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HuMUS
Healthy Municipal Soils

Factsheets with quick and easy methods to carry out soil health assessments

Deliverable D1.1

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Preface

Soil health is vital not only for food production but also for the environment, human well-being, and our economy. It warrants an equal level of protection as afforded to water, air, and the marine environment. Currently, over 60 % of European soils are in an unhealthy state[1]. For this reason, major efforts have been made in the last few years to protect soils, for example within the EU Soil Strategy 2030 and the Mission: A Soil Deal for Europe. In July 2023 the EU proposed a new Soil Monitoring Law[1] to protect and restore soils, and ensure that all soil ecosystems are in an healthy condition by 2050.

Safeguarding soil health inherently encompasses the imperative of conducting soil health assessments. Consequently, there is a need for the development of accessible on-site methods and tools to facilitate soil health testing in the field. This manual introduces such a method to evaluate the soil health condition without the need for expensive instruments in relation to the eight EU Mission Soil objectives. This guide also includes some basic information on soil health and descriptors.

Summary

The factsheet describes and defines what soil and soil health is, as well as why soil health is so important for mankind. The factsheet is focused on physical, chemical and biological characteristics of soil health that are all linked to important soil functions. The factsheet gives an overview how to sample soil and what materials are needed. The factsheet provides seven easy in field soil health assessment methods that can be carried out by all the stakeholders involved in the HuMUS project. The information gathered through this deliverable will be crucial for the dialogues performed in WP2 of the HuMUS project.

1. Introduction

1.1. What is soil?

Soil is not an inert growing medium—it is a living and life-giving natural resource. Soil is the top layer of the Earth's crust situated between the bedrock and the land surface, which is composed of mineral particles, organic matter, water, air, and living organisms[1].

> INFOBOX. *Soil* is defined as "the top layer of the Earth's crust situated between the bedrock and the land surface, which is composed of mineral particles, organic matter, water, air, and living organisms"[1]

Soil is the principal substrata for life on earth and the source of nutrients and water for plants, as well as for their structural support. It is a habitat for various organisms, contributes to water filtration, pH buffering and purification, and plays a role in carbon and nutrient cycling. Soil can vary greatly in its physical, chemical, and biological properties. Processes such as leaching and weathering, influenced by the parent material and microbial activity, interact to create a whole range of different soil types. The diversity of soils is immense, and every type of soil has its own properties.

[1] Directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law); 2023

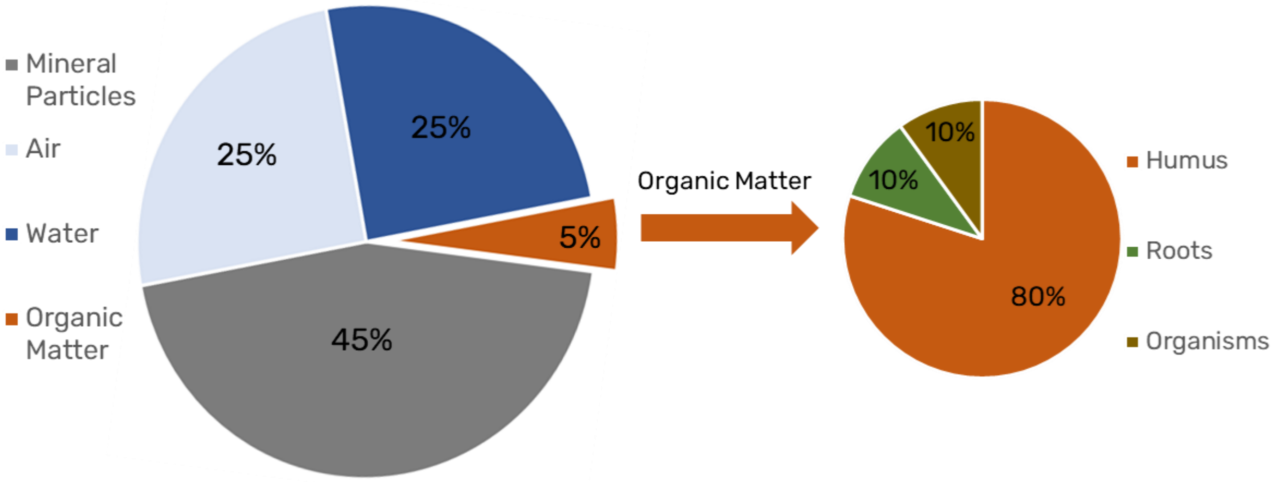

Figure 1. Components of soil

The basic components of soil are minerals, organic matter, water, and air (figure 1).

