in regions with saline soils, and is less important in rain-fed agriculture. But with increasing use of irrigation where water may have salt concentrations, there will be greater emphasis on EC measurement in the future.

Measuring Electrical Conductivity

An EC measurement detects the amount of cations or anions (salts) in solution. The greater the amount of anions or cations, the greater the electrical conductivity reading. Ions generally associated with salinity are Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+ (cations), or NO_3^-, SO_4^-, Cl^-, HCO_3^-, OH^- (anions). EC is normally expressed in deci-Siemens per meter (dS m^{-1}) relative to the soil water mixture it is determined from (usually a 1:5 ratio). As with pH, it is one measure of the ease by which plants may uptake water and nutrients from soil solution.

Measurement of EC though soil water extracts are rapid, and can be completed using an 'EC meter'. The total salt content of a soil can then be estimated from this measurement, as well as a soil's cation exchange capacity. Generally, the electrical conductivity of a solution increases with temperature at a rate of approximately 1.9% per 1°C increase (Rhoades, 1993). Most conductivities are measured at between 20-25ºC and many general recommendations are standardized in this temperature range. SIMLESA sites may therefore have significant deviations due to temperature. Most EC meters adjust for deviations from 25ºC within a specific temperature range. Therefore, conductivity measurements must be taken within this temperature range (Refer to instructions packaged with the EC meter you are using) to avoid under- or overestimating the electrical conductivity

The basic methodology and principles of EC measurement is given in USDA Handbook 60 (Richards, 1954). Here we provide a protocol for measuring EC using tap water (instead of distilled or deionized water as with most published methods). When distilled water is not available, tap or rain water can be used and corrected for in the final calculations. It is highly recommended that soil pH is also measured on the same day as soil EC as the processes are similar.

Measure the conductivity of the water source, and subtract the water source EC value from the sample EC value. The relationship between electrical conductivity and salt concentration is only approximate.

Materials (What do I need?)

'Soil EC Input Sheet' – see appendix 1

Electrical conductivity meter (see Section 5 for details on where to purchase)

Whatman filter paper (No.1)

Measuring cylinder (a small measuring cup for cooking will do)

Field balance (with 0.1g accuracy)

50 mL falcon tube (or container with lid for mixing soil and water)

Timer (mobile phone stopwatch will do)

Box of tissues

Deionized Water (500 mL or more, you will need 35 mL per sample and extra for rinsing the probe)

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
    a. Enter the unique field code from the Site Characterisation in the 'Soil EC Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Collect a representative soil sample
    a. You will need at least 7 g of soil for each sample being tested
    b. We recommend bulking 5-15 cores into each composite sample for testing to ensure a representative sample (see section 2 for details).
    c. Test to 180 cm depth (if possible) separating as recommended in Table 1, Section 2.3.2
6. Calibrate the EC meter according to the instructions from the manufacturer
7. Weigh the falcon tube with lid on and record weight in the 'Soil EC Input Sheet'
8. Add 35 mL of water to the measuring cup
9. Place the EC meter 3 cm into the water to record the EC value of the tap/bore water in the 'Soil EC Input Sheet'.
10. Weigh 7g of the field moist soil sample (record exact weight in the input sheet) and place into a 50 mL falcon tube (or container with lid).
11. Add the 35 mL of water and carefully seal the tube/container with a lid
12. Setup the stopwatch or phone to time for 3 minutes.
    - Mix the solution well by shaking it with your hands in an end-over-end fashion.
13. Time of mixing is important. Mix for a minimum of 3 minutes per sample.
14. After mixing, note the final volume of the soil-water mixture (it should have reduced during mixing) in the 'Soil EC Input Sheet'
15. Take a circular piece of Whatman filter paper and cut a line through from edge to the middle. Shape the filter paper into a cone and place pointed end of the cone onto the surface of the soil-water mixed solution.
16. Allow to stand for a minimum of 3 minutes (use timer again)
17. Prepare the timer for 30 seconds
18. Put the EC meter in the filtered soil-water mixture that appears above the filter paper (about 3 cm deep). Record the value to one decimal place (in the input sheet) after 30 seconds, or when the EC meter value is the same for more than 10 seconds.
19. Remove the EC meter from the soil-water mixture and rinse the glass electrode tip thoroughly with tap water
20. Carefully dry excess water off by dabbing with a tissue before resting the EC meter or taking another measurement.
21. Repeat steps 7-19 for all samples to be tested

Notes

- Readings are recorded in deci-Siemens per meter (dS/m).
- The EC should be measured as soon as the extracts are prepared
- If the EC reading on the meter becomes erratic and does not settle then the EC meter may need cleaning. This needs to be completed using an acid dichromate cleaning solution or Nochromix detergent (see Section 5 for suppliers) overnight and rinsing with deionized water.

How to interpret the results, and What does this mean for the farmer?

Salinity affects plants at all stages of development and for some crops sensitivity varies from one growth stage to another. Its effect is also dependent on the depth in the soil profile, with salinity in shallow soil more detrimental to plant growth than in subsoils (Hazelton and Murphy 2007). In general, on the basis of an EC measurement in a 1:5 soil-to-water extract, values of ≤ 0.07 dS/m are safe for all crops in all soil types (Table 10). Readings from 0.07-0.15 dS/m will affect only sensitive crops. Values between 0.15-0.45 dS/m will not affect yields of maize but may potentially affect legume yields, while values from 0.34-1.8 dS/m can correspond to high salinity that is detrimental to productivity of all maize and legume varieties (Hazelton and Murphy 2007). Table 10 below provides values for categorising salinity specific to each soil texture (use Protocol 3.1 to determine soil texture).

Table 10: Soil salinity classification for soils of varying textures. Adapted from Hazelton and Murphy (2007), Source: Shaw 1999)

Soil texture	Degree of salinity (Electrical Conductivity)*‡					
	Very low	Low	Medium	High	Very High	Extreme
	----------------------------------dS/m----------------------------------					
Coarse sand, loamy sand, sandy loam (0-20% clay)	<0.07	0.07-0.15	0.15-0.34	0.34-0.63	0.63-0.93	>0.93
Sandy loam or Sandy clay loam (20-40% clay)	<0.09	0.09-0.19	0.19-0.45	0.45-0.76	0.76-1.21	>1.21
Sandy clay, sandy clay loam, Loam (40-60% clay)	<0.12	0.12-0.24	0.24-0.56	0.56-0.96	0.96-1.53	>1.53
Loam, Silt loam, Clay loam, Clay (60-80% Clay)	<0.15	0.15-0.30	0.30-0.70	0.70-1.18	1.18-1.87	>1.87

* EC measurement values based on a 1:5 soil-water extract

‡ 'Very low': no effect; 'Low': moderately sensitive crops affected; 'Medium': moderately tolerant crops affected; 'High': tolerant crops affected; 'Very High': very tolerant crops affected; 'Extreme': too saline for crop production

Universal measurements for soil salinity

As you can see, understanding how EC values from meter readings relates to soil salinity is difficult due to the effect of soil texture. A universal measurement called Electrical Conductivity from a Saturated Extract (ECe) can be used to more easily interpret a wide range of soils. Table 11 below provides multiplication factors (for different soil textures) to convert your 1:5 EC readings to an estimate Electrical Conductivity from a Saturated Extract (ECe). Use these to calculate estimated ECe values from your EC meter reading.

Example: The EC reading at Sussundenga Research Station in Mozambique was 0.089 dS/m (Table 19, Section 4). The soil is a fine sandy clay loam (Table 18, Section 4). According to Table 11 (below), the multiplying factor for this soil texture is 9.5. So therefore:

ECe value = 0.089 dS/m x 9.5 = 0. 8455 dS/m.

Once you have an ECe estimate, you can quickly assess the salinity of a soil using Table 12. According to Table 11 our estimated ECe value for Sussundenga Research Station indicates the soil is non-saline soil because it is less than 2. If a soil is saline, information in Table 13 provides suggestions on which crops may be more suited to the field.

Table 11: Conversion factors for estimating ECe from EC values (Hazelton and Murphy 2007)

Soil texture	Multiplying factor (EC to ECe)
Sand, Loamy sand, Clayey sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loam, fine sandy loam, silty loam, sandy clay loam	9.5
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	8.6
Light medium clay	8.6
Medium clay	7.5
Heavy clay	5.8

Table 12: Threshold ECe values for classifying salinity level of soil and their associated effect on plant growth (adapted from Hazelton and Murphy 2007)

Rating	ECe (dS/m)	Effect on plants
Non-saline	< 2	Mostly negligible
Slightly saline	2-4	Yields of sensitive crops affected
Moderately saline	4-8	Yields of many crops affected
Highly saline	8-16	Only tolerant crops can be grown
Extremely saline	> 16	Only very tolerant crops can be grown

Table 13: Salt tolerance of different crop species commonly grown in Eastern and Southern Africa. Adapted from Estefan et al. (2013) and Hazelton and Murphy (2007). Sources: Ayers (1977); California Fertilizer Association (1980); Ayers and Westcot (1985).

Crop type	Crop	Maximum ECe value causing no yield loss	ECe value causing 50% yield loss
	-------------------dS/m------------------		
Legumes	Beans	1.0	
	Groundnut	-	4.9
	Cowpea (forage)	-	7.0
	Soybean	5.0	8.0
	Cowpea (grain)	1.3	9.1
Grain crops	Maize	1.7	6.0
	Rice	3.0	-
	Sorghum	4.0	10.0
	Wheat	6.0	13.0
	Barley	8.0	18.0
Oil seed crops	Safflower	5.3	12.0
	Sunflower	-	14.0
Vegetable crops	Onion	1.3	4.0
	Carrot	-	4.5
	Lettuce	1.0	5.0
	Capsicum (bell pepper)	-	5.0
	Potato / Sweet potato	1.7	6.0
	Cabbage	1.8	7.0
	Spinach	2.0	8.0
	Tomato	2.5	8.0

Inferring other soil properties from EC readings

Finally, another way to use EC readings is to infer other soil attributes using general relationships that have been established. Rhoades (1996) outlined the following relationships:

1. Total cation (or anion) concentration (meq/L) ≈ 10 x EC (dS/m).
2. Total dissolved solids (mg/L) ≈ 640 x EC (dS/m).
3. Osmotic pressure (kPa at 25EC) ≈ 0.36 x EC (dS/m).

