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A field manual for soil health assessment by farmers

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Photos 2 and 3. Soil health testing in Africa. CIAT/Georgina Smith.
Photo 4. Bean seeds sprouting in healthy soil. CIAT/Georgina Smith.

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The views expressed in this document are those of the authors and cannot be taken to reflect the official opinions of these organizations.

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Preface

The importance of soil has been recognized since Vedic times. Political leaders such as American President Franklin Roosevelt and Mahatma Gandhi, the father of India, have emphasized the importance of soil. Soil health is the foundation of sustainable agriculture. Healthy soils not only support high yields but also ensure high efficiency of utilization of applied inputs as well as natural resources. It is, therefore, imperative that soil health is assessed so that corrective action can be taken as and when required. Therefore, soil health assessment is a continuous process.

This manual presents a set of indicators and their measurements, adapted for easy application in the field for assessing soil health. It is hoped that this will be useful as a reference manual for farmers to assess the soil health status of their fields themselves. This manual also gives some basic information on the indicators, which is expected to be useful for field extension workers to understand the functions of the different soil health indicators and help in adapting the management practices to effectively overcome any constraints.

Contents

Photo: CIAT/G. Smith

Introduction

Soil resource management is an important element for increasing crop yields and meeting the needs of a growing population; therefore, soil health has ramifications for food security.

What determines soil health? In addition to soil's physical and chemical properties, biological properties play a critical role in maintaining soil productivity.

By conducting extensive soil testing, it is possible to identify deficient nutrients and develop recommendations to supplement these deficient nutrients through external application; however, nutrient recommendations alone are not enough to maintain sustainable yields.

Assessment of soil health is one of the tools at the hands of farmers that can inform decisions related to maintenance of soil and productive capacity, hence a very important component of citizen science.

Research studies have prioritized a number of physical, chemical and biological indicators of soil health, and easy-to-use assessment kits have been developed for assessment by the farmers themselves.


Photo: Bioversity International/S. Padulosi

However, soil health assessment and its practical use in management decisions is still at an early stage. To address this, studies to develop a holistic soil health assessment framework were carried out under the German Federal Ministry for Economic Cooperation and Development (BMZ)/Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), under project No. 16.7860.6-001.00 Contract No 81206856) and ICAR–Bioversity International workplan.

One of the project activities involved training farmers to be aware of and assess the three dimensions of soil health. During the training, the need for a pictorial “Do it Yourself” manual was realized.

This manual, therefore, compiles a set of simple indicators and the methods of their assessment, to be used as a reference by farmers for soil health assessment of their fields. As a first step to present soil health assessment protocols, adapted in a manner for easy adoption by farmers, the manual uses pictorial depictions of the protocols with minimum text content.

While a number of factors contribute to soil health, eight indicators have been widely used and are known to be critical. The protocols for estimation of these eight indicators are described in this manual.

The first step to assess soil health is choosing the monitoring sites. This should be based on soil type and land management units. It is important that the sites chosen represent actively farmed areas and are within the same soil type and land management unit.

Sampling from at least 5 points along a transect needs to be carried out for each field. This needs to start from an identifiable point in the field. The spacing of each of the 5 sample points may be decided based on the size of the field, but should preferably be of at least 5 meters. At each of the 5 sample points, a sample of soil may be dug out using a spade so as to get two cubes of soil that are approximately 20 x 20 x 20 cm for estimation of those indicators which do not require *in situ* measurement.

Regarding frequency of soil health assessment, it is recommended at least once a year. Sampling around the same time each year is also important for effective comparison of the indicator status over the years. Moreover, in areas with seasonal rainfall, it is important to choose the time of the year when the soil is moist (near the field capacity) i.e. neither too dry nor too wet. The collected soil may be air dried in shade and stored in clean muslin cloth bags for analysis.


Photo: CIAT/G. Smith

Soil pH

What is soil pH?

- Soil pH refers to the acidity or alkalinity of soil.
- Soils with pH lower than 7 are acidic and soils with pH above 7 are alkaline soils.
- Values between 6.5 and 7.5 are ideal (most nutrients have maximum availability in this range).
- At pH ranges 6.0 to 6.5 and 7.5 to 8.0 ameliorative action through management practices may be sufficient.
- In soils with pH less than 6.0 or more than 8.0, application of soil amendments would be required.

Photo: CIAT/N. Palmer

Why is soil pH important?

