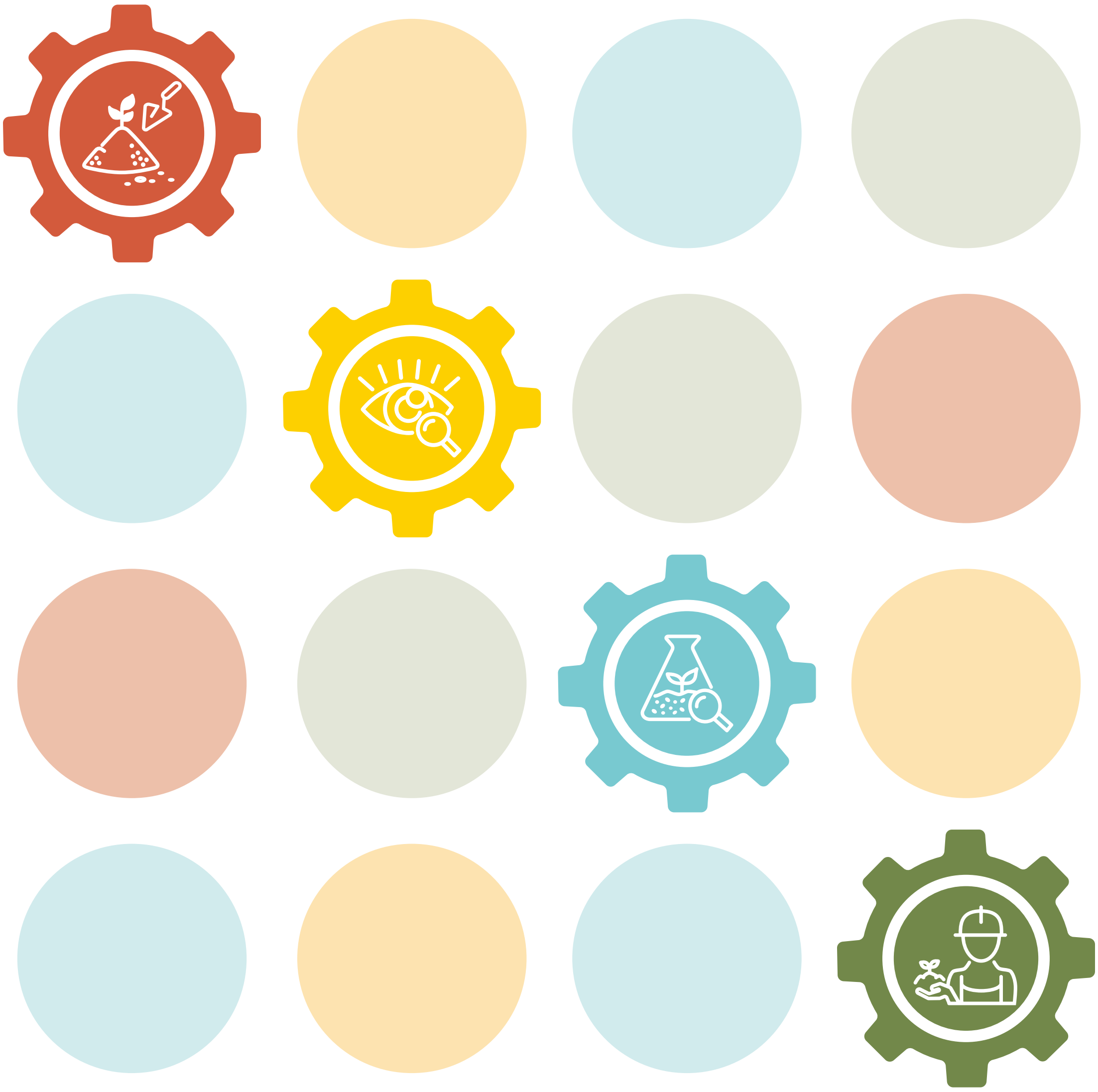
Guidelines on Soil Improvement



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Greening, Landscape and Tree Management Section

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TABLE OF CONTENTS

INTRODUCTION

Urban soils are a byproduct of urbanization, with human activity being the predominant active agent in the modification process, creating urban soils with characteristics unlike those occurring in the natural environment.

In the urban areas of Hong Kong, with the lack of site soil, fabricated soil mix is commonly specified as the planting medium in landscape projects. Decomposed granite (DG), due to its local abundance, is used in the growth medium as a component of the fabricated soil mix. DG has intrinsically poor mineralogical and structural properties which are unfavourable to tree growth. These inferior characteristics which include incomplete weathering, coarse grain size, as well as low pH, organic matter and major plant nutrients, are typically amended in the initial planting stage for new landscape projects using peat moss to address physical constraints, and commercial fertiliser(s) to increase nutrient contents (Craul, 1985 & 1992; Jim 1998). These can moderately mitigate the problems, but are not ideal or sustainable, as the long-term effectiveness of peat moss is unknown, and nutrients in chemical fertiliser(s) are readily leached and lost from the rooting soil profile. Soil in existing tree pits or planters may be worsened after startup modification to meet contractual soil specifications due to restrictive surface working area and rooting volume, and compaction after planting.

With deteriorating soil quality, appropriate remediation measures are deemed necessary, but soil testing and amendments are generally not carried out on a regular basis. Also, scheduling and application of improvement practices depend very much on the individual experience and knowledge of the fieldworkers involved.

In this respect, the Greening, Landscape and Tree Management Section (GLTMS) of the Development Bureau (DevB) has commissioned Earthasia Ltd. as the main consultant, supported by Professor CHU Lee Man, to formulate a set of Soil Improvement Guidelines (hereinafter called the Guidelines) to assist and guide parties responsible for roadside vegetation management and maintenance to carry out routine soil management and soil amendments in a systematic and timely manner.

It is also the purpose of these Guidelines to promote a better understanding on the key soil parameters affecting plant growth, and to raise awareness of practitioners on the importance of routine soil management.

Urban trees are vital components and valuable assets to the high-density city of Hong Kong, bringing along many environmental and social benefits such as providing shade, improving air and water quality, moderating temperature, enhancing the visual and ecological environment and enhancing quality outdoor space. Most benefits associated with urban trees are however accruing until they reach their mature state, street trees should therefore be supported to grow to their maturity to maximise their benefits. Soils being the vital reservoir for trees to get nutrients, water and air, their quality and performance should therefore not be neglected.

CH0: HOW TO USE THESE GUIDELINES

This section introduces the different parts of these Guidelines, with suggestions for when and how to use the Guidelines in a tree monitoring / soil improvement workflow.

USING THESE GUIDELINES

GOOD PRACTICES FOR STREET TREE PLANTING

Trees are living organisms, and a good planting space is vital for their sustained healthy growth. Creating a good planting space is to respect the basic requirements for tree growth, i.e. to give them good quality soil with adequate soil volume for root growth below ground, and to give them sufficient space for canopy growth above ground (*Figure 1*).

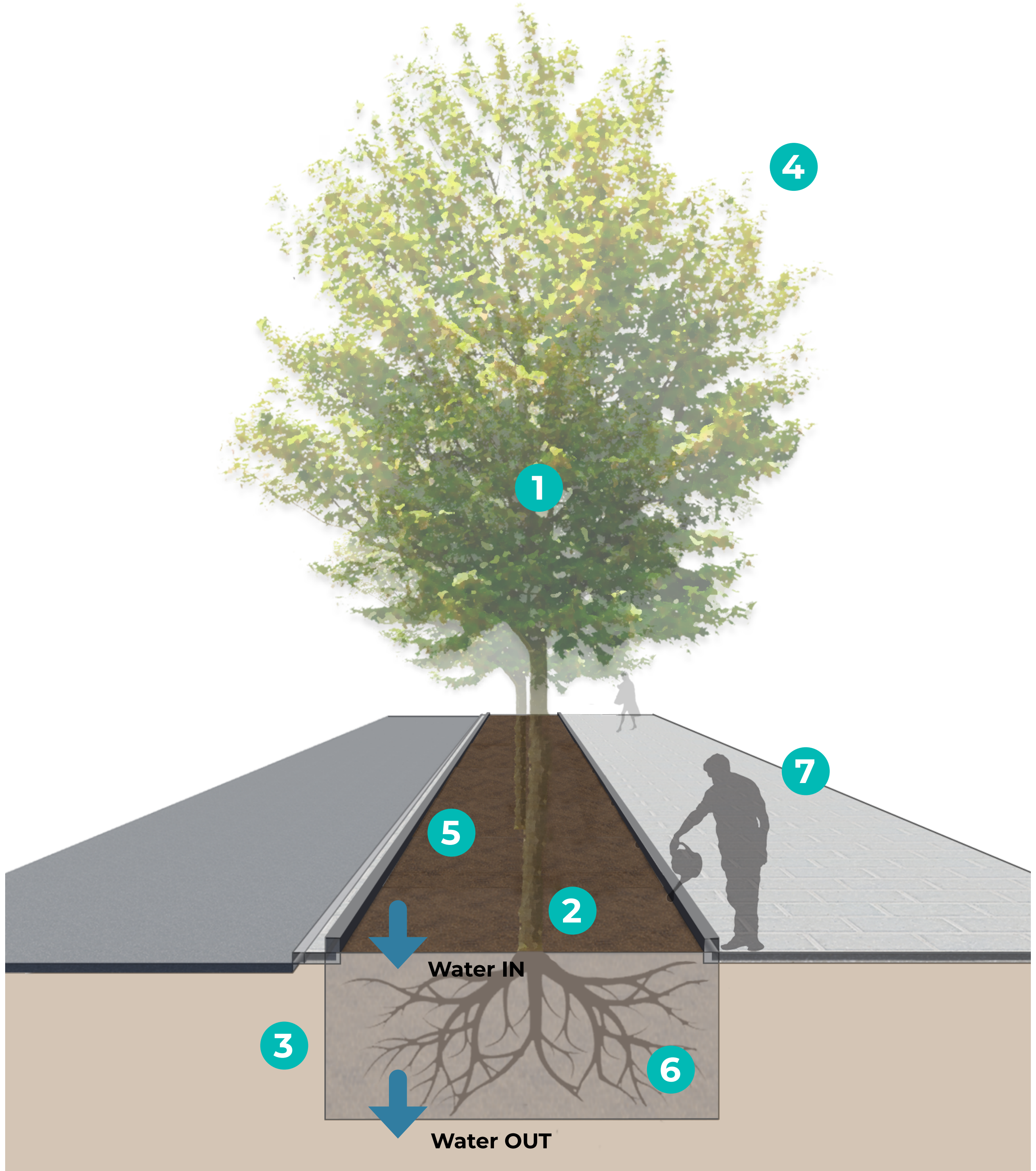


Figure 1. Good practices of urban tree growth.

Table 1. List of good practices of urban tree growth.

Good Specimens

1 Good specimens
Reference:
DEVB's Proper Planting Practice – 'Select and Plant Good Specimens'

2 Plant trees at the correct soil level
Reference:
DEVB's Proper Planting Practice – 'Do Not Plant Too Deep'

Sufficient Soil Volume

3 Maximise soil volume for the selected tree to support growth to desired size at maturity
Reference:
'Application of Innovative Measures to Achieve the Recommended Soil Volume for Urban Trees' under the study 'Street Ecology Strategy for Hong Kong (Phase 2)'

Spatial Allowance

4 Provide room for future canopy growth
Reference:
DEVB's Proper Planting Practice – 'Provide Adequate Growing Space for Future Growth of Canopy' and 'Provide Sufficient Growing Space between Trees and Adjacent Buildings / Structures'

5 Maximise open soil around the base of a tree for trunk flare to prevent girdling and encourage water infiltration into the ground
Permeable paving is recommended around the tree base where provision of large open soil area is not feasible.

Soil Quality

6 Provide suitable planting soil
Soils should be free from deleterious materials and have suitable quality regarding texture, nutrient levels and drainage properties.

7 Carry out routine soil management: Monitor soil quality and improve as needed

Selecting and planting the right tree at the right place is essential for a tree's long term success. While Good Practices 1 to 6 above are crucial basic factors affecting tree performance, maintaining the soil quality after planting is an important but often-neglected aspect affecting the continued healthy performance of trees, which will be the focus of these Guidelines.

USING THESE GUIDELINES
HOW TO USE THESE GUIDELINES

Sections in these Guidelines

As described in the preceding section, managing soil quality first requires the provision of suitable soil at the planting stage. They should be prepared to meet standards laid down in relevant specifications for soil mix. The main focus of these Guidelines is on the post-planting stage that can be taken to ensure continued suitability of the soil for tree growth. Assistance for monitoring and improving soil quality of urban street trees is provided in the following sections of these Guidelines. *Table 2* below is a summary of the sections and their use.

Not all soil problems can be assessed visually. As such, soil analysis through handy quick tests in Chapter 3 can be carried out for further interpretation of potential soil problems. However, since there is no good handy quick test available for some parameters, such as organic matter content and cation exchange capacity, they have to be tested by accredited soil laboratories for professional advice.

Table 2. Summary of sections in these Guidelines.

Section	Summary	Refer to this section when...
CH 1: SOIL PARAMETERS	Introduction to the major soil properties of soil that affect tree growth. *Points to simple ways to assess their levels in* ***CH 2*** *&* ***CH 3***.	· Understanding major potential problems with soil contributing to tree/soil issues.
CH 2: VISUAL ASSESSMENT	Guide to observing tree / soil signs to infer underlying soil issues. *Points to applicable improvement measures in* ***CH 4***.	· Carrying out routine checkups of street trees. · Trying to match observable indicators to potential soil problems.
CH 3: HANDY QUICK TESTS	Guide to using handy quick methods to infer underlying soil issues. *Points to applicable improvement measures in* ***CH 4***.	· Suspected problem(s) cannot be observed directly. · Trying to confirm suspected issues from observation of trees and soil.
CH 4: IMPROVEMENT MEASURES	Matching soil issues identified in ***CH 2*** & ***CH 3*** to possible solutions. *Points to suggested amendments in* ***APPX A***.	· Indicators show a soil issue. · Trying to decide on the appropriate treatment(s) for an identified issue.
APPX A: SOIL AMENDMENT INFO SHEETS	Data sheets with properties and usage of various soil amendments.	· Further confirming applicability of the amendment methods. · Looking for general application how-to's for each amendment.
APPX B: SOIL TESTING CHECKLIST	List of soil laboratory tests for the soil analysis parameters.	· High certainty of soil issue diagnosis is required (e.g. in case of OVT). · No improvement is seen after amendment (e.g. trees repeatedly fail in the same soil area).

USING THESE GUIDELINES
HOW TO USE THESE GUIDELINES

Suggested Flow for Soil Improvement

At the post-planting stage, it is a good practice to monitor soil performance and to keep soil quality records for future reference, as it can inform potential soil problem issues. The Guidelines cover a step-by-step approach for managerial and field staff to monitor and undertake timely soil improvement measures. Areas of soil problems / deficiencies must be identified in order for the selected improvement measure to be effective. *Figure 2* summarises the schematic flow of the soil management process as well as the steps in identifying soil problems for improvement.

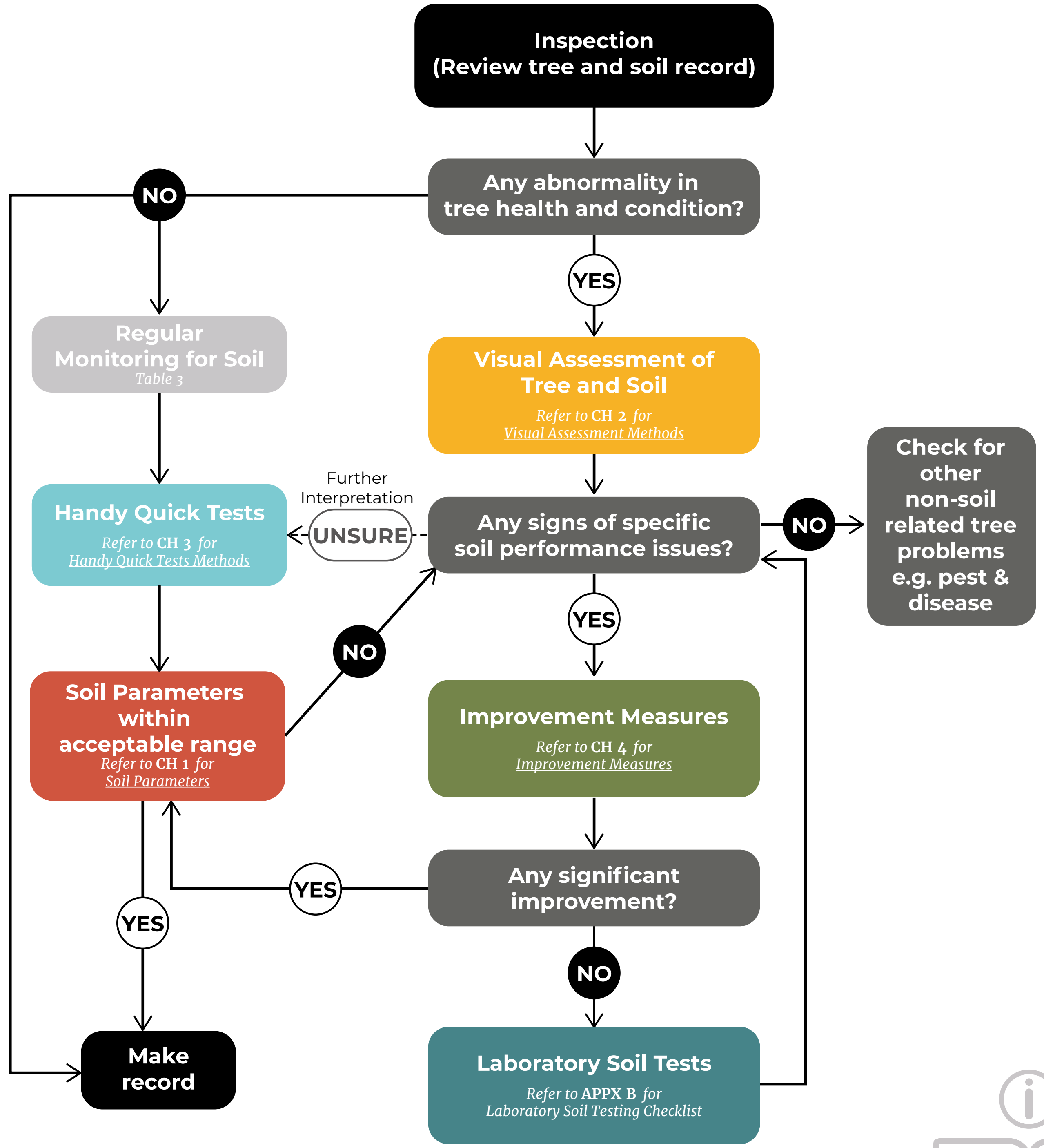


Figure 2. Schematic flow of assessment and improvement for urban soils.

USING THESE GUIDELINES

TIMING FOR INSPECTION

Soil in pits and planters for tree and shrub planting should have met the general soil specifications and contractual requirements, but the soil status may be difficult to be discerned by those in charge of ongoing maintenance works. It is therefore important to carry out routine soil management to monitor soil quality.

Visual soil assessment discussed in these Guidelines is easy to follow and can be carried out at any time and frequency or as needed, as a good soil management practice. It is recommended to conduct such visual soil assessment as a regular monitoring at an interval of every 6-12 months.

For the handy quick tests, they are also recommended to be carried out at regular intervals (*Table 3*) to safeguard the healthy and sustainable growth of our urban vegetation.

Some parameters can be more easily and conveniently measured using handy quick tests than others, which afford more regular assessment. These include some soil physical properties such as texture and bulk density, and chemical properties such as pH. As they also contribute to the majority of urban tree growth issues in Hong Kong, they can be conducted more often, once every 6-12 months. This can provide timely information on selected parameters to see if any improvement practice is needed. Some parameters can be assessed on a less frequent basis, e.g. organic matter, nitrogen (N) and phosphorus (P) at every 1-2 years, while a few can be adopted in every 3-5 years. For parameters that cannot be determined using handy quick tests, professional testing by accredited soil laboratories is required. A soil testing checklist for laboratory tests is included in ***APPX B***.

The best time of year to sample and test is in the dry season in autumn when the soil is drier for sampling, and soil improvement can be planned to be carried out in spring when the growing season commences.

Table 3. Testing parameters and their testing frequency.

Testing frequency	Testing parameter(s)	Handy quick test available
Every 6-12 months or as necessary	Texture	✓
	Bulk Density and Compaction	✓
	Infiltration Rate	✓
	pH	✓
Every 1-2 years or as necessary	Soil Organic Matter (SOM)	×
	Electrical Conductivity / Salinity	✓
	Nitrogen (N)	✓
	Phosphorus (P)	✓
	Cations: Potassium (K), Calcium (Ca), Magnesium (Mg)	✓
Every 3 years or as necessary	Porosity	✓
	Aggregate Stability	✓
	Cation Exchange Capacity (CEC)	×
	Sulphur (S) and Micronutrients (e.g. Boron (B), Cobalt (Co), Iron (Fe))	×

USING THESE GUIDELINES

ASSUMPTIONS / LIMITING CONDITIONS

Prioritising Possible Testing Parameters

It is always important to determine soil properties to have a better picture of the soil conditions that the tree in question is facing. Ideally, a full list of soil quality indicators (*Table 4*) could be obtained, not to mention the various forms (total, available and soluble) of some chemical indicators like nutrients. However, it will be impractical to test as many parameters as possible, as there are resource implications. Alternatively, it can be focused, but there is no point to get the wrong parameters for soil testing. These Guidelines thus focus on the parameters that have the biggest effects on tree stress (*Figure 3*).

Table 4. Commonly used soil indicators for reflecting urban soil quality and health.