Where NO3 is the predominant ion in the soil solution, a very useful relationship has been established between the EC (in 1:1 soil to water mixture) readings and soil nitrate (NO3-) concentrations (Smith and Doran, 1996).

EC (dS/m) x 140 ≈ mg NO3-N / kg of soil

This relationship assumes the complete extractability of NO3 - in water and that NO3- is the major anion in the soil solution.

Useful Unit Conversions for Electrical Conductivity

1 dS/m (decisiemens per meter) = 1 mmhos/cm (millimhos per centimeter)

1 dS/m (decisiemens per meter) = 1000 µS/cm (microsiemens per centimeter)

1000 µS/cm (microsiemens per centimeter) = 1 mS/cm (millisiemens per centimeter)

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3.7. Soil mineral nitrogen

Soil mineral nitrogen is of great importance to crop production. Nitrogen (N) is an essential plant macronutrient. It contributes to development of plant protein and chlorophyll. As a result, the use of N fertilisers (e.g. urea) to supplement soil N supply remains a key practice in high yielding crop production (Smil, 1999). Soil N is dynamic in nature, rapidly changing forms as it cycles within the soil. This makes it difficult to measure and estimate any change in soil mineral N supply to a crop over time without retesting. However, it is critical to test soils for plant-available N (i.e. inorganic, nitrate, ammonium) prior to each season. This ensures proper assessment of N fertiliser needs, avoiding over-application and subsequent economic losses and environmental pollution (Mosier et al. 2004). Despite the importance of N management and proper soil testing being known for more than half a century (Keeney and Bremner 1966), few farmers test their soils every season even in high intensity cropping regions (Schmidhalter 2005).

Why is soil N testing so rare?

In many parts of sub-Saharan Africa, access to laboratories for timely testing of soil samples is extremely rare. According to traditional methodology, soil testing for inorganic N must take place within at most 4 days of field sampling (Rayment and Lyons, 2011). Samples should also be extracted and kept below 4°C until they are analysed (Rayment and Lyons, 2011). Outside of South Africa, Zimbabwe and Kenya (www.sgs.co.za, www.sgs.co.ke, http://www.cropnuts.com/, http://www.zimlabs.co.zw/), pre-season soil N testing in Eastern and Southern Africa is unavailable in a practical sense. High temperatures and large distances to labs act as barriers to accurate testing even in countries where laboratories do exist. Finally, high costs mean traditional analysis is not possible for most farmers.

Yet N deficiency is regarded as a major constraint to much of African crop production (Fischer et al. 2014). Investment in N fertilisers remains a major risk in variable environments where African smallholders are without proper support and thus vulnerable (Rodriguez et al. 2017). To help overcome this constraint, it is important that extension officers can recommend fertiliser use where it is most appropriate, and offer alternative management strategies for those who cannot afford them but have low N soils.

Rapid N testing

Since the 1980s, scientists have explored the possibility of using rapid nitrate colorimetric test strips in conjunction with a reflectometer as a quick and low-cost alternative method for testing soil for plant-available N (Schaefer 1996; Jemison and Fox 1988). This research continued throughout the 1990s and refined protocols, identifying factors affecting accuracy of the results (Hunt et al. 1991; Liebig et al. 1996; Westelaar et al. 1998). The result of this research indicates that with a proper protocol, colorimetric nitrate strips in conjunction with a reflectometer can measure soil nitrate levels to an accuracy comparable to traditional methods. This is extremely valuable for the African context where laboratories are scarce and N is so often limiting crop production.

The following protocols were prepared with the intention of allowing extension officers to better identify nitrogen deficiencies in farmers' fields. In order to be easily performed, it follows the Quick Test Method B outlined by Schmidhalter (2005). This uses large soil sample volumes (suited to lower N soils), uses tap water (instead of deionised water) along with a correction factor for water nitrate levels, and allows the estimation of sample gravimetric water content (instead of drying samples in a laboratory). However, soil nitrate testing with quick test strips has been consistently shown to vary with temperature above or below 20°C (Westelaar et al. 1998; Schmidhaldter 2005). Therefore, the first protocol we have included is one that gives instruction on how to prepare nitrate standard solutions of known concentrations. This should be done by national research organisations with laboratory facilities. Extension officers should be able to take subsamples of solutions to the field when needed in order to build relevant calibrations for their tests.

The second protocol instructs on soil extraction, filtration and testing, as well as testing of tap water used in this process and (optional) nitrate standards. While this protocol is the longest and most detailed of all in this manual, it is not overly complex and can be performed easily with the necessary equipment.

For soil nitrate measurements to be meaningful, the soil gravimetric moisture content must be known. The necessary measurements for this estimation are included in this protocol and calculations are embedded into the accompanying excel spreadsheet. In addition, soil nitrate readings using test strips are temperature sensitive. They are most accurate at 20 °C. If temperatures are higher or lower you will need to measure a series of solutions with known nitrate N concentrations to develop a correction. This is included as a final part of the protocol.

3.7.1. Preparing nitrate standards for temperature correction

These solutions will need to be prepared by national research institutions. We recommend that they store large supplies of these solutions which be made available to local extension officers when nitrate testing in very cold or warm weather (i.e. more than 5°C above 20°C). It is best to prepare these solutions in larger quantities and simply take subsamples to the field.

Nitrate is most commonly purchased in a solid form for making solutions as KNO3, or potassium nitrate (see Section 5 for where to purchase). The compound is 61.33% nitrate and 39.67% potassium. Parts per million (the measurement unit of nitrate) are equivalent to mg/L. For a 1 L solution that is 1 ppm nitrate, you need 1mg of nitrate added to 1 L of distilled or deionized water. To calculate the mass in mg of potassium nitrate needed in a 1 L solution for a desired ppm, multiply by the final nitrate ppm value you want by 1.6305 (this corrects for the fact that KNO3 is 39.67% potassium). The following protocol gives you the amount of KNO3 in mg needed to make the standard solutions of nitrate. We have also included one example of calculating the amount of KNO3 needed for a nitrate solution below in case you wish to make different solutions to those in the protocol.

- Total final nitrate solution volume = 2 L
- Desired nitrate ppm concentration = 15
- 15 ppm of nitrate = 15 mg/L, x 2 L = 30 mg of nitrate needed
- KNO3 is only 61.33% nitrate
- How many times does 61.33 need to be multiplied to equal 100 (i.e. to get 100% of the nitrate needed)?
- 61.33/100 = 1.6305
- Multiply 30 ppm x 1.6305 (correction for KNO3) = 48.915 mg of KNO3 per 2 L of water
- So 48.915 mg of KNO3 needs to be added to 2L of distilled/deionized water to make 2 L of 15 ppm nitrate solution.

Materials (What will I need?)

10 g of KNO3

12 L of distilled or deionized water

A laboratory balance accurate to 0.1 mg

White masking tape

A black marker

6 large sealable glass bottles (for preparing and storing the solutions)

Method (What do I do?)

You will be making six solutions.

1. Take out the five large bottles and label them 'distilled/deionized water', '5 ppm nitrate', '10 ppm nitrate', '20 ppm nitrate', '50 ppm nitrate', '100 ppm nitrate' using the marker and white masking tape
2. For the bottle labelled 'distilled/deionized water', pour 2 L of deionized or distilled water into it
3. Weight the following amounts of KNO3 pellets and add to the relevant bottle listed
   a. '5 ppm nitrate', add 16.3 mg of KNO3
   b. '10 ppm nitrate', add 32.6 mg KNO3
   c. '20 ppm nitrate', add 65.2 mg KNO3
   d. '50 ppm nitrate', add 163.1 mg KNO3
   e. '100 ppm nitrate' add 326.1 mg KNO3
4. Add 2 L of distilled/deionized water to each bottle.
5. Store the bottles in a dark cupboard at a stable temperature (e.g. 20-24°C) making sure they are properly sealed
6. Prior to going to the field for testing, provide 6 x 500 mL bottles, label them using the same six labels from step 3, subsample of 200 mL of each relevant nitrate solution (or DI water).

3.7.2. Field testing soil for nitrate levels

This protocol is suited for extension officers or advisors wishing to test farmers' fields for nitrate concentrations. If the temperature in the field is more than 5°C above or below 20°C then protocol 3.7.3. must also be completed to correct for temperature effects.

Materials (What do I need?)

'Soil Nitrate Input Sheet' – see Appendix 1

(For standard testing to correct for temperature (recommended)

Small stapler

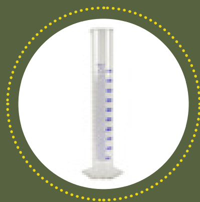
A pair of scissors

1 x measuring cup

Field balance (with 0.1g accuracy)

Soil samples (see protocol 2.2)

Filter paper (Whatman No. 42 ash less recommended) – see Section 5 for where to purchase



1 x 500 mL graduated cylinder (50mm diameter) with lid – see section 5 on where to purchase

A calibrated test strip reflectometer (see instructions for how to calibrate machine) – see Section 5 for where to purchase

Full bottle of water (at least 1.5 Litres)

6 x 500 mL bottles labelled and filled with relevant 250 mL standards (See protocol 3.7.1):

- 0'5 ppm nitrate'
- '10 ppm nitrate'
- '20 ppm nitrate'
- '50 ppm nitrate'
- '100 ppm nitrate'

Nitrate colorimetric strip tests (Merck recommended) – see Section 5 on where to purchase

Method (What do I do?)