The mineral fraction is usually the largest (approximately 45%) and includes primary minerals such as silicates as well as secondary minerals derived from the weathering of the former. The grain size of the mineral particles and aggregates determines the physical and chemical characteristics of soil. The chemical characteristics of soil determine soil fertility. The majority of soil consists of minerals that are composed by arrays of silicate ions (SiO_4^{4-}) together with charged ions (e.g. sodium, potassium, calcium, ammonium, iron, phosphate). The surface charge of those molecules defines the chemical reactivity of the soil. Clay are very fine particles (<0.002 mm), followed by silt (0.002-0.05 mm) and sand (0.05-2 mm). The porosity and structure of soil determines the capacity of soil to hold air and water and transport fluids.

Water is in most cases the second largest component (approximately 25%) of soil and is essential for the survival of all living organisms. Water is responsible for most of the transportation of nutrients to plant roots and necessary for all the chemical reactions in soil.

Soil air is the air (approximately 25%) that occupies the tiny spaces or pores within the soil. It is a crucial component of the soil ecosystem, with a composition similar to the Earth's atmosphere, although proportions may vary. Soil air is important for supporting plant growth as it provides oxygen for root respiration. The availability of oxygen in soil air is essential for plant roots to carry out metabolic processes and extract nutrients from the soil.

The smallest component of soil is organic matter (approximately 0.5-10%), however it is one of the most important. Soil organic matter is described as the non-living product of the decomposition of plant and animal substances. It determines both physical and chemical properties of soil, as well as nutrient cycling, cation exchange capacity, buffering pH, and detoxification of hazardous elements. Organic matter has high "plant-available" water holding capacity, which can enhance the growth potential of soils with poor water holding capacity, such as sand. Thus, the percent of decomposed organic matter in or on soils is often used as an indicator of soil productivity or fertility.

Soils are biologically extremely active environments, the habitat of a plethora of living organisms. One kilogram soil may contain 500 billion bacteria and 1 billion fungi. Mites, springtails, earthworms, millipedes, thousands of insects and of course plants inhabit soil. The microbial activity influences and enables nutrient cycling (for example carbon and nitrogen cycles) and the buildup of humus in the soil.

1.2. Why is soil so important?

As the global population and the need for food production continue to increase, maintaining the health and productivity of soil is vital. According to the European Union "*Soil health*" means the physical, chemical, and biological condition of the soil determining its capacity to function as a vital living system and to provide ecosystem services[2]. The benefits of healthy soil go far beyond crop production. Ecosystem services of soil include nutrient cycling, support of plant growth and productivity, energy provision, carbon sequestration, support of biodiversity, habitat provision, prevention of erosion, buffering of pH, regulation of disease or water management and filtration, natural hazard regulation, and cultural preservation. These ecosystem services highlight the importance of soil in supporting life and maintaining the health and functionality of ecosystems for humans. It is essential to manage soil resources sustainably to ensure the continued provision of these ecosystem services for current and future generations. Unfortunately, intensive agricultural production, industrialization, and environmental pollution has brought over 60% of EU soils into an unhealthy state. When soil is not functioning to its full capacity, sustainable productivity, environmental quality, and net farmer profits are threatened over the long term.

1.3. Indicators of soil health: Soil descriptors

There are many indicators that provide information about how well a soil functions. The indicators can be of physical, chemical and biological nature, or about yield. A single measurement, however, does not provide enough cues about soil health. Recently, the term soil descriptor was introduced to describe a physical, chemical, or biological characteristic of soil health. Chemical soil parameter assessment has a long history, but only the integration of all three, physical, chemical, and biological, characteristics of soil can give a comprehensive view of *soil health*. However, often this is not possible due to various circumstances, such as the lack of proper laboratory equipment or high testing costs. In our guide, we have selected a few of the descriptors that can be measured without special tools or laboratory equipment *directly in the field.*

Describing soil is crucial for farmers, advisors, landowners, and citizens alike, as it directly impacts agriculture, land management, and environmental well-being. For farmers, knowing the type of soil they are working with, can help them make informed decisions about crop selection, nutrient management, and irrigation practices, ultimately influencing crop yield and quality. Agricultural advisors rely on soil information to provide tailored recommendations to optimize farming practices and mitigate risks. Landowners use soil characteristics to plan land use, assess property value, and make informed decisions about development. Citizens benefit from understanding soil as it contributes to environmental awareness, sustainable land use, and water quality considerations. In

[2] Directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law); 2023

essence, describing soil is a fundamental aspect of informed decision-making across agricultural, environmental, and land management domains.