Type	Indicator(s)	Related soil function(s)
Physical	Texture	Soil structure, drainage, water and nutrient cycling
	Bulk density	Air and water movement, root development
	Porosity	Soil hydraulic properties, aeration
	Pore size distribution	Air and water movement, water storage, soil-plant interaction
	Aggregate stability	Soil structure, aeration, water movement, water storage, soil-plant interaction
	Infiltration rate	Soil aeration, water movement, water storage
Chemical	pH	Soil reaction, nutrient cycling, mineralisation
	Electrical conductivity / Salinity	Soil water balance, nutrient availability, microbial activity
	Organic matter / Organic C	Soil structure and aggregation, water and nutrient cycling, carbon (C) source and sink, chemical buffering, soil biodiversity and activities
	Macronutrients, e.g. N, P, K, Mg, Ca, Na, S	Nutrient cycling
	Cation exchange capacity (CEC)	Nutrient availability
	Micronutrients, e.g. B, Co, Fe, Mn, Mo, Zn, Cl	Nutrient cycling
	Heavy metals, e.g. Cd, Cu, Ni	Soil toxicity
Biological	Microbial diversity	Soil health and litter decomposition
	Microbial activity	Soil fertility and metabolism
	Faunal diversity and abundance	Soil biodiversity, health and nutrient cycling

USING THESE GUIDELINES

ASSUMPTIONS / LIMITING CONDITIONS

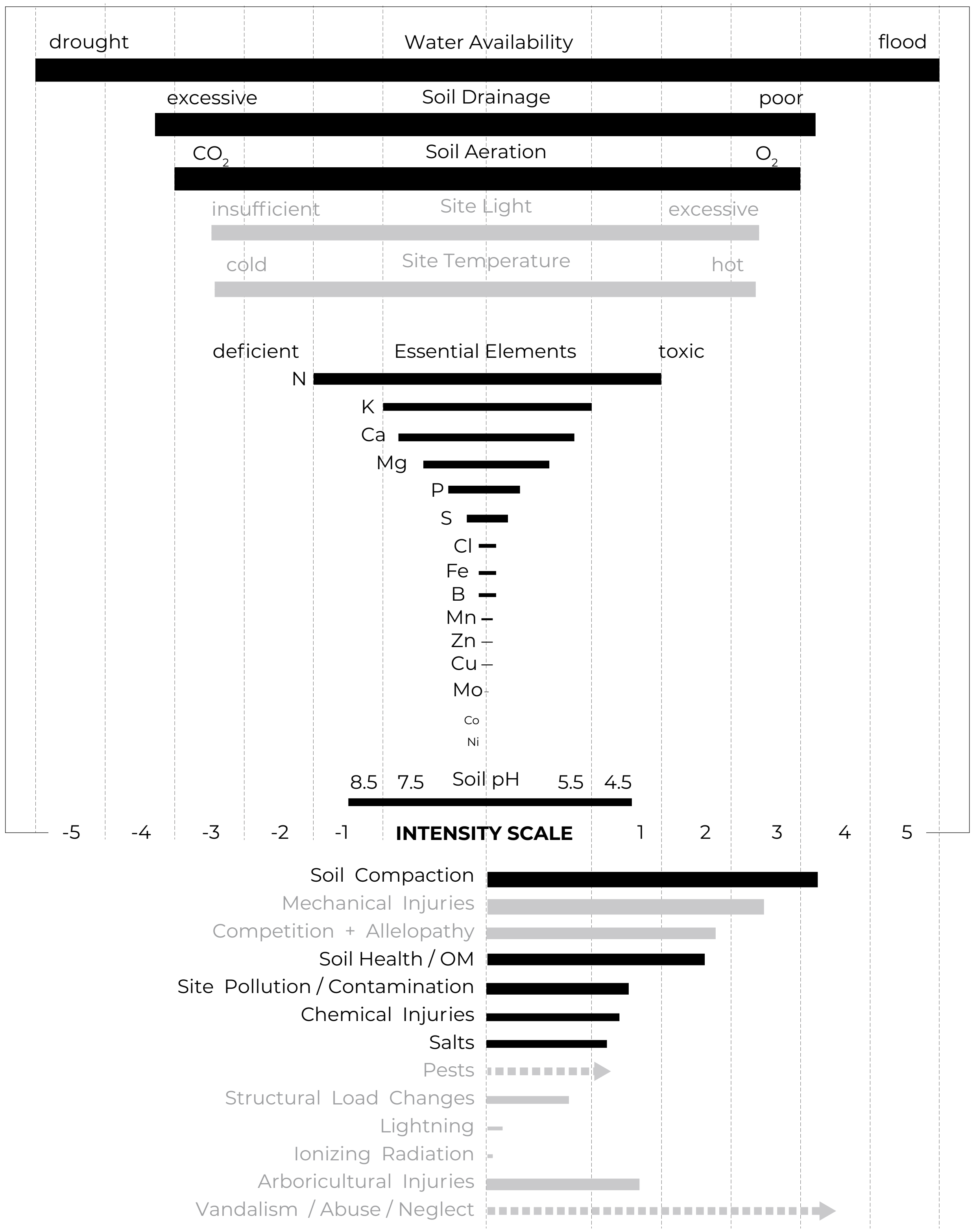


Figure 3. Relative stress on trees from different environmental factors. Black bars: parameters affected by soil quality; Grey bars: other parameters. Dotted grey bars: other parameters with highly variable levels of impact. (Modified from: Coder, 2016).

USING THESE GUIDELINES

OVERALL CONCERNS AND CHALLENGES

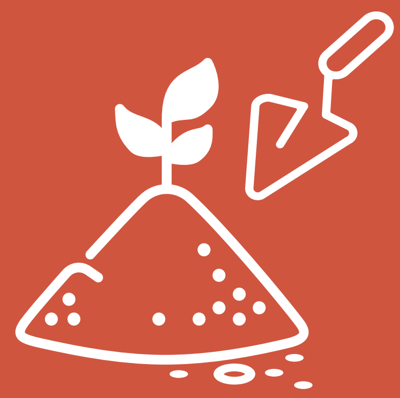
Poor tree growth can be attributed to different factors, namely air pollution, pests and diseases, and soil problems. Tree pests and diseases may have various signs and symptoms that are characteristics to experienced arborists, but may be similar to nutrient deficiency which is one of the soil problems. Soil contamination and insufficient rooting space are other soil constraints that are easier to trace; poor soil structure which affects drainage appears simpler in diagnosis. However, it can be difficult to gauge poor soil chemical quality by eye. There is a need to select performance indicators to identify soil problems at the appropriate time to see if soil is a significant contributor to the signs and symptoms observed.

Testing Difficulties

Soil testing for key parameters such as pH and nutrient contents is usually taken for granted and is regarded as low-priority task, as it is not a common practice in Hong Kong, can be an extra cost item in operation, and is considered tedious when scientific soil sampling and laboratory analyses are involved. There is also a paucity of choices for soil improvement even if soil deficiency is known. There is a need to develop simple and rapid diagnosing tests as practical measures for common parameters such as soil pH and major nutrient contents to provide information on soil improvement. It is also necessary to formulate performance measures to guide frontline staff to sample, measure and analyse soil, and interpret and report on soil quality. With information on selected soil properties, practical soil improvement which is suitable for addressing the soil problems can be recommended.

Lack of Application Knowledge

There is a lack of understanding on the soil problems and the corresponding treatment methods. Frontline staff may not be knowledgeable of the soil problems that the tree is facing, and are not familiar with the know-how to assess the problem. In case they find out the problem(s), there are not many improvement measures available to address them.



CH1: SOIL PARAMETERS

This section is a short introduction to the importance of each soil property, with cross-references to recommended methods of simple in-situ visual soil assessment and suggestions of optimal ranges. Anomalies with any of these parameters can hinder healthy tree growth.

SOIL ANALYSIS PARAMETERS

MAJOR PARAMETERS OF URBAN SOIL

The many factors contributing to proper functioning of soils can largely be categorised into physical, chemical and biological parameters. Having any of these parameters in unsuitable ranges can often negatively affect other parameters as well as plant growth. *Table 5* below lists some of the more common issues of Hong Kong's urban soils mostly consisting of DG.

Table 5. Typical shortcomings of urban soil (Craul, 1985 & 1992; Jim, 1998a & 2001).

Parameter	Issue	Possible effect(s) on planting	Possible effect(s) on other soil parameters
Soil texture	High sand content	Nutrient deficiency	Excessive macroporosity Poor water and nutrient retention
Bulk density	High bulk density	Impeded root development Shallow rooting	Low porosity High soil compaction Low infiltration rate
Porosity	High porosity	Limited water and nutrient uptake	Low water holding capacity High infiltration rate
Aggregation	Lack stable soil aggregates	Exposed roots	Low water holding capacity
pH	Acidic pH		Low nutrient availability
Organic matter	Organic matter deficiency	Nutrient deficiency	Low nutrient levels Low porosity Poor soil aggregation Poor infiltration Low water holding capacity Low diversity and activity of soil microflora and fauna
Macronutrients	Low levels of major nutrients	Nutrient deficiency	

Desired characteristics of urban soils vary widely, depending on factors such as site conditions / microclimate, species to be planted, intended purpose of the landscaped areas, and expected maintenance. Nevertheless, characteristics such as resistance to compaction, good aeration and drainage, sufficient water holding capacity and permeability, and appropriate pH and fertility status are some commonly desired qualities of urban soils.

When evaluating different urban soils, the following introductions to common parameters can be referenced for a better understanding of how soil should function as a system of interrelated factors.

SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

P1/ Soil Texture

Soil texture is a parameter used to classify soil types based on the proportion of sand, silt and clay particles that make up the mineral fraction of the soil. There are 11-12 major textural classes according to different soil taxonomy or classification systems (e.g. USDA system, *Figure 4*) using the soil texture triangle, which are typically described by the primary constituent soil separate(s), e.g. sandy clay, silty clay. Loam refers to a friable mixture of roughly equal proportions of sand, silt and clay.

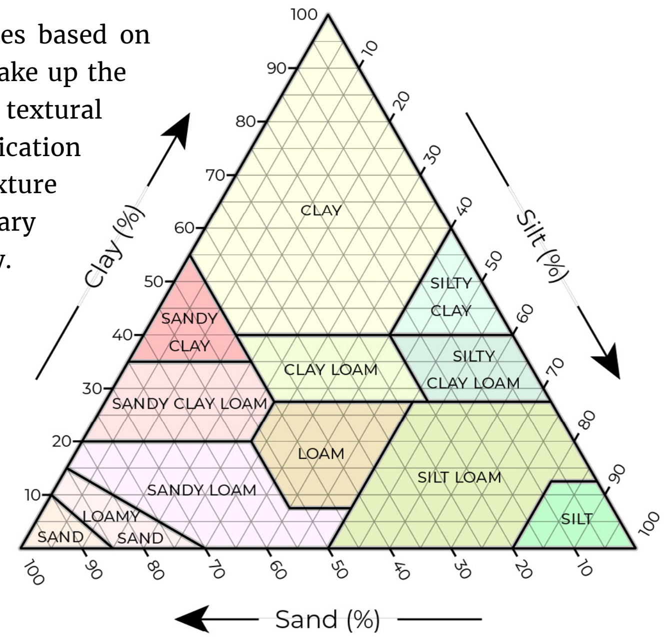


Figure 4. USDA Soil texture triangle (Modified from: Christopher, 2018, Licensed under CC BY-SA 4.0).

Relationship to Other Soil Parameters

Texture and particle size distribution govern major physical and chemical properties of a soil, such as porosity and water and nutrient retention capacities. They determine soil structure, drainage and infiltration rate, and have important agricultural and horticultural implications.

Implications for Plant Growth

Unsuitable soil textures cause a variety of physical soil issues and may require modifications. Sandy soils have better drainage, though they are scattered and loose, with lower retention capacity for water and nutrients. Heavy clay or silt soils are typically more fertile with better water and nutrient holding capacities, but drain slowly and are prone to compaction or waterlogging when wet. Combining the observation on soil textures with other symptoms such as compaction or drainage indicators will help with the selection of suitable solutions.

Quick Test Method(s)

Visual Assessment	Waterlogging (p.46) Dry Soil (p.47) Soil Loss (p.48) Surface Crust (p.51) Hard Soil (p.52) Tree Signs and Symptoms (p.58) - Chlorosis, Leaf Discolouration, Necrosis, Brown Edges	Handy Quick Test	P1/ Test 1. Feel Method (p.73) P1/ Test 2. Jar Method (p.75)

Optimal Range of Soil Texture

The most commonly acceptable soils are loam (which has 40%, 40% and 20% of sand, silt and clay respectively) and its different subtypes. However, trees grow in a variety of soil textures, so there is no poor soil texture per se. As a component of blue-green stormwater management systems, more sandy or clayey soils may be preferred for better water drainage or retention respectively.

In general, it is better to avoid extreme proportions of sand, clay or silt particles. "Ideal" soils vary based on factors such as site condition / microclimate, plant species, and expected level of maintenance.

SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

P2/ Bulk Density

Soil bulk density reflects how dense and tight a soil sample is. Bulk density is usually expressed as the dry weight of soil per unit bulk soil volume which includes that of soil particles and that of pores among soil particles (*Figure 5*), and ranges from 0.5 to 2.0 Mg/m³. It takes into account particle density and porosity, which is affected by soil mineral composition and the extent of compaction.

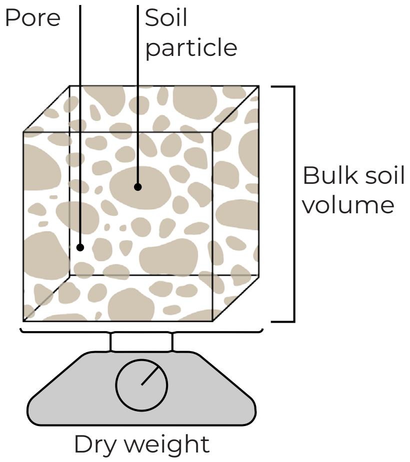


Figure 5. Bulk density = Dry weight / Bulk soil volume.

Relationship to Other Soil Parameters

High bulk density is an indicator of high soil compaction and low soil porosity. Bulk density decreases with soil organic matter content.

Implications for Plant Growth

While soil compaction increases soil strength, i.e. the ability of soil to resist being moved by an applied force, roots must also exert more force to penetrate the soil (*Cotching & Davies, 2021*). Though some compaction is needed to stabilize trees, high soil compaction may hinder root penetration and movement of air and water through the soil, resulting in shallow rooting and poor plant growth. Soil with a bulk density > 1.6 Mg/m³ tends to restrict root growth.

Quick Test Method(s)

High bulk density is easily observed by examining roots or soil. Growing roots that fail to overcome soil mechanical resistance imposed by compacted soil which has low macropore connectivity will concentrate on the soil surface or squeeze through paved materials instead of growing downwards. Compacted soil also reduces pore space within soil and results in low drainage or even waterlogging during wet periods.

Visual Assessment	Waterlogging (p.46) Hard Soil (p.52) Visible Roots (p.53) Few Soil Animals (p.55) Weeds (p.56) Tree Signs and Symptoms (p.58) - Leaf Fall, Chlorosis, Leaf Discolouration, Necrosis, Stunted Growth
Handy Quick Test	P2/ Test 1. Spade Test (p.76) P2/ Test 2. Soil Penetrometer (p.76)

Table 6. Effects of different bulk densities on root growth by soil type (Arshad et al., 1996; Jim, 2021).

Bulk density (Mg/m³)			General effect on root growth
Sandy soil	Silty soil	Clayey soil	
< 1.60	< 1.40	< 1.10	Ideal
1.60 – 1.80	1.40 – 1.65	1.10 - 1.47	Acceptable
> 1.80	> 1.65	> 1.47	Restricted

Table 7. Effects of soil compaction level on root growth (Cotching & Davies, 2021).

Force required to penetrate soil	General effect on root growth
< 1.5 MPa	Acceptable
1.5 - 2.5 MPa	Restricted
> 2.5 MPa	Severely restricted

Optimal Range of Bulk Density

For topsoils, values <1.5 Mg/m³ are considered optimal, although the optimal ranges vary with the soil texture (*Table 6*). For soil compaction, values < 1.5 MPa are considered optimal with regard to root penetration (*Table 7*).

SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

P3/ Porosity

Soil porosity refers to the space between soil particles, which forms a complex interconnected network occupied by air and water. It plays a significant role in the retention and conduction of air, water, nutrients and heat in the soil matrix.

Soil textural pore space is usually expressed as a ratio or percentage of the total soil volume. Childs (1940) referred to the pore space formed by ultimate particles as textural pore space and that formed by aggregates as structural pore space (*Figure 6*).

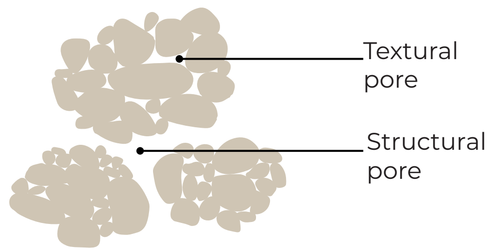


Figure 6. Textural and structural pore space.

Relationship to Other Soil Parameters

Soil porosity controls many of the important functions and properties of soil. It is the result of soil particle organization, and is dependent on soil texture / type, bulk density, organic matter level, aggregation, shrinking and swelling of clay particles, soil dispersion caused by various cations, tillage and traffic (Baver et al., 1972; Barral et al., 1998). Together with pore size distribution, it affects soil aeration and hydraulic properties such as water holding capacity, water availability, infiltration and hydraulic conductivity, and plays a vital role in all soil transport processes (Luxmoore, 1981; Reynolds et al., 2002; Kutilek, 2004; Reynolds et al., 2009). For example, porous soils with a high proportion of large pores have low water retention capacity and become saturated quickly.

Implications for Plant Growth

Clay is the most porous but the least permeable soil, while sand is porous and permeable (Barnes, 2016). In healthy soil, these pores are large and abundant enough to retain water, oxygen and nutrients for plant uptake through their roots. Soil compaction compressing soil particles and lack of stable aggregates as well as organic matter can reduce the space available for air and water.

Quick Test Method(s)

Visual Assessment	NA	Handy Soil Test	P3/ Test 1. Soil Porosity from Bulk Volume (p.78) P3/ Test 2. Pore Counting Method (p.79)

*Soil porosity (%) can be calculated from bulk density as 100% × (1−BD/2.65) where 2.65 Mg/m³ is taken as the absolute density of soil particles. For information on measuring bulk density, refer to Section *P2*.

Optimal Range of Porosity

Optimal total porosity in a mineral soil typically ranges between 40-60 %. Compaction decreases porosity as bulk density increases. If compaction increases bulk density from 1.3 to 1.5 Mg/m³, porosity decreases from 50% to 43%. Plant growth is impeded when the soil porosity falls below 10%.

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

P4/ Pore Size Distribution

Pore size distribution is the relative abundance of each pore size in a soil sample, which can be used to predict water retention capacity and plant available water content (*Figure 7*), infiltration rate, and air to water ratio. Soil pores can be classified according to their size, origin, location and function (Lebron et al., 2002; Kutilek, 2004; Nimmo, 2004) (*Table 8*). Soil pores are commonly characterised by their size into macropores, micropores and ultramicropores (*Figure 8*). Pore size is primarily determined by aggregate size and soil chemistry (Lebron et al., 2002), but there are pores formed from biogenic processes.

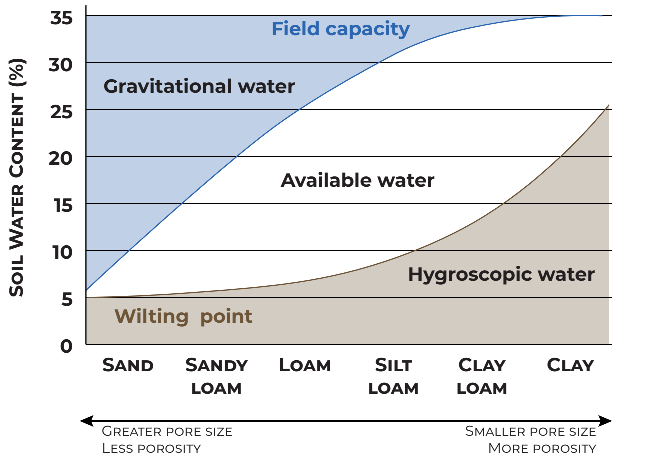


Figure 7. The relationship between soil texture and plant-available water content. (Redrawn from: The COMET program,2020 ©1997-2021 UCAR).

Table 8. Soil pore types and classification (Lebron et al., 2002; Kutilek, 2004; Nimmo, 2004).

Criterion	Type	Description
Size	Macropore	Large pore >80 μm; freely drained by gravity, houses soil organisms
	Micropore or capillary pore	Small pore <80 μm; water held tightly, suction required to remove
	Ultramicropore or submicroscopic pore	Pore <5 μm created by organic matter and inhabited by microorganisms; water tightly bound
Origin	Physical pore	Pore formed by wet-dry and freeze-thaw events which results in swelling and shrinkage
	Chemical pore	Pore formed by stabilizing or cementing material, e.g. oxides
	Biogenic pore	Channel and tunnel left by decayed roots and burrowing animals; usually macropores in size
Location	Intra-aggregate pore	Space inside soil aggregate; mostly micropores
	Inter-aggregate pore	Crack and void formed by arrangement of soil aggregates; micropores or macropores

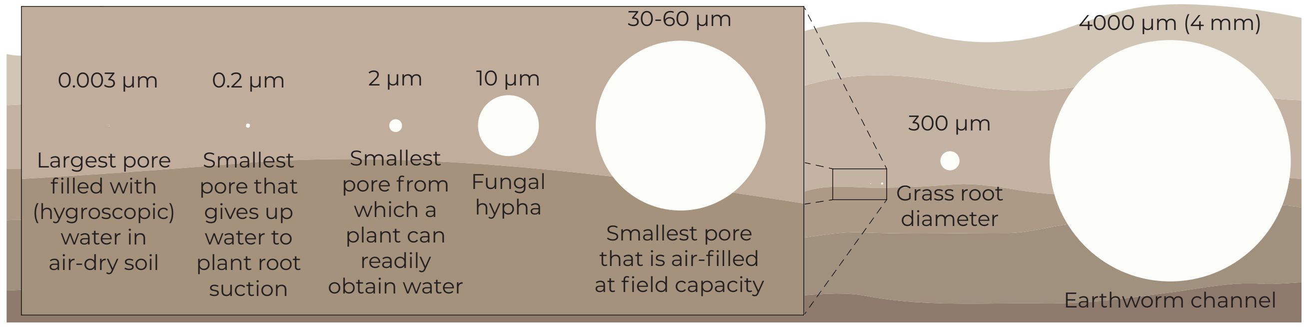


Figure 8. Different pore sizes in soil (Rowell, 1994).

SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

Relationship to Other Soil Parameters

Pore size distribution is a fundamental parameter in the transmission and storage of soil water and nutrients, soil aeration and root growth (Lipiec & Stepniewski, 1995; Pagliai and Vignozzi, 2002; Valentine et al., 2012). Issues with pore size distribution generally indicate problems with soil texture, compaction and aggregation as well as a lack of organic matter.

Soil physical quality could be quantified using the optimal ranges of the soil pore size distribution curves, along with important indicators of relative field capacity, plant available water, air capacity, macroporosity, bulk density, organic carbon (C) content and structural stability.

Implications for Plant Growth

Pore size distribution, a temporal and structural dynamic phenomenon, is important in governing soil-plant interaction.

Though both micropores and macropores can hold water, nutrients and air for plant uptake, macropores contribute more to soil aeration but easily lose water to gravity. Contrastingly, micropores are more effective in holding water but may trap moisture as hygroscopic water that binds tightly to soil particles and is not available for root absorption even in drought. There seems a close relationship between plant available water and the frequency of smaller pores (Ugalde et al., 2009).

Sandy soil has excessive macropores, while heavy clay soil has too many micropores. However, it is erroneous to add clay to sand, as the tiny clay particles will fill up the space between sand particles producing an even denser soil.

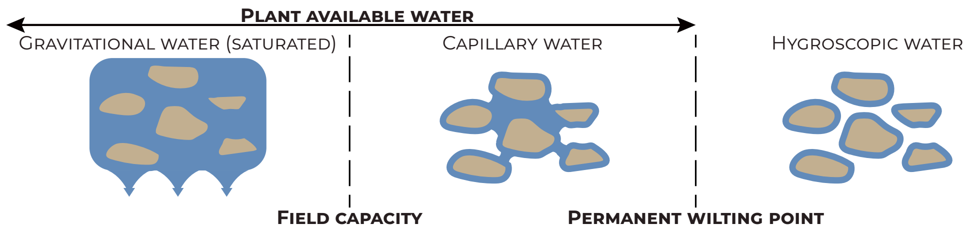


Figure 9. Available water for plant uptake. Excess water is drained out of the root zone by gravity, while water held in micropores (capillary water) is available for absorption by roots. The water film (hygroscopic water) adhering to soil particles is unavailable for plant uptake.

Quick Test Method(s)

No quick tests are available for the measurement of pore size and its distribution. Laboratory examination of pore size distribution is time-consuming and expensive. In a field setting, the best guess at a soil's pore size distribution may be gained from investigating soil texture (how coarse or fine it is), aggregation and compaction.

Visual Assessment	NA
Handy Quick Test	NA

Optimal Range of Pore Size Distribution

Optimal soil pore size distribution is the range that gives the best plant available water and least limiting water range. The optimal pore volume distribution had modal, median and geometric mean equivalent pore diameters of 60-140, 3-7 and 0.7-2.0 μm, respectively (Reynolds et al., 2009).

SOIL PARAMETERS | VISUAL ASSESSMENT | HANDY QUICK TESTS | IMPROVEMENT MEASURES

SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

P5/ Aggregate Stability

Soil aggregates are clumps of soil that are formed through physical, chemical and biological processes to bind soil particles together. They vary in size and shape, and play a key role in soil structure formation and soil health.

Relationship to Other Soil Parameters

The stability of aggregates is of utmost importance, as water-stable aggregation resists particle disintegration and compaction from raindrop impact, and contributes to soil sustainability. Water stable aggregates which are formed through flocculation and cementation of soil particles are effectively dependent on organic matter, multivalent ions (aluminium (Al^{3+}), calcium (Ca^{2+}), iron (Fe^{2+})) and biological activities (Baver et al., 1972), and have pronounced effect on soil quality and pore characteristics.

Implications for Plant Growth

Large pores associated with large, stable aggregates favour good drainage and improved aeration for plant growth. Pore space maintained by aggregates provides weak zones for root penetration. In contrast, unstable aggregates easily break up into loose soil particles which maintain less pore space and are carried away by wind and water, exposing tree roots. Small particles settle into and block surface pores, causing the surface to be sealed. When the soil dries up, a hard crust is formed, blocking water from soaking into the soil for root absorption.