1. Make sure you have completed a site characterisation (see protocol 2.2).
   - Enter the unique field code from the Site Characterisation in the 'Soil Nitrate Input Sheet'
2. Record your name and contact details (phone number, email address) and institution
3. Record the date of sampling
4. If you have not completed a site characterisation, note the GPS coordinates of the field.
5. Collect a representative soil sample.
   1. You will need at least 300 mL of soil volume for each sample being tested.
   2. We recommend bulking 5-15 cores into each composite sample for testing to ensure a representative sample (see section 2 for details).
   3. Test to 180 cm depth (if possible) separating as recommended in Table 1, Section 2.3.2.
6. Measure the height of the measuring cylinder and record it in the 'Soil Nitrate Input Sheet' in mm
7. Measure the diameter of the measuring cylinder and record it in the 'Soil Nitrate Input Sheet' in mm
8. Weigh your graduated cylinder (with lid) and record the weight in the 'Soil Nitrate Input Sheet' in grams

Preparing the sample (do this for each soil sample position / depth to be tested)

9. Give your sample a number and record it in the 'Soil Nitrate Input Sheet' (start at 1 and number upwards for all tests on the same date)
10. Record the soil depth interval being tested (e.g. 0-15 cm, 15-30 cm, etc.)
11. Record the number of individual soil cores that were bulked into this sample being tested (it recommended to bulk and mix at least 3 samples per field to capture variability – do this mixing separately for each depth being tested)
12. Add 250 mL of tap water to the measuring cylinder with soil.
13. Weigh sealable measuring cylinder and water (lid on) and record weight to closest 1 g on the 'Soil Nitrate Input Sheet'
14. Add scoops of soil (use teaspoon) into the cylinder with water until volume of the mixture reaches 350 mL (i.e. add 100 mL of soil)
15. Weigh the sealable container (lid on) with water and soil and record weight to closest 1 g on the 'Soil Nitrate Input Sheet'
16. Prepare time for 3 minutes (do not start timing)
17. Start timer and shake sample for 3 minutes (5 minutes for clayey soils, see protocol 3.1 for how to measure soil texture)
18. After shaking, place soil-water extract down, record the volume of the shaken solution in the 'Soil Nitrate Input Sheet' (it should have reduced slightly from 350 mL)
19. Use the scissors to cut a radius line (from edge to the centre) into a piece of Whatman filter paper.
20. Roll the filter paper into a cone shape, staple it together near the outer edge to hold the cone shape
21. Open the measuring cylinder lid and dip the pointed end into the soil-water extract in the container.

Preparing the reflectometer and testing water for nitrate-N (Do this once per batch of tap water)

22. Take out the reflectometer, and:
    1. Turn it on
    2. Press the TEST button until the arrow indicates the desired test method memory (from earlier calibration)
    3. Ensure that the reference number is the same as the reference number on the nitrate test strips package (see instructions for details)
23. Pour a 50 mL of water into the measuring cup.
24. Press the START button on the reflectometer (reaction time will be shown on the screen)
25. Take a nitrate test strip from the packet. Dip it into the water (from step 22) and immediately press the START button on the reflectometer to activate the reaction timer
26. Allow any excess water to drip off the nitrate strip.
27. When the reflectometer timer reaches 5 seconds remaining, it will make a sound. Place the nitrate strip into the reflectometer when you hear it or when 5 seconds is remaining.

28. Record the reading displayed at the end of the timer (after 60 seconds) in the 'Soil Nitrate Input Sheet'.

29. Repeat steps 24-28 for two more nitrate strips so that you have a total of three measurements of the water nitrate levels

Testing the soil sample extract

30. Once some of the extract has filtered through the paper, ensure the reaction timer is displayed on the reflectometer (if not, press the START button)

31. Take a nitrate test strip from the packet. Dip it into the filtered extract and press the START button again on the reflectometer to start the reaction timer.

32. Allow the excess solution to drip off the nitrate test strip while timing the reaction.

33. When the reflectometer timer reaches 5 seconds remaining, it will make a sound. When this happens, place the nitrate strip into the reflectometer.

34. Record the reading displayed at the end of the timer in the 'Soil Nitrate Input Sheet'.

35. Repeat steps 30-34 for two more nitrate strips so that you have a total of three measurements per soil sample

36. Once you have the three measurements you can calculate an average nitrate-N value for the soil water extract, the gravimetric water content and the soil nitrate in ppm using the excel spreadsheet available here at: https://cloudstor.aarnet.edu.au/plus/index.php/s/u8hwzbCZJV9rpQX

37. Empty the measuring cylinder and wash out all soil with tap water before beginning to test the next sample.

Testing nitrate standard solutions in the field (temperature calibration)

If the temperature is below 15°C or above 25°C when you are testing soils, you will also need to test standard nitrate solutions at a range of concentrations. This will allow you to correct for the effect of temperature on the nitrate strips. Details on preparing the nitrate solutions are included in protocol 3.7.1.

38. Repeat steps 24-29 for each standard solution (including distilled/deionized water) collected from the national research team (see protocol 3.7.1)

- Be sure to record all measurements in the relevant part of the 'Soil Nitrate Input Sheet'

Technical notes

The equation used in the associated excel spreadsheet to correct final soil nitrate-N concentrations for nitrate contamination via tap water was:

M_S×0.226×(V_e+V_SW)-(M_e×0.226×V_e))×(1+ǂ_g)/W_i

Where Ms = measured nitrate value of soil sample/extract mixture [mg L-1], 0.226 = factor to convert NO3- into NO3-N. Ve = volume of extract liquid [L], VSW¬¬ = volume of water contained in the soil sample [L], Me = measured nitrate value of nitrate containing extract liquid (i.e. water) [mg L-1], Wi = the initial moist weight of the soil sample [kg], and ǂg = the gravimetric soil water content [g g-1]. VSW is equivalent to the weight of water contained in the soil sample (by assuming a density for water of 1 kg L-1). It is calculated as Wi (weight of initial moist soil sample) – Wd (weight of dry soil sample).

Final calculation of the amount of nitrogen in the form of soil nitrate on a weight per soil area basis (i.e. kg ha-1) can only be completed with the soil bulk density (see protocol 3.3).

How to interpret the results, and What does this mean for the famer?

Using the results from these protocols, you will be able to calculate the ppm measurement of soil nitrate N in the farmer's field at each depth you have tested. The easiest way to calculate these final values is to enter the data recorded on the 'Soil Nitrate Input Sheet' into the associated excel spreadsheet which has been pre-programmed to calculate the final nitrate-N values for your samples. As a general rule of thumb, **soil nitrate-N concentrations below 20 ppm are considered low** and crop growth will most likely be limited without N fertiliser (NSW DPI 2004). Nitrate levels **below 11 ppm are considered to be very low** (Estefan et al. 2013). **Soil nitrate-N levels below 50 kg N / ha are also considered low** and crops are likely to respond favourably to N fertilisers assuming agronomic management is adequate (Cox and Strong 2009). It is important to point out that this assumes no other issues limit crop growth – a big assumption especially in smallholder farms of East and Southern Africa.!

As stated earlier, you will need to know the bulk density of the soil to be able to calculate the plant available soil nitrogen (in the form of nitrate) in kg per hectare (the same values used for fertiliser recommendations). You can perform a quick bulk density measurement by following protocol 3.3 in this manual. According to AfSIS data, most soils in East and Southern Africa have bulk density values between 1.3 and 1.6 g cm3 in shallow soil and up to 1.7 g cm3 in subsoil (Hengl et al. 2017).

The amount of nitrate-N needed to grow a crop depends on many factors. Most important of these are the type of crop and the target yield (itself dependent on rainfall and soil moisture). It is possible to estimate the amount of nitrogen needed for the farmer's yield target and to use this to help inform fertiliser decisions. Ask the farmer what they consider to be a good yield (use a previous yield they nominate as desirable) and compare this yield with those listed in Table 14 to see a rough estimate of total N needed.

Remember that the crop will require adequate rainfall to reach a higher yield. It is handy to know whether the season is likely to be above or below average in rainfall. That can help you and the farmer plan to manage for a drier, wetter or normal season. In East and Southern Africa, seasons are usually drier during El Niño years (when the ENSO index is negative down to -10) and wetter in La Niña years (when the ENSO index is positive up to 10) (Nicholson and Kim 1997). ENSO index values of close to 0 indicate a neutral year. You can check the current prediction for ENSO at the Earth Institute website located at: http://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/.

When nitrate levels are below the threshold values provided in table 14, crops are likely to suffer N deficiency. In such cases, farmers may manage this deficiency through N fertilisers or through adjusting their agronomic management to reduce plant competition for limited soil N (Keating et al. 1988; Dimes et al. 2014; Roxburgh and Rodriguez 2016).

Table 14: Estimated maize crop demand for nitrogen when targeting various yields. Values assume a maize grain protein content of 9.5%, total crop N content is 1.7 times the final protein content in grain, and a fraction of N in maize protein equal to (10/6.25). Compare the average yield of the farmer in previous years to the values here and you can estimate the need for N. Compare this with the amount of soil N you have measured and you will have a rough idea how much fertiliser is needed. Adapted from Cox and Strong (2009).

Seasonal outlook guide (ENSO forecast)	Target yield (kg ha-1)	Estimated total crop N demand (kg ha-1)
El Niño (ENSO negative)	1000	26
El Niño (ENSO negative)	1500	39
El Niño (ENSO negative)	2000	52
El Niño (ENSO negative)	2500	65
La Niña (ENSO positive)	3000	78
La Niña (ENSO positive)	3500	90
La Niña (ENSO positive)	4000	103
La Niña (ENSO positive)	4500	110

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4. SIMLESA long-term trial site analysis reports

During the SIMLESA project, long-term agronomic trials were undertaken in each of the five core countries. Research staff on the project took soil samples from some of these sites in Ethiopia, Malawi and Mozambique. As a reference, we have included these data in this section. They may be used when conducting future experimental work at these research stations. Please note that the sampling and analysis undertaken for these soils were all performed by experienced soil scientists using the highest quality laboratory facilities and techniques. Protocols in this manual will not be able to provide the same level of detail about the soils.

4.1. Ethiopia

In Ethiopia, two research stations were characterised and sampled and analysed for soil attributes. These were located in Bako and Melkassa. The Bako Agricultural Research Station was established in 1964 and is one of the oldest research stations in Ethiopia (EIAR 2017a). It is located in a sub-humid zone and is broadly said to be on a Nitosol soil (FAO classification system). The Melkassa Agricultural Research Station was established in 1969 in the semi-arid region of Ethiopia. The soil type of the research station is an alkaline volcanic Andosol (EIAR 2017b). Both the Bako and Melkassa research stations are located in the Oromoia region.