- Soil pH affects the soil's physical, chemical, and biological properties that are vital for plant growth.
- At very low or high pH, the availability of many essential macro and micro nutrients is affected. The figure on page 8 shows that the band of nutrient availability is broad at pH range 6.5 to 7.5, indicating high availability of most nutrients at this pH range.
- Soil microbial activity is also optimum at a pH of 6.5–7.5.
- At very low or high pH, the breakdown of organic matter and release of nitrogen is reduced because of poor microbial activity.
- Soil structure is also degraded at high soil pH leading to detrimental effects on plant growth.

Nutrient availability at different pH ranges

Rating:

If soil pH is less than 6.5, it is acidic soil

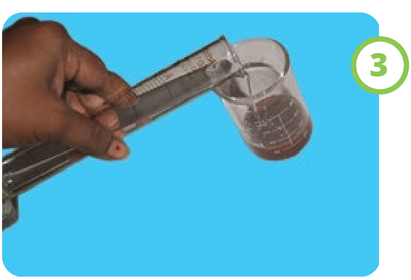
If soil pH is more than 7.5, it is alkaline soil

If soil pH is between 6.5 and 7.5, it is considered as having optimum pH.

How is soil pH measured?

Place 20 g of soil in a beaker.

Measure 50 ml of distilled water.



Add the 50 ml of distilled water to the soil in the beaker.

Mix well using a glass rod and allow the soil to settle to the bottom of the beaker.

Take a strip of litmus paper.

Dip the litmus strip into the supernatant solution in the beaker.

Remove the strip after a minute and compare the colour of the strip with the standard colours of different pH ranges, noting the corresponding pH range. This is the pH of the soil sample.

Water Stable Aggregates

What are water-stable aggregates?

- *Soil aggregate* refers to the soil clods formed through root exudates and activities of soil fauna (e.g. earthworms) and microorganisms (e.g. fungi) which bridge soil particles together.
- The ability of the aggregates to hold together in spite of the disruptive action of water is referred to as aggregate stability, e.g. splashing impact of raindrops.
- When aggregates are not strong enough to withstand internal stresses caused by rapid water uptake, it leads to the break up of soil particles which is called slaking.
- Therefore, a soil with high water stable aggregates is desirable.

Why are water-stable aggregates important?

- Soils with high aggregate stability will have good porosity/ aeration, water holding capacity, organic matter protection and will also promote root penetration and microbial activity.
- Poor water-stable aggregates lead to loss of organic matter and settle the soil particles into the soil pores.
- This causes sealing of the soil surface, which is called crusting.
- Crusting leads to reduction of infiltration and thus water available to the plant roots.
- Reduced organic matter and infiltration leads to increased runoff and soil erosion.

How is soil water aggregate stability measured?

Pour a little water (enough to make about 1 cm layer of water) in a glass petri dish.

Place a small soil clod (3-5 mm) collected from 10 cm soil depth and air dried for 1-2 days at the centre of the petri dish.

Observe the slaking of the soil clod after 10 minutes and rate the extent of slaking as given in the table below.

Nil Slaking	Slight Slaking	Strong: Up to 70% Slaking	Complete Slaking
Very Good (score 3)	Good (score 2)	Moderate (score 1)	Poor (score 0)
No slaking at all	Only clod edges collapse	Up to 70% collapse	Complete collapse

Soil Porosity

What is soil porosity?

- Soil porosity is the proportion of a given volume of soil that is unfilled space (also called pore space).
- Soil porosity indicates the amount of space available for water and air.
- Soil porosity can be due to texture of the soil, i.e. light soils have higher porosity.
- Soil porosity is also caused by good soil structure, i.e. soils with a crumbly structure have higher porosity.

Why is soil porosity important?

- Soil porosity facilitates air and water movement in soil that is critical for root growth, as well as for hosting soil fauna and microbes.
- Soils with optimum porosity (10–25 %) facilitate unhindered root growth and can also retain high amounts of water and organic matter.
- Soil porosity indicates the compactness of the soil and thus indicates the need for changes in soil management.
- Soil porosity is one of the best indicators of soil health.