INFOBOX. *Soil descriptors* "indicates a parameter describing a *physical, chemical, or biological* characteristic of soil health"[1]

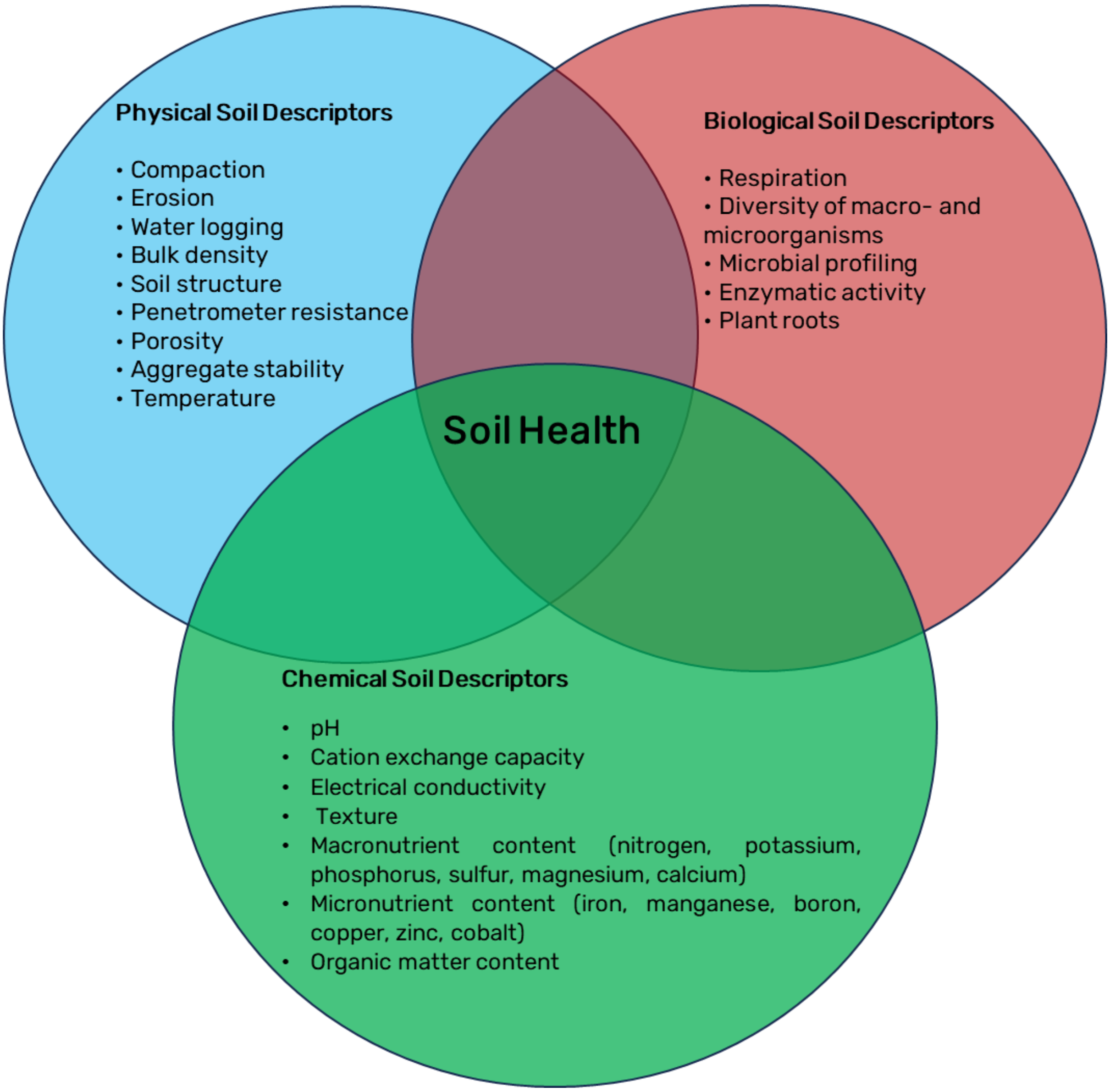

Figure 2. Soil health

2. Sampling general information

In this guide you will learn how to perform basic and simple soil health assessment without any special tools.