Quick Test Method(s)

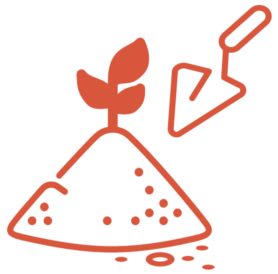
Visual Assessment		Handy Quick Test	
	Soil Loss (p.48) Surface Crust (p.51) Visible Roots (p.53)		P5/ Test 1. Drop Test (p.80) P5/ Test 2. Slake Test (p.81)

Table 9. Soil aggregate stability and physical quality (Sundermeler et al., n.d.).

Soil aggregate stability (%)	Soil physical quality
<25	Poor
25-50	Low to medium
50-75	Medium to good
>75	Excellent

Optimal Range of Aggregate Stability

Soil aggregate stability of >60% can be considered optimal, while <25% is considered poor physical quality, scaled over similar textured soils (*Table 9*).



SOIL ANALYSIS PARAMETERS

PHYSICAL PARAMETERS

P6/ Infiltration Rate

Soil infiltration refers to the ability of a soil to allow water movement from the surface into and through the soil profile as a result of gravitational force. Infiltration rate denotes the speed of water volume flux flowing into the soil and is commonly expressed in mm per hour (mm/h). Alternatively, it can be expressed as the time taken for the soil to absorb each centimetre of water applied on the soil surface.

Relationship to Other Soil Parameters

While infiltration is a surface phenomenon that is determined largely by the condition of the soil surface, drainage is usually used to describe an internal soil property associated with water movement through the soil, which can be divided into different classes from poor to good drainage. Infiltration is under the influence of soil texture (*Table 10*), soil porosity and compaction, organic matter content and the presence of vegetation.

Table 10. Steady infiltration rates for different general soil textural groups.

Soil type	Infiltration rate (mm/h)	
	FAO, 1990	Cotching, 2009
Clay	1-5	0.1-5
Clay loam	5-10	2-15
Loam	10-20	1-20
Sandy loam	20-30	10-80
Sand	30-40	20-250

Infiltration rates can indicate soil drainage that is too fast or too slow. When soil drains too quickly, no water puddles on the surface but less water is retained in the soil for plant absorption. On the other hand, when soil does not drain well, the space between soil particles will be filled with water instead of air, which reduces soil aeration.

Implications for Plant Growth

Infiltrated water is temporarily stored and becomes available for uptake by plants and soil organisms. Water infiltrating too fast will move out the soil profile in a short time (well-drained soil) but recharge groundwater aquifers, while water infiltrating too slow may result in erosion from surface runoff or even ponding and root decay in extreme cases (poorly-drained soil). Both lead to inadequate moisture for soil animal and plant uptake.

The resulting plant dehydration often manifests as leaf fall, leaf necrosis and browning as well as stunted growth. Weeds adapted to these conditions may establish, while the effects of poor drainage on soil chemistry and biology are present as distinctive colours and odours.

Quick Test Method(s)

Visual Assessment	Waterlogging (p.46) Dry Soil (p.47) Abnormal Soil Colour (p.49) Root Decay (p.54) Few Soil Animals (p.55) Weeds (p.56) Tree Signs and Symptoms (p.58) - Leaf Fall, Necrosis, Brown Edges, Stunted Growth
Handy Quick Test	P6/ Test 1. Infiltrometer Method (p.83)

Optimal Range of Infiltration Rate

Based on the infiltration rates of different soil textures (*Table 10*), the optimal rates should be in the range of 5-20 mm/h.

SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

C1/ pH

pH is a critical indicator of a soil's health status. Soil pH measures the concentration of hydrogen ions in a soil solution.

Relationship to Other Soil Parameters

Soil pH affects soil chemistry, microbiology and enzyme activities, nutrient availability, as well as the dissolution and mineralisation of organic matter (Brady & Weil, 1999; White, 2006). Soil alkalinity is often caused by high calcium carbonate levels, observable as white powder on aggregates.

Optimal Range of pH

Most plants prefer a neutral soil pH at around 6.5 to 7.5, and will grow favourably in the range of 5.5 to 8.0. Some plants can grow well over a fairly wide pH range, while others have very specific soil pH requirements.

Implications for Plant Growth

When the soil is very acid or very alkaline, most nutrients are more strongly bound to soil particles and are less available to plant absorption, causing poor growth. Most nutrients are more available at slightly acidic to neutral pH of 6-7. Micronutrients like iron (Fe), manganese (Mn) and boron (B) become more available in acidic soil (*Figure 10*). All plants are affected by extremes of pH, but they vary widely in their tolerance of acidity and alkalinity. Some plant genera like Rhododendron, Hibiscus, Ilex, Gardenia and Magnolia prefer more acidic soils. As different pH can lead to various nutrient deficiencies, noting any appearance of weeds adapted to more extreme pH ranges may assist soil diagnosis.

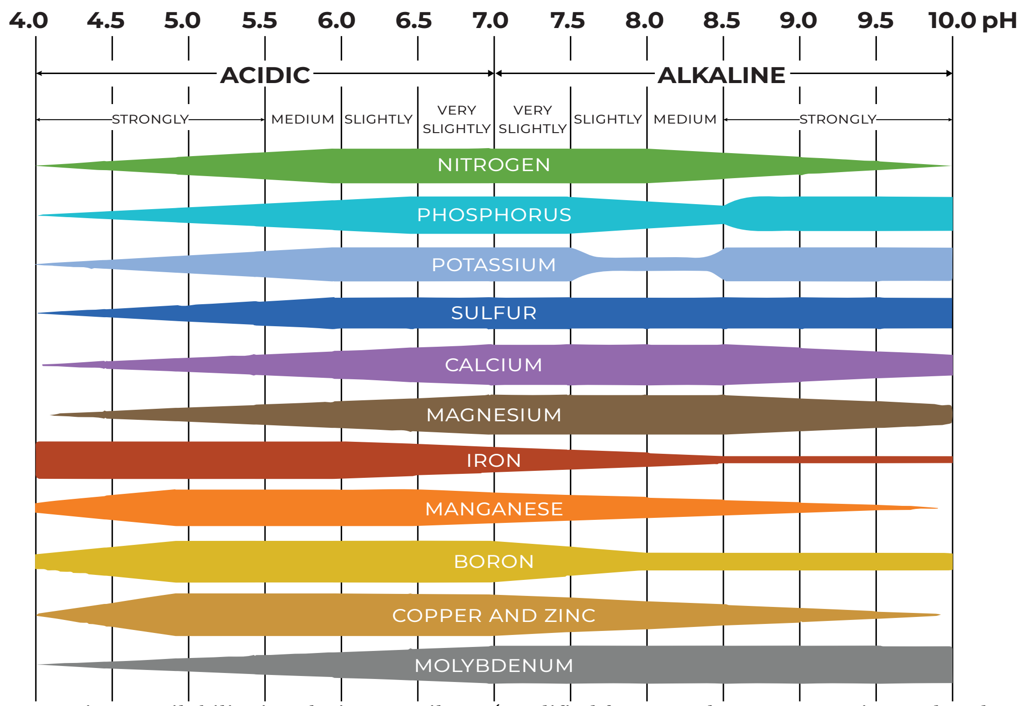
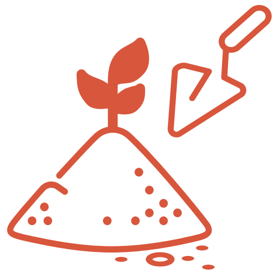


Figure 10. Plant nutrient availability in relation to soil pH. (Modified from: CoolKoon, 2018, Licensed under CC BY 4.0).



Quick Test Method(s)

Visual Assessment		Handy Quick Test	
	Abnormal Soil Colour (p.49) Weeds (p.56) Tree Signs and Symptoms (p.58) - Stunted Growth		C1/ Test 1. pH Test Kits / Strips (p.84) C1/ Test 2. pH Meter (p.85)

SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

C2/ Electrical Conductivity (EC) / Salinity

Soil electrical conductivity (EC) is a mean of estimating ion concentration in soil. Conductivity is the ability of water to conduct an electrical current, and the dissolved ions, including cations like sodium (Na^+), calcium (Ca^{2+}), potassium (K^+) and magnesium (Mg^{2+}), and anions such as chloride (Cl^-), sulphate (SO_4^{2-}), carbonate (CO_3^{2-}) and bicarbonate (HCO^{3-}), are the conductors. Soil salinity which measures the amount of salts in the soil is not typically an issue with Hong Kong's urban soils and few treatments are available other than to replace soil.

Relationship to Other Soil Parameters

Conductivity is generally related to soil salinity. It affects plant nutrient availability, soil microbial activities, plant suitability and biomass yield. Overly high electrical conductivity can indicate excess salinity levels or nutrients in the soil.

Implications for Plant Growth

Soil EC provides valuable information on the soil condition for plant growth, nutrient cycling and biological activity. Excessive salts hinder plant growth by upsetting soil-water balance. Soil EC is affected by irrigation and fertiliser application.

Quick Test Method(s)

High level of salts in the soil can be observed as a white crust when salts are drawn up to the soil surface during evaporation. In addition to general poor plant performance, the presence of salt-tolerant weeds can suggest soil salinity. While there is no handy kit for electrical conductivity, the use of a portable ohmmeter for conductivity alone or a combined pH and conductivity meter for the simultaneous measurement of the two parameters is the standard equipment in most laboratories.

Visual Assessment		Handy Quick Test	
	Abnormal Soil Colour (p.49) Surface Crust (p.51) Weeds (p.56) Tree Signs and Symptoms (p.58) - Brown Edges, Stunted Growth		C1/ Test 3. Ohmmeter (p.86)

Table 11. EC ranges (mS/cm) of salinity classes for different soil textural groups (Smith & Doran, 1996).

Texture	Degree of salinity (Salinity classes)				
	Non-saline	Slightly saline	Moderately saline	Strongly saline	Very saline
Silty clay loam to clay	0-1.4	1.5-2.8	2.9-5.7	5.8-11.4	>11.5
Silt loam to clay loam	0-1.3	1.4-2.5	2.6-5.0	5.1-10.0	>10.1
Loamy fine sand to loam	0-1.2	1.3-2.4	2.5-4.7	4.8-9.4	>9.5
Coarse to loamy sand	0-1.1	1.2-2.4	2.5-4.4	4.5-8.9	>9.0

Optimal Range of Electrical Conductivity

Soil with EC <1 mS/cm is considered non-saline. However, the optimal EC in soil ranges between 1-5 mS/cm (*Table 11*), as our plants need nutrients in the form of free ions for healthy growth.

SOIL ANALYSIS PARAMETERS
CHEMICAL PARAMETERS

C3/ Soil Organic Matter (SOM)

Soil organic matter (SOM) is the organic component of soil, consisting of plant and animal materials at various stages of decomposition. It is made up of three major components, namely plant residues and microbial biomass, active SOM (detritus) and stable SOM (humus). The former two are the soil nutrient pool which releases different plant nutrients upon mineralization, and contribute to soil fertility.

Relationship to Other Soil Parameters

SOM is partitioned into different fractions, the dynamic of which is a function of organic matter inputs and litter decomposition, and is governed by soil properties like texture, pH, temperature, moisture, aeration, clay mineralogy and soil biological activities (Condron et al., 2010; Murphy, 2015). It is linked to soil structure and porosity, soil aggregation, water infiltration and drainage, moisture retention, cation exchange capacity, plant nutrient availability, and the diversity and activity of soil microflora and fauna (Bot & Benites, 2005).

Implications for Plant Growth

SOM benefits the chemical and physical properties of the soil and its overall health. It contributes to soil productivity in many different ways, through physical, chemical and biological modifications. It also acts as a major sink and source of soil C. Low SOM causes poor soil structure, leaf loss, and supports fewer soil animals which feed on it.

Visual Assessment	Abnormal Soil Colour (p.49) Surface Crust (p.51) Hard Soil (p.52) Few Soil Animals (p.55) Weeds (p.56) Tree Signs and Symptoms (p.58) - Leaf Fall
Handy Quick Test	NA

Quick Test Method(s)

Soil colour provides a feasible method of predicting soil organic C content which can been visually gauged using Munsell soil colour book or less subjective chroma meter colour readings (Konen et al., 2003), but different soil orders can have differing soil colour–organic matter relationships which limits its prediction accuracy (Shield et al., 1968; Wills et al., 2007). However, there currently seem to be no good quick tests for SOM determination.

The most accurate SOM determination which has to be done in the laboratory is by either dry ashing (loss on ignition using muffle furnace) at 550ºC or wet oxidation (Walkley and Black Method) using sulphuric acid - dichromate. The wet combustion method for the determination of organic C in soils has been modified to use automated instrument for the colorimetric analysis instead of titration. The dry combustion method measures total C whereas the wet dichromate method determines only easily oxidisable C.

NB: Organic matter % = Organic C × 1.72 (assuming about 58% of organic matter exists as organic C in soil)

Optimal Range of SOM

SOM concentration generally ranges from 1-6 % in topsoil. Most productive agricultural soils have between 3-6 % organic matter (Fenton et al., 2008). It is suggested that lawns should contain at least 2-3 % organic matter, while gardens and landscapes should have 4-6 % SOM.

The optimal level of SOM varies with soil type, climate and management, but it is generally considered that optimal SOM levels range between 2-6 %.

SOIL ANALYSIS PARAMETERS
CHEMICAL PARAMETERS

C4/ Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is the total quantity of negative charges on particle surface, and is the capacity of a soil to hold positively-charged ions (cations) such as K^+, Ca^{2+}, Mg^{2+} and Na^+. The higher the CEC, the more negative charges it has, and the more cations it can hold. It is suggested to group soils based on their CEC for soil test for fertiliser recommendations (Cope & Evans, 1985).

Relationship to Other Soil Parameters

CEC is an important soil property for estimating plant nutrient retention and availability in soil; it is the potential available nutrient supply rather than a direct measurement of available nutrients. It affects soil structural stability, nutrient availability, pH and reaction to fertilisers and other ameliorants (Hazleton & Murphy 2007). It governs the ability to hold essential cationic nutrients in exchangeable forms, and provides a buffer against soil acidification by controlling the relative proportion of base cations and acidic cations (like hydrogen (H^+) and aluminium (Al^{3+})) on the exchange sites. The percentage of CEC occupied by base cations contributes to base saturation. Soils with higher clay contents tend to have higher CEC. Low CEC may be an indicator of low soil pH, low clay content in soil texture, or low levels of organic matter.

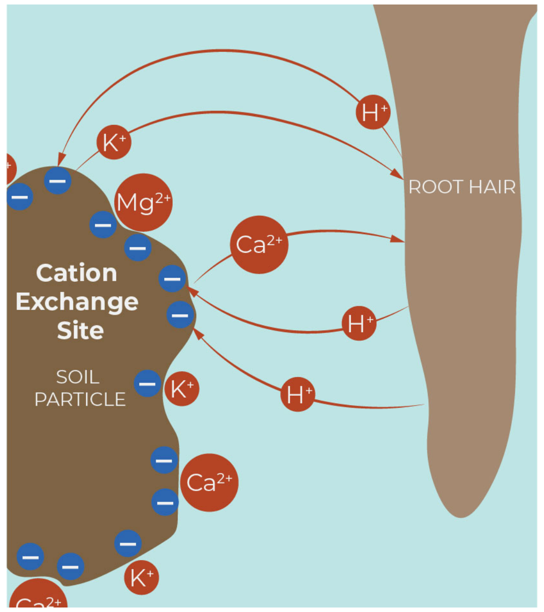


Figure 11. Soil particles have surface negative charges which act as cation exchange sites.

Implications for Plant Growth

Cations that are important to plant nutrition are those alkaline-forming cations, e.g. Ca^{2+}, Mg^{2+}, K^+ and Na^+, while acid-forming cations, e.g. H^+ and Al^{3+}, are not plant nutrients. They are chemically adsorbed to surfaces of SOM or clay particles which are negatively charged. Cations removed by plants from the soil solution are replaced by those exchangeable cations held on the surfaces of soil components which act as cation exchange sites (*Figure 11*). Cation exchange also occurs on root surfaces which release H^+ to replace the cations adsorbed.

Quick Test Method(s)

CEC can be estimated by summation of exchangeable K, Ca and Mg and neutralisable acidity, which is acceptable for most soils (Warncke et al., 1980). A simple, single-step extraction with LiEDTA for the estimation of CEC and exchangeable bases has been developed for non-calcareous soils, in which multivalent cations are removed from the soil adsorption sites by strong chelating agent EDTA, which are replaced by Li (Begheyn, 1987). A rapid method for CEC estimation using methylene blue adsorption measured by its absorbance at 510 nm after a 2-h equilibration has been proposed (Soon, 1988). CEC can also be estimated from soil texture and colour as it is attributed to the clay and organic matter present.

Visual Assessment	NA	Handy Quick Test	NA

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

Optimal Range of CEC

CEC >10 meq/100 g is considered optimal to plant growth.

Clay particles have more surface charges per particle and per unit volume than sand (*Figure 12*). Soil CEC thus varies with the contents of clay and organic matter (*Table 12*), and soil pH. Organic matter have very high CEC (200–400 meq/100 g), while sandy soils have low CEC (<10 meq/100 g). Soils with low CEC are susceptible to cation (e.g. K^+, Mg^{2+}) deficiencies as a result of leaching.

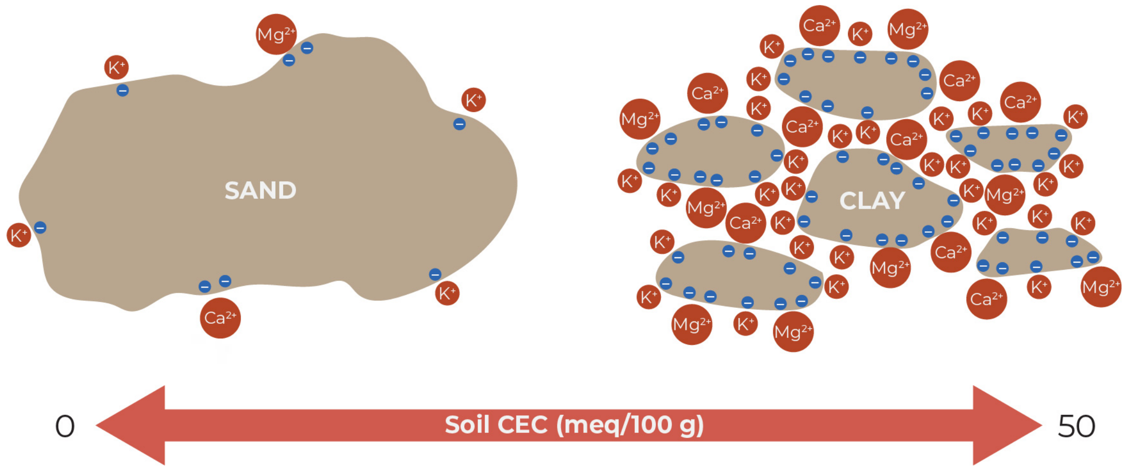
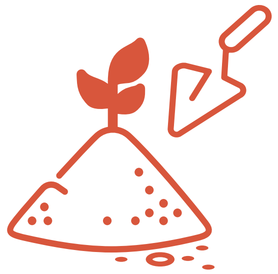


Figure 12. Sand particles have few negative charges and hence lower CEC while clay particles have more negative charges and hence higher CEC.

Table 12. CEC of soils of different texture (Culman et al., 2019).

Texture	CEC (meq/100 g soil)
Sand	3-5
Loam	10-15
Clay and clay loams	20-50
Organic soils	50-100

NB: CEC is commonly expressed as milliequivalents per 100 grams soil (meq/100 g) which is equivalent to centimoles of positive charge per kilogram of soil (cmol/kg).



SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

Plant Nutrients

Soil contains essential nutrient elements that plants need for their growth and metabolism. Some nutrients, e.g. nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca), are required in greater amounts and are thus referred to as major or macro-nutrients. Others like boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) are taken up in relatively lower quantities, and are called minor or micro-nutrients (also trace elements). Nutrients, whether major or minor, can become toxic when present in excessive concentrations.

Chemically and analytically, these nutrients exist in different forms in the soil:

Soluble form

Free ions that are dissolved in soil solution (soluble form) are usually taken up by plant roots together with water. They can be either positively-charged (K^+, Ca^{2+}, Na^+, ammonium (NH_4^+), copper (Cu^{2+}), Zinc (Zn^{2+})) or negatively-charged (nitrate (NO_3^-), Phosphate (PO_4^{3-}), Sulphate (SO_4^{2-})).

The soluble form is like cash in our wallet.

Available form

Ionic nutrients are adsorbed by soil materials carrying opposite charges on their surface, which replace ions of different affinities, a process called ion exchange reaction. Clay particles and organic matter have surface negative charges that bind cations; they remove cations selectively and replace them. They are exchangeable and are available to plant uptake. Their concentrations in soil are determined using specific extractants, hence extractable fraction that denotes available or exchangeable form.

The available form is like money that can be readily obtained from an automatic teller machine.

Total form

The abovementioned soluble and available forms, together with the fraction that is insoluble in soil water, constitute the total content of the nutrient in soil. This total form, though less important to plant nutrition, is the reserve and can be released slowly through organic matter decomposition and mineral weathering.

The total form is like fixed assets that we have to sell for cash.

SOIL ANALYSIS PARAMETERS
CHEMICAL PARAMETERS

Plant nutrients are basic to the chemical fertility of soils. Besides C, hydrogen (H), and oxygen (O) that are taken up from the atmosphere and water, other essential nutrients come from the soil. A deficiency of any one of these nutrients will retard plant growth and reduce plant yield. In natural ecosystems, soil nutrient levels are governed by nutrient cycle. In agricultural and horticultural soils, plant production is usually sustained by external supplies in the form of fertilisers. There are different classifications and types of fertilisers: organic and inorganic, quick and slow release, complete and incomplete, solid and liquid. Most synthetic fertilisers are mixed ones with the three important essential elements: N, P and K, hence commonly called NPK fertilisers. Their rating or content, e.g. 15-15-15 or 12-8-6, spells out the amount of the three nutrients in the fertiliser. They denote the percentage of N, phosphorus pentoxide (P_2O_5) and potash (K_2O) respectively in the products.

In managed soils, soil fertility evaluation is typically done by soil testing using chemical extraction to estimate the plant available nutrient status. This is usually worked out by the relationship between the soil available contents and the relative yield along a yield response curve (*Figure 13*) (Fixen & Grove, 1991; McGrath et al., 2014). The following sections thus express optimal or ideal soil concentrations of plant nutrients in terms of available content. Though optimal concentrations are expressed differently in different sources and vary among locations, soil types (e.g. texture), soil chemistry (e.g. pH, organic content), plant types and extraction methodology (e.g. extractant), the optimal ranges given here are generalised from different sources for reference.

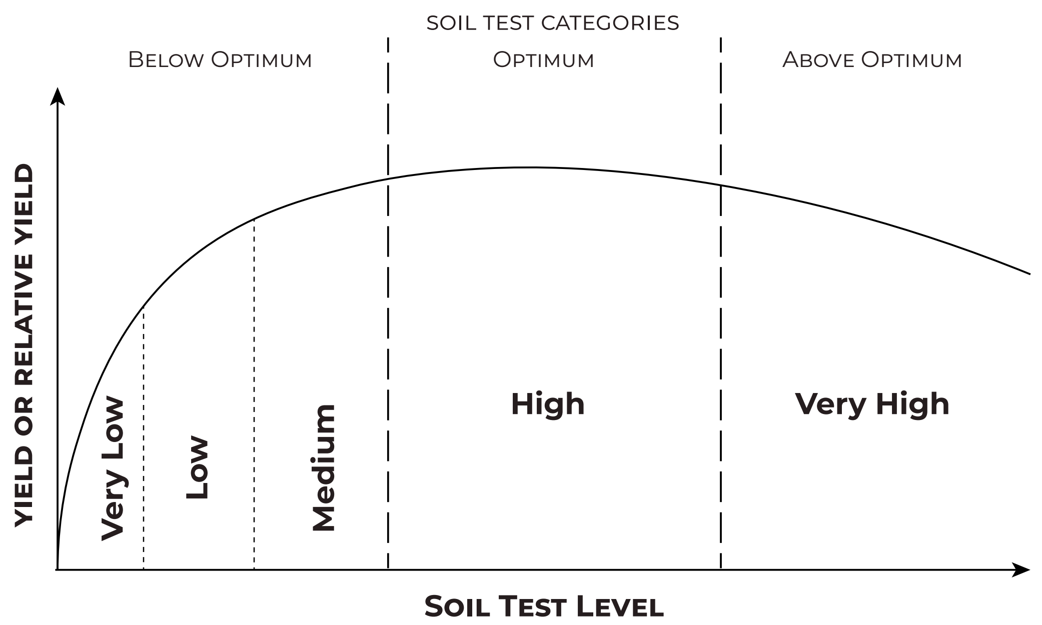


Figure 13. Conceptual relationship between soil nutrient concentrations and plant yield response (Heckman, 2006). Soil concentrations are depicted low to medium (below optimum) when the relative yields are less than 75%, while concentrations are optimal when the relative yield is approaching 100%. When very high concentrations are reached, the relative yield will decline to below 100%.