Calculation to ascertain soil porosity

Pore volume = (B−C)

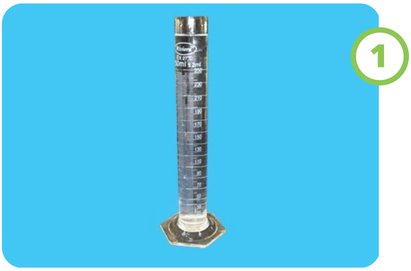
Total volume = 200 + (B−C)

Porosity = (Pore volume/Total volume) *100

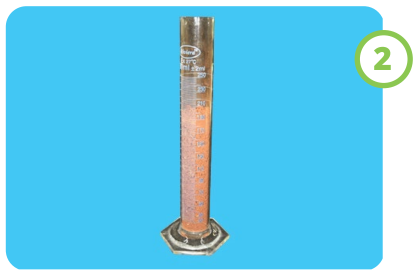
Rating for soil porosity

Soil compactness	% pore space
Soil is very compact	< 5
Soil is compact	5–10
Soil is moderately porous	10–25
Soil is highly porous	25–40
Soil is extremely porous	> 40

How is soil porosity measured?



Take a cylinder with 200 ml of water and mark its level as (A).



Remove the water and fill the cylinder up to the level marked (A) with soil tapping gently intermittently.

In another cylinder, take 300 ml of water (B) and slowly pour this water into the cylinder (A) containing the soil sample until the soil is saturated, i.e. a thin film of water is seen at the top of the soil layer. Note the volume of water left in the cylinder (C).

Calculate the volume of water added to bring the soil to saturation (B-C) and calculate pore space as given.

Soil Texture

What is soil texture?

- Soil texture refers to the proportion of different sized soil particles, i.e. sand, silt and clay, present in a soil sample.
- It also indicates the workability of the soil, its water and nutrient retention and supplying capacities.
- By knowing the soil texture, management practices can be tailored accordingly.

How is soil texture measured?

Take enough soil to fit into the palm of your hand, removing any large stones, twigs, etc.

Moisten the soil with water, a little at a time, and knead to form a ball of soil that just fails to stick to your fingers. Work the soil in this manner for one to two minutes. Inspect the sample to see if sand is visible. Even if not visible, it may still be felt or heard as the sample is worked.

Why is soil texture important?

- Soil texture affects drainage, water holding capacity, aeration and susceptibility to erosion.
- Coarse-textured soils have high drainage, low water holding capacity and are more prone to water and wind erosion than fine textured soils.
- Soil texture further determines the cation exchange capacity and thus the capacity of the soils to retain essential nutrients.
- The type of crops and many of its management practices are determined by the texture of the soil.

If ball shape is not formed, add slightly more water and knead it so that the soil becomes sticky.

Moisten the soil with water, a little at a time, and knead until the ball of soil just fails to stick to your fingers.

Squeeze and feed the ball out between thumb and forefinger to form a ribbon.

Note the maximum length of self-supporting ribbon formed and determine the texture as per explanation overleaf.

Based on the ball formation, length of ribbon and feel decide the texture as below.

- If balls are not formed, ribbon length is less than 0.5 cm and feel is that single grains of sand stick to fingers then the texture is **SAND**.
- If balls just hold together, ribbon length is 1.3 to 2.5 cm and feel is very sandy and single grains of sand are visible then the texture is **LOAMY SAND**.
- If balls hold together, ribbon length is about 2.5 cm and feel is slightly spongy; fine sand can be felt then the texture is **LOAMY FINE SAND**.
- If balls hold together, ribbon length is 1.3 to 2.5 cm and feel is that fine sand can be felt then the texture is **FINE SANDY LOAM**.
- If balls hold together, ribbon length is about 2.5 cm and feel is spongy smooth not gritty or silky then the texture is **LOAM**.
- If balls hold together, ribbon length is about 2.5 cm and feel very smooth to silky then the texture is **SILT LOAM**.
- If balls hold together very strongly, ribbon length is 2.5 to 4.0 cm and feel is sandy to tough and medium sand grains are visible then the texture is **SANDY CLAY LOAM.**
- If balls hold together, ribbon length is 5.0 to 7.5 cm and feel is plastic, smooth slight resistance to shearing between thumb and forefinger then the texture is **LIGHT CLAY**.
- If balls hold together strongly, ribbon length is > 7.5 cm and feel is plastic, smooth, handles like plasticine; can mould into rods without fracture; moderate shearing resistance, then the texture is **MEDIUM CLAY**.
- If balls hold together strongly, ribbon length is > 7.5 cm and feel is plastic and smooth, handles like stiff plasticine; can mould into rods without fracture; very firm shearing resistance, then the texture is **HEAVY CLAY**.