Prior to sampling

INFOBOX. Ask your best question! Clearly define your goal! You can be interested in a few soil descriptors or just in one. According to that decision, you will need to adjust your sampling.

The initial stage in evaluating soil health involves selecting monitoring locations. This selection should be guided by the aim/objective of your soil analysis. It is crucial to ensure that the chosen sites accurately reflect areas under similar usage (e.g. agricultural, forests, urban) and are situated within the same soil type and land management category.

Soil is very diverse. Even a small monitoring site can have very different properties within just a few meters. Therefore, it is critical to select a representative site for your specific question. The to be sampled site should visibly represent the whole sampling location. Locations with visibly impaired soil structure should be avoided (e.g. turnlands in agriculture). Fertilizer depots, different heights, different irrigated zones should all be avoided unless the aim is to sample exactly those zones.

Do not sample just one spot but several different points. The more the better, but generally at least five samples are recommended to represent a site. A single soil sample should be created by combining more than two (the more samples used, the higher the representability of the sample) sub-samples collected within a short distance of a few meters. Keep in mind that if your goal is to sample just one spot or point then those steps are not necessary.

INFOBOX. Each soil sample should be a composite of several sub-samples within a radius of a few meters.

Furthermore, the sampling pattern is of crucial importance (figure 3). The sampling pattern needs to represent the whole area of interest. Random sampling for instance prevents systematic errors but necessitates many samples. A line pattern is systematic and can introduce systematic error but necessitates less work. Generally, we recommend a random sampling with a sufficient number of samples (at least 5).

Get as much information about the sampling location as possible such as:

- Name of the site
- Area in m²
- Municipality
- Altitude
- Land use
- Cultivar (if applicable)
- Situation (flat, steep, hilly, slightly inclined)
- Soil moisture (dry, normal, wet, waterlogging)
- Irrigation (if applicable)
- Growth
- Fertilization (if applicable)

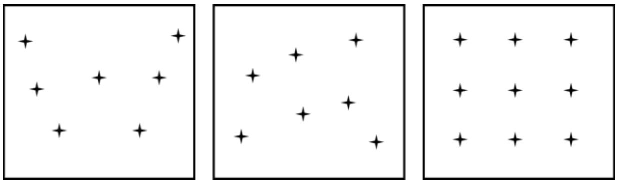

Figure 3. Different sampling patterns: W pattern, random pattern, line pattern.

Border and irregular areas should be avoided, unless a sample is specifically being collected from those areas to identify constraints.

The frequency of soil health assessment depends on the research question. Consistently sampling at approximately the same time each year is crucial for ensuring meaningful comparisons of the indicator's status across multiple years. Moreover, the soil should be moist, but sampling directly after rainfall should be avoided.

Make sure to label your samples and mark all the peculiarities you find as well as date and location (GPS if possible),

Before you sample soil, remove surface debris and the grass layer if that is not of research interest.

Determine the appropriate depth for the samples based on the objective. Typically, samples are taken from the surface (0-30 cm)[3] for routine soil testing, but they may need to go deeper for specific purposes such as sub soil analysis (deeper than 30 cm).

Mark or designate the specific areas where you plan to collect soil samples. This could involve using GPS coordinates, flags, or other markers.

INFOBOX. The proposed easy to use, in field soil health analysis methods are of qualitative nature and work the best when comparing the same or similar sites or different time frames. Comparison between very heterogeneous sampling sides is not recommended with the here proposed simple methods.

3. Visual inspection of the sampling site

Before performing the actual soil sampling, it is recommended to visually inspect the sampling site since this helps you identify potential factors that could affect the quality and representativeness of your soil samples.