Table 15: Wet Chemistry results from soil sample analysis of SIMLESA long-term trial site at Bako Agricultural Research Station, Ethiopia. Samples collected by Stuart Irvine-Brown in 2016

Depth	pH	EC	P	K	Ca	Mg	Mn	S	Cu	B	Zn	Al	Na	Fe	CEC
(cm)	(H2O)	(µS/cm)	------------------------------------ppm------------------------------												(cmol(+)/kg)
0-15	7.18	55	43.5	985	3340	397	252	5.18	1.43	0.44	5.06	837	69.9	91.6	23.8
15-30	7.81	59	9.89	902	3680	454	209	4.45	1.39	0.47	2.9	835	224	80	26.4
30-60	7.96	70	25.9	1030	3020	442	190	8.03	1.52	0.29	3.12	801	448	94.2	24.2
60-90	-	-	9.47	1320	2620	519	172	2.63	1.79	0.44	8.71	-	998	79	-

Table 16: Wet Chemistry results from soil sample analysis of SIMLESA long-term trial site at Melkassa Agricultural Research Station, Ethiopia. Samples collected by Stuart Irvine-Brown in 2016

Depth	pH	EC	P	K	Ca	Mg	Mn	S	Cu	B	Zn	Al	Na	Fe	CEC
(cm)	(H2O)	(µS/cm)	------------------------------------ppm--------------------------------												(cmol(+)/kg)
0-15	-	-	-	6.3	1110	255	172	19	2.66	0.23	3.03	-	25.9	56.3	-
15-30	5.43	35	0.63	2.27	1070	243	131	22.9	2.7	0.25	0.61	1290	33.1	69.1	12.6
30-60	5.45	50	0.5	0.41	1070	248	76.3	14	2.14	0.12	0.53	1330	41.1	53.6	12.5
60-90	4.75	65	1.49	<0.2	811	186	74.7	19.2	2.13	0.15	0.48	1590	73.6	43.4	14.6

4.2. Mozambique

Two sites in Mozambique were characterised, sampled and analysed for soil attributes during the SIMLESA project. These were both located in the Manica province in Central Mozambique. The Instituto Superior Politecnico de Manica is a higher education institution located close to the provincial capital of Chimoio. It hosted numerous SIMLESA-associated trials including research by Nyagumbo et al. (2016; 2017) and PhD work by Dr Nascimento Nhantumbo and Dr Caspar Roxburgh.

The Sussundenga Research Station (SRS) has a documented history of agricultural experiments going back to the 1960s (Curtin and Smith 1968). It has previously been characterised in detail by Wijnhoud (1997) and later Famba (2011). The soils at SRS are Rhodic Ferralic Abruptic Lixisols (World Reference Base soil classification). It is a red, texture-contrast soil with clay loam surface overlying a permeable neutral to acid subsoil. It is referred to as a Chromosol in the Australian soil classification system. The information provided in this section is the result of work by Stuart Irvine-Brown and Ben Harms.

Table 17 provides basic site characterisation information for the soil at SRS, comparable to some of the information which can be collected using Protocol 2.3. Table 18 provides information on soil texture and colour at SRS which can be determined using Protocols 3.1 and 3.2 in this manual.

Table 17: Site description of Sussundenga Research Station

Site characteristic	Estimate for Sussundenga
Slope	2-3%
Landform	Gently undulating rises
Geology (parent material)	Granite
Land use	Rainfed cropping
Surface condition	Loose, soft
Surface coarse fragments	None
Runoff	Moderately rapid
Permeability	Moderately permeable
Drainage	Moderately well-drained
Location GPS coordinates	-19.31523 S, 33.23970 E
Elevation	630 m

Table 18: Soil texture and colour measurements for Sussundenga Research Station

Soil depth (cm)	Soil texture	Soil colour (Munsell Chart code)
0-15	Clay loam, fine sandy	Dark brown (5YR 3/3)
15-30	Clay loam, fine sandy	Dark brown (7YR 3/3)
30-60	Light medium clay	Reddish brown (5YR 4/4)
60-140	Medium clay	Yellowish red (5YR 4/6)

Table 19: Wet Chemistry results from soil sample analysis of SIMLESA long-term trial site at ISPM, Vanduzi district, Manica, Mozambique. Samples collected by Stuart Irvine-Brown in 2016

Depth	pH	EC	P	K	Ca	Mg	Mn	S	Cu	B	Zn	Al	Na	Fe	CEC
(cm)	(H2O)	(µS/cm)	------------------------------------ppm-------------------------------												(cmol(+)/kg)
0-15	6.07	89	28.1	348	643	108	207	9.45	4.64	0.26	1.58	950	13.9	71.5	6.27
15-30	-	-	6.45	224	561	94.9	128	6.23	4.54	0.42	2.82	-	23.4	62.6	-
30-60	5.91	53	2.83	162	394	86.4	103	10.7	3.34	0.32	0.9	907	41.5	58	4.28
60-90	5.83	42	2.22	182	362	95.3	91.9	11.3	2.85	0.36	0.91	924	53	48.7	4.45
90-120	-	-	10.5	258	463	90.5	65.6	10.9	2.6	0.5	3.22	-	42	43.3	-

Table 20: Wet Chemistry results from soil sample analysis of SIMLESA long-term trial site at Sussundenga Research Station. Samples collected by Stuart Irvine-Brown in 2016.

Depth	pH	EC	P	K	Ca	Mg	Mn	S	Cu	B	Zn	Al	Na	Fe
(cm)	(H2O)	(µS/cm)	------------------------------------ppm-------------------------------											
0-15	5.31	49	30.1	189	289	58.1	208	11.6	2.42	0.1	1.57	945	31.4	93.3
15-30	-	-	8.79	106	363	69.9	168	15.4	2.54	0.2	2.82	-	24.8	78.8
30-60	5.83	23	1.98	88.8	366	87.4	94.1	25.5	1.92	0.13	0.49	1090	22.6	59.8
60-90	-	-	1.8	71.6	375	92.2	65.6	17.7	1.27	0.31	3.29	-	27.7	36.2
90-120	-	-	1.39	59.8	302	109	54	7.28	0.98	0.37	4.3	-	20.6	43.8
120-150	5.23	27	0.35	27.8	199	125	39.6	6.83	1.05	0.31	0.63	997	27.6	34.9
150-180	-	-	0.43	35.5	234	112	39.1	1.83	1.13	0.4	2.96	-	31.9	28.1

Table 21: Physical and chemical properties of soils in three fields at the Sussundenga Research Station. Analysis work undertaken by Ben Harms on samples taken November 2016.

Site	Depth (cm)	pH (H2O)	Texture*	OC (%)	Ca	Mg	Na	K	CEC (cmol(+)/kg)
Field 1 (photos)	30-40	5.8	LMC	-	1.28	0.61	0.08	0.226	2.86
	90-100	6.0	MC	-	1.74	0.44	0.10	0.081	2.01
Field 2	0-20	6.1	SL	1.57	7.90	1.50	-	0.50	7.2
	20-50	5.3	SCL	0.79	4.00	0.70	-	0.30	6.0
	50-60	5.2	SC	0.52	2.80	0.40	-	0.20	4.3
	60-90	5.2	SC	0.44	2.70	0.50	-	0.20	5.0
Field 3	0-20	6.3	SL	0.99	5.40	0.90	0.30	1.10	4.0
	50-60	5.1	C	0.52	3.90	0.40	0.40	0.30	7.4
	60-90	4.9	C	0.23	2.90	0.50	0.50	0.30	7.1

*LMC = Light medium clay; MC = Medium clay; SL = Sandy loam; SCL = Sandy clay loam; SC = Sandy clay; C = Clay

4.3. Malawi

In Malawi, the SIMLESA long term trials were located at the Chitala Research Station. It is located in the Salima district of Central Malawi.

Table 22: Wet Chemistry results from soil sample analysis of SIMLESA long-term trial site at Chitala Research Station, Malawi. Samples collected by Stuart Irvine-Brown in 2016.

Depth	pH	EC	P	K	Ca	Mg	Mn	S	Cu	B	Zn	Al	Na	Fe
(cm)	(H2O)	(µS/cm)	--ppm----------------------------------											
0-15	5.7	76	6.07	200	1930	390	127	8.05	3.87	0.089	1.77	880	35.3	136
15-30	-	-	2.65	95.1	1900	379	88.9	6.65	4.01	0.16	3.55	-	21.8	151
30-60	6.22	30	<0.20	75.3	2030	465	53.3	8.24	3.51	0.053	1.05	841	27.9	69.6
60-90	-	-	0.28	78.8	1990	514	47.5	5.01	4.01	0.16	3.55	-	29.3	59.1
90-120	6.7	28	<0.20	90.3	1990	597	39.6	5.96	2.85	<0.02	0.54	728	60.7	66.7
120-150	6.83	22	0.41	99.2	2120	663	52.7	4.55	3.11	<0.02	0.73	724	43.4	96.2
150-180	-	-	<0.20	99.8	2280	627	125	2.11	2.53	0.095	1.79	-	29	96.7
0-15	5.53	78	7.06	100	960	146	174	8.83	2.3	0.068	2.97	533	26.3	79.6
15-30	-	-	1.7	93.3	1490	286	117	7.67	3.31	0.15	3.72	-	31.3	111
30-60	-	-	0.97	71.1	1350	341	91.2	11.2	3.04	0.13	2.51	-	37.3	71.1
60-90	-	-	<0.20	67.2	1210	359	107	18.2	2.43	0.13	3.42	-	35.5	56.9
90-120	-	-	0.35	70.4	1250	387	110	23.5	2.67	0.11	3.22	-	37.3	70.2
120-150	-	-	<0.20	69.5	1380	416	134	38.8	2.44	0.1	3.42	-	57.2	94.6
150-180	-	-	0.33	70.2	1320	405	145	24.7	1.86	0.089	3.36	-	46.9	69.5

References

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EIAR (2017a) Bako Agricultural Research Station. Ethiopian Institute for Agricultural Research. Available at: http://www.eiar.gov.et/index.php/bako-national-maize-research-center [Accessed 28 August 2017].

EIAR (2017b) Melassa Agricultural Research Station. Ethiopian Institute for Agricultural Research. Available at: http://www.eiar.gov.et/index.php/melkassa-agricultural-research-center [Accessed 28 August 2017].

Famba SI (2011) The challenges of conservation agriculture to increase maize yield in vulnerable production systems in central Mozambique. PhD Thesis. Available at http://www.iiam.gov.mz/documentos/isfm/CA_Thesis_Famba.pdf [Accessed 25 August 2017].