Photo: CIAT/G. Smith

Soil with a high proportion of:

Sand - will feel gritty

Silt - will feel silky

Clay - will feel sticky

Infiltration Rate

What is infiltration rate?

- When water is applied to the soil, either through rain or irrigation, some of the water is lost through runoff and the rest enters into the soil. The process of entry of the water into the soil is called infiltration.
- The rate at which the water enters the soil is the infiltration rate.
- Infiltration rate is dependent on soil texture, structure, compaction, organic matter content and surface crusts.

Why is infiltration rate important?

- Rain or irrigation water must first enter into the soil to be of value to crops.
- In soils with high infiltration rate, most of the water would enter the soil and would be available to the plants.
- If infiltration rate is poor, then the water would move out of the fields by surface runoff causing erosion as well as carrying away nutrients.

Typical values infiltration rates of different soil types

Soil type	Infil. rate mm/h
Clay	2.5
Silty loam	4.0
Clay loam	5.0
Loam	5.0
Fine sandy loam	6.5
Sandy loam	6.5
Loamy sand	9.0
Sand	10.0

How is infiltration rate measured?

1

Take a PVC cylindrical core of about 15 cm length.

2

Push the cylindrical core slightly into the soil so that it is tightly fixed in the soil and about 8 cm is above the soil. It is important that the core is tightly fixed in the soil.

3

Pour a measured quantity of water into the core e.g. 250 ml.

4

Note the time taken for the water to completely soak into the ground.

5

The time taken for 250 ml water to completely enter the soil is taken as the infiltration rate expressed as ml/hr.

Water Holding Capacity

What is water holding capacity?

- It is the amount of water that a given volume of soil can hold.
- In soils with low water holding capacity, the water would either percolate beyond the root zone as drainage loss or flow out of the field as surface runoff.

Why is water holding capacity important?

- Water holding capacity indicates the amount of water that is available for plant growth.
- Soils rich in organic matter generally have high water holding capacity i.e. they can retain a high proportion of the irrigation water or rainfall and thus support plant growth for a longer period before the next irrigation or rainfall.
- Water holding capacity is another soil property which can be used as a management technique to overcome limitation due to the soil property.

Rating

Figures are mean values and may vary with structure and organic matter content of the soil.

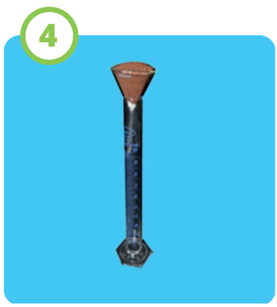
Soil type	Status	Water holding capacity %
Coarse sand	Poor	<6.0
Fine sand		6-10
Loamy sand	Average	10-14
Sandy loam		14-20
Light sandy clay loam		20-23
Loam	Optimum	23-27
Sandy clay loam		27-28
Clay loam	Good	28-32
Clay		32-40

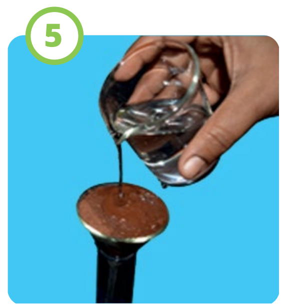
How is water holding capacity measured?

Take 100 ml of air dry soil.

Take a funnel and close the neck of the funnel with a little cotton.

Put the soil sample on the funnel and gently tap it to make it compact as in natural field condition.





Place the funnel with soil on the measuring cylinder and gently pour 100 ml of water on the soil.

After pouring all the 100 ml water, wait for one hour for the last drop of excess water to drain into the cylinder. Measure the drained water using a measuring cylinder.

100 minus drained water volume = water holding capacity of the soil (expressed in percentage)

Soil Bulk Density

What is bulk density?

- It is the amount of soil particles that are packed in a given volume of soil.
- Hence, bulk density indicates the compactness of the soil.
- Lower bulk density means the soil is less compact.

Why is bulk density important?

- It indicates the extent of soil compaction.
- It reflects the soil's ability to provide structural support since compactness diminishes soil structure and thus root penetration, resulting in poor plant growth.
- The water and solute movement as well as aeration, soil fauna and microbial activities are also restricted in compact soils.
- Bulk density is another property which can be manipulated and can be used to minimize the adverse impact soil property.

How is bulk density measured?