Walk around the site and take note of any potential sources of contamination or disturbances, such as:

- Nearby roads and traffic
- Industrial facilities or waste disposal sites
- Agricultural activities and pesticide use
- Construction or excavation
- Any visible signs of erosion or sedimentation
- Presence of standing water or recent flooding
- Vegetation types and density
- Evidence of previous soil sampling or testing

Take photographs of the site and the field, including close-up shots of any unusual or relevant features. These photos can serve as visual documentation.

Thoroughly inspecting the soil sampling site and addressing any potential sources of bias or contamination increase the reliability and accuracy of the soil sample data, which is crucial for making informed decisions related to soil management, agriculture, environmental assessment, or research.

[3] Indicaton of topsoil from JRC/ Land Use and Coverage Area frame Survey (LUCAS)

4. Sampling

General list of materials

- Shovel (approximately 25 cm long and 20 cm wide)
- Bucket
- Plastic bags
- Markers
- Ruler (facultative)
- Plastic mat
- Small pot

4.1. Bucket sampling

Once the sampling site has been established and all the information has been assessed the sampling can start.

1. Remove the grass layer with the shovel.
2. Dig a small hole at a depth according to the sampling goals (0-30 cm if you are interested in the topsoil).
3. Withdraw a small amount (approx. half a shovel) from the hole and put it into the bucket.
4. Restore the grass layer.
5. Repeat step 1, 2, 3 and 4 for at least another 4 sampling points within your site.
6. The soil in the bucket is mixed and ready for soil health analysis.

For specific analysis such as the earthworm count it is recommended to dig approximately 20x20x20 cm soil pit and place the excavated soil on a mat. Alternatively, the width of the shovel can be used to make dig a block of soil.

5. Soil health methods

5.1. Earthworm count

Earthworms (figure 4) play a pivotal role in shaping the soil environment, contributing to carbon cycling, enhancing soil structure, and boosting plant growth. They also serve as a vital food source for indigenous fauna such as birds and as a valuable gauge of soil well-being. Abundant earthworm populations signal healthy soil.

Earthworm count is best performed in early spring or autumn when the soil is wet and the temperatures moderate as this provides the most representative population counts. Earthworms both hibernate during winter and during a hot summer.

Step by step guide

1. Dig a 20x20x20 cm soil pit and place the block on a soil mat.
2. Disaggregate the soil by hand and place every earthworm in a small pot
3. Count the earthworms

In healthy soil at least **four** worms should be found in every spadeful. This equals to around 100-200 worms per square meter and is the minimum to be considered as healthy for a functioning soil. Generally, the more the better.

Figure 4. Earthworms play a vital role in a healthy soil.

5.2. Slake test

The slake test is a straightforward method for evaluating the **stability of soil**. It tests the durability of soil particles and demonstrates its ability to endure external physical influences, thus ensuring its integrity in delivering air and water for plant growth and soil organisms (figure 5).

Biological activities such as the presence of earthworms and root-related fungal filaments, root expansion, decomposition, and the secretions from various soil organisms, including fungi and bacteria, collectively contribute to the formation of soil aggregates and the durability of large pores within the soil. These robust, large pores enhance the capacity for water to penetrate the soil, reducing water runoff, erosion, and the formation of surface crusts, thus playing a huge role in soil health.

Low soil stability can result from various factors such as erosion, compaction, lack of organic matter, anthropogenic activities, etc.

Material list:

- Glass jars/beaker
- Mesh support (for instance a kitchen sieve) that fits into the glass jar
- Water

Step by step guide

INFOBOX. *Principle of the analysis*. When soil is placed into water, the water is drawn into the soil and the air displaced. If the large pores within the soil are stable, water can move into the soil without causing the aggregate to break apart.

1. Collect a fist-sized sample of soil.
2. Let it dry for a few days (the analysis has to be done on completely dry soil)
3. Insert the mesh into the jar.
4. Place a bit of soil onto the wire mesh in the jar.
5. Fill the jars with water to a depth that will submerge the soil samples.

6. Wait for 5 minutes.

Observe if the soil holds together or falls apart.

Table 1. Slake test interpretation

High stability	Aggregates maintain their structure and resist disintegration even after prolonged immersion in water
Moderate stability	Some disintegration of soil aggregates occurs during the test, but not to the extent of complete breakdown.
Low stability	Soil aggregates quickly break down into individual particles upon immersion in water, indicating low stability.