Wijnhoud JD (1997) Solos e outros recursos naturais de Estação Agrária de Sussundenga [Soils and other natural resources of the Sussundenga Research Station]. Earth and Water series of the National Institute for agronomic investigation. Communication No.93. Available at http://library.wur.nl/isric/fulltext/isricu_i26532_001.pdf. [Accessed 25 August 2017].

5. Relevant resources for team leaders

5.1. List of suppliers details

Please note that all of the following information was accurate at the time of publication. Suppliers are likely to change in the future and we advise teams do their own research to find the most suitable and affordable suppliers of equipment.

5.1.1. General supplier local distributor lists

Lab equipment and chemical reagent supplier

Sigma Aldrich (now owned by Merck) is an international scientific chemical supplier. It has local distributors responsible for each SIMLESA country. They are listed in Table X below.

Table 23: List of local distributors for Sigma Aldrich in each SIMLESA country.

Country	Supplier details
Ethiopia	Afro German Chemicals Est. PLC. Addis Ababa, Ethiopia Phone: 251 11 1550200 Fax: 251 11 1551057 Email: afrogerman@ethionet.et Website: Export Sales and Service
Kenya	Kobian Kenya Limited Nairobi, Kenya Phone: 254 20 21 61 265 Fax: 254 20 21 61 265 Email: sales@kobianscientific.com Website: www.kobianscientific.com
Tanzania	Harel Mallac Tanzania Ltd. 15, Kigogo Road, Ubungo Industrial Area PO Box 9474 Dar Es Salaam, Tanzania Phone: 255222451940 Fax: 2550222451939 Website: Export Sales and Service Sigma-Aldrich Chemie Gmbh Munich, Germany Phone: 49 89 6513 1807 Fax: 49 89 6513 1877 Email: deuexport@europe.sial.com Website: Export Sales and Service

Country	Supplier details
Malawi	Sigma-Aldrich Chemie Gmbh Munich, Germany Phone: 49 89 6513 1807 Fax: 49 89 6513 1877 Email: deuexport@europe.sial.com Website: Export Sales and Service
Mozambique	Sigma-Aldrich Chemie Gmbh Munich, Germany Phone: 49 89 6513 1807 Fax: 49 89 6513 1877 Email: deuexport@europe.sial.com Website: Export Sales and Service

Lab equipment supplier

Hach is a scientific materials supplier based in the United States. It has local distributors in most SIMLESA countries (Malawi is serviced by their South African office). You can see each relevant supplier in the table below.

Table 24: List of local Hach distributors for SIMLESA countries

Country	Distributor	Address	Email	Phone
Ethiopia	Ageca (Ethiopia) Company	Gobena Abba Teggu Street, P.O.Box 477, Addis Ababa	ageca@ethionet.et	(251)(1) 1551044/1551306
Kenya	Aquatreat Solutions LTD	MKI House, 1st Floor, Dar Es Salaam Road, Industrial Area, Nairobi	injenga@aquatreat.co.ke	(254) 20 2317314
	Nesvax Innovations Limited	2nd Floor, Odyessey Plaza, Mukoma Road, South B, Nairobi	jpgule@nesvax.com	(254) 020 6552096
Tanzania	Mainland Agencies LTD	Regent House, Plot 964 Olympio Street, Upanga, PO Box 10311, Dar Es Salaam	allen@rtl.co.tz or omar@rtl.co.tz	(255) 22 215 3296 & 215 3298
Malawi	Hach South Africa	n/a	salesza@hach.com and Rbollea@hach.com	27 11 708 3705
Mozambique	Aquarel LDA	Rua DA Juventude N180 Matola	geral@aquarel.co.mz	(258) 82 7179450

Soil sampling equipment suppliers

Cole Parmer is a US-based company that sells scientific sampling equipment such as soil samplers. It ships worldwide.

Cole Parmer, US Office

Telephone: +1 847-549-7600

Fax: +1 847-549-1700

Website: https://www.coleparmer.com/

Email: export@coleparmer.com

5.1.2. Soil sampling equipment

Soil Augurs

For augers 3-inch diameter. Cost at time of publication was US $2220.

http://www.coleparmer.com/Product/Soil_Auger_Kit_with_Carrying_Case_for_3_Diameter_Samples/EW-99026-40

Soil sampling tubes

Tubes for taking soil cores. A range of options with cost at time of publication between US $122 - $268.

https://www.coleparmer.com/p/sampling-tubes/5437

Hand held soil sampling cores

For hand held soil sampling devices which take intact cores (suitable for Bulk Density measurements. Cost at time of publication was US $58.50.

https://www.coleparmer.com/i/lamotte-1055-ep-handheld-soil-sampler-10-length-1-core-diameter/9902700

5.1.3. Balances (field and lab)

Field balances are sold by many suppliers and shopping around can save you money. We have listed several suppliers below. Note that Hach also supplies lots of other lab equipment and has local distributors in each SIMLESA country except for Malawi. The details of these distributors is included in the section on soil nitrate testing equipment (page 72). At the time of publication, the BR ML-T field balance from Hach (via local distributor in Nairobi - Sciencescope) was quoted at 532,500 KSh.

https://www.hach.com/instruments/balances/family?productCategoryId=35547105112

5.1.4. Soil pH test kits

A pH test strip kit available for online purchase in Kenya. This kit has enough colour strips to test 1600 samples indicating a pH value between 1-14. Price at time of publication was KSh 530.

http://www.kilimall.co.ke/item-489950-20pcs-1-14-acid-alkaline-paper-ph-indicator-test-strips-litmus-lab-tester-1600-as-picture.html

5.1.5. Whatman filter paper

GE Life Sciences

GE Life Sciences reportedly supplies to Africa via local distributors. GE supply **the full range of Whatman filter paper.** You need to look at the size of your sample tube to select the appropriate filter paper diameter (filter paper should be greater in diameter than your sealable sample tubes where soil and water is being mixed together). The site below includes a tool to help you find the right filter product for your work.

http://www.gelifesciences.com/webapp/wcs/stores/servlet/catalog/en/GELifeSciences/service-and-support/whatman-filter-selector

The **No. 42 ashless paper** used for soil nitrate testing in Protocol 3.7 is available via GE Health here:

http://www.gelifesciences.com/webapp/wcs/stores/servlet/catalog/en/GELifeSciences/products/AlternativeProductStructure_16163/28418038

It is also possible to use **syringe filters** instead of Whatman paper itself. This is recommended as being the easiest filtration system by Westelaar et al. (1998). The product details as sold by GE Life Sciences are available here:

http://www.gelifesciences.com/webapp/wcs/stores/servlet/catalog/en/GELifeSciences/products/AlternativeProductStructure_27164/29189079

Local distributors for GE Life Sciences can be found by selecting your country in the menu on this site:

http://www.gelifesciences.com/webapp/wcs/stores/servlet/catalog/en/GELifeSciences/about-us/distributors/

Lab Equipment Supplies – Southern Africa

A South African company 'Lab Equipment Supplies' sells Whatman filter paper (along with other lab supplies). You can view their website and Whatman range here:

http://www.labequip.co.za/pg3/2961/filter-paper

Alibaba

Alibaba is a Chinese online marketplace offering a wide range of vendors with delivery options to Africa varying with individual sellers. You can browse their filter paper sellers at the URL below

https://www.alibaba.com/showroom/whatman-filter-paper.html

5.1.6. Soil pH and EC meters + buffer / cleaning solutions

pH meter only

pH Meter Cost at time of publication was US $45

http://hannainst.com/hi98115-hydroponics-ph-tester.html

Pocket pH tester:

https://www.hach.com/pocket-pro-ph-tester-with-replaceable-sensor/product?id=17990686211&callback=pf

Portable pH tester

https://www.hach.com/hq11d-portable-ph-meter-with-gel-ph-electrode-1-m-cable/product?id=7640489893&callback=chem

Two in one pH and EC meters

This pH and EC meter includes a temperature correction and is calibrated very easily. The cost at time of publication was US $159.

http://hannainst.com/hi98131-ph-ec-tds-groline-tester.html

Portable pH tester from Hach:

https://www.hach.com/hq40d-portable-ph-and-conductivity-tds-meter-field-kit-for-environmental-monitoring-with-gel-ph-electrode-and-conductivity-cell-1-m-cable/product?id=7640501641&callback=chem

Soil EC meters only

Cost at time of publication was US $89

http://hannainst.com/hi98331-soil-testtm-direct-soil-ec-tester.html

pH buffer kit

Hach:

https://www.hach.com/ph-buffer-solution-kit-color-coded-ph-4-01-ph-7-00-and-ph-10-01-500-ml-each/product?id=7640205069&callback=chem

Glass Electrode Nochromix detergent

https://www.hach.com/detergent-nochromix-cleaning-reagent-for-cleaning-glass-10-packet-bx/product?id=7640231040&callback=qs

5.1.7. Soil nitrate

Merck Millipore (recommended)

Two types of nitrate test strips are available from Merck Millipore (www.merckmillipore.com). One type measures a range of 3 – 90 mg/L (Catalogue ID: 1169950001) while the other tests the range 5-225 mg/L (Catalogue ID: 1169710001). We recommend using the 3-90mg/L range as this is more suited to low N soils expected for East and Southern Africa. Merck is also the most well-known manufacturer of reflectometers. These are designed to work with the nitrate strips listed above. There are two reflectometer models on the market. The basic RQFlex® Reflectoquant® is suitable for using with test strips to determine soil nitrate accurately and rapidly. The alternative is the RQFlex® Plus Reflectoquant®.

Unfortunately, Merck Millipore does not provide clear price information on their website. You will need to go to their site, select your country and send an inquiry to a sales representative about the product(s) you wish to order. During the drafting of this manual, we contacted Merck to ask for prices of both nitrate strip types as well as their reflectometers (see below). Prices were only given for Australia.

Table 25: Prices for nitrate testing equipment from Merck Millipore specific to each country

Country	Item	Price at time of publication
Australia	Nitrate strips 3 – 90 mg/L (ID: 1169950001)	AU $
	Nitrate strips 5 – 225 mg/L (ID: 1169710001)	AU $
	RQ Flex Reflectometer (Reflectoquant) (ID: 116970)	AU $1458
	RQ Flex Plus Reflectometer (Reflectoquant) (ID: 116955)	AU $

Hach

An alternative supplier to Merck Millipore for nitrate test equipment is Hach. Although it is a US-based company, it has numerous distributors in Africa. You can see a full list at https://www.hach.com/global-distributor-support#africa.