SOIL ANALYSIS PARAMETERS
CHEMICAL PARAMETERS

C5/ Macronutrient - Nitrogen (N)

N exists predominantly in gaseous form in the atmosphere, which is not available for plant uptake. Over 95% of the N in soil is in organic forms which are mineralized and become the source of N usable by plants, although a certain fraction is biologically converted from molecular N_2 by N-fixation. N turnover via mineralization is crucial in governing N supply in soil. However, soil N in the form of nitrate and ammonium which are available for plant use are highly mobile and readily lost via leaching. Therefore N is the most limiting major nutrient in soil and its management becomes critical.

Implications for Plant Growth

Unlike other major plant nutrients, soil parent material contains no N, so weathering does not supply N to the soil for plant nutrition. However, N is the most essential plant nutrient for the production of proteins, nucleic acids (DNA and RNA) and chlorophyll. Plants need N for healthy growth and development, and this has to be provided through organic matter decomposition and biological fixation of gaseous N_2, or artificially thorugh N fertilisers.

Without this major component, older leaves first appear yellow and wither, as plants often respond to N deficiency by moving N to new growth. Root growth is enhanced while shoot growth is stunted (Agren & Franklin, 2003), and water regulation is affected, showing symptoms of water stress. The growth of N-fixing weeds can hint at low N in the soil.

Quick Test Method(s)

Visual Assessment	Weeds (p.56) Tree Signs and Symptoms (p.58) - Leaf Fall, Chlorosis, Necrosis, Delayed Bloom	Handy Quick Test	C5/ Test 1. Nitrate and Nitrite Test Kits / Strips (p.87) C5/ Test 2. Nitrogen Electrode Methods (p.87)

Optimal Range of N

The optimal range of N will vary with soil conditions and plant requirements, but for most plants, 40-150 mg/kg is considered optimal.

Higher levels may be needed for especially high yields and for certain plants. Plant growth will be very good at the high concentration range but may need attention for the risk of eutrophication if excessive N is removed in surface runoff. Plants will be generally deficient if soil N falls below the lower range, which can be improved by fertiliser application.

SOIL ANALYSIS PARAMETERS
CHEMICAL PARAMETERS

C6/ Macronutrient - Phosphorus (P)

In soils, P is mainly derived from the weathering of mineral apatite (Schlesinger, 1997). Soil P can be classified into four pools: dissolved, sorbed to surfaces of clay minerals, organic form and primary phosphate minerals. Most soil P is fixed, either tightly bound to mineral particles or tied up in the organic matter pool. Some is in labile form that is readily released into the soil solution and become available to plants, while less is in soluble form as free ions.

Relationship to Other Soil Parameters

P availability to plants is dependent on soil pH, aeration, clay content and SOM. At low pH, P is mainly adsorbed on Al and Fe oxides while at neutral pH it is fixed as $Ca_3(PO_4)_2$ (Liu et al., 2008). P is released faster in well aerated soil. Inorganic P exists as phosphate or orthophosphate which has three derived anions ($H_3PO_4 \rightleftharpoons H_2PO4^- \rightleftharpoons HPO_4^{2-} \rightleftharpoons PO_4^{3-}$) coexisted according to dissociation equilibrium.

Implications for Plant Growth

P is required for the production of energy (via adenosine triphosphate (ATP)), nucleic acids and sugars. It is essential to root development and plays an important role in plant growth and health.

P deficiency often inhibits shoot growth and causes poor root development, while root:shoot ratio also decreases. Old leaves wither and fall as P is moved to support energy production and tissue development in new leaves which become small and dark green or purplish. Water regulation is also affected and water stress symptoms may develop. Overall, plants become less hardy and may both flower and mature later. Weeds adapted to low P levels can be useful indicators.

Quick Test Method(s)

Visual Assessment		Handy Quick Test	
Visual Assessment	Weeds (p.56) Tree Signs and Symptoms (p.58) - Leaf Fall, Necrosis, Brown Edges, Delayed Bloom, Stunted Growth	Handy Quick Test	C6/ Test 1. Phosphorus Test Kits / Strips (p.88) C6/ Test 2. Phosphorus Electrode Methods (p.88)

Optimal Range of P

The optimal range of P in soil is between 30 and 120 mg/kg for most plants.

Many determinations express the concentration of P as P_2O_5 (phosphorus pentoxide) ($P = 0.44 \times P_2O_5$).

SOIL ANALYSIS PARAMETERS
CHEMICAL PARAMETERS

C7/ Macronutrient - Potassium (K)

K has important role in enzyme activation, photosynthesis, protein formation and sugar transport. It exists in three forms: unavailable form fixed or trapped between clay layers, exchangeable form that are available by being adsorbed on the surface of soil colloids, and soluble form by existing as ions in the soil solution.

Implications for Plant Growth

K regulates stomatal aperture and hence water and gaseous exchange, controls water movement and water turgor pressure to prevent wilting, promotes fruit development, and enhances disease resistance by building a thicker cuticle which protects against diseases and water loss. Soil K is a major plant nutrient that is less affected by soil pH.

With poor regulation of water turgor pressure and underdevelopment of cuticles, K-deficient plants wilt or droop readily and become more susceptible to pests, diseases and water loss. Water stress symptoms are seen. Leaf discolourations develop, first in the older leaves. Finding weeds adapted to low K can increase confidence in diagnosis.

Quick Test Method(s)

Visual Assessment		Handy Quick Test	
Visual Assessment	Weeds (p.56) Tree Signs and Symptoms (p.58) - Chlorosis, Leaf Discolouration, Necrosis, Brown Edges, Delayed Bloom, Stunted Growth	Handy Quick Test	C7/ Test 1. Potassium Test Kits / Strips (p.89) C7/ Test 2. Potassium Electrode Methods (p.89)

Optimal Range of K

The optimal range of K in soil is between 100 and 300 mg/kg for most plants (*Table 15*). Most K in soil comes from the weathering of minerals especially mica in the clay fraction and feldspar in the sand and silt fractions.

Many determinations express the concentration of K as K_2O (potash) ($K = 0.83 \times K_2O$).

SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

C8/ Other Macronutrients - Magnesium (Mg), Calcium (Ca) and Sulphur (S)

Mg, Ca and S are secondary macronutrients which come after N, P and K in importance as essential plant nutrients. Ca and Mg form cations (Ca^{2+} and Mg^{2+}) which are attributed to the base saturation and CEC of the soil. S is mainly supplied by organic matter via mineralisation. It is taken up primarily as SO_4^{2-} which is mobile in the soil, while Ca^{2+} is relatively less mobile than Mg^{2+}.

Implications for Plant Growth

Mg is central to chlorophyll formation and serves as activator for many enzymes, while Ca provides structural support to cell walls and contributes to normal development of the root system. S is essential to protein synthesis, enzyme formation and chlorophyll development.

In plants, Mg is a mobile nutrient that will move to growing tissues, thus deficiency symptoms will show up first in older tissues. On the other hand, Ca and S are immobile in plant tissue, and symptoms of their deficiencies are localised in younger leaves.

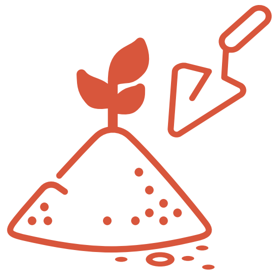
Quick Test Method(s)

Visual Assessment		Handy Quick Test	
	Tree Signs and Symptoms (p.58) - Chlorosis, Leaf Discolouration, Necrosis, Delayed Bloom		C8/ Test 1. Test Kits for Macronutrients (p.89)

Optimal Range of Other Macronutrients

Table 13. Optimal ranges for levels of other macronutrient concentration in soils.

Macronutrient	Optimal range (mg/kg)
Ca	500-2000
Mg	100-500
S (as SO_4^{2-})	25-100



SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

C9/ Micronutrients

Micronutrients are essential elements that are used by plants in smaller quantities. While plants typically require less micronutrients than macronutrients, a deficiency can still limit plant functions and cause growth problems. There are eight of them, viz. boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn).

Implications for Plant Growth

Despite lower requirement, micronutrients are important to plant growth and development, and are keys to plant health. Most micronutrients are involved in vital enzyme reactions in photosynthesis and respiration (*Table 14*).

Table 14. Role of micronutrients in plant growth and quick testing methods for their deficiency.

Micronutrient	Significance in plant growth	Quick Test Method	
		Visual Assessment	Handy Soil Test
B	Flowering and fruiting; cell wall formation; amino acid synthesis; carbohydrate metabolism	Stunted growth, leaf deformation and chlorosis, poor flowering	Test kit
Cl	Energy reactions; turgor regulation; stomatal opening	Leaf wilting, chlorosis and necrosis	Test kits
Cu	Enzyme activation; photosynthesis; respiration; protein production; carbohydrate metabolism; vitamin A production	Chlorosis (new leaves)	Test kits
Fe	Chlorophyll formation, enzyme production; energy transfer; N reduction and fixation	Interveinal chlorosis (new leaves)	Test kits
Mn	Chloroplast production; enzyme activation; seed germination; plant maturity	Interveinal chlorosis (new leaves)	Test kit
Mo	Enzymes in nitrate assimilation, sulphite detoxification, auxin synthesis and purine degradation Ni fixation	Interveinal and marginal chlorosis (old leaves)	NA
Ni	Urease synthesis; seed germination	Chlorosis (new leaves)	NA
Zn	Enzyme activation; photosynthesis; phytohormone activity; protein synthesis; carbohydrate metabolism; root, seed and fruit development	Stunted growth, reduced internode length, chlorosis (old leaves)	Test kit

NA = not available

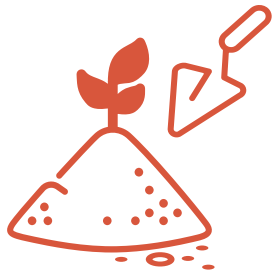
Quick Test Method(s)

Micronutrient availability to plants is under the influence of a number of soil factors including SOM, pH and soil texture. Commercial field test kits are available for a number of micronutrients, e.g. Fe, Cu, Cl. Many use colorimetric methods in developing colour or turbidity in soil samples. However, as micronutrients are usually present in soil in relatively low concentrations, these kits are qualitative and are not accurate enough if quantitative data are needed. The colour of the soil extracts obtained will also interfere with the colorimetric assessment in most cases.

Optimal Range of Micronutrients

Table 15. Optimal ranges for levels of micronutrient concentration in soils.

MIcronutrient	Optimal range (mg/kg)
B	1-3
Cl	30-100
Cu	2-6
Fe	30-100
Mn	10-50
Mo	1-3
Ni	0.5-1.5
Zn	4-10



C10/ Heavy Metals

Heavy metals are a loosely classified group of elements with density greater than 5. Out of the over 20 heavy metals, several are essential nutrients (notably Cu, Fe, Mn, Mo, Ni and Zn), but most are toxic to plants, accumulating in plant tissues and producing common negative effects on growth.

Normal horticultural soils should be devoid of heavy metals. Elevated concentrations in soil are usually the result of contamination from industrial sources. Some are from other intended applications, e.g. copper-based fungicides. As in cationic nutrients, their availability to plants is determined by soil characteristics such as pH, clay content, SOM and metal species. If metal concentrations are high, soil removal may be the only option, as treatments may only be transitional in effect.

Implications for Plant Growth

All heavy metals are phytotoxic and will have inhibitory effects on plant cellular, biochemical, and physiological structures and processes. Common impairments are nutrient imbalance, photosynthetic damage, oxidative stress and morphological discolouration (*Table 16*), with reduction in plant biomass and death as the severe case.

Table 16. Effects of common heavy metals on plant growth when present in toxic levels.

Heavy metal	Phytotoxic toxic effect
Arsenic (As)	Inhibited seed germination and root growth; young seedlings more susceptible Damaged root system (primary phytotoxic effect on root tip) Inhibited cell division; altered root membrane structure and function; reduced photosynthetic efficiency Interfered uptake and transport of P, S, Ca, Mg, Mn and Fe
Cadmium (Cd)	Interfered uptake and transport of P, K, Ca, Mg and water Reduced nitrate absorption and transport to shoot Reduced membrane ATPase activity Disintegrated photosynthetic apparatus and subcellular organelles Oxidative damage
Chromium (Cr)	Impaired photosynthesis: chlorophyll disintegration; damaged chloroplast ultrastructure Reduced nutrient and water uptake Inhibited Calvin cycle and electron transport; depressed amylase activities
Copper (Cu)*	Inhibited root elongation; damaged root morphology and function Induced Fe deficiency
Iron (Fe)*	Impaired photosynthesis and chlorophyll synthesis Damaged cellular structures and macromolecules (lipids, proteins and DNA)
Lead (Pb)	Oxidative stress Inhibited seed germination and seedling growth Inhibited root and stem elongation
Manganese (Mn)*	Inhibited chlorophyll and carotenoid synthesis
Mercury (Hg)	Interfered uptake and transport of P, stomatal closure; hindered water flow Oxidative stress; interfered mitochondrial activity Disrupted cell metabolism
Nickel (Ni)*	Interfered uptake and transport of P Impaired nutrient balance and water uptake Decreased chlorophyll content and stomatal conductance Cell membrane disorder
Zinc (Zn)*	Oxidative damage Reduced photosynthetic energy conversion and synthesis of chlorophyll, carotenoid and amino acids P, Mn and Cu deficiencies in shoots

**micronutrient*

SOIL ANALYSIS PARAMETERS

CHEMICAL PARAMETERS

Quick Test Method(s)

Quick testing methods for heavy metals are not commonly available. Visually, affected plants show various symptoms, though many of which can be ambiguous as they are easily confused with those nutrient deficiency symptoms (*Table 17*). Analytically, since heavy metals are usually present in ppm levels in soil, sophisticated instruments such as atomic absorption spectrophotometry (AAS) and inductively-coupled plasma (ICP) mass spectrometry are normally used, especially for research-graded data. There are very crude indications of the presence of certain metals by the formation of coloured precipitate after adding colouring agent to solution obtained by repeated heating rinsing and centrifugation. Recently, rapid methods using portable X-ray fluorescence spectroscopy (PXRF) has been developed to determine the total concentrations of As, Cu, Ni, Pb and Zn in soil (Hu et al., 2017), but the device has to be used by highly trained personnel.

Toxic levels of heavy metals in the soil are typically difficult to infer from visual or handy tests as well as to treat apart from replacing soil or controlling road runoff into planters and avoiding contaminated soil amendments. Therefore, they are not discussed in detail in the following sections of this guide. If heavy metal toxicity is suspected, it can be determined through laboratory testing.

Table 17. Quick test methods for common heavy metals.

Heavy metal	Visual Assessments
As	Foliar symptoms similar to those of P & Mg deficiencies: dark green or purplish leaves, interveinal chlrosis and necrosis; root growth inhibition
Cd	Leaf chlorosis, leaf rolling; browning of root tips; retarded growth
Cr	Chlorosis (new leaves); wilting of tops; retarded growth
Cu*	Stippling (phytotoxic burn); purpling of leaf tips; retarded shoot and root growth, blackened root tips
Fe*	Chlorosis (new leaves); necrosis (leaf margin and apex); inhibited root elongation
Pb	Chlorosis; retarded growth and abnormal morphology
Mn*	Chlorosis and necrotic spotting (from lower to upper leaves); crinkling in young leaves; drying leaf tips
Hg	Chlorosis; reduced plant height and seed germination; reduced flowering and fruiting
Ni*	Chlorosis and necrosis; inhibited root growth
Zn*	Chlorosis (younger leaves); purplish red colour in leaves; retarded growth and senescence

**micronutrient*

SOIL ANALYSIS PARAMETERS

BIOLOGICAL PARAMETERS

Soil Biota

Soil is a living system that houses biota consisting of microorganisms and animals (fauna) of different sizes. These communities of living soil organisms interact to form complex ecological relationships in terms of feeding preferences and energy flow.

The structure of soil biotic communities is usually described by assessing the microbial diversity or microbial biomass which have a unimodal (hump-back) relationship (Bastida et al., 2021), or microbial activity which measures function. Microbial diversity dominates soil biodiversity, though its relationship with soil functioning remains controversial (Maron et al., 2018).

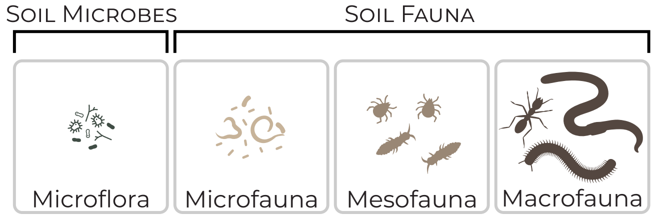


Figure 14. Major categories of soil biota.

Soil fauna are usually studied in terms of their diversity and abundance. Soil fauna which are mostly invertebrates can be categorised by their size into micro-, meso- and macro-fauna with different roles (*Table 18*). They are vital to soil ecosystem integrity and functioning, e.g. biogeochemical cycling; their digging and burrowing activities create new microsites in soil to promote soil aeration and good soil structure. Some groups are chosen as indicators for soil health status in soil successional development and ecological restoration.

Table 18. Soil faunal classes and their roles in the soil ecosystem.

Faunal type	Size (mm)	Roles	Examples
Microfauna	<0.1	Act as primary consumers Feed on and regulate microbial population Distribute microbes through the soil and along roots	Protozoans, nematodes, rotifers
Mesofauna	0.1-2.0	Act as secondary consumers Prey on fungal hyphae and microfauna Break down litter into tiny fragments in decomposition	Springtails, mites
Macrofauna	2-20	Act as top predators Prey on micro- and meso-fauna Masticate litter to smaller fragments in decomposition Mix soil and create channels for water and air	Earthworms, ants, termites, beetles, centipedes

SOIL ANALYSIS PARAMETERS

BIOLOGICAL PARAMETERS

B1/ Microbial Diversity and Activity

Soil microbes (typically referring to soil microflora) are an integral and dynamic part of a functional soil, and contribute to soil formation and its biological fertility. It is composed of decomposers such as bacteria and fungi at the bottom of the detritus food web. They interact trophically with a wide array of life strategies and feeding niches, providing food for consumers of higher trophic levels. In addition, they play an important part in developing healthy soil through secreting chemicals that bind soil particles into aggregates, as well as suppressing the growth of disease-causing pathogens. They drive key ecological processes in the soil, including litter decomposition, humus formation, mineralisation and greenhouse gas storage.

Microbial activity can be estimated using physiological performances (respiration, C uptake, growth) or metabolic activity of the microbial communities. It is linked with the functioning of microbial biomass or soil reaction rate in processes like SOM turnover, biodegradation, nutrient transformation and fertiliser application (*Figure 15*), all of which are related to soil fertility; it is dependent on soil moisture and pH, and increases with SOM and temperature.

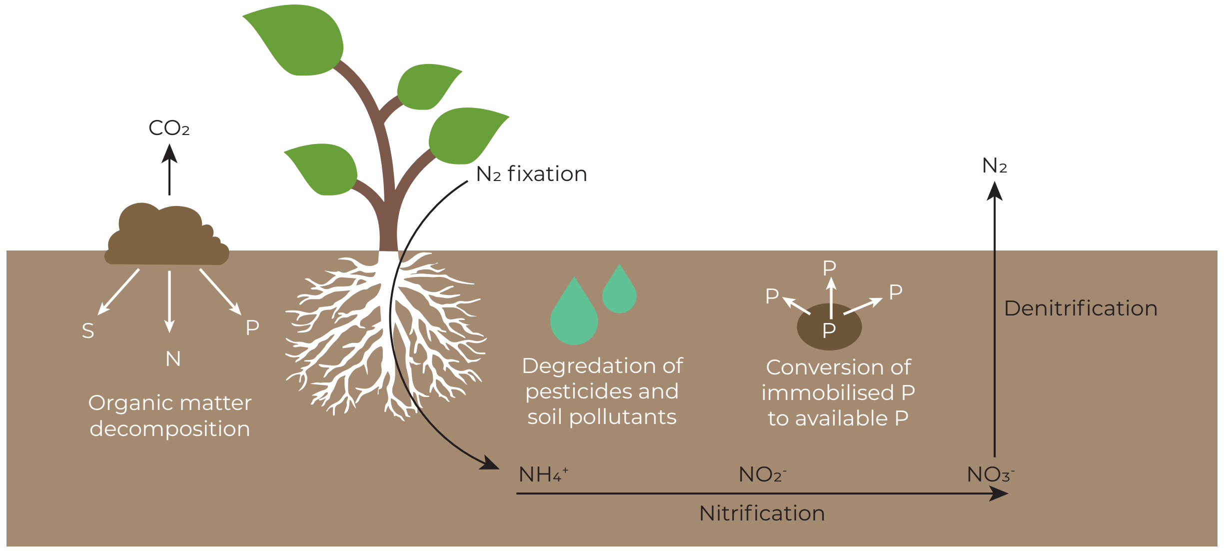
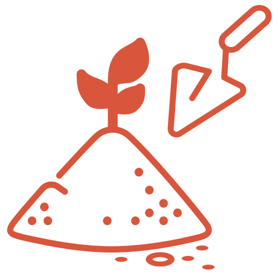


Figure 15. Roles of microbes in soil

Quick Test Method(s)

Soil microbial diversity is usually measured in a laboratory setting. It can be enumerated by classical microscopic observations or microbiological culturing techniques, e.g. plate count, or more recently using nucleic acid-based approaches, e.g. polymerase chain reaction (PCR) technologies. Alternatively, soil microbial biomass or microbial biomass C is estimated. ATP assay, which distinguishes viable from nonviable cells, is considered to be more reliable than measuring the biomass or C content.

Visual Assessment	Abnormal Soil Colour (p.49)
Handy Quick Test	NA



Microbial activity is typically measured either as O_2 uptake, CO_2 evolution or enzyme activities.

There are no direct simple tests, but since microbial diversity, biomass and microbial activity are often related to SOM, soil colour which reflects the organic content of soil is sometimes used as a surrogate indicator.

SOIL ANALYSIS PARAMETERS

BIOLOGICAL PARAMETERS

B2/ Faunal Diversity and Abundance

Soil fauna is crucial to litter decomposition, nutrient cycling and soil development. The diverse soil animals form soil food webs that are vital to the maintenance of the soil biological communities, habitat stability and ecosystem functioning. Their feeding preferences and relationship as well as burrowing activities enhance soil structure, spatial porosity and aeration that are important to their life processes and plant growth.

Quick Test Method(s)

Macrofauna like earthworms, ants and centipedes are visible to the naked eye, so their presence and abundance can be observed to extrapolate soil faunal diversity and abundance. On the other hand, the use of functional classifications and functional traits have become more popular in soil community ecology.

Visual Assessment	Few Soil Animals (p.55)	Handy Quick Test	NA

CH2: VISUAL ASSESSMENT

Observing signs and symptoms on a tree and interpreting them together can help infer underlying soil issues that require improvement. Some soil problems can be visually assessed using visual soil evaluation (VSE) techniques which require no equipment and produce immediate useful information that correlate well with quantitative measurements. Other soil properties that are harder to observe such as salinity and soil texture would require quick tests to identify.