Soil that disintegrates has a poorer structure and lower organic matter content than one which remains intact. This is an indication of low soil health (table 1).

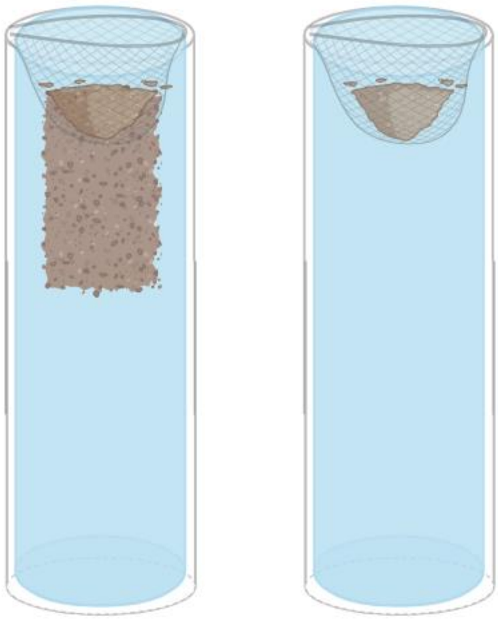

Figure 5. Slake test. Left: disintegrated soil with poor structural integrity. Right: soil with high stability.

5.3. Infiltration test

The infiltration test is used to determine the **soil texture** (figure 6), which corresponds to the size of the soil particles. Soil texture is classified into sand, silt and clay with decreasing particles size. The particle size influences important soil characteristics, such as water infiltration and retention, fertility (nutrient content), water movement as well as aeration.

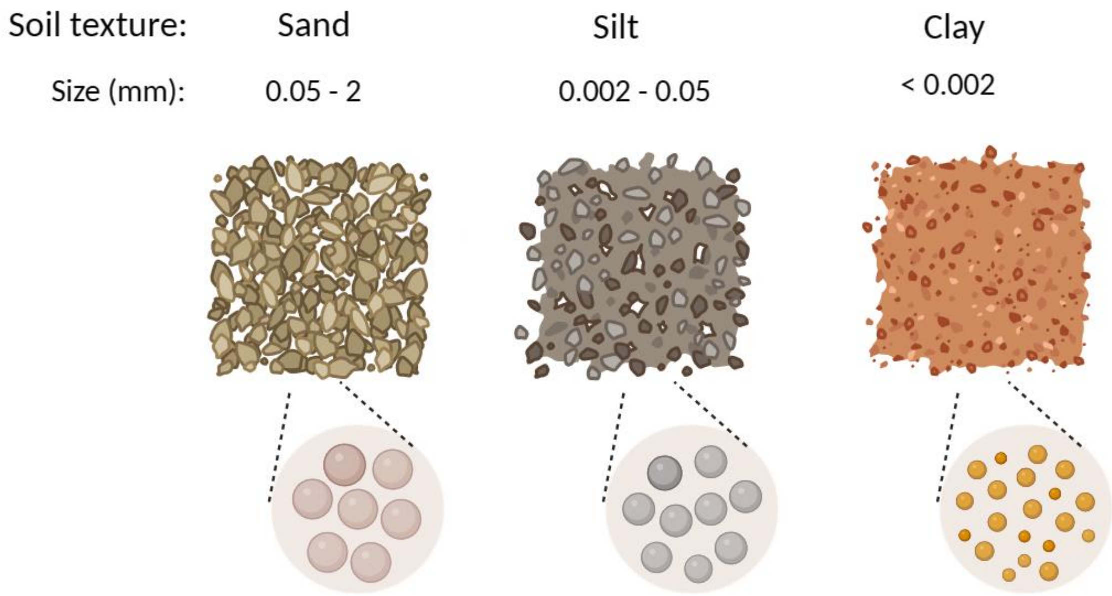

Figure 6. Soil texture

Sandy soils (light soils) are generally less fertile, having a low nutrient content, a high water infiltration rate and low water retention capacity.

Clay soils (heavy soils) have a high(er) nutrient content but due to compactness and small particle size, they restrict root growth and impede water from entering. On the other hand, clay soils can retain more water.

S**ilty soil** sits in between the two.

Soil texture can vary greatly from one site to another. Moreover, most soils do not have one type of particle size, but rather a combination of all three resulting in a fertile combination for plant growth.