The full Hach catalogue of various test strips is available here: https://www.hach.com/test-strips/test-strips/family?productCategoryId=35547009709

Hach nitrate test strips are developed for measurements between 0 – 50 mg/L which are suited to low N soils expected in most of Africa. You can view this product at https://www.hach.com/nitrate-and-nitrite-test-strips/product?id=7640211606&callback=pf. Hach sells colorimeter reflectometers for use with their nitrate test strips. You can view the product information at https://www.hach.com/pocket-colorimeter-ii-nitrogen-nitrate/product?id=7640442955&callback=pf.

5.1.8. Measuring cylinders and solution bottles

https://www.hach.com/glassware-plasticware/cylinders/family?productCategoryId=35547009750

https://www.hach.com/glassware-plasticware/bottles/family?productCategoryId=35547009747

5.2. Further resources on soil testing, characterisation and management

Open Access Publications

The United States Department of Agriculture (USDA) has developed many useful resources for understanding soil attributes and guides for testing. Their soil health for educators is particularly useful for training staff in soil testing skills. You can find these materials (including factsheets and YouTube videos) at the website below.

https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/assessment/?cid=nrcs142p2_053870

Scientists at the Agricultural Production Simulation Research Unit (APSRU) developed a guide to soil testing for the most critical components needed in crop simulation modelling. The unit is based in Toowoomba, Queensland, Australia and the guide (titled Soil Matters) is tailored to the soils found in south eastern Queensland – particularly in the Darling Downs. Nonetheless, it provides a practical guide to sampling, testing and interpreting key soil components such as bulk density, water holding capacity and nitrogen. Many of the protocols in the SIMLESA Soil Manual were based on this work and readers may find their tips for 'when things go wrong' particularly helpful. You can find the guide online for free at:

https://www.apsim.info/Portals/0/APSoil/Soil%20matters.pdf.

The Food and Agriculture Organization of the United Nations (FAO) has also compiled comprehensive information on the science of soil testing for key characteristics. Their 4th edition of 'Guidelines for Soil Description' was released in 2006 and is freely available online at http://www.fao.org/docrep/019/a0541e/a0541e.pdf.

The Australian Centre for International Agricultural Research (ACIAR) supports international research projects that build understanding and capacity for agricultural research in developing countries. ACIAR has a series of Monographs detailing important project findings and these are available for free online. In particular, Monograph No. 130 by Moody and Cong (2008) provides a guide for upland tropical soils. It is particularly relevant as a guide to soil testing and interpretation for the developing world. You can access this document for free at http://aciar.gov.au/publication/mn130.

Paid publications

The AfSIS project has led to a range of publications on soils in Africa. While most of these require payment to read from academic journals, the abstracts are freely available to read and can nonetheless provide some information on many soil properties. A list of these publications can be found at http://africasoils.net/publications/

The Commonwealth Scientific Industrial and Research Organisation (CSIRO) is Australia's national scientific research body. It has published several valuable books on soil measurement methods. These are usually more suited to research scientists looking for more detailed a technical information on soil testing and interpretation. In particular, we recommend Rayment and Lyons (2011) for soil chemical analysis (http://www.publish.csiro.au/book/6418) and McKenzie et al. (2002) for physical analysis (http://www.publish.csiro.au/book/3147/).

The CSIRO also published an extremely useful handbook by Hazelton and Murphy (2007) called Interpreting soil test results: what do all the numbers mean? This publication is strongly recommended for practical guides in turning soil information into actionable knowledge for farm management. It can be found online here: www.publish.csiro.au/book/7386/.

Another useful but unfortunately paid publication is Juo and Fanzluebbers (2003) Tropical Soils: properties and management for sustainable agriculture. This covers a full range of soil topics for tropical regions at a level suited to soil researchers. It can be purchased online from Amazon, Google, and other online book sellers.

J R Landon's 'Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics' is a valuable further reading resource. It is suited for those looking for a more comprehensive handbook that goes beyond the low-tech options provided for in the SIMLESA Soil Manual, covering the full range of possible analyses needed in soil surveying and evaluation. The 1991 edition of the handbook was republished in 2013 by Routledge. The use of this publication is unfortunately limited by its unavailability online in an open access format. It can be purchased online through 'Book Depository' (www.bookdepository.com) and 'Amazon' (www.amazon.com) and was priced at $101 at the time of publication.

Appendix 1: Input sheets for protocols

A1.1. Site characterisation input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. Be sure to note that a by taking a smartphone into the field (even without internet access), more valuable data can be collected. If you are taking a smartphone into the field, be sure to download a free GPS / altimeter app beforehand so you can record GPS, elevation and calculate slope gradients.

<table>
<tr><td>1a Name of soil surveyor</td><td colspan="4">Name</td><td colspan="8">Family Name</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="8"></td></tr>
<tr><td>1b Contact information</td><td colspan="4">Phone number</td><td colspan="4">Email address</td><td colspan="4">Institution</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>2. Date</td><td colspan="4">Day</td><td colspan="4">Month</td><td colspan="4">Year</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>3. Field GPS coordinates</td><td colspan="4">Latitude</td><td colspan="4">Longitude</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>4. Climate Information</td><td colspan="4">Was there recent rainfall?</td><td colspan="4">If yes, how many days since the rainfall?</td><td colspan="4">How many days of rain?</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td></td><td colspan="4">Was there a recent heat event?</td><td colspan="4">If yes, how many days since heat?</td><td colspan="4">How many days of heat?</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td></td><td colspan="4">Was there a recent frost event?</td><td colspan="4">If yes, how many days since frost?</td><td colspan="4">How many days of frost?</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>5. Landform</td><td colspan="3">Is the field located on a floodplain?</td><td colspan="3">Is the field located on a slope?</td><td colspan="3">Is the field located on a terrace?</td><td colspan="3">Is the field located in a valley?</td></tr>
<tr><td></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>6a. Elevation (optional – requires smartphone)</td><td colspan="12">Measure and record the elevation of the field you are characterising (you can use a smartphone to do this - see notes at the end of this document for instructions)</td></tr>
<tr><td>6b. Estimated Slope</td><td colspan="12">Does the field have a slope (i.e. is it on a hillside)?

Please note if the slope is slight, medium or steep.

If there is a slope, you can measure its gradient using your smartphone (use the instructions notes at the end of this document to fill out the information below).</td></tr>
</table>

6c. Measuring slope gradient NOTE: You will need a smartphone and specialised app for this. See notes at the end of this document for details and advice.	Elevations at top of slope (m above sea level)	Elevation at bottom of slope (m above sea level)	Distance between top and bottom of slope (m)
7. Uniformity	Are there any changes in soil colour within the field?	Are there any notable areas of gravel?	Are there areas with many rocks?
8. Aspect	If the field is on a hillslope, mark which direction it is facing (e.g north, south, northwest, etc)		
9. Drainage	Are there signs of flooding?	Are there signs of ponding?	Does the farmer agree that the field is prone to ponding during rains?
10. Soil surface cover / ground cover	Examine the soil surface. Using the pictures provided in the notes section (at the end of this document) estimate the percentage of soil cover.		
11. Erosion See notes at the end of this document on identifying different types of erosion.	Is there evidence of sheet erosion?	Is there evidence of rill erosion?	Is there evidence of gully erosion?
12. Surrounding vegetation	Make a note of any major grass species growing near the field	Make a note of the types of trees growing near the field.	Make a note of which crops have been grown on this field (for the past 3 seasons)
13. Photos	Take out your smartphone or camera and photograph any important areas of the field (e.g. signs of erosion, soil colour changes, plant species growing, etc.)		

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/EE6XdvOzENpHWcQ

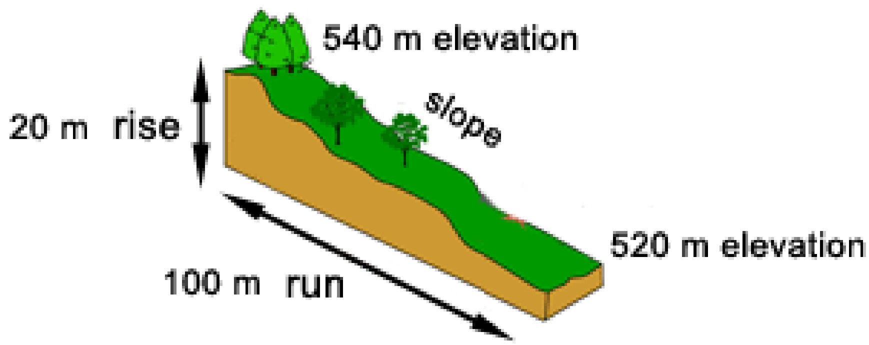
Notes
Calculating the slope of a field

NOTE: If you do not have a smartphone, you will not be able to calculate an estimated slope gradient. In these cases, just note if the field has a slope and mark if it is a slight, medium or steep slope.

Calculating an estimated slope of a field (% gradient) is easy if you have a smartphone. All you need to do is measure the elevation at the top and bottom of the slope and then estimate the distance between the two points. You can get a free on your smartphone that can measure elevation.

- If you have an Android phone we recommend downloading the free 'Accurate altimeter' app from here: https://play.google.com/store/apps/details?id=com.arlabsmobile.altimeterfree&hl=en
- If you use an Apple smartphone, we recommend downloading the free 'Travel Altimeter Lite' app from here: https://itunes.apple.com/au/app/travel-altimeter-lite-gps-altitude-map-elevation/id486556174?mt=8

The picture below demonstrates how to measure elevations and distance and use these to calculate the % slope of the gradient.



$$\text{Slope} = \frac{\text{height difference (m)}}{\text{horizontal difference (m)}}$$

$$\text{Slope} = \frac{540\text{ m} - 520\text{ m}}{100\text{ m}} = \frac{20\text{ m}}{100\text{ m}} = .20 \times 100 = 20\%$$

Estimating the percentage of soil surface cover

An estimation of the amount of soil surface cover can be easy made using photos as a guide.

Below are photos of maize, soybean and sorghum stubble at four different ground cover levels (Shelton and Ajas 1995). Use these as a guide with the farmer to estimate the percentage of ground cover in the field on the day of sampling.