Core Method (No sub sampling)

- Drive a cylindrical metal sampler into either a vertical (after opening a pit) or horizontal soil surface far enough to fill the sampler with soil.
- Remove the sampler and its contents and transfer the soil to a tray of known weight.
- Place it in an oven at 105°C for 24 hours or sun dry for 3-4 days or more till the soil appears fully dry and weigh it again.

Calculations

- Weight of empty tray = **M1 g**
- Weight of the tray + Oven dry soil = **M2 g**
- Weight of oven dry soil **(M3) = M2-M1 g**
- Volume of bulk sample i.e. of core sampler **(V cm^3)** = $\pi r^2 h$ (cm^3)
- Where **r** is the radius in cm, and **h** is the height of the core in cm.
- **Bulk density =** Dry wt of bulk soil sample ÷ Volume of soil core
- **Bulk density = M3 / V (gm/cm^3)**

Rating

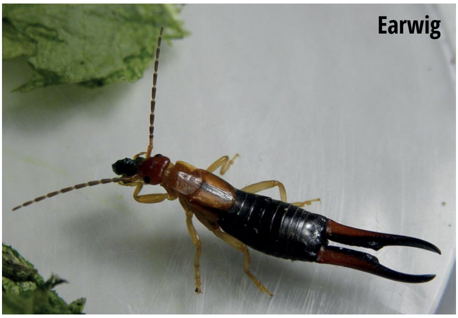
Figures are mean values and may vary with structure and organic matter content of the soil.

<table>
<tr><th>Soil type</th><th>Bulk density g.cm3</th><th>Status</th></tr>
<tr><td>Coarse sand and fine sand</td><td>1.80</td><td rowspan="3">Poor</td></tr>
<tr><td>Loamy sand and sandy loam</td><td>1.75</td></tr>
<tr><td>Loam and sandy clay loam</td><td>1.70</td></tr>
<tr><td>Clay loam</td><td>1.65</td><td rowspan="2">Average</td></tr>
<tr><td>Sandy clay</td><td>1.60</td></tr>
<tr><td>Silt and silt loam</td><td>1.55</td><td rowspan="2">Optimum</td></tr>
<tr><td>Silty clay loam</td><td>1.50</td></tr>
<tr><td>Clay</td><td>1.40</td><td>Good</td></tr>
</table>

Soil Macro Fauna

What is soil macro fauna?

- Soil is a living entity.
- It is inhabited by a wide range of macro and micro organisms.
- Soil organisms that have body widths >2 mm and can be seen with the naked eye are macro organisms.
- The diversity and population of macro fauna are an indicator of soil biological health.



Why soil macro fauna is important?

- Soil macro fauna are involved in shredding of plant residues.
- Soil macro fauna are involved in organic matter decomposition and nutrient cycling.
- As ecological engineers, they provide a congenial environment for the growth of roots.
- They also play a role in pest regulation.

How is soil macro fauna recorded?

- Examine the soil surface for holes and casts.
- Excavate soil from a 10 cm x 10 cm area to a depth of 10 cm.
- Examine the macro fauna present in this soil volume. You may find the fauna as shown in the photographs visible to the naked eye.
- Count the number and type of each macro fauna present in this soil volume.

Rating

Good	Many holes and casts - > 7 worms or macro life
Fair	Few holes and casts – 4 - 6 worms or macro life
Poor	No or little sign of worm activity 0 – 3 worms or macro life

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Glossary

Casts	Refers to the excreted material of earthworms.
Crusting	Refers to sealing of the soil surface.
Infiltration rate	Refers to the rate of entry of water into the soil. Soils with high infiltration rate will absorb most of the water and runoff losses would be minimal.
Litmus paper	Are chemical-coated paper strips which give different colours depending upon the soil pH when dipped in supernatant soil solution.
Porosity	Is the amount of air space in the soil.
Slaking	It is the process of breaking up soil particles or disintegration of clods i.e. moving apart of soil particles.
Soil aggregates	Small soil clods formed through binding of soil particles.
Soil macro fauna	Refers to the fauna in the soil which can be seen with the naked eye when soil is dug and spread out.
Soil structure	Arrangement of sand, silt and clay particles in the soil.
Soil texture	The proportion of sand, silt and clay particles in a given soil sample.
Water holding capacity	The amount of water that the soil can hold without allowing it to leach out of the root zone.

Photo: CIAT/G. Smith

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Bioversity International and the International Center for Tropical Agriculture (CIAT) are part of CGIAR, a global research partnership for a food-secure future.

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