Soil texture can be estimated with a water infiltration test.

Material list:

- Glass/plastic tube or beaker (approx. 10 cm diameter x 20 length cm)
- Water
- Graduated beaker/cylinder
- timer

The testing area should not be saturated with water so do not perform the infiltration test after heavy rainfall.

Step by step guide

1. Insert the tube into the soil at 10 cm depth.
2. Measure approximately 800 mL water.
3. Pour the water into the tube and start timing.
4. Measure the time taken for the water to drain into the soil.

For a healthy soil, the water should drain within 2 to 5 minutes. A heavy clay soil with poor structure could take 20 minutes or longer (table 2).

Table 2. Soil type based on the water infiltration rate

Infiltration rate (mm/h)	Soil type
>30	Sand
20-30	Sandy loam
10-20	Loam
5-10	Clay loam
1-5	clay

5.4. Soil organic matter

Soil organic matter (SOM) is of huge importance for soil health and one of the most important soil descriptors. It is the portion of soil that is composed of living and dead organic materials in various states of decomposition.

SOM provides essential nutrients for plants, feeds diverse soil organisms, is crucial for a healthy soil structure and water management, to name just a few of the important tasks.

A healthy and fertile soil generally contains more than 2% organic matter, but the content depends on the soil type. A sandy soil contains only up to 2% SOM but a clayey also up to 8% (table 3).

Table 3. Soil Organic Matter content according to soil texture.

Class	**Soil Organic Matter (%)**			
	Sand	**Sandy loam**	**Loam**	**Clay Loam/Clay**
Low	<0.9	<1.5	<2	<2.5
Moderate	0.9-2	1.5-2.5	2-3.5	2.5-5
High	>2	>2.5	>3.5	>5

Humus, which is the final stage of organic matter breakdown is black.

INFOBOX. The color of soil is one of the most visible characteristics. It can give valuable insights into some important measures such as mineral composition, organic matter content, iron content and moisture content.

Step by step guide

1. Take a small amount (spoon full) of moist soil.
2. If the soil is dry, moisten it.
3. Match your sample with the colour chart below (figure 7).

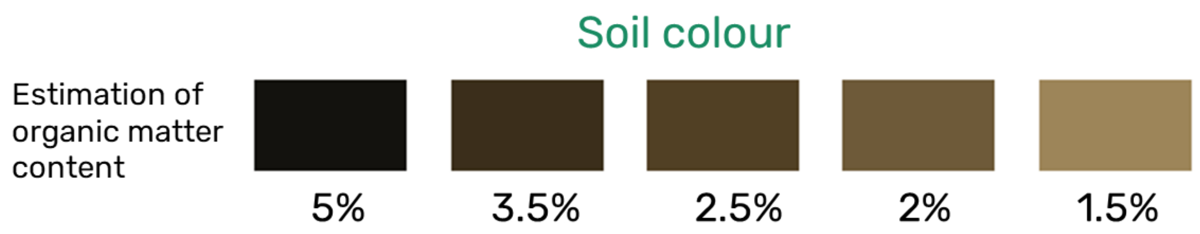

Figure 7. Soil colour chart. Compare the colour of your soil to these charts (hex color codes: 5% = #5ec1d8, 3.5% = #3b2f1b, 2.5% = #524024, 2% = #6e5a38, 1.5% = #9d8559)

5.5. Soil pH

INFOBOX. The acidity or alkalinity of a medium is measured as pH in a scale from 0 to 14. Water for instance has a neutral pH of 7. A pH of 0 to 7 indicates an acidic pH, while 7 to 14 indicate a basic (or alkaline) pH.

Soil pH is the most important chemical soil property due to the wide reaching influence it has on every other soil component. pH directly affects nutrient availability. Nutrients like nitrogen, phosphorus, potassium or iron have specific pH values in which they are bioavailable. Iron for example is soluble at lower acidic pH values and often is a limiting factor in agricultural production. Furthermore, pH influences the biological activity in the soil. Most organisms, like plants and microorganisms have pH preferences and their populations can be affected by acidic or alkaline pH. pH influences all chemical reactions in soil, which are crucial for a soil´s nutrient availability. pH can even affect soil structure as in acidic soils soluble aluminum can disrupt root growth and affect soil structure negatively.