Percentage cover | Maize | Soybean | Sorghum

25%

50%

75%

90%

Identifying the different types of erosion

Sheet erosion

Sheet erosion is the type of erosion that occurs across the entire field surface. It is very hard to observe evidence of sheet erosion. Key questions:

- Are there any areas of the field that are bare (i.e. without soil cover)?
- Are there areas of the field where tree or grass roots are exposed?
- Are there areas where subsoil or stony soils can be seen?
- Is there any build up of soil between the on the hillside and objects in the field that might obstruct erosion (e.g. large rocks, trees, etc.)?
- Can the farmer identify parts of the field that become puddles as soon as there is rainfall?

Rill erosion

Rill erosion is a kind of erosion usually caused by water/rainfall. It occurs when rainfall water runs off down the field slope in small channels. Rills are defined as shallow channels in the soil (less than 0.3 metres deep) where erosion occurs. If the channels are deeper than 0.3 metres this is referred to as 'Gully erosion'.

Figure A1: An example of shallow channels that suggest rill erosion has occurred in a field. (DEHP 2015 - https://www.qld.gov.au/environment/land/soil/erosion/types)

Gully erosion

Gully erosion occurs when water flows enough to displace soil and develop deep trenches (i.e. > 0.3 metres). These often occur with small waterfalls, meaning greater force upon impact. Gully erosion can even erode the subsoil and will eventually cease at the point of the bedrock or parent materials beneath the subsoil – usually at 10 metres. Gullies occur in areas of water flow, and in farmers' fields they can develop if rill erosion is allowed to continue and advance. Gully erosion is especially damaging for both farming activities and nearby infrastructure.

Gully erosion can be caused by a number of different factors. Some soils are simply more erodible and therefore prone to erosion if poorly managed (for grazing or cropping).. Maintaining adequate surface cover (grasses, mulches or other residues) is the best protection against developing erosion.

Figure A2: Example of advanced gully erosion in unconsolidated sediments, southern Africa. This kind of erosion can reach up to 10 metres depth and is very damaging.

Further reading

Read more about gully erosion at: https://www.qld.gov.au/dsiti/assets/soil/gully-erosion.pdf

Read more about different types of erosion at:

https://www.qld.gov.au/environment/land/soil/erosion/types http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/255153/fact-sheet-1-types-of-erosion.pdf

Find more resources on identifying, understanding and managing soil erosion at: http://www.dpi.nsw.gov.au/agriculture/soils/erosion/soil-erosion-factsheets

References

DEHP (2015) Types of erosion. Queensland Department of Environment and Heritage Protection. The State of Queensland. Available at: https://www.qld.gov.au/environment/land/soil/erosion/types. Accessed 1 August 2017.

NSW DPI () http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/255153/fact-sheet-1-types-of-erosion.pdf

Shelton DP, Jasa PJ (1995) G95-1134 Estimating percent residue cover using the photo-comparison method. Historical materials from the University of Nebraska-Lincoln Extension. Paper 782. Available at: http://digitalcommons.unl.edu/extensionhist/782 Accessed 3 August 2017.

A1.2. Soil texture input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This input sheet has space for recording the texture of five soil samples. If you are going to test more samples, print out multiple copies of this sheet document.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.1). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
7-8. Assessing soil texture (Write sample number and depth in this box) Sample number: Sample depth:	What is the 'feel' of the wet soil? (Sandy/gritty, silky)	Will the soil form a ball? (no, only just forms, ball holds together, ball holds together strongly)	How many cm long is the 'ribbon' before it breaks?
7-8. Assessing soil texture (Write sample number and depth in this box) Sample number: Sample depth:	What is the 'feel' of the wet soil? (Sandy/gritty, silky)	Will the soil form a ball? (no, only just forms, ball holds together, ball holds together strongly)	How many cm long is the 'ribbon' before it breaks?
7-8. Assessing soil texture (Write sample number and depth in this box) Sample number: Sample depth:	What is the 'feel' of the wet soil? (Sandy/gritty, silky)	Will the soil form a ball? (no, only just forms, ball holds together, ball holds together strongly)	How many cm long is the 'ribbon' before it breaks?
7-8. Assessing soil texture (Write sample number and depth in this box) Sample number: Sample depth:	What is the 'feel' of the wet soil? (Sandy/gritty, silky)	Will the soil form a ball? (no, only just forms, ball holds together, ball holds together strongly)	How many cm long is the 'ribbon' before it breaks?

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/qhuilKxP9YMjnfJ

Notes

You can classify the soil texture using the information you noted about the soil with the table below.

Table 1: Guide to determining soil texture based on a) whether it will form a ball; b) how many centimetres that ball can be made into a ribbon; and c) the feel, appearance and durability of the wet soil in the hand. Adapted from Dalgliesh and Foale (2005).

Ball	Ribbon (cm)	Feel	Texture
Will not form a ball	0.5	Single grains of sand stick to fingers	Sand (S)
Ball just holds together	1.3-2.5	Feels very sandy, visible sand grains	Loamy sand (LS)
Ball holds together	2.5	Fine sand can be felt	Fine sandy loam (FSL)
Ball holds together	2.5	Spongy, smooth, not gritty or silky	Loam (L)
Ball holds together	2.5	Slightly spongy, fine sand can be felt	Loamy fine sand (LFS)
Ball holds together	2.5-4	Very smooth to silky	Silt loam (SL)
Ball holds together strongly	4-5	Samdy to touch, medium sand grains visible	Sandy clay loam (SCL)
Ball holds together	5-7.5	Plastic, smooth to manipulate	Clay loam (CL)
Ball holds together strongly	>7.5	Plastic, smooth, slight resistance to shearing (breaking when squeezed) between thumb and forefinger	Light clay (LC)
Ball holds together strongly	>7.5	Plastic, smooth, handles like plasticine, can be moulded into rods without fracture, moderate shearing resistance	Medium clay (MC)
Ball holds together strongly		Plastic and smooth, handles like stiff plasticine, can be moulded into rods without fracture, very firm shearing resistance	Heavy clay (HC)

Further reading

FAO (2006) Guidelines for soil description, 4th Edition. (FAO: Rome). Available at http://www.fao.org/docrep/019/a0541e/a0541e.pdf [Accessed 3 August 2017].

Dalgliesh N, Foale M (1998) Soil matters: monitoring soil water and nutrients in dryland farming. Agricultural Production Systems Research Unit, Cranbrook Press: Toowoomba).

USDA (1999) Soil quality test kit guide. United States Department of Agriculture. (USDA: Washington D.C.). Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf [Accessed 3 August 2017]

A1.3. Soil colour input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This input sheet has space for recording the colour of five soil samples. If you are going to test more samples, print out multiple copies of this sheet document.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.2). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
6-7. Assessing soil colour (Write sample number and depth in this box) **Sample number:** **Sample depth:**	Overall Colour (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Is there another colour that could describe this soil? (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Does the soil show mottling? (yes/no)
6-7. Assessing soil colour (Write sample number and depth in this box) **Sample number:** **Sample depth:**	Overall Colour (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Is there another colour that could describe this soil? (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Does the soil show mottling? (yes/no)
6-7. Assessing soil colour (Write sample number and depth in this box) **Sample number:** **Sample depth:**	Overall Colour (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Is there another colour that could describe this soil? (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Does the soil show mottling? (yes/no)
6-7. Assessing soil colour (Write sample number and depth in this box) **Sample number:** **Sample depth:**	Overall Colour (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Is there another colour that could describe this soil? (Black, White, Red, Yellow, Yellow-Brown, Grey/blue-grey, Mottled)	Does the soil show mottling? (yes/no)

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/wOoVI8MpZdlAeQv

Notes

You can determine some likely soil attributes based on the soil colour using the information in the table below.

Table 1: Main soil colour groups, corresponding Munsell chart details, and their characteristics. Adapted from Moody and Cong (2008).

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 Soils derived from limestone under reduced conditions	
White, pale or bleached Red	-/8/<4 10R/-/6-8 2.5YR/-/6-8	Sandy soils 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 2.5YR/<5/2-6	Moderate soil organic matter levels, and some iron oxides	
Greyed, 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

Further reading

FAO (2006) Guidelines for soil description, 4th Edition. (FAO: Rome). Available at http://www.fao.org/docrep/019/a0541e/a0541e.pdf [Accessed 3 August 2017].

Moody P, Cong PT (2008) Soil constraints and management package (SCAMP): guidelines for sustainable management of tropical upland soils. ACIAR Monograph No. 130. (Australian Centre for International Agricultural Research: Canberra). Available at: http://aciar.gov.au/publication/mn130 [Accessed 14 August 2017].

USDA (1999) Soil quality test kit guide. United States Department of Agriculture. (USDA: Washington D.C.). Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf [Accessed 3 August 2017]

A1.4. Soil bulk density input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. In order to calculate final bulk density, you will either need to i) complete a traditional analysis by drying the sample and collecting a final dry weight, or ii) estimate gravimetric water content using Protocol 3.3 on the same sample day.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.2). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
5-7. Sample cylinder volume	Length of sample cylinder (mm)	Diameter of sample cylinder (mm)	Weight of sample cylinder (g)
12. Distance from top of cylinder to soil surface	Measurement 1 (mm)	Measurement 2 (mm)	Measurement 3 (mm)
15. Weight of cylinder and moist soil	Weight of cylinder and field moist soil (g)		
16a ii Weight of cylinder in wet-strength paper bag (Traditional Method)	Weight of cylinder in wet-strength paper bag and wet soil (g)		
16a iv Weight of cylinder and dry soil (Traditional Method)	Weight of cylinder in wet-strength paper bag and dry soil (g)		

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/EE6XdvOzENpHWcQ

Notes

If the traditional drying method is not being performed, an estimated calculation of gravimetric water content is needed to determine the final bulk density. This can be performed using protocol 3.3.

Further Reading

FAO (2006) Guidelines for soil description, 4th Edition. (FAO: Rome). Available at http://www.fao.org/docrep/019/a0541e/a0541e.pdf [Accessed 3 August 2017].

Schmidhalter (2005) Development of a quick on-farm test to determine nitrate levels in soil. Journal of Plant Nutrition and Soil Sciences 168, 432-438.

Dalgliesh N, Foale M (1998) Soil matters: monitoring soil water and nutrients in dryland farming. Agricultural Production Systems Research Unit, Cranbrook Press: Toowoomba).

USDA (1999) Soil quality test kit guide. United States Department of Agriculture. (USDA: Washington D.C.). Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf [Accessed 3 August 2017]

A1.5. Gravimetric water content input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This sheet contains space for recording the data for 5 samples. If more are needed, print multiple copies of the sheet.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.4). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
6-8. Measuring cylinder volume	height of cylinder (mm)	Diameter of cylinder (mm)	Weight of cylinder (with lid) (g)
9-12. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 100mL soil (g)	Final volume of soil and water mixture after 3 minutes shaking (mL)
9-12. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 100mL soil (g)	Final volume of soil and water mixture after 3 minutes shaking (mL)

9-12. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 100mL soil (g)	Final volume of soil and water mixture after 3 minutes shaking (mL)
9-12. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 100mL soil (g)	Final volume of soil and water mixture after 3 minutes shaking (mL)
9-12. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 100mL soil (g)	Final volume of soil and water mixture after 3 minutes shaking (mL)

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/rA76zpP0P2CTwfn

Further reading

Schmidhalter (2005) Development of a quick on-farm test to determine nitrate levels in soil. Journal of Plant Nutrition and Soil Sciences 168, 432-438.

A1.6. Soil pH input sheet – Test kit

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This sheet is for protocol 3.5.1 which uses a pH soil test kit. It contains space for recording the data for 5 samples. If more are needed, print multiple copies of the sheet.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.5.1). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
7. Soil pH readings **Sample number:** **Sample depth:**	Sample number	Sample depth (cm)	Soil pH reading
7. Soil pH readings **Sample number:** **Sample depth:**	Sample number	Sample depth (cm)	Soil pH reading
7. Soil pH readings **Sample number:** **Sample depth:**	Sample number	Sample depth (cm)	Soil pH reading
7. Soil pH readings **Sample number:** **Sample depth:**	Sample number	Sample depth (cm)	Soil pH reading
7. Soil pH readings **Sample number:** **Sample depth:**	Sample number	Sample depth (cm)	Soil pH reading
7. Soil pH readings **Sample number:** **Sample depth:**	Sample number	Sample depth (cm)	Soil pH reading

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/kVWBwCRaZRp6cvj

A1.7. Soil pH input sheet – pH meter

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This sheet is for protocol 3.5.2 which uses an electronic pH meter. This protocol also requires deionized water and a pH buffer solution. It contains space for recording the data for 5 samples. If more are needed, print multiple copies of the sheet.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.5.2). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
6-9. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) (g)	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 50mL soil (g)
16. Soil pH readings Sample number: Sample depth:	Sample number	Sample depth (cm)	pH meter reading
6-9. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) (g)	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 50mL soil (g)
16. Soil pH readings Sample number: Sample depth:	Sample number	Sample depth (cm)	pH meter reading

6-9. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) (g)	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 50mL soil (g)
16. Soil pH readings Sample number: Sample depth:	Sample number	Sample depth (cm)	pH meter reading
6-9. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) (g)	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 50mL soil (g)
16. Soil pH readings Sample number: Sample depth:	Sample number	Sample depth (cm)	pH meter reading
6-9. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth:	Weight of cylinder (with lid) (g)	Weight of cylinder (with lid) + 250mL water (g)	Weight of cylinder (with lid) + 250mL water + 50mL soil (g)
16. Soil pH readings Sample number: Sample depth:	Sample number	Sample depth (cm)	pH meter reading

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/kVWBwCRaZRp6cvj

A1.8. Soil EC input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This sheet is for protocol 3.6 which uses an electronic EC meter. The protocol also requires you use deionized water. It contains space for recording the data for 5 samples. If more are needed, print multiple copies of the sheet.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.6). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
6-8. Tube and water weight, water EC value (record sample number and depth) Sample number: Sample Depth:	Weight of falcon tube (with lid) (g)	EC meter reading of 35mL of water	
9-17. Soil weight, mixture volume and EC readings Sample number: Sample depth:	Weight of soil sample (g)	Final soil-water solution volume after mixing (mL)	EC meter reading of soil-water mixture
6-8. Tube and water weight, water EC value (record sample number and depth) Sample number: Sample Depth:	Weight of falcon tube (with lid) (g)	EC meter reading of 35mL of water	
9-17. Soil weight, mixture volume and EC readings Sample number: Sample depth:	Weight of soil sample (g)	Final soil-water solution volume after mixing (mL)	EC meter reading of soil-water mixture

6-8. Tube and water weight, water EC value (record sample number and depth) Sample number: Sample Depth:	Weight of falcon tube (with lid) (g)	EC meter reading of 35mL of water

9-17. Soil weight, mixture volume and EC readings Sample number: Sample depth:	Weight of soil sample (g)	Final soil-water solution volume after mixing (mL)	EC meter reading of soil-water mixture

6-8. Tube and water weight, water EC value (record sample number and depth) Sample number: Sample Depth:	Weight of falcon tube (with lid) (g)	EC meter reading of 35mL of water

9-17. Soil weight, mixture volume and EC readings Sample number: Sample depth:	Weight of soil sample (g)	Final soil-water solution volume after mixing (mL)	EC meter reading of soil-water mixture

6-8. Tube and water weight, water EC value (record sample number and depth) Sample number: Sample Depth:	Weight of falcon tube (with lid) (g)	EC meter reading of 35mL of water

9-17. Soil weight, mixture volume and EC readings Sample number: Sample depth:	Weight of soil sample (g)	Final soil-water solution volume after mixing (mL)	EC meter reading of soil-water mixture

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/YZp3Ubz5LGBcTRR

A1.9. Soil nitrate input sheet

Before going to the field for soil testing, the investigator and their supervisor should review this sheet together. This sheet is for recording data when completing nitrate analysis using protocol 3.7.2. Note that it is advised researchers test standard solutions of known nitrate concentrations to control for temperature effects in conditions below 15°C or above 25°C. Standard solutions can be prepared using Protocol 3.7.1. This document contains space for recording the data for 5 samples. If more are needed, print multiple copies of the sheet.

Be sure to check over all the materials you will need to complete this analysis (see Protocol 3.7.2). It is highly recommended that a site characterisation is completed (see Protocol 2.2). If this is not completed, bring a smartphone and record the GPS coordinates of the field.

1a Unique Field Code (from site characterisation)			
2a Name of soil surveyor	Name	Family Name	
2b Contact information	Phone number	Email address	Institution
3. Date	Day	Month	Year
4. Field GPS coordinates (To be completed only in the absence of site characterisation)	Latitude	Longitude	
6-8. Measuring cylinder volume	height of cylinder (mm)	Diameter of cylinder (mm)	Weight of cylinder (with lid) (g)
9-18 & 30-34. Soil and water weight and volume (record sample number and depth) Sample number: Sample Depth: Number of bulked cores in sample:	Weight of cylinder (with lid) + 250 mL water (g)	Weight of cylinder (with lid) + 250 mL water + 100 mL soil (g)	Final volume of soil and water mixture after shaking (mL)
	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
24-28. Tap water nitrate measurements	Nitrate strip test reading 1	Nitrate strip test reading 2	Nitrate strip test reading 3

<table>
<tr><td rowspan="4">9-18 & 30-34. Soil and water weight and volume
(record sample number and depth)
Sample number:
Sample Depth:
Number of bulked cores in sample:</td><td>Weight of cylinder (with lid) + 250 mL water (g)</td><td>Weight of cylinder (with lid) + 250 mL water + 100 mL soil (g)</td><td>Final volume of soil and water mixture after shaking (mL)</td></tr>
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<tr><td>Nitrate strip test reading 1:</td><td>Nitrate strip test reading 2:</td><td>Nitrate strip test reading 3:</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="4">9-18 & 30-34. Soil and water weight and volume
(record sample number and depth)
Sample number:
Sample Depth:
Number of bulked cores in sample:</td><td>Weight of cylinder (with lid) + 250 mL water (g)</td><td>Weight of cylinder (with lid) + 250 mL water + 100 mL soil (g)</td><td>Final volume of soil and water mixture after shaking (mL)</td></tr>
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<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="4">9-18 & 30-34. Soil and water weight and volume
(record sample number and depth)
Sample number:
Sample Depth:
Number of bulked cores in sample:</td><td>Weight of cylinder (with lid) + 250 mL water (g)</td><td>Weight of cylinder (with lid) + 250 mL water + 100 mL soil (g)</td><td>Final volume of soil and water mixture after shaking (mL)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Nitrate strip test reading 1:</td><td>Nitrate strip test reading 2:</td><td>Nitrate strip test reading 3:</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="4">9-18 & 30-34. Soil and water weight and volume
(record sample number and depth)
Sample number:
Sample Depth:
Number of bulked cores in sample:</td><td>Weight of cylinder (with lid) + 250 mL water (g)</td><td>Weight of cylinder (with lid) + 250 mL water + 100 mL soil (g)</td><td>Final volume of soil and water mixture after shaking (mL)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Nitrate strip test reading 1:</td><td>Nitrate strip test reading 2:</td><td>Nitrate strip test reading 3:</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Testing nitrate standard solutions in the field (temperature calibration) – highly recommended!

38. Testing Standard concentration:	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
0 ppm nitrate (Deionized water)			
38. Testing Standard concentration:	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
5 ppm nitrate			
38. Testing Standard concentration:	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
10 ppm nitrate			
38. Testing Standard concentration:	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
20 ppm nitrate			
38. Testing Standard concentration:	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
50 ppm nitrate			
38. Testing Standard concentration:	Nitrate strip test reading 1:	Nitrate strip test reading 2:	Nitrate strip test reading 3:
100 ppm nitrate			

An excel spreadsheet for entering the data collected on this input sheet is available at:

https://cloudstor.aarnet.edu.au/plus/index.php/s/u8hwzbCZJV9rpQX

Further reading

Schmidhalter (2005) Development of a quick on-farm test to determine nitrate levels in soil. Journal of Plant Nutrition and Soil Sciences 168, 432-438.

ETHIOPIA KENYA MALAWI MOZAMBIQUE TANZANIA AUSTRALIA

QAAFI Queensland Alliance for Agriculture and Food Innovation

CIAT Centro Internacional de Agricultura Tropical

ASARECA Transforming Agriculture for Improved Livelihoods

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ILRI