VISUAL ASSESSMENT

TROUBLESHOOTING DIAGRAM

SOIL AND ROOT INDICATORS: WATER RELATED (Waterlogging, Dry soil); SOIL RELATED (Soil loss, Abnormal soil color, Surface crust, Hard soil); ROOT RELATED (Visible roots, Root decay); SOIL BIOTA (Few soil animals, Weeds)

TREE SIGNS AND SYMPTOMS: LEAF RELATED (Leaf fall, Chlorosis, Leaf discoloration, Necrosis, Brown edges); GROWTH RELATED (Delayed bloom, Stunted growth)

POSSIBLE SOIL PROBLEMS	Waterlogging	Dry soil	Soil loss	Abnormal soil color	Surface crust	Hard soil	Visible roots	Root decay	Few soil animals	Weeds	Leaf fall	Chlorosis	Leaf discoloration	Necrosis	Brown edges	Delayed bloom	Stunted growth
Soil Structure																	
Unsuitable Soil Texture	●	●	●		●	●						●	●	●	●		
High Compaction / Bulk Density	●					●	●		●	●	●	●	●	●			●
Soil Lacks Aggregates			●		●		●										
Low Water Holding Capacity		●	●	●			●								●		●
Poor Drainage	●	●		●				●	●	●	●			●	●		●
pH & Salinity																	
High pH				●						●							●
Low pH										●							●
High EC / Salinity				●	●					●					●		●
Nutrient Deficiency																	
Organic Matter Deficiency				●	●	●			●	●	●						
N Deficiency*										●	●	●		●		●	
P Deficiency*										●	●			●	●	●	●
K Deficiency*										●		●	●	●	●	●	●
Other Macronutrient Deficiency*												●	●	●		●	
Micronutrient Deficiency*												●					

* May be caused by unsuitable pH. Refer to C1/ pH (p.24) for more information.

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Waterlogging

Water stands on top of soil for a long time, leaving above-ground portions of trees submerged after watering or raining. Drainage is poor (0-2 mm/h) and there is little water movement down the soil, causing flooding when rainfall exceeds infiltration.
Soils high in clays, silts and excess organic matter or those prone to surface-sealing (described below under the indicator "Surface Crust") can be more likely to waterlogging.

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (*p.94*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*)	• Jar Method (*p.75*)

High Compaction / Bulk Density....(*p.95*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*) • Soil Penetrometer (*p.76*) • Drop Test (*p.80*)	• Jar Method (*p.75*) • Slake Test (*p.81*)

Poor Drainage.................... (*p.96*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*) • Infiltrometer (*p.83*)	• Jar Method (*p.75*)

Soil odour

The smell of soils can be an alternative sensory indicator even when the soil is dry. Healthy soils usually have a pleasant and earthy smell with little odour. Ammonia or rotten odours from the soil can indicate waterlogging or anaerobic soil lacking in oxygen (Meganathan, 2016). However, it should be differentiated from other strong odours that can be produced by certain fresh soil amendments (e.g. animal manure, bone meal).

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Dry Soil

Soil visibly dries excessively and / or rapidly in dry spells or under insufficient irrigation. Dehydration aggravates in hot weather which is the growing season with intense water demand.

Drying will often result in surface crust (*p.51*) or cracks, and the soil will become hard and compact (*p.52*). Soil microbes and animals may not survive under prolonged drought (*p.55*), and plants may wilt or die.

Coarser soils retain less water, and soils without a good surface layer of organic matter are more liable to drought.

Image credit: David, 2014. Licensed under CC BY 2.0

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (*p.94*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*)	• Jar Method (*p.75*)

Low Water Holding Capacity ...... (*p.96*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*)	• Jar Method (*p.75*)

Poor Drainage.................... (*p.96*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*) • Infiltrometer (*p.83*)	• Jar Method (*p.75*)

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Soil Loss

Surface soil is easily washed or blown away. Crusted soil has relatively smooth surface that increases the risk of water and wind erosion of loose soil particles.

Fine, light soils such as fine sandy soils and silt are usually more susceptible to being carried away by wind or water. Wind, water droplets from rain or irrigation water break aggregates into individual soil particles that can be easily detached.

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... *(p.94)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)*	• Jar Method *(p.75)*

Soil Lacks Aggregates.............*(p.95)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)* • Pore Counting Method *(p.79)* • Drop Test *(p.80)*	• Jar Method *(p.75)* • Soil Porosity from Bulk Volume *(p.78)* • Slake Test *(p.81)*

Low Water Holding Capacity ...... *(p.96)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)*	• Jar Method *(p.75)*

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Abnormal Soil Colour

Soil has a wide spectrum of colour from black, grey, brown, red, yellow and white, which is determined by colouring agents such as organic matter, iron and manganese. Soil colours can suggest the chemical and physical properties of the soil, such as soil reaction, mineral composition, humus content and soil age. Colour charts are often used to identify soil colours.

Wet soil will appear darker than dry soil, and may be grey or green owing to the presence of reduced ferrous oxide because of poor aeration.

Munsell soil colour charts

Common Urban Soil Colours and Possible Soil Problems

Highly Sandy Soil

Whitish

Low Water Holding Capacity ...... *(p.96)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)*	• Jar Method *(p.75)*

Carbonates, High pH

White nodules, powders or films on soil aggregates

Image credit: Ivtorov. Licensed under CC BY-SA 4.0

High pH ....*(p.97)*

Further interpretation	
Field tests	Office tests
• pH Test Kits / Strips *(p.84)* • pH Meter *(p.85)*	NA

High EC / Salinity

White film on soil surface

High EC / Salinity..................*(p.97)*

Further interpretation	
Field tests	Office tests
• Ohmmeter *(p.86)*	NA

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Low Organic Matter

Lighter

Organic Matter Deficiency ....(p.98)

Further interpretation	
Field tests	Office tests
NA	NA

Presence of Goethite / FeO(OH) Bounded to Clay

Yellowish brown / orange colours

Poor Drainage.................... (p.96)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Infiltrometer (p.83)	• Jar Method (p.75)

Other Common Urban Soil Colours

Clay Minerals / Signs of Iron

Reddish

High Organic Matter

Darker

Colour charts

The Munsell system is one of the more commonly used standard methods to describe soil colour. To determine a soil's colour in Munsell notation, compare a soil sample against the colour swatches under natural daylight. From the matching swatch, read off the colour value.

For more information on how to interpret soil properties using the Munsell system, refer to the USDA's web page on soil colour:

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054286

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Surface Crust

Surface crusts are thin layers of platy hardened soil with sealed surface, made up of fine particles that built up as a smooth and hard layer.

Fine-textured soil subject to physical forces like trampling and heavy traffic may develop crusts, and structural soil crusts are formed by in-situ sorting and rearrangement of loosened particles without lateral movement (Bresson & Valentin 1990).

They have poor water infiltration, and seed emergence and plant establishment are usually hindered as a result of mechanical impedance.

Typically clay and loamy textured soils with low organic matter and low soluble salts are more prone to forming surface crusts; a white surface crust could indicate a high proportion of exchangeable Na in the soil (DPIRD 2021).

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (p.94)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73)	• Jar Method (p.75)

Soil Lacks Aggregates.............(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Pore Counting Method (p.79) • Drop Test (p.80)	• Jar Method (p.75) • Soil Porosity from Bulk Volume (p.78) • Slake Test (p.81)

High EC / Salinity.................(p.97)

Further interpretation	
Field tests	Office tests
• Ohmmeter (p.86)	NA

Organic Matter Deficiency ....(p.98)

Further interpretation	
Field tests	Office tests
NA	NA

VISUAL ASSESSMENT
SOIL AND ROOT INDICATORS

Hard Soil

Hard or compacted soil can be difficult to drive a shovel or trowel into. Indents from pressure such as footprints cannot be observed. Puddling may be observed due to low porosity, and there may be bare areas where even weeds cannot grow.

Clay / Sandy clay and loam soils are typically more susceptible to hardening by compaction.

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (p.94)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73)	• Jar Method (p.75)

High Compaction / Bulk Density....(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Soil Penetrometer (p.76) • Drop Test (p.80)	• Jar Method (p.75) • Slake Test (p.81)

Organic Matter Deficiency ....(p.98)

Further interpretation	
Field tests	Office tests
NA	NA

VISUAL ASSESSMENT
SOIL AND ROOT INDICATORS

Visible Roots

Surface roots can be problematic as they crack surfaces, lift pavements and damage sidewalks.

While some tree species have shallow roots and many others develop surface roots in later developmental stages, compacted and poorly aerated soil will lead to shallower rooting, as soil compaction hinders lateral and fine root development, particularly roots that are strongly associated with mycorrhizae. These tree roots may become exposed and visible due to erosional loss of the surface soil.

Possible Soil Problems (Visual Diagnoses)

High Compaction / Bulk Density....(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Soil Penetrometer (p.76) • Drop Test (p.80)	• Jar Method (p.75) • Slake Test (p.81)

Soil Lacks Aggregates..............(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Pore Counting Method (p.79) • Drop Test (p.80)	• Jar Method (p.75) • Soil Porosity from Bulk Volume (p.78) • Slake Test (p.81)

Low Water Holding Capacity ...... (p.96)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76)	• Jar Method (p.75)

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Root Decay

Poor soil structure like compacted soil and poor drainage can lead to root rot. Trees can develop soft and brown / black roots or dark brown discoloured wood at the base of the trunk.

Hibiscus root rot

Possible Soil Problems (Visual Diagnoses)

■ Poor Drainage . . . . (*p.96*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*) • Infiltrometer (*p.83*)	• Jar Method (*p.75*)

Brown root rot disease

Root decay can be a symptom of brown root rot disease (BRRD), caused by the aggressive fungal pathogen *Phellinus noxius*, which could result in rapid health and structural deterioration of trees. In case of suspected BRRD, refer to DevB's Tree Management Practice Note No.4: Management of Brown Root Rot Disease Infected Tree and online Knowledge Database on Brown Root Rot Disease for guidance on identifying and managing infected trees.

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Few Soil Animals

The observation of large numbers and many types of animals (faunae) such as earthworms, millipedes and ants in soil indicates high faunal diversity and abundance. Earthworms can often be easily spotted on and around soil surfaces during and after rains. Worm casts found on soil surfaces can indicate their presence as well.

Worm casts

Image credit: Kris, 2018, Licensed under CC BY 2.0

Possible Soil Problems (Visual Diagnoses)

■ High Compaction / Bulk Density. . . .(*p.95*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*) • Soil Penetrometer (*p.76*) • Drop Test (*p.80*)	• Jar Method (*p.75*) • Slake Test (*p.81*)

■ Poor Drainage . . . . (*p.96*)

Further interpretation	
Field tests	Office tests
• Feel Method (*p.73*) • Spade Test (*p.76*) • Infiltrometer (*p.83*)	• Jar Method (*p.75*)

■ Organic Matter Deficiency . . . .(*p.98*)

Further interpretation	
Field tests	Office tests
NA	NA

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Weeds

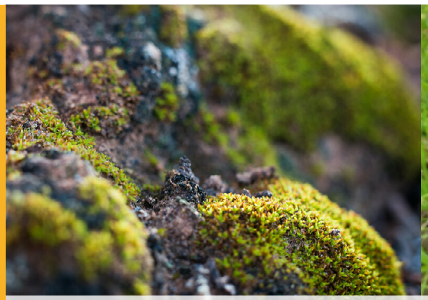
For the purpose of these Guidelines, weeds are plants growing in the urban landscape where they are not wanted, as they compete with the landscape plants for resources such as water, nutrients, space and light. They can be used as a visual indicator of soil conditions.

Weeds are more competitive under increased levels of disturbance (Fried et al., 2010), with the capacity to adapt to extreme conditions. While there are no well-documented soil conditions in relation to the presence of particular weed species, they can provide preliminary hints to be confirmed with further observation or assessment.

Presence of Weeds

Generally suggests poor soil structure, poor drainage, lack of fertility, acidity and salinity.

Wet Acidic Infertile Soil



Mosses

Sedges, e.g. *Fimbristylis* spp.

Rushes

Wild Daisies

Sow-thistles

Compact Acidic Soil

Knotweeds

Wet Acidic Clayey Soil

Plantains

Alkaline Soil

Chenopodium spp.

N Deficient Soil

Legumes, e.g. Clover

VISUAL ASSESSMENT

SOIL AND ROOT INDICATORS

Are weeds always harmful?

The same plant can be considered a weed in one setting and beneficial in another. For example, many plants which are considered weeds in the urban landscape can actually benefit other plants in a natural landscape setting, by acting as living mulch to reduce and filter water runoff, preventing soil erosion, as well as suppressing other harmful weeds. Left alone, leguminous "weeds" help fix nitrogen and enrich the soil with utilisable nitrogen.

Possible Soil Problems (Visual Diagnoses)

High Compaction / Bulk Density........*(p.95)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)* • Soil Penetrometer *(p.76)* • Drop Test *(p.80)*	• Jar Method *(p.75)* • Slake Test *(p.81)*

Poor Drainage........................*(p.96)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)* • Infiltrometer *(p.83)*	• Jar Method *(p.75)*

High / Low pH........................*(p.97)*

Further interpretation	
Field tests	Office tests
• pH Test Kits / Strips *(p.84)* • pH Meter *(p.85)*	NA

High EC / Salinity....................*(p.97)*

Further interpretation	
Field tests	Office tests
• Ohmmeter *(p.86)*	NA

N Deficiency ....*(p.98)*

Further interpretation	
Field tests	Office tests
• N Test Kits / Strips *(p.87)*	• Electrode Method *(p.87)*

P and K Deficiency....................*(p.99)*

Further interpretation	
Field tests	Office tests
• P and K Test Kits / Strips *(p.88)*	• Electrode Method *(p.88)*

Organic Matter Deficiency ....*(p.98)*

Further interpretation	
Field tests	Office tests
NA	NA

*However, species that are invasive or can endanger the health of plants, such as parasitic species and those on AFCD's list of Invasive Alien Species, should be removed. Consult relevant professionals in case of doubt.

VISUAL ASSESSMENT

TREE SIGNS AND SYMPTOMS

Some soil symptoms such as soil coarseness, compaction and waterlogging are easily and simply assessed by visual inspection. However, tree symptoms such as stunted growth or leaf discolouration, chlorosis and necrosis of leaves, though visible, are less conclusive, and can be due to pests, diseases, nutrient deficiency, salinity or metal toxicity. Signs and symptoms caused by insect pests or microbial pathogens can be nonspecific, and require pathological knowledge for correct identification. The chance of soil being saline and / or toxic can be eliminated if the source of the soil mix used is known and confirmed to be innocuous. This leaves nutrient deficiency as the problem, which is usually manifested in foliage discolouration or distortion, but the particular nutrient(s) deficient in the soil cannot be confirmed solely by observation, and requires soil testing (Chapter 3) and / or plant tissue analysis to back up.

General visual symptoms for the deficiency of major plant nutrients are listed in *Table 19*. Symptoms for the deficiency of mobile nutrients (e.g. nitrogen (N), phosphorus (P), potassium (K), chlorine (Cl), Magnesium (Mg) and Molybdenum (Mo)) will occur initially in older or lower leaves. Conversely, symptoms for the deficiency of immobile nutrients (boron (B), calcium (Ca), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni) and sulphur (S)) will occur in the younger or upper leaves first, and are localized. To gain a greater likelihood of correct diagnosis, multiple symptoms should preferably be noted and interpreted together. Among the three macronutrients, N is the most deficient in urban soils which lack organic matter and nitrogenous materials, while P is the least possible culprit, which is rarely missing in most soils. Ideally, soil testing is the best way to determine if nutrient levels are suboptimal, but nutrient deficiency can be complex, and there can be complications between nutrient availability and soil pH, SOM and CEC.

Table 19. General visual symptoms for deficiency of major plant nutrients

Nutrient	Main roles in plant growth	Nutrient deficiency symptoms*
N	Directly related to plant growth and vigour; essential role in energy metabolism as well as protein and chlorophyll synthesis.	General chlorosis, stunted growth and shorter internodes; small pale yellow leaves. Symptoms first appear in older leaves. Necrosis of lower leaves in severe cases.
P	Essential in most metabolic processes; involved in transporting and storing energy; significant role in root growth as well as flowering and fruiting.	Slow and stunted growth. Burnt leaf tips followed by older leaves turning dark green, red or purplish, especially undersides. Lower stems may be purplish. Loss of lower leaves. Poor root growth. Flowering may be reduced. Death of tissue or necrosis may follow. Plants tend to be weak and maturity is delayed.
K	Major role in water regulation and carbohydrate synthesis, plant resistance to pests and diseases as well as resilience to unfavourable environments.	Bronzing and burning inward from leaf margin. Chlorosis begins on leaf tip, then on entire leaf. Necrotic spots may develop; some interveinal spottings; stunted internodes and roots. Tendency to wilt readily.
Ca	Essential in cell growth and development; involved in cell wall formation and contributes to mineral transport.	Inhibition of bud growth; terminal bud dies. Newest leaves hooked. New leaves are yellow, while older leaves dark green. Curled and rolled up mature leaves.
Mg	Essential for photosynthesis and enzyme activation.	Interveinal chlorosis in older leaves while veins remain green. Yellow areas may turn brown and die. Decreased seed production.
S	Involved in protein and chlorophyll synthesis; important in tissue formation and N metabolism.	General chlorosis (similar to N deficiency)

*Unsuitable pH may be an underlying cause of low nutrient availability to plants. Refer to Chapter 1 Section C1/ pH (p.24) for more information.

VISUAL ASSESSMENT

TREE SIGNS AND SYMPTOMS

Leaf Fall

Trees suffering from deficiency of N or P may lose their older leaves. Mg deficiency can result in early leaf fall. This results in sparse leaves and thin canopy. However, this is not specific to the interpretation of the symptom. Many insects, nematodes and diseases damage the root system, causing the lower leaves to turn chlorotic or necrotic and eventually fall off. Leaf drop can also be caused by the release of ethylene as a response to stress.

Possible Soil Problems (Visual Diagnoses)

High Compaction / Bulk Density. . . .(p.95)

Further interpretation	
Field tests	**Office tests**
• Feel Method (p.73) • Spade Test (p.76) • Soil Penetrometer (p.76) • Drop Test (p.80)	• Jar Method (p.75) • Slake Test (p.81)

Poor Drainage. . . . . (p.96)

Further interpretation	
Field tests	**Office tests**
• Feel Method (p.73) • Spade Test (p.76) • Infiltrometer (p.83)	• Jar Method (p.75)

N Deficiency . . . .(p.98)

Further interpretation	
Field tests	**Office tests**
• N Test Kits / Strips (p.87)	• Electrode Method (p.87)

P Deficiency. . . . . (p.99)

Further interpretation	
Field tests	**Office tests**
• P Test Kits / Strips (p.88)	• Electrode Method (p.88)

Organic Matter Deficiency . . . .(p.98)

Further interpretation	
Field tests	**Office tests**
NA	NA

VISUAL ASSESSMENT

TREE SIGNS AND SYMPTOMS

Chlorosis

Chlorosis can result in either the whole plant or leaf turning yellow or appear more localized as yellow spotting. Leaf and interveinal chlorosis is a symptom for deficiency in nutrients necessary for photosynthesis or chlorophyll formation.

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (p.94)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73)	• Jar Method (p.75)

High Compaction / Bulk Density....(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Soil Penetrometer (p.76) • Drop Test (p.80)	• Jar Method (p.75) • Slake Test (p.81)

N Deficiency ....(p.98)

Further interpretation	
Field tests	Office tests
• N Test Kits / Strips (p.87)	• Electrode Method (p.87)

K Deficiency...................... (p.96)

Further interpretation	
Field tests	Office tests
• K Test Kits / Strips (p.89)	• Electrode Method (p.89)

Other Macronutrient (Mg) Deficiency .... (p.99)

Further interpretation	
Field tests	Office tests
NA	NA

Micronutrient (Fe/Zn) Deficiency ....(p.100)

Further interpretation	
Field tests	Office tests
NA	NA

VISUAL ASSESSMENT

TREE SIGNS AND SYMPTOMS

Leaf Discolouration

Purplish-red discolouration in plant stems and leaves is due to the accumulation of anthocyanin pigments when plant functions are disrupted or stressed. It commonly occurs in P-deficient soil, but deficit in N or K also causes anthocyanin synthesis (Close & Beadle, 2003); not all purple plants are P deficient, and not all P deficient plants turn purple. This symptom can be particularly difficult to diagnose because low temperature, diseases and drought can also upregulate the production of anthocyanins (Bennett, 1993; Chalker-Scott, 1999).

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (p.94)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73)	• Jar Method (p.75)

High Compaction / Bulk Density....(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Soil Penetrometer (p.76) • Drop Test (p.80)	• Jar Method (p.75) • Slake Test (p.81)

Pale brownish / purple spots: Other Macronutrient (Mg) Deficiency .... (p.99)

Further interpretation	
Field tests	Office tests
NA	NA

Browning K Deficiency ....(p.99)

Further interpretation	
Field tests	Office tests
• K Test Kits / Strips (p.89)	• Electrode Method (p.89)

VISUAL ASSESSMENT

TREE SIGNS AND SYMPTOMS

Necrosis

Necrosis is the browning of dying tissues, which generally appears at later stages of the deficiency of a number of nutrients. It can appear as brown edges (necrosis of leaf margins) or interveinal necrosis. Diagnosing these nutrient deficiencies can be difficult because similar symptoms can be caused by many other problems such as toxicities.

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (p.94)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73)	• Jar Method (p.75)

High Compaction / Bulk Density....(p.95)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Soil Penetrometer (p.76) • Drop Test (p.80)	• Jar Method (p.75) • Slake Test (p.81)

Poor Drainage.................... (p.96)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Infiltrometer (p.83)	• Jar Method (p.75)

N Deficiency ....(p.98)

Further interpretation	
Field tests	Office tests
• N Test Kits / Strips (p.87)	• Electrode Method (p.87)

P and K Deficiency................ (p.99)

Further interpretation	
Field tests	Office tests
• P and K Test Kits / Strips (p.88)	• Electrode Method (p.88)

Other Macronutrient (Mg) Deficiency....................(p.99)

Further interpretation	
Field tests	Office tests
NA	NA

Other Possible Issues:
Various Chemical Toxicities e.g. Heavy Metals

As mentioned in CH1, chemical toxicities are not discussed in depth in these Guidelines as they are less common in urban soils and difficult to properly diagnose and treat. For an overview of heavy metals, their effects on plant growth and possible testing methods, refer to Chapter 1 Section C10/ Heavy Metals (p.37).

VISUAL ASSESSMENT

TREE SIGNS AND SYMPTOMS

Brown Edges

Brown edges is a form of necrosis seen on the edges of leaves. They can be associated with nutrient deficiencies as well as poor water uptake and soil salinity.

Possible Soil Problems (Visual Diagnoses)

Unsuitable Soil Texture .... (p.94)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73)	• Jar Method (p.75)

Low Water Holding Capacity ...... (p.96)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76)	• Jar Method (p.75)

Poor Drainage.................... (p.96)

Further interpretation	
Field tests	Office tests
• Feel Method (p.73) • Spade Test (p.76) • Infiltrometer (p.83)	• Jar Method (p.75)

High EC / Salinity..................(p.97)

Further interpretation	
Field tests	Office tests
• Ohmmeter (p.86)	NA

P and K Deficiency................ (p.99)

Further interpretation	
Field tests	Office tests
• P and K Test Kits / Strips (p.88)	• Electrode Method (p.88)

VISUAL ASSESSMENT
TREE SIGNS AND SYMPTOMS

Delayed Bloom

Flowering trees suffering from deficiency in N can bloom late, with flower buds being small or poorly developed. Fewer flower buds being produced could indicate P, K or Ca deficiency instead. Excessive N could produce lush green foliage but impede flower production.

Possible Soil Problems (Visual Diagnoses)

Pale brownish / purple spots: Other Macronutrient (Ca) Deficiency .... *(p.99)*

Further interpretation	
Field tests	Office tests
NA	NA

Few buds: P and K Deficiency .... *(p.99)*

Further interpretation	
Field tests	Office tests
• P and K Test Kits / Strips *(p.88)*	• Electrode Method *(p.88)*

Late bloom: N Deficiency .... *(p.98)*

Further interpretation	
Field tests	Office tests
• N Test Kits / Strips *(p.87)*	• Electrode Method *(p.87)*

Low flower production with lush green foliage: Excessive N

Further interpretation	
Field tests	Office tests
• N Test Kits / Strips *(p.87)*	• Electrode Method *(p.87)*

VISUAL ASSESSMENT
TREE SIGNS AND SYMPTOMS

Stunted Growth

Stunted growth is observed when a tree is unable to grow to its normal size. This may be the direct result of N or P deficiency, though it can be caused by a wide range of soil and environmental issues leading to poor nutrient and water uptake. Observing other symptoms can help narrow down possible causes.

Possible Soil Problems (Visual Diagnoses)

High Compaction / Bulk Density ....*(p.95)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)* • Soil Penetrometer *(p.76)* • Drop Test *(p.80)*	• Jar Method *(p.75)* • Slake Test *(p.81)*

Low Water Holding Capacity ...... *(p.96)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)*	• Jar Method *(p.75)*

Poor Drainage .... *(p.96)*

Further interpretation	
Field tests	Office tests
• Feel Method *(p.73)* • Spade Test *(p.76)* • Infiltrometer *(p.83)*	• Jar Method *(p.75)*

High / Low pH ....*(p.97)*

Further interpretation	
Field tests	Office tests
• pH Test Kits / Strips *(p.84)* • pH Meter *(p.85)*	NA

High EC / Salinity ....*(p.97)*

Further interpretation	
Field tests	Office tests
• Ohmmeter *(p.86)*	NA

P and K Deficiency .... *(p.99)*

Further interpretation	
Field tests	Office tests
• P and K Test Kits / Strips *(p.88)*	• Electrode Method *(p.88)*

CH3: HANDY QUICK TESTS

Observing signs and symptoms on a tree and interpreting them together can help infer underlying soil issues that require improvement. Some soil properties that are harder to observe such as salinity and soil texture would require quick tests to identify.

SOIL PERFORMANCE INDICATOR

IMPORTANCE OF SOIL TESTS

Why are Soil Tests Important?

Not all soil parameters can be assessed visually, not to mention accuracy and reliability. In that case, soil analyses, whether they are handy quick tests mentioned in these Guidelines, or more professional soil tests done by scientific soil laboratories are required to ascertain the soil problems. Observing signs and symptoms of tree and soil and interpreting them together with soil tests can help confirm underlying soil issues for timely improvement.

Handy Quick Tests (Field Tests and Office Tests)

These Guidelines have included easy tests that can be done at field and in office to assist the ascertaining of soil physical and chemical deficiencies. Deficiencies associated with biological properties of soil, such as microbial diversity, microbial activity and faunal diversity and abundance are not included as there are no direct simple tests for these microbial parameters. As a quick reference, microflora diversity, microbial biomass and microbial activity are often related to SOM, and soil colour which reflects the organic content of soil may be used as an indirect indicator. As for macrofauna, it can be directly observed by eye or under a magnifying glass, while mesofauna and microfauna have to be observed under a microscope.

Toxic levels of heavy metals in soil are typically difficult to infer from visual or handy tests as well as to treat, apart from replacing soil or controlling road runoff into planters and avoiding contaminated soil amendments. Testing of heavy metals is therefore not discussed in these Guidelines. If heavy metal toxicity is suspected, it should be determined through laboratory testing.

Laboratory Tests

Some soil parameters can neither be visually assessed nor measured using the handy quick tests such as soil kits or soil meters discussed in these Guidelines. In addition, these methods do not offer high accuracy or precision. In that case, testing by certified soil testing laboratories that are equipped with sophisticated analytical tools and equipment for more accurate determination of various soil parameters (***APPX B***) is recommended. Most will list their soil test procedures adopted for different parameters. They use reagent grade chemicals, replicated samples and scientific methods to provide more complete and accurate results in the form of soil test report than soil kits as basis for improving soil health. Fertiliser recommendations may occasionally be given in the soil report.

When more accurate soil data are needed, soil analyses conducted by accredited soil laboratories using different approved protocols with standard procedures and instrumentation are required.

SOIL PERFORMANCE INDICATOR

HOW TO USE SOIL TESTS

Handy or rapid soil assessments represent a valuable alternative to laboratory analysis because they are convenient, fast, easy to use, inexpensive and can be done on site. They provide a real time evaluation of the soil parameters for generating quick information for decision making in tree management. They are constantly upgraded to meet the growing demand; new versions using mobile phone apps are available for a few soil parameters, e.g. bulk density and inorganic nitrogen (N).

Rapid soil tests are available for a number of soil physical parameters, e.g. texture, bulk density, infiltration, and aggregate stability, many of which use homemade devices for estimating the values. Simple soil chemical analysis can be done semi-quantitatively using commercially available DIY test strips or test kits, and portable measuring devices, but which one to choose may need fundamental knowledge of the soil being used, aided by observation. The most common ones are those for pH or major nutrients like N, phosphorus (P) and potassium (K), which deploy ready-to-use reagents for colorimetric results. There are also analogue or digital soil meters for rapid determination of pH, water content and nutrient content, mainly for gardening and farming purposes. Manifold (e.g. three-in-one) testers for more than two soil parameters are also available in the market, and many are operated by direct insertion into soil without the need to prepare soil solution for testing, though they are not research-grade and are regarded as relatively less accurate in measurement.

In the following sections, soil tests for each parameter are listed in the order of handiness from approximately the most to least easy and feasible to carry out rapidly in a field / office setting.

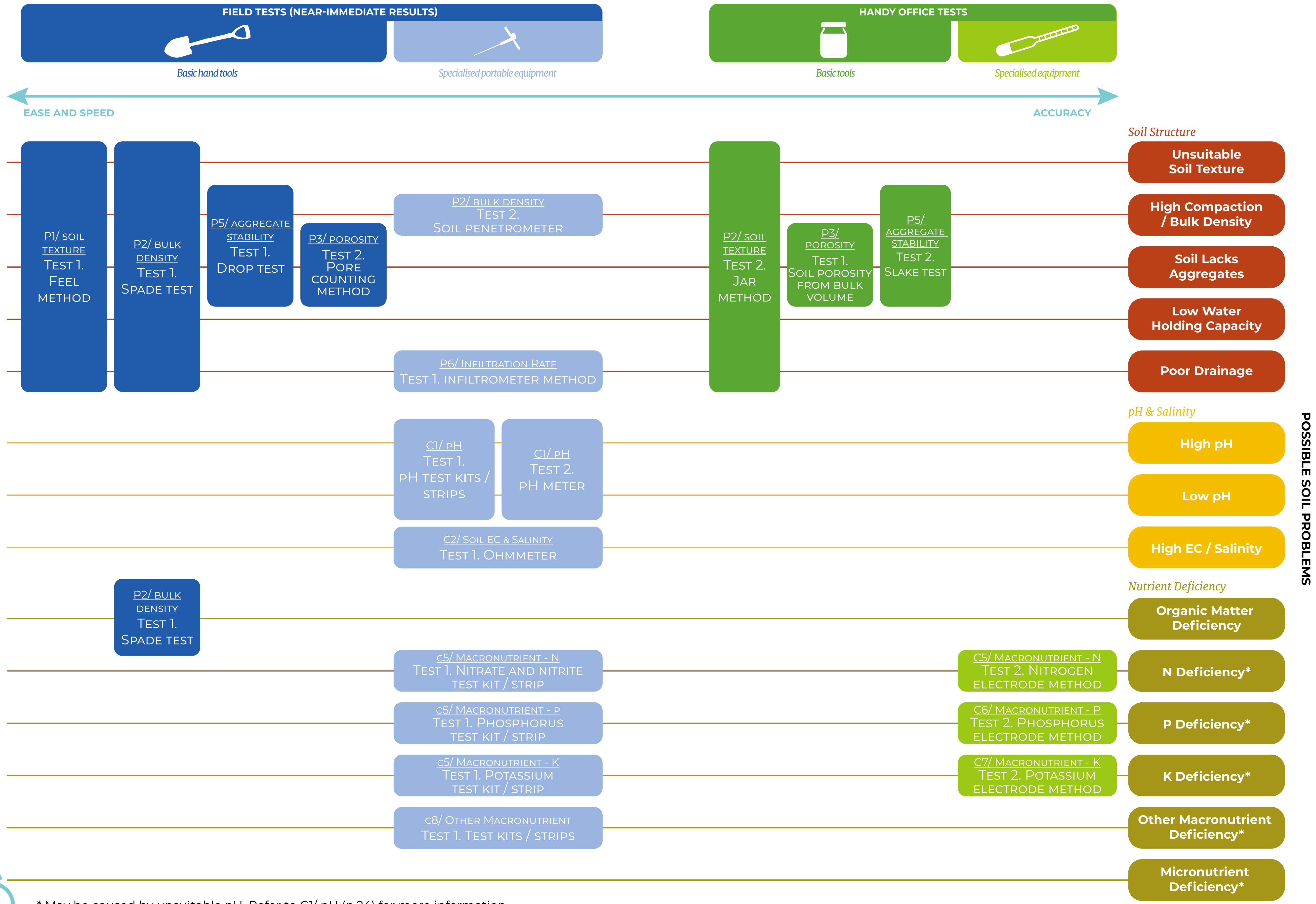
Handy Soil Test Kits

Simple soil analysis on pH, water content and macronutrient content can be done using soil kits or soil meters, but the former are semi-quantitative and may have low detection sensitivity, while the latter are miniaturized instruments using portable spectrometers or electrochemical sensors, which yield quantitative results with compromised accuracy on few soil parameters. There are mobile integrated packages which use reagents and portable meters for measuring different soil parameters (Dimkpa et al., 2017). One such application that is widely used in the United States is the SKW500 Complete Soil Kit which determines pH, EC, salinity, extractable macronutrients (N, P, K, sulphur (S), magnesium (Mg) and calcium (Ca)), micronutrients (aluminium (Al), chloride (Cl), copper (Cu), iron (Fe) and manganese (Mn) (Figure 16). It has been referred to bringing the soil laborartory to the field and is available via online ordering. The determined parameters are analysed, interpreted through a direct-reading, waterproof photometer. The information for the key parameters of each soil sample is able to be transmitted to USB or hard drive, and effective soil management is feasibly achieved by a number of analytical techniques associated with critical information.

Figure 16. SKW500 Complete Soil Kit (left) and direct-reading, waterproof photometer – Soiltest 10 (right) uses battery-powered instruments to test soil pH, electrical conductivity, macronutrients and micronutrients. The kit offers an economical and simple test solution which is ideally suited to field testing.
(Image credit: Palintest, 2021)

HANDY QUICK TESTS
TROUBLESHOOTING DIAGRAM

*Only the simplest tests corresponding to each soil issue are presented in this table. For additional and more accurate ways to confirm soil properties, refer to each individual section in this Chapter.



* May be caused by unsuitable pH. Refer to C1/ pH (p.24) for more information.

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

SOIL TESTS

SAMPLING FOR SOIL TESTS

Good soil sampling to obtain representative soil materials in the field is important to soil testing. Sampling place and sample number have to be considered to ensure accuracy and reliability of the data obtained. Sampling depth for most purposes is the rooting depth, though it may sometimes be restricted by pit depth or planter height. Sampling number usually ranges 3-10, as a minimum of 3 will avoid unreliable information, while >10 will result in excess workload; a good compromise is between 4 and 8.

Typically, each tree pit or planter is considered a sampling unit. A sample of 0.25 – 0.5 kg soil is typically taken depending on the type and number of soil analyses to be done. More than one sample can be obtained from a tree pit or planter, but these samples can be mixed to form a composite sample per sampling unit so as not to increase the analytical workload, while soil heterogeneity within a tree pit or planter is well taken care of.

Sampling Procedures

1. Sample soil at rooting depth of 15 or 20 cm, or 10-cm intervals if more than one depth is sampled. (Sampling depth may be increased, e.g. to 50 cm, for larger / deep-rooted trees as needed.)
2. Take samples using a suitable tool in a simple random pattern, with tree pits or planters as sampling units. Avoid damaging tree roots during soil sampling.
3. Take around 5 soil replicates for analysis, or take >2 soil samples but mix them to form a composite sample per sampling unit for analysis.
4. Remove matter other than soil, such as litter, tree roots and mulch.
5. Soil samples are preferably analysed fresh for nitrate (NO_3^-), ammonium (NH_4^+) and microbial count.
6. For storage prior to analysis, air-dry samples as follows (USDA, 2007):
   i. Spread soil samples on paper to dry at room temperature. (Spread soil and break clods to hasten drying.)
   ii. Break up soil and sieve using 2-mm mesh sieve.
   iii. Keep in zip plastic bags, label properly and store in room temperature or in refrigerator (under 4°C) for prolonged storage.
7. Backfill sampled soil body with suitable planting soil as necessary.

Actual sampling steps and tools used (*Figure 17*) may vary depending on the parameter tested. For example, soil should not be broken up or sieved for most tests of soil structure such as bulk density and porosity. Clods should be preserved for soil aggregate tests. For information on the treatment of soil samples for specific handy quick tests, note the initial steps of the test methods described in the following sections.

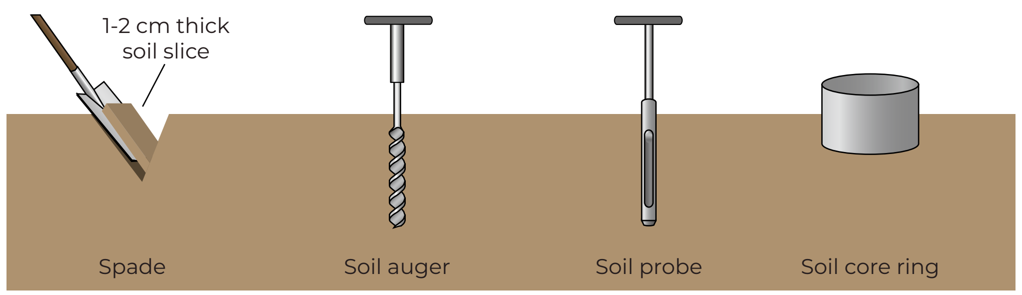


Figure 17. Examples of tools used for soil sampling.

SOIL TESTS

HANDY QUICK TESTS (PHYSICAL)

P1/ Soil Texture

P1/ Test 1. Feel Method

The feel method (or hand analysis) involves wetting a soil sample (about 2 tablespoons or 20 g) and kneading or rubbing then feeling and observing the moist soil. Refer to the following for guides to texture by touch.

A. Simplified soil texture test based on forms or moulds produced (FAO, 2011):

1. Take and break up a handful of soil, then add water and knead until it is the consistency of putty.
2. Try to manipulate the wetted soil sample into the following shapes (*Figure 18*).
3. Roll soil sample into a ball, then roll the ball into a cylinder, then try to bend the cylinder into a circle.
4. Infer soil texture from the forms produced.

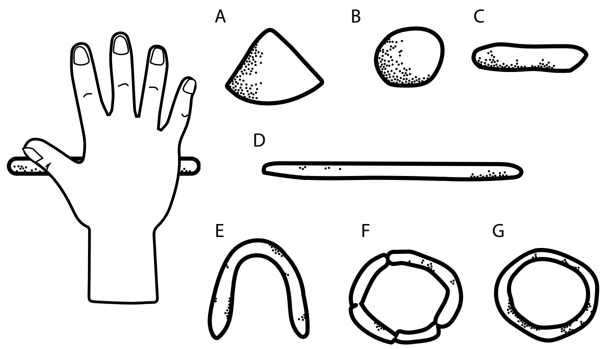


Figure 18. Hand analysis of soil texture (Redrawn from: FAO, 2011).

A. Sandy
The soil stays loose and separated and can be accumulated only in the form of a pyramid.

B. Sandy loam
The soil contains enough silt and clay to become sticky, and can be given the shape of an easy-to-take-apart ball.

C. Silty loam
Similar to a sandy loam, but the soil can be shaped by rolling it into a small short cylinder.

D. Loam
The soil contains almost equal amounts of sand and silt, and some clay. Can be rolled into approximately 14 cm long cylinder that breaks when bent.

E. Clayey loam
Similar to loam, but the rolled cylinder can be bent to a U shape (without forcing it) without breaking.

F. Fine clay
The soil cylinder can be bent into a circle, but shows some cracks.

G. Heavy clay
The soil can be shaped as a circle without any cracks.

B. Simplified soil texture test based on ribbon length (Queensland Government, 2016):

1. Squeeze the wetted soil sample between thumb and forefinger to form a flat ribbon.
2. Infer soil texture from the length of the ribbon that can be formed without breaking (*Table 20*).

Table 20. Soil texture based on ribbon length.

Texture	Ribbon length (mm)
Sandy	<15
Sandy loam	15-25
Loam	25
Silty loam	25
Clay loam	40-50
Clay	50-75
Heavy clay	>75

SOIL TESTS

HANDY QUICK TESTS (PHYSICAL)

C. Soil texture estimation by feel and eye when manipulated by hand (Thien, 1979):

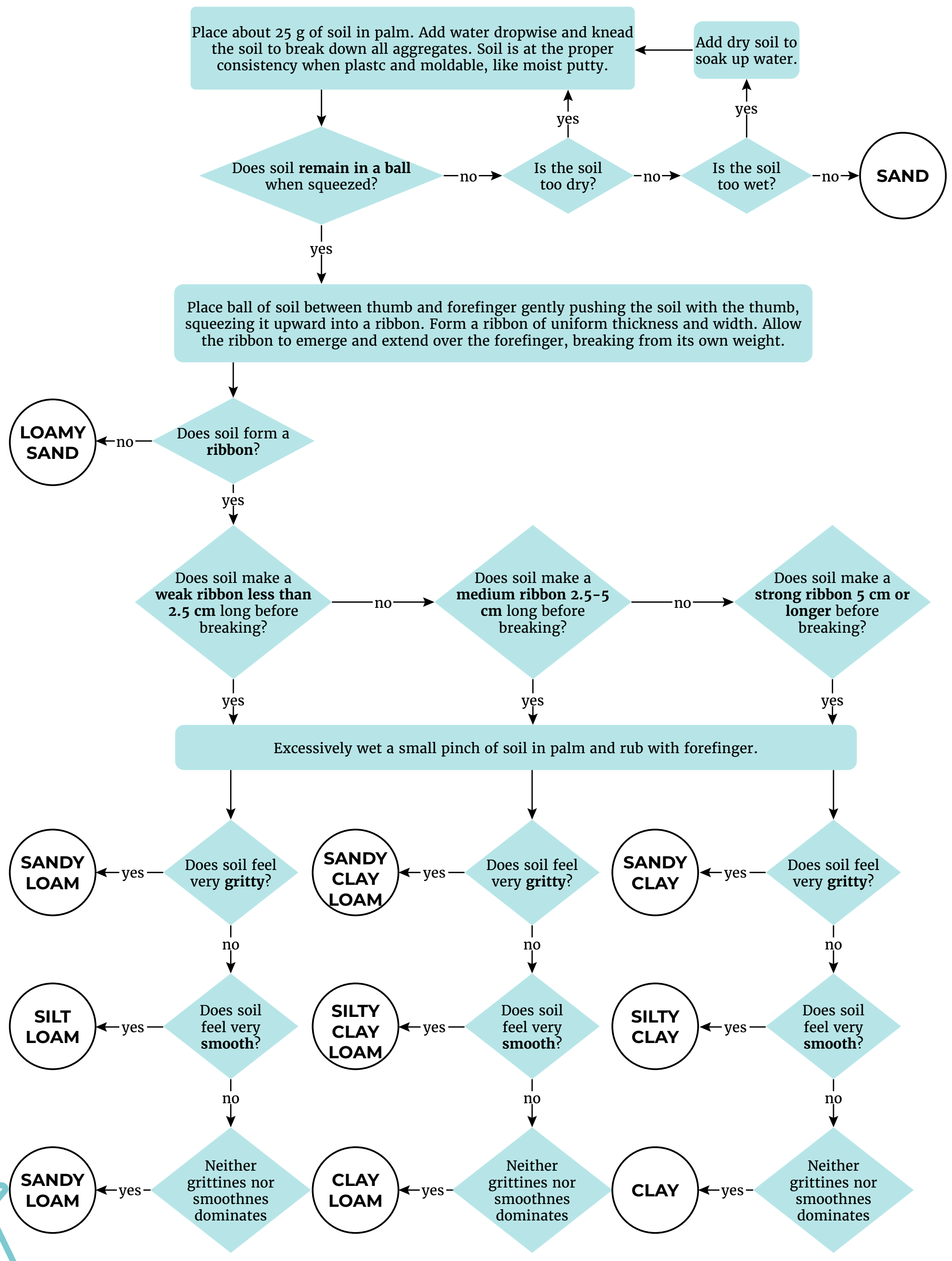


Figure 19. Guide to texture by feel method or hand analysis (Modified from: Thien, 1979).

SOIL TESTS

HANDY QUICK TESTS (PHYSICAL)

P1/ Test 2. Jar Method

Testing procedures (Whiting et al., 2016):

1. Fill about one-quarter of a clear slender jar with an air-dried soil sample (with rocks and debris removed) and the rest by water.
2. Add a teaspoon of nonfoaming detergent and shake for about 15 minutes.
3. Allow jar to stand while soil separates settle according to their sizes.
4. Measure thickness of each layer:
   i. the bottom layer after **one minute** of settling indicates the sand portion
   ii. the layer settled after **two hours** indicates the silt portion
   iii. the layer below marks the clay portion when the supernatant water clears after about **two days**
5. The thickness of each layer to the total thickness represents the proportion of the sand, silt and clay separates (*Figure 20*). Soil textural class can be read from the textural triangle (*Figure 21*) using the sand, silt and clay percentages obtained.

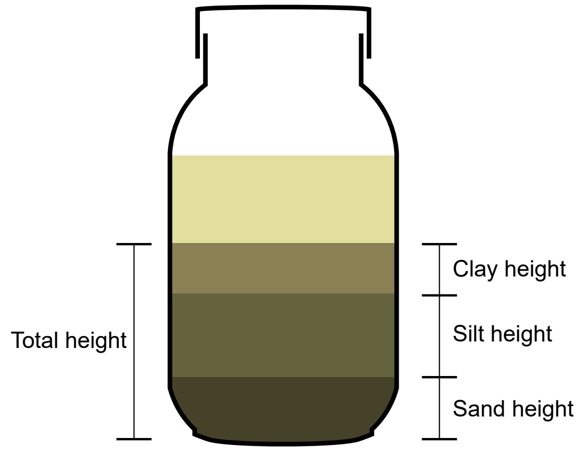


Figure 20. Jar method for soil texture testing. (Adapted from: Whiting et al., 2016).

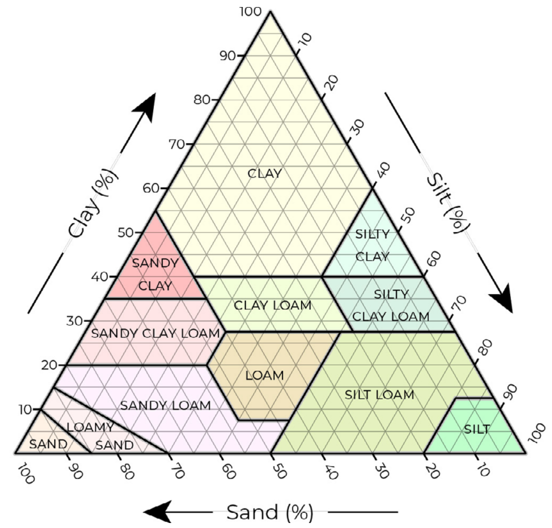


Figure 21. USDA Soil texture triangle. (Modified from: Christopher, 2018, Licensed under CC BY-SA 4.0).

Alternative Method

Remote Sensing Method

With the advancement of remote sensing technology and equipment, a spectroscopic strategy using radar and optical data to map soil texture has been developed (Curcio et al., 2013; Tümsavaş et al., 2018). Multi-sensor satellite data have recently been used. However, this approach could be limited to bare soils only, as tree canopies can block and create noise to the analysis.

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

P2/ Bulk Density and Compaction

P2/ Test 1. Spade Test

Testing procedures:

1. Extract a soil block (typically 20 × 20 × 25 cm³) with a spade, shovel or trowel; try to obtain an undisturbed sample.
2. Note the force used.
3. The chance can be taken to use the extracted soil sample to make other observations. Use a quick hand test (or the feel method) for soil texture and drop test for soil structure.
4. Interpret observations as below:

Diagnostic test		Observation	Interpretation
Force used		Weak	Low bulk density
		Strong	High bulk density
Other possible observations	Colour (*p.49*)	Light	Low soil organic matter (SOM) content
		Dark	High soil organic matter (SOM) content
	Odour (*p.46*)	Mild	Well drained
		Strong	Waterlogged
	Root penetration	Less	Poor soil structure
		More	Good soil structure
	Feel test (*p.73*)	Gritty	Sandy soil texture
		Sticky	Clayey soil texture
	Drop test (*p.80*)	Loose and crumbly	Good soil structure
		Intact and firm clods	Poor soil structure

P2/ Test 2. Soil Penetrometer

A cone penetrometer measures soil compaction instead of bulk density at precise locations and various depths. This standard tool has a rod with an attached cone which is pushed into the soil, mimicking root growth (*Figure 22*). Analog gauge indicates the pressure applied to the cone when penetrating the soil, which gives numerical readings of the pressure needed to break through the soil according to soil resistance.

Testing procedures (Duiker, 2002):

1. Ideally, take readings 24 hours after soaking rain / watering.
2. Drive penetrometer rod into soil at around 25 mm/s.
3. To determine compaction zone(s), note the depths at which the reading exceeds acceptable range of about 1.5 MPa (218 psi) (*Table 7*).
4. Take multiple measurements at different spots to increase accuracy and interpret results (*Table 21*).

Precaution has to be taken that penetrability can be due to firm aggregates in no-till soil, but not necessarily to soil compaction as there are networks of pores that allow aeration, percolation and root penetration.

Figure 22. A penetrometer softness measurement being taken in a runway test pit. (Image credit: The U.S. National Archives, 1980)

Table 21. Interpretation of penetration resistance measurements (Murdock et al., 1995).

Percentage of measuring points with readings >2 MPa in top 600 mm	Compaction rating	Treatment recommended*
<30	Weak	No
30-50	Moderate	No
50-75	Strong	Yes
>75	Severe	Yes

*For reference only; treatment for compact soil depends on sensitivity of tree to compaction and overall condition of soil.

Alternative methods

Soil Core / Ring (determines bulk soil volume)

Bulk density is typically determined by taking the dry weight of an intact soil core sample using a metal soil corer or soil ring sampler (*Figure 23*) with a known volume (Blake & Hartge, 1986). This method works best for moist soils without gravel (> 2 mm). However, rock fragments impede ring insertion or can be easily dislodged during the extraction (Muller & Hamilton, 1992; Van Remortel & Shields, 1993). The accuracy is also affected as the soil core may be distorted when hammering the corer or pushing the sampler into the soil.

Clod Method (determines bulk soil volume)

Soil clod obtained is coated by dipping into semipermeable resin (e.g. paraffin wax), which is then submerged in water to determine its volume by displacement method (Brasher et al., 1966; Blake & Hartge, 1986; Hirmas & Furquim, 2006).

Soil Mobile Device Photogrammetry (determines bulk soil volume)

Recent development in high resolution photography on mobile device and computational software allow the use of cloud-based photogrammetry to calculate volume in a rapid and low-cost way. Photogrammetry which involves the determination of shape and volume from multiple-overlapping photos has found to be an easier and less costly option for measuring bulk density (Moret-Fernández et al., 2016; Whiting et al., 2020). Volume of a soil sample is measured by taking digital imagery of the soil using a phone camera (eight megapixels). The images are uploaded to a free photogrammetric server providing three-dimensional (3D) reconstruction services, e.g. Autodesk Recap™ software or Get 3D in the cloud server, and a fully surfaced 3D render is downloaded and manually trimmed to remove the sample stand that has been included in the render.

Figure 23. Bulk density soil sampler ring with intact sore core inside. (Image credit: Zineb, 2016)

SOIL TESTS

HANDY QUICK TESTS (PHYSICAL)

P3/ Porosity

P3/ Test 1. Soil Porosity from Bulk Volume

Soil porosity is a measure of the volume occupied by the pores divided by the volume occupied by the total soil sample. It can be determined by directly measuring bulk volume of the soil sample and the volume of the soil remaining when pore space is removed from the sample.

A. Testing procedures (using a blender):

1. Take a soil sample using a soil core and note its initial bulk volume.
2. Blend the soil sample using an electrical blender to destroy soil aggregates.
3. Measure the volume of the resultant soil which has no pores after blending.
4. Soil porosity (%) = (bulk volume – solid volume) / bulk volume × 100% (*Figure 24*).

Alternatively, the volume of water in the soil sample at saturation can be used to infer volume of pore space, as the density of water is 1 g/cm³.

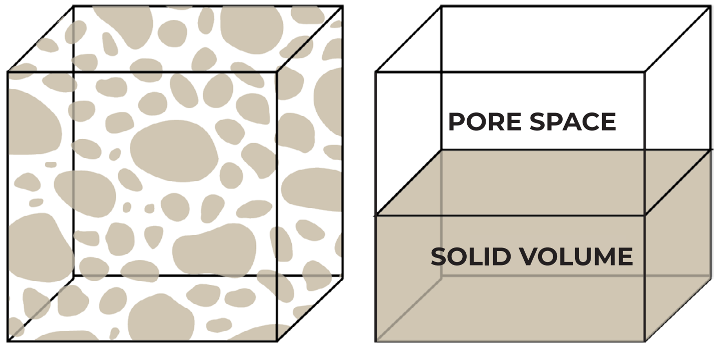


Figure 24. Illustration of soil bulk volume (left) being separated into solid volume and pore volume (right). (Adapted from: The Plant and Soil Sciences e-Library, 2022)

B. Testing procedures (using saturated weight):

1. Take a soil sample using a soil core and note its initial bulk volume.
2. Note the initial weight of the soil sample when dry.
3. Saturate the soil sample with water and take its weight again.

Volume of soil pores (cm³) = (saturated sample weight - dry sample weight) (g)

Soil porosity (%) = Volume of soil pores (cm³) / bulk volume (cm³) × 100%

SOIL TESTS

HANDY QUICK TESTS (PHYSICAL)

P3/ Test 2. Pore Counting Method

Visually, mesopores and micropores are too small to spot and can be inferred from other parameters such as soil texture and compaction. However, a simple field test can be conducted to estimate porosity of the soil in relation to soil water conductivity based on macropore counts.

Testing procedures (Cockroft, 1970):

1. Prepare two wires of 0.1 mm and 0.5 mm diameter.
2. Extract a moist sample of soil.
3. On an undisturbed face of a clod, select a representative 25 mm² section (i.e. 25 mm × 25 mm).
4. Count all pores in the size range 0.1-0.5 mm using the 2 wires as a guide. Repeat 3 times at each site/ depth.
5. Interpret results as below:

Table 22. Irrigation classification and rate of soil water conductivity at varying soil pore levels (Cockroft, 1970).

Number of soil pores (per 25 mm x 25 mm area)	Soil water conductivity (mm/h)	Irrigation classification
10	0.6	Poor
15	1.3	
20	2.3	Acceptable for irrigation
25	3.5	
30	4.9	Good for irrigation
40	8.5	
50	12.9	Excellent

P4/ Pore Size Distribution

No quick tests are currently available for the measurement of pore size distribution.

SOIL TESTS
HANDY QUICK TESTS (PHYSICAL)

P5/ Aggregate Stability

P5/ Test 1. Drop Test

This is a semi-quantitative field test for aggregate size distribution. Degraded soil tends to have a greater proportion of coarse structure units than a well-structured soil (*Table 23*).

Testing procedures (Shephard et al., 2000):

1. Drop a spadeful of soil from a uniform height (e.g. 1.5 m) to the ground onto a plastic sheet or into a rectangular shaped basin.
2. Once the soil shatters into its individual aggregates, sort them so that the largest are placed at the top and the smallest at the bottom.
3. If the soil is not completely broken into individual units, use gentle hand manipulation to break up the aggregates.

Table 23. Soil aggregate size distribution test.

Soil condition	Description	
Good	Good distribution of friable finer aggregates with no significant clodding.	
Moderate	Soil contains significant proportions of both coarse firm clods and friable, fine aggregates.	
Poor	Soil dominated by extremely coarse, very firm clods with very few finer aggregates.	

Image credit: Graham Shepherd, 2000

SOIL TESTS
HANDY QUICK TESTS (PHYSICAL)

P5/ Test 2. Slake Test

Soil stability can be tested qualitatively by exposure to rapid wetting which is highly disruptive to weak or unstable aggregates. When an aggregate is wetted quickly, the osmotic forces pull water in between aggregates which results in swelling and breakage of the bonding that cement the particles together.

A. Testing procedures (using petri dish) (Field et al., 1997):

Other than falling apart into smaller fragments, soils can disperse when immersed in water.

1. Collect 3 soil fragments and air dry for about 2-3 days.
2. Gently put soil fragments onto a petri dish or other shallow dish with water.
3. After a set period of time, e.g. 30 minutes, observe the level of dispersion (*Figure 25*). Aggregates that do not disperse have higher stability; those that disperse more are less stable.

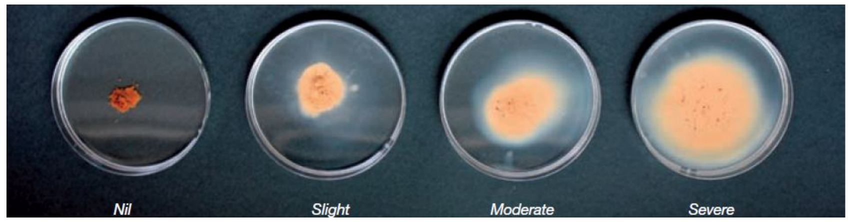


Figure 25. Soils which do not disperse (left), and those that highly disperse (right).
Image credit: © State of Western Australia (Department of Primary Industries and Regional Development, WA, 2021)

B. Testing procedures (using hand sieve or wire gauge):

1. Place soil sample onto a hand sieve (mesh size around 0.5 mm).
2. Sit the sieve on a container filled with water (*Figure 26, left*).
3. Alternatively place the soil sample on a wire gauge mounted on the rim of a transparent plastic cup while submerged in water (*Figure 26, right*).
4. Note how much the soil aggregates disperse or collapse after a set period of time, e.g. 30 minutes.
5. Collect the soil retained by the sieve or gauge (as the stable fraction), and those dispersed at the bottom of the container (dispersed fraction).
6. Dry the two fractions in an oven at 105°C overnight and weigh the dried fractions.
7. Calculate the percentage of the stable aggregates using the equation as below.

Stable aggregates (%) =
Weight of stable fraction / (Weight of stable fraction + Weight of dispersed fraction)

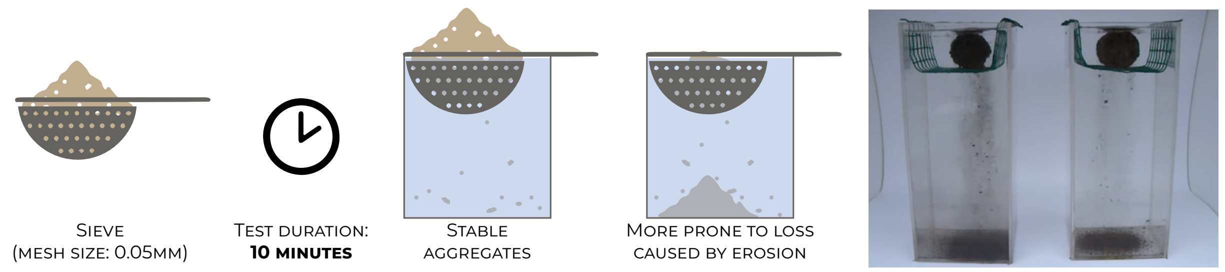


Figure 26. Slake test using a sieve. (CIAT / JL Urrea. 2018) (left) and a wire gauge. (CIAT / JA Cardoso. 2018) (right).
(Images licensed under CC BY NC 4.0).

HANDY QUICK TESTS (PHYSICAL)

C. Testing procedures (soil stability kit) for a larger number of samples (Herrick et al., 2001):

1. Prepare plastic box (21 × 10 × 3.5 cm) with 18 equal compartments each of which contains a 2.5 cm sieve (mesh size of 1.5 mm) (*Figure 27*).
2. Fill compartments with water.
3. Place a soil fragment onto each sieve which is immersed in its compartment.
4. Allow soil to soak for 5 minutes.
5. Raise sieve up and down four times.
6. Interpret results:

Figure 27. Plastic compartmentalized box ("soil stability kit") with 2.5cm sieves (Image credit: USDA. 1999)

The stability rating system is based on a scale of 0-6, with 0 indicating weakest soil aggregate structure and 6 indicating strongest soil aggregate structure. (*Table 24*). A smart-phone app has been developed for this purpose (Fajardo & McBratney, 2019).

Table 24. Criteria for the assignment of soil to stability classes (Herrick et al., 2001).

Stability class	Criteria for assignment to stability class
0	Soil too unstable to sample (fall through sieve)
1	50% of structural integrity lost within 5 seconds of immersion in water
2	50% of structural integrity lost within 30-300 seconds of immersion in water
3	<10% of soil remains on sieve after 5 dipping cycles
4	10-25 % of soil remains on sieve after 5 dipping cycles
5	25-75 % of soil remains on sieve after 5 dipping cycles
6	>75% of soil remains on sieve after 5 dipping cycles

Alternative Method

Wet Sieving (USDA, 1999)

Gravels, rocks, roots and seeds are handpicked from the soil sample. About 10 g of 2-mm sieved air-dried soil are transferred to a preweighed 0.25-mm sieve on a distilled water moistened towel on a flat surface. The soil is allowed to wet up slowly for five minutes. The sieve with the soil is soaked with distilled water to about the soil surface in a container, which is oscillated up and down for a distance of 1.5 cm at 30 oscillations/min for three minutes, keeping the soil in water during oscillation. Oscillation should remove unstable aggregates (<0.25 mm). The sieve is weighed after being placed on a piece of dry towel and dried using a hair dryer at the coolest setting. The sieve containing the dried aggregates is then immersed in water containing water softener (e.g. Calgon), moving up and down periodically. This removes all soil particles except sand. After drying, the sand in the sieve is weighed. Water stable aggregates (%)(>0.25 mm) is calculated as follows:

(Weight of dry aggregates – Weight of sand) / (Weight of dry soil – Weight of sand) × 100

A simple inexpensive setup / method using wet sieving with instructions for apparatus assembly is proposed for measuring stable aggregate content of soil (Patton et al., 2001).

HANDY QUICK TESTS (PHYSICAL)

P6/ Infiltration Rate

P6/ Test 1. Infiltrometer Method

Infiltration can vary temporally and spatially which affects the selection of measurement techniques and data analysis methods. Areal infiltration estimation involves the analysis of rainfall-runoff data, while point infiltration measurements are normally done by applying water to a finite area at a specific site and measuring the intake of the soil. Infiltration rate for point measurement can be made using a single- and double-ring infiltrometer, tension infiltrometer, minidisk infiltrometer, Guelph permeameter, Phillip-Dunne permeameter or modified Phillip-Dunne infiltrometer (Gulliver & Anderson, 2008). Infiltrometers help us estimate infiltration rate by recording the time it takes for a specified volume of water to infiltrate into the ground.

Testing procedures

1. Insert a 10-cm metal, PVC or perspex pipe as infiltrometer into the soil to a shallow depth, e.g. 5 cm below the soil surface (*Figure 28*).
2. Fill infiltrometer with a specified level of water (e.g. 10 cm).
3. Monitor water level change inside the pipe with time.
4. In determining infiltration rate, it is sometimes necessary to bring the soil water content to near field capacity as infiltration is affected by the initial water content during measurement.

Figure 28. Infiltrometer test. (Image credit: Mississippi Watershed Management Organization, 2019. Licensed under CC BY-NC 2.0).

SOIL TESTS
HANDY QUICK TESTS (CHEMICAL)

There are commercially available portable soil testing kits that are for multiple tests and use colorimetric method for measuring soil chemical properties such as pH, N, P and K (Figure 29). There are complete soil kits that cover as many as eight soil parameters. However, these test kits could not be taken as perfect alternative to laboratory testing, as they have variable accuracy. Despite this, they are still useful, but wise selection is crucial to the rapid and economic data production for knowing and better managing your soil fertility (Faber et al., 2007).

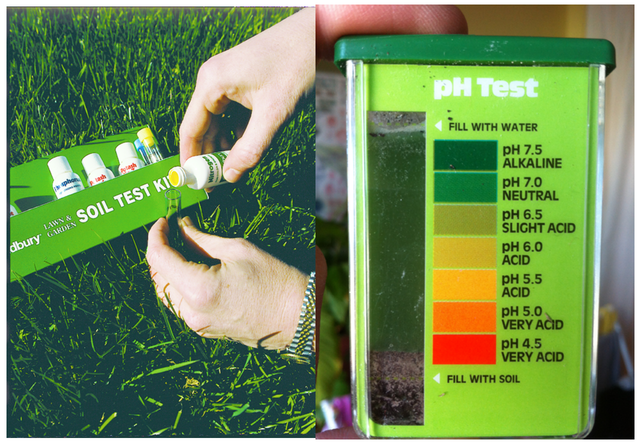


Figure 29. Soil test kits for determining concentrations of N, P and K (left) (Photo by Lynn, USDA Natural Resources Conservation Service, 2011), and portable test kit for determining soil pH (right) (Image credit: Wayan, 2012. Licensed under CC BY-NC-SA 2.0).

C1/ pH

C1/ Test 1. pH Test Kits / Strips

This can be done using soil pH testing kits commercially available in the market according to their instruction. For dye indicators, the indicator is often added to moisten the soil sample thoroughly and forms certain colour under the pH of the soil, which is checked against the colour chart of the kit to indicate the pH of the soil (*Figure 30*). Steps specified by suppliers should be followed.

pH paper strips

1. Add distilled water to soil sample to prepare a 1:1 soil:water suspension.
2. Wait for 30 minutes.
3. Dip pH paper into soil suspension for 1 minute.
4. Compare test paper against the pH scale for reading.

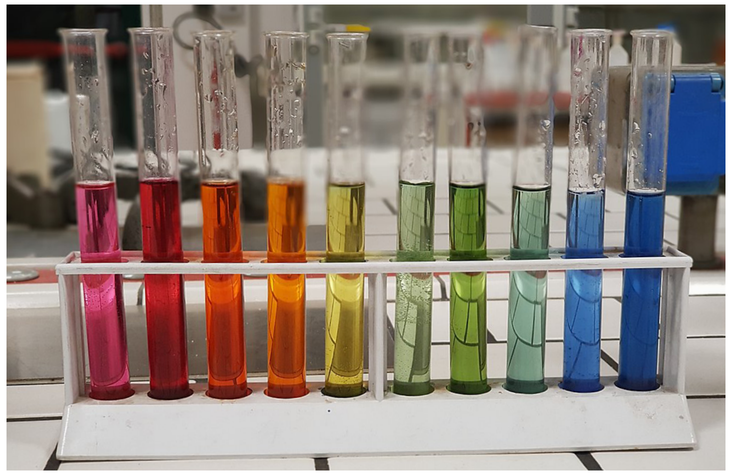


Figure 30. Test tubes containing solutions of pH 1–10 coloured with an indicator. (Image credit:Alvy16, 2016. Licensed under CC BY 4.0).

SOIL TESTS
HANDY QUICK TESTS (CHEMICAL)

C1/ Test 2. pH Meter

pH can be measured conventionally using a standard pH meter and electrode, a pocket meter or a pH probe (*Figure 31*). Pocket meters have been developed for measuring ion-related parameters, such as pH, conductivity and macronutrient concentrations. They are small, handy flat sensors that are reasonably accurate for assessing a number of chemical parameters in the field. While pocket meters are more convenient to use in the field, using pH probe with a soil water suspension is considered more accurate.

A. Pocket meter (Instrument Choice, 2020)

1. For higher accuracy, remove about 5 cm of topsoil at the test location.
2. Perforate soil using a shovel or auger to a depth of 20 cm or more.
3. If soil is dry, moisten with a small amount of distilled water.
4. Using gentle pressure, push the electrode into the soil.
5. Observe the measurement when the reading settles.
6. Clean off the meter probe between tests.

Figure 31. A pocket soil pH meter (Image credit and adapted from: rukawajung, 2019).

B. pH meter using soil suspension

1. Add distilled water to soil sample to prepare a 1:1 soil:water suspension.
2. Wait for 30 minutes.
3. Dip measuring meter into soil suspension.
4. Observe the measurement when the reading settles.
5. Clean off the meter probe between tests.

* Calibrate the meter occasionally with two buffer solutions for higher accuracy.

Other soil:water ratios, including soil water saturation, 1:2 and 1:5, are sometimes used. However, it should be noted that higher proportions of water can increase the measured soil pH. Alternatively, extractants having the same ionic strength as the soil solution to minimise ionic interference, like 0.01M $CaCl_2$, are used.

Alternative Method

DIY Kit

Soil pH can be estimated with a DIY kit using white vinegar and baking soda. If it fizzles when 200 mL of baking soda is added to two spoonfuls of soil in a beaker, very likely the soil is acidic with a pH 5-6. If it fizzles when 200 mL of white vinegar is added, the soil is alkaline with a pH 7-8.

SOIL TESTS

HANDY QUICK TESTS (CHEMICAL)

C2/ Electrical Conductivity and Salinity

C1/ Test 3. Ohmmeter

EC is measured by an ohmmeter which has a probe with a pair of metal electrodes. This can be a laboratory or handheld conductimeter, or a combined meter for both pH and conductivity. The soil suspension prepared for measuring pH can be used for determining EC. There is also portable EC-probe connected to a stainless steel bar for in-situ salinity measurements of soil up to 1-meter depth in the field.

A. Portable EC-probes

Follow the same steps listed for pocket pH meters above, using the EC meter.

B. Probes using soil suspension

Refer to general testing procedures for electrode methods, but use the EC meter instead.

NB: dS/m = mS/cm = 1000 µS/cm

C3/ Soil Organic Matter (SOM)

No handy quick tests are currently available for the measurement of soil organic matter.

C4/ Cation Exchange Capacity (CEC)

No handy quick tests are currently available in the market for the measurement of CEC.

Alternative Method

Colorimetric Method

A colorimetric method based on methylene blue adsorption has been developed for rapid analysis of soil CEC (Soon, 1988), however they are not widely available in the market.

SOIL TESTS

HANDY QUICK TESTS (CHEMICAL)

C5/ Macronutrient - Nitrogen (N)

C5/ Test 1. Nitrate and Nitrite Test Kits / Strips

There are many nitrogen testing kits in the market. Instructions from the suppliers should be followed.

Nitrate/Nitrite test strips are available for testing soil N concentration (Hartz, 1994). The strips are coated with a reagent that forms a colour product when it reacts with nitrate. The soil suspension for pH measurement can be used for dipping test strip and matching its colour with the colour scale provided for quantifying concentration. The concentration in soil is obtained using a correction factor (Schmidhalter, 2005). Contrastingly, test strip for ammonium is less precise presumably due to interference by nitrate (Maggini et al., 2010).

Alternatively, there are commercial soil test kits for NO_3^- and NH_4^+; they have a container for the soil to be analysed and extractant is added. The colour obtained after a specified time is compared with a colour card corresponding to a categorical concentration level.

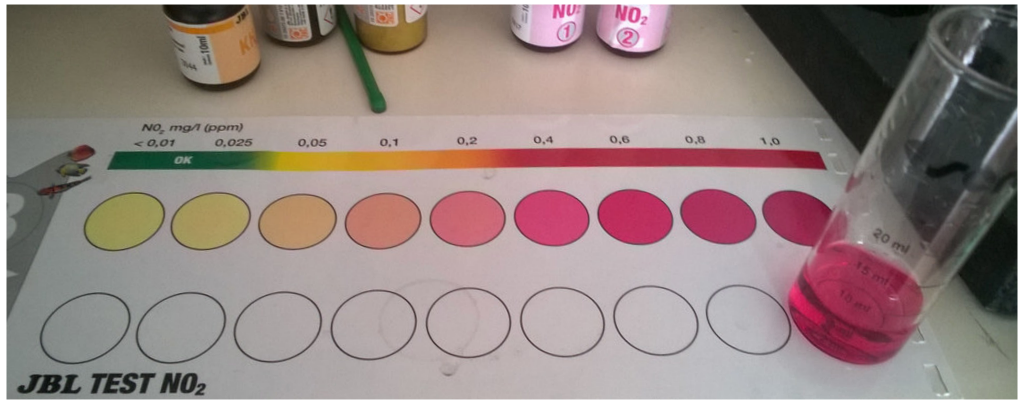


Figure 32. Commercial nitrate and nitrite test.
(Image credits: KoiQuestion, 2016 Licensed under CC BY-SA 2.0).

Recently, the use of smartphone app (Akvo Caddisfy available via the Android Google Play Store) as portable soil analyser (reflectometer) which relates the concentration of nitrate and ammonium to the colour intensity of commercially available test strips (Golicz et al., 2019).

There are also combo soil test kits for a number of soil parameters, e.g. pH, N, P and K.

C5/ Test 2. Nitrogen Electrode Methods

Nitrate-selective electrode measures the level of free nitrate in solution. The electrode method is rapid, simple and relatively inexpensive, but is subject to low sensitivity, numerous interferences and fluctuations in sample handling and electrode calibration (Keeney & Nelson, 1982; Gelderman & Fixen, 1988). Possible interferences may come from some commonly occurring anions in soils, like sulphide (S^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), carbonate (CO_3^-), sulphate (SO_4^{2-}) and dihydrogen phosphate ($H_2PO_4^-$) (Yu, 1985). Despite these disadvantages, nitrate electrode has been used by some soil laboratories for the analysis of routine soil samples. Similarly, ammonia electrode has been used satisfactorily for determination of ammonium in soil extracts (Banwart et al., 1972).

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

C6/ Macronutrient - Phosphorus (P)

C6/ Test 1. Phosphorus Test Kits / Strips

There are various commercial test kits that employ soil strips for colour development for soil P. Instructions from the suppliers should be followed.

One uses reactive strips and a hand-held reflectometer for quantitative determination. The Reflectoquant® test kits (Merck, Darmstadt, Germany) have been used in conjunction with the RQFlex Plus portable reflectometer, which combines the operational simplicity of colorimetric methods and the accuracy of photometric measurement. A proper amount of reagent is added to the sample and the test strip is immersed. With colour development after a few minutes, the strip is inserted into the reading chamber of the reflectometer. The best measuring range is 5-120 mg phosphate (PO_4^{3-})/L.

These are also iron oxide impregnated paper (FeO paper) test and anion-exchange resin paper test for available P (Menon et al., 1990). P measured from soils fertilised with phosphate rock-based fertilisers has shown very good correlation with plant response (Menon & Chien, 1995).

The choice of extractant is critical in the assessment of available PO_4^{3-}. For different soil types, there are different extractants, e.g. calcium chloride, sodium bicarbonate (Olsen), ammonium lactate, acetic acid, diluted hydrochloric acid, diluted sulfuric acid (Truog), solution of ammonium fluoride and hydrochloric acid (Bray-2), double acid (hydrochloric and sulfuric acid) (Mehlich-1) and solution of acetic acid, ammonium fluoride, nitric acid and EDTA (Mehlich-3), which are strongly related to soil pH (Wuenscher et al., 2015). The accuracy of different commercial test kits is governed by the composition of the extractants used (Faber et al., 2007).

C6/ Test 2. Phosphorus Electrode Methods

PO_4^{3-} in water or extractant can be measured using electrode methods, among which cobalt-based electrode is more sensitive for soil P sensing over the typical range of soil concentrations (Kim et al., 2007).

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

SOIL TESTS
HANDY QUICK TESTS (CHEMICAL)

C7/ Macronutrient - Potassium (K)

C7/ Test 1. Potassium Test Kits / Strips

There are garden soil test kits which are good for measuring K in soil (Faber et al., 2007). Instructions from the suppliers should be followed. Soil is usually extracted for their soluble and available K using water and 1M ammonium acetate respectively.

C7/ Test 2. Potassium Electrode Methods

Ion specific electrodes are available for determining the K concentration in soil. The extraction method is the same as the laboratory method. A handheld and screen-printed solid-state electrode with an electrochemical reader has been developed for the first time for measuring soil K in the field (Rosenberg et al., 2018).

C8/ Other Macronutrients - Magnesium (Mg), Calcium (Ca) and Sulphur (S)

C8/ Test 1. Test Kits for Macronutrients

There are soil analysis test kits for Mg, Ca and S, most of which are in combination with pH, N and P, or with at least cationic macronutrients (e.g. K, Ca and Mg). Instructions from the suppliers should be followed.

Alternative Methods

Electrode Methods for Macronutrients

Although ion-selective electrode has been experimented for measuring a variety of nutrient ions, commercial electrode for soil analysis is only available in the market for Ca (*Table 25*). Pocket ion meter using electrode technology is also available for measuring soil Ca.

Table 25. Electrode methods for measuring soil Ca, Mg and S.

Elements	Electrode methods	Possible interferences	Commercial electrodes
Ca	Ion selective electrode	H^+, Na^+, K^+ and Mg^+	Yes
Mg	Ion selective electrode	H^+, Na^+, K^+ and Ca^{2+}	No
S	Ion selective electrode	Ca^{2+}, Cl^-	No

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

SOIL TESTS

HANDY QUICK TESTS (CHEMICAL)

C9/ Micronutrients

Commercial field test kits are available for some micronutrients, e.g. Cu and Fe. However, most are colorimetric kits that are largely qualitative for crude approximation of their concentrations in soil.

C10/ Heavy Metals

Toxic levels of heavy metals in the soil are typically difficult to infer from visual or handy tests as well as to treat apart from replacing soil or controlling road runoff into planters and avoiding contaminated soil amendments, therefore they are not discussed in detail in these Guidelines. If heavy metal toxicity is suspected, it can be determined through laboratory testing.

SOIL TESTS

HANDY QUICK TESTS (BIOLOGICAL)

B1/ Microbial Diversity and Activity

There are no direct simple tests for microbial diversity and activity. However, microflora diversity, microbial biomass and microbial activity are often related to SOM, and soil colour which reflects the organic content of soil may be used as an indirect indicator.

B2/ Faunal Diversity and Abundance

Macrofauna can be directly observed by eye or under a magnifying glass, while mesofauna and microfauna can be observed under a microscope.

SOIL PARAMETERS
VISUAL ASSESSMENT
HANDY QUICK TESTS
IMPROVEMENT MEASURES

CH4: IMPROVEMENT MEASURES

This section matches targeted soil issues identified from interpreting indicators to suggested solutions in the form of soil amendments and / or root invigoration methods.

IMPROVEMENT MEASURES

TARGETING PHYSICAL ISSUES

Unsuitable Soil Texture

Soil texture problems usually come with the soil imported for planting. In Hong Kong, sand or soil mix high in sand content is most commonly used for filling up tree pits or planters, which results in all the associated soil physical, chemical and biological constraints to plant growth.

Other possible related issues:

- *P1/ Soil Texture*
- *P2/ Bulk Density*
- *P3/ Porosity*
- *P4/ Pore Size Distribution*
- *P5/ Aggregate Stability*
- *P6/ Infiltration Rate*
- *C4/ Cation Exchange Capacity (CEC)*

Prevention and Possible Solutions

Overly sandy soils are generally not preferred. However, as DG is the most available soil locally, and is coarse-textured, the best solution is to increase the capacity of the soil to hold water and nutrients.

Adding organic matter like peat moss, compost and mulch is a medium-term option, while adding biochar is suggested as a longer-term alternative, though there is cost implication. Amendments can be applied to meet the soil specifications before planting or in later stages when a soil texture problem emerges.

Suggested Soil Amendments for UNSUITABLE SOIL TEXTURE

- M1/ Peat Moss
  (does not address the problem of nutrient shortage)
- M2/ Biochars
  (do not change soil texture but address the problem of coarse-textured soil)
- M4/ Composts
  (good quality mature composts from organic wastes with minimal or no heavy metal contamination including rotted grass clippings and leaf moulds)

IMPROVEMENT MEASURES

TARGETING PHYSICAL ISSUES

High Compaction / Bulk Density

In the urban context, compaction, low porosity and poor pore size distribution often occurs from machinery traversal during construction and vehicular or foot traffic. Large areas of bare soil and lack of stable aggregates can cause soil to be easily compacted by the impact of rainwater.

Other possible related issues:

- *P1/ Soil Texture*
- *P3/ Porosity*
- *P4/ Pore Size Distribution*
- *P5/ Aggregate Stability*
- *P6/ Infiltration Rate*

Prevention and Possible Solutions

Compaction is best prevented by appropriate planning of soil backfill procedures to avoid any vehicular traffic over planting soil.

Amendment strategies include replacing soil, using mechanical methods to revitalize soil, and adding amendments that improve soil structure / aggregation and reduce bulk density.

Suggested Soil Amendments for HIGH SOIL COMPACTION

- M1/ Peat Moss
- M4/ Composts
- M11/ Vertical Mulching
- M2/ Biochars
- M13/ Air Vacuum
- M14/ Hydro Excavation

Soil Lacks Aggregates

Soil that lacks organic matter and other binding agents will result in poor structure and low soil aggregation. In connection to this, sand which is single-grained forms no aggregate, particularly water-stable aggregates.

Other possible related issues:

- *P1/ Soil Texture*
- *P3/ Porosity*
- *P4/ Pore Size Distribution*
- *P6/ Infiltration Rate*
- *C3/ Soil Organic Matter (SOM)*
- *C4/ Cation Exchange Capacity (CEC)*
- *B1/ Microbial Diversity and Activity*
- *B2/ Faunal Diversity and Abundance*

Prevention and Possible Solutions

As in the case for soil texture, it is always better to replace loose, sandy soil with one that has reasonable organic matter or clay content for the sake of soil aggregates. However, when market availability is taken into account, it seems more convenient to modify DG by adding organic matter like peat moss and composts before planting or in later stages when amelioration is deemed necessary.

Suggested Soil Amendments for POOR SOIL AGGREGATION

- M1/ Peat Moss
- M4/ Composts

IMPROVEMENT MEASURES

TARGETING PHYSICAL ISSUES

Low Water Holding Capacity

Soil texture and organic matter content are the key parameters that govern soil water holding capacity. DG which is coarse-textured with high macroporosity and low organic content has inevitably low water retention capacity.

Other possible related issues:

- *P1/ Soil Texture*
- *P3/ Porosity*
- *P4/ Pore Size Distribution*
- *C3/ Soil Organic Matter (SOM)*
- *C4/ Cation Exchange Capacity (CEC)*

Prevention and Possible Solutions

Correction or prevention is again related to the use of soil mixes other than DG if supply is available. When DG is used, the best possible option is to increase its soil organic matter in the usual recommended ways. Alternatively, we can add biochar or hydrogel to increase the retention capacity for water.

Suggested Soil Amendments for LOW WATER HOLDING CAPACITY

- M1/ Peat Moss
- M2/ Biochars
- M4/ Composts
- M7/ Hydrogels

Poor Drainage

Soil drainage is largely controlled by soil permeability, infiltration rate and water holding capacity, which are greatly affected by soil texture. Drainage will be much reduced in compacted soil which has poor soil permeability. Contrastingly, drainage will be too high in coarse-textured soil which has low water retention capacity.

Other possible related issues:

- *P1/ Soil Texture*
- *P2/ Bulk Density*
- *P3/ Porosity*
- *P4/ Pore Size Distribution*
- *P5/ Aggregate Stability*
- *C3/ Soil Organic Matter (SOM)*

Prevention and Possible Solutions

If poor drainage is the result of soil compaction, any solution that alleviates compaction will work to improve drainage. On the contrary, if poor drainage is due to high porosity and low water holding capacity, then improvement for increasing available water content is applicable.

Suggested Soil Amendments for OVERLY LOW DRAINAGE

- M1/ Peat Moss
- M4/ Composts
- M11/ Vertical Mulching
- M2/ Biochars
- M12/ Air Spading
- M14/ Hydro Excavation

Suggested Soil Amendments for OVERLY HIGH DRAINAGE

- M1/ Peat Moss
- M2/ Biochars
- M4/ Composts
- M7/ Hydrogels

IMPROVEMENT MEASURES

TARGETING PHYSICAL ISSUES

High / Low pH

DG used is inherently acidic in nature and results in lower soil pH commonly found in tree pits. The addition of peat moss which is generally acidic can further reduce the pH of the soil mix. However, soil in planters can be slightly alkaline due to the presence of calcareous materials in the concrete and cement for building the planters.

Other possible related issues:

- *P1/ Soil Texture*
- *P3/ Porosity*
- *P4/ Pore Size Distribution*
- *C3/ Soil Organic Matter (SOM)*
- *C5 – C9/ Nutrient Availability*
- *B1/ Microbial Diversity and Activity*
- *B2/ Faunal Diversity and Abundance*

Prevention and Possible Solutions

The use of less acidic soil by replacing DG with other soil mix can help. The addition of pH-adjusted peat moss, lime or composts that have buffering effect will ameliorate the unfavourable pH. For planter soils that are slightly alkaline, the use of DG or the addition of acidic peat moss can be complementary.

Suggested Soil Amendments for OVERLY HIGH pH

- M1/ Peat Moss
- M4/ Composts

Suggested Soil Amendments for OVERLY LOW pH

- M1/ Peat Moss (pH-balanced)
- M4/ Composts
- M9/ Lime / Calcite

High Electrical Conductivity (EC) / Salinity

Soil volumes in close proximity to coastlines can be susceptible to salt spray and, while poor drainage can cause a buildup of salts in the soil.

Other possible related issues:

- *C5 – C9/ Nutrient Levels*
- *B1/ Microbial Diversity and Activity*

Prevention and Possible Solutions

Where high salinity is caused by salt spray, species that are adapted to higher salinity may be selected. Otherwise, flushing or replacing the soil may be helpful.

Suggested Soil Amendments for EXCESS SALINITY

- Soil replacement
- Planting salt-tolerant species

IMPROVEMENT MEASURES
TARGETING CHEMICAL ISSUES

Organic Matter Deficiency

High quality topsoil is commonly unavailable, while the DG or subsoil used is generally deficient in organic matter and appears light-coloured.

Other possible related issues:

- *P1/ Soil Texture*
- *P3/ Porosity*
- *P5/ Aggregate Stability*
- *P6/ Infiltration Rate*
- *C1/ pH*
- *C4/ Cation Exchange Capacity (CEC)*
- *C5 – C9/ Nutrient Availability*
- *B1/ Microbial Diversity and Activity*
- *B2/ Faunal Diversity and Abundance*

Prevention and Possible Solutions

The use of organic rich soil, if it can be sourced despite its low availability, can avoid the problem. Incorporation of organic matter effectively improves soil physical, chemical and biological properties, as the organic matter becomes the driving force for soil structural modification, nutrient pool via decomposition and energy source for soil organisms. Organic matter source, decomposition level and C:N ratio of the organic materials are important criteria in their selection.

Suggested Soil Amendments for ORGANIC MATTER DEFICIENCY

- M1/ Peat Moss
- M4/ Composts
- M5/ Woodchip / Bark Mulches
- M6/ Sawdust Mulches

Nitrogen (N) Deficiency

DG is deficient in most plant nutrients, especially N that is not present in soil parent materials. The addition of peat moss does not help, so inorganic fertilisers are commonly added to produce a good soil mix for tree planting. However, inorganic forms of N are very mobile under water and are liable to leaching loss, hence N deficiency unless there is repeated fertiliser application.

Other possible related issues:

- *P1/ Soil Texture*
- *C1/ pH*
- *C3/ Soil Organic Matter (SOM)*
- *C4/ Cation Exchange Capacity (CEC)*

Prevention and Possible Solutions

Fertilisers can rectify N deficiency in soil. Adding organic forms of N is preferred. Compost addition, though having less instant effect, offers a longer-term solution through releasing N over time. Planting N-fixing plants or green manure crops (typically cover plants turned into the soil to serve as mulch or soil amendments for other plants) is more ecological as a solution.

Suggested Soil Amendments for N DEFICIENCY

- M3/ Green Manure (especially legumes)
- M4/ Composts
- Fertilisers (preferably organic)

IMPROVEMENT MEASURES
TARGETING CHEMICAL ISSUES

Phosphorus (P) and Potassium (K) Deficiency

Apart from N deficiency, DG is very low in available P and K contents despite the presence of phosphate (PO_4^{3-}) and K, the release of which are too slow to be agronomically effective. This compares less favourably with volcanic rock which has relatively faster rate of weathering and release of their contained macro- and micro-nutrients. P deficiency is sometimes resulted by the release of carbonate from calcareous construction waste in urban soil (Jim, 1998).

Other possible related issues:

- *P1/ Soil Texture*
- *C1/ pH*
- *C3/ Soil Organic Matter (SOM)*
- *C4/ Cation Exchange Capacity (CEC)*

Prevention and Possible Solutions

Correction of pH should first be considered if P deficiency is induced by overly alkaline pH. DG amended with NPK fertiliser is the norm in soil mix for planting, which addresses the problem in the short and medium terms. However, nutrient deficiency occurs due to plant removal and leaching loss, and has to be corrected by repeated application of inorganic fertiliser, or more preferably using organic amendments like composts.

Suggested Soil Amendments for P / K DEFICIENCY

- M4/ Composts
- Fertilisers (preferably organic)

Other Macronutrients Deficiency – Magnesium (Mg), Calcium (Ca) and Sulphur (S)

Secondary macronutrients are generally deficient, though not necessarily limiting, in DG, but Ca may be present in substantial amount in subsoil and urban soil materials. Soil S status is less known and is generally considered low, though atmospheric deposition from industrial activities used to be a route of influx to urban soil.

Other possible related issues:

- *P1/ Soil Texture*
- *C1/ pH*
- *C3/ Soil Organic Matter (SOM)*
- *C4/ Cation Exchange Capacity (CEC)*

Prevention and Possible Solutions

The addition of lime (calcitic lime primarily of $CaCO_3$; dolomitic lime a combination of $CaCO_3$ and $MgCO_3$) to address soil acidity problem may alleviate Ca and Mg problems, though liming is not a common local practice. Gypsum ($CaSO_4$) is a good source of Ca (22%) and S (19%) especially at high soil pH. Composts contain many plant essential nutrients and are enriched with Ca, Mg and sodium (Na) though high soluble salt contents can be a minor concern.

Suggested Soil Amendments for NUTRIENT DEFICIENCY

- M4/ Composts
- Fertilisers (preferably organic)

IMPROVEMENT MEASURES
TARGETING CHEMICAL ISSUES

Micronutrient Deficiency

Micronutrients are required in very small amounts. More frequently, their availability rather than their supply is a question. Their deficiencies, especially those of iron (Fe) and zinc (Zn), can result from high pH induced by carbonate or calcium cations (Ca^{2+}) in calcareous construction waste. Zn deficiency is also common in highly weathered acid soils and is often associated with Fe deficiency (Lohry, 2007). As many micronutrients are considered toxic in elevated concentrations, their deficiencies in urban soils have been given less attention than their contamination.

Other possible related issues:

- *P1/ Soil Texture*
- *C1/ pH*
- *C3/ Soil Organic Matter (SOM)*
- *C4/ Cation Exchange Capacity (CEC)*

Prevention and Possible Solutions

Micronutrient fertilisers certainly work if we have the right diagnosis, but normally we can correct their deficiencies by adding composts that have an ample supply of most nutrient elements. It is also important to obtain representative soil samples for testing as micronutrient concentrations fluctuate greatly spatially in the field.

Suggested Soil Amendments for MICRONUTRIENT DEFICIENCY

- M4/ Composts
- Fertilisers (preferably organic)

IMPROVEMENT MEASURES
SELECTING IMPROVEMENT METHODS

In general, we can match the different soil improvement methods to the different soil problems encountered, as shown in *Table 26* and *Table 27*.

Peat moss is conventionally added to soil to address physical constraints such as sandy permeable soils that lack organic matter, but most peat moss sold is acidic, which may aggravate soil acidity in DG. Composts are considered a better alternative as they contain slow-release nutrients in organic form, enhance water retention, and buffer extreme pH. Hydrogel can improve drainage and water holding capacity, while biochars are effective in improving soil water and nutrient retention (refer to ***APPX A*** for soil amendment information sheets). Mulching materials of different sorts can be applied to soil surface to conserve water and control weeds.

Root invigoration by vertical mulching, air spading or hydro-excavation can also be considered especially when soil compaction is the issue. However, there are no similar invigoration methods for acid soil and nutrient and organic matter deficiencies.

Table 26. Recommended solutions for common soil problems.

Soil problem	Potential solution(s)
Weeds	Mulching
Soil too coarse	Soil amendments, e.g. peat moss, composts
Soil freely drained	Soil amendments, e.g. peat moss, composts, biochar, hydrogel
Soil too compact	Soil amendments, e.g. peat moss, composts Root invigoration, e.g. vertical mulching, air spading, hydro-excavation
Soil too acidic	Soil amendments, e.g. lime
Soil too alkaline	Soil amendments, e.g. peat moss
Soil too infertile	Soil amendments, e.g. organic fertilisers, composts, green manure

When selecting soil amendments, the environment should be considered as well. For example, methods such as vertical mulching which have the potential to injure tree roots and require digging / trenching deeper into the soil may not be applicable in most small tree pits, where major roots are likely present close to the surface of the open soil. In this case, gentler methods such as air spading may be more suitable.

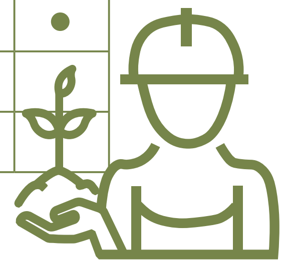
IMPROVEMENT MEASURES

SELECTING IMPROVEMENT METHODS

Table 27. Matching soil problems to solutions.

	TARGET SOIL ISSUE	Unsuitable soil texture	Soil too compact	Soil lacks aggregates	Low water holding capacity	Poor drainage	High pH	Low pH	Organic matter deficiency	Low CEC	Nutrient deficiency	Weeds	Prone to diseases	POTENTIAL DRAWBACK										
	SOIL IMPROVEMENT STRATEGY	Modify soil texture	Reduce soil bulk density	Improve aggregation	Increase water holding capacity	Improve drainage	Lower pH	Raise pH	Increase organic matter	Increase CEC	Increase nutrient contents	Control weeds	Control diseases	Limited availability	High pricing	Large amount required	Potential N immobilization	Potential N leaching	Salts	Odour	Contaminants	Labour intensive	Potentially destructive*	Sensory disturbance**
SOIL AMENDMENT	M1/ Peat Moss	●	●	●	●	●	◐		●	◐					●	○	○							
SOIL AMENDMENT	M2/ Biochars		●	●	●	●	●			●				◐	●		●				●			
SOIL AMENDMENT	M3/ Green Manure		○	●		◐			○		○	●						●		○				
SOIL AMENDMENT	M4/ Composts	●	●	●	○	◐	●		●	●	○	○				●		○	○		○			
SOIL AMENDMENT	Compost tea			●					●	●	●			●	○									
SOIL AMENDMENT	Organic fertiliser	●							●	●	●				●			○						
SOIL AMENDMENT	Manure	●	●	●	○	◐			●	●	○					●		○	●	●	●			
SOIL AMENDMENT	Sludge	●	●	●	○	◐			●	◐	○					●		◐	●	●	●			
SOIL AMENDMENT	Peanut cake		○	○	○				○	○	●							○						
SOIL AMENDMENT	Bone / blood meal										●									●				
SOIL AMENDMENT	M5/ Woodchip / Bark Mulches	●	●			●						○				○								
SOIL AMENDMENT	M6/ Sawdust Mulches	●	●	●	●	●						●				○	○							
SOIL AMENDMENT	M7/ Hydrogels		●		●	●									●									
SOIL AMENDMENT	M8/ Perlite/ Vermiculite	○	●		●	●									○									
SOIL AMENDMENT	Gypsum lime	●		◐	◐	○	●				◐													
SOIL AMENDMENT	M9/ Lime / Calcite	◐		◐	◐	○		●			◐													
SOIL AMENDMENT	M10/ Chitosan					●							●	●	●									
ROOT INVIGORATION	M11/ Vertical Mulching		◐			◐																◐	○	
ROOT INVIGORATION	M12/ Air Spading		●			●									○							○		●
ROOT INVIGORATION	M13/ Air Vacuum		●			●									○									
ROOT INVIGORATION	M14/ Hydro Excavation		●			●									●							○	◐	