The pH of soils can range from very acidic (values of 3-4) to very alkaline (8-9). Acidic soils can for instance be found in humid northern temperate coniferous forests or humid tropical rainforests, while alkaline soils are present usually in semiarid and arid climates. Optimal pH for plant growth depends on a plethora of variables but generally a slight acidic pH (approximately 6-6.5) offers the best compromise for most species.

In terms of soil health, pH is one of the most important descriptors. It is possible to test the soil pH with vinegar and baking soda. This simple analysis will give us a ballpark idea whether the soil is alkaline or acid.

Material list:

- Small containers for a handful of soil and 100 mL liquid
- Measuring cup
- Spoon
- Approximately 200 mL of water
- Approximately 100 mL of white vinegar
- Approximately 100 mL of baking soda

Step by step guide

Alkalinity test

1. Pour approximately 100 mL of water into a vessel containing a handful of soil.
2. Add approximately 100 mL of vinegar.

3. Mix with the spoon.

The soil has an alkaline pH when it shows a visible fizzing/bubbling. This is due to the reaction between the acid vinegar and the alkaline soil. The stronger the reaction and the bubbling is, the more alkaline the soil is.

INFOBOX. The bubbling through the addition of vinegar indicates that the soil contains carbonates. They play a significant role in soil chemistry, affecting soil pH, nutrient availability, and plant growth.

Acidity test

1. In another new container add again 100 mL of water to a hand full of soil.
2. Add approximately 100 mL of baking soda.
3. Mix with the spoon

If the pH of the soil is acid the soil will start to bubble. Similarly, to the first test, if the pH is very low the bubbling/fizzing will be stronger and last for more time.

As the ideal pH for most plant growth is slightly acidic a small bubbling during the baking soda test can be considered as beneficial and a sign of a healthy soil. However, keep in mind that it really depends on the specific case.

INFOBOX. Proper pH indicator test kits, with pH strips are very cheap today and can be found in most pharmacies. The use of pH strips significantly enhances the test's reliability, repeatability, and accuracy.

5.6. Underwear test[4]

The underwear test is used to demonstrate the presence or absence of soil biology and microorganisms capable of a fast decomposition of organic matter. It is a simple but effective method.

Material list

- Shovel
- Cotton underwear
- Smartphone or camera

Step by step guide

1. Dig a 20 cm deep hole in the soil.
2. Bury a piece of cotton underwear.
3. Take a photo of the underwear.
4. Cover the piece of underwear with soil.
5. Wait for approximately 2 months.
6. After 2 months, dig the underwear out and compare the photos with the original photo.

[4] https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/oregon/soil-your-undies-challenge

If the underpants are still intact after 2 months, the soil is relatively sterile, and this indicates a poor soil biology. If the underwear is decomposed and only small pieces are left, the soil is healthy and has a healthy biological community.

5.7. Soil bulk density

INFOBOX. The soil bulk density is the mass of soil that is packed in a given volume.

The bulk density of a soil is an indicator of its degree of compaction. The higher the bulk density the more compact the soil is. It is an important soil descriptor for soil health due to the soil's ability to provide structural support for plant growth. Water infiltration, air and solute movement all depend greatly on the soil density. Soils that are highly compacted pose challenges for plant growth and hinder the establishment of a thriving microbial community.

Material list

- Cylindrical metal/plastic tube with a known volume (in cm^3)
- Scale
- Tray/container

Step by step guide

Once the grass layer of the soil is removed insert the cylindrical tube vertically into the soil until the hole tube is immersed in soil. Remove the tube and place the soil into a tray. Let it air-dry for 3-4 days. Weigh the soil in grams. Divide the mass of soil in g by the volume of the metal tube in cm^3. Check your results with the table below (table 4).

1. Remove the grass layer above soil
2. Insert the tube into the soil
3. Remove the tube
4. Place the soil widely onto a tray for drying
5. Let the soil dry for 3-4 days
6. Weigh the soil (in grams)
7. Divide the mass of soil in g by the volume of the metal tube in cm^3. Check your results with the table below (table 4).

Table 4. General relationship between soil bulk density and root growth

Soil texture	Ideal bulk density for plant growth (g/cm^3)	Bulk density which restricts root growth (g/cm^3)
Sandy	<1.6	>1.8
Silty	<1.4	>1.65
Clayey	<1.1	>1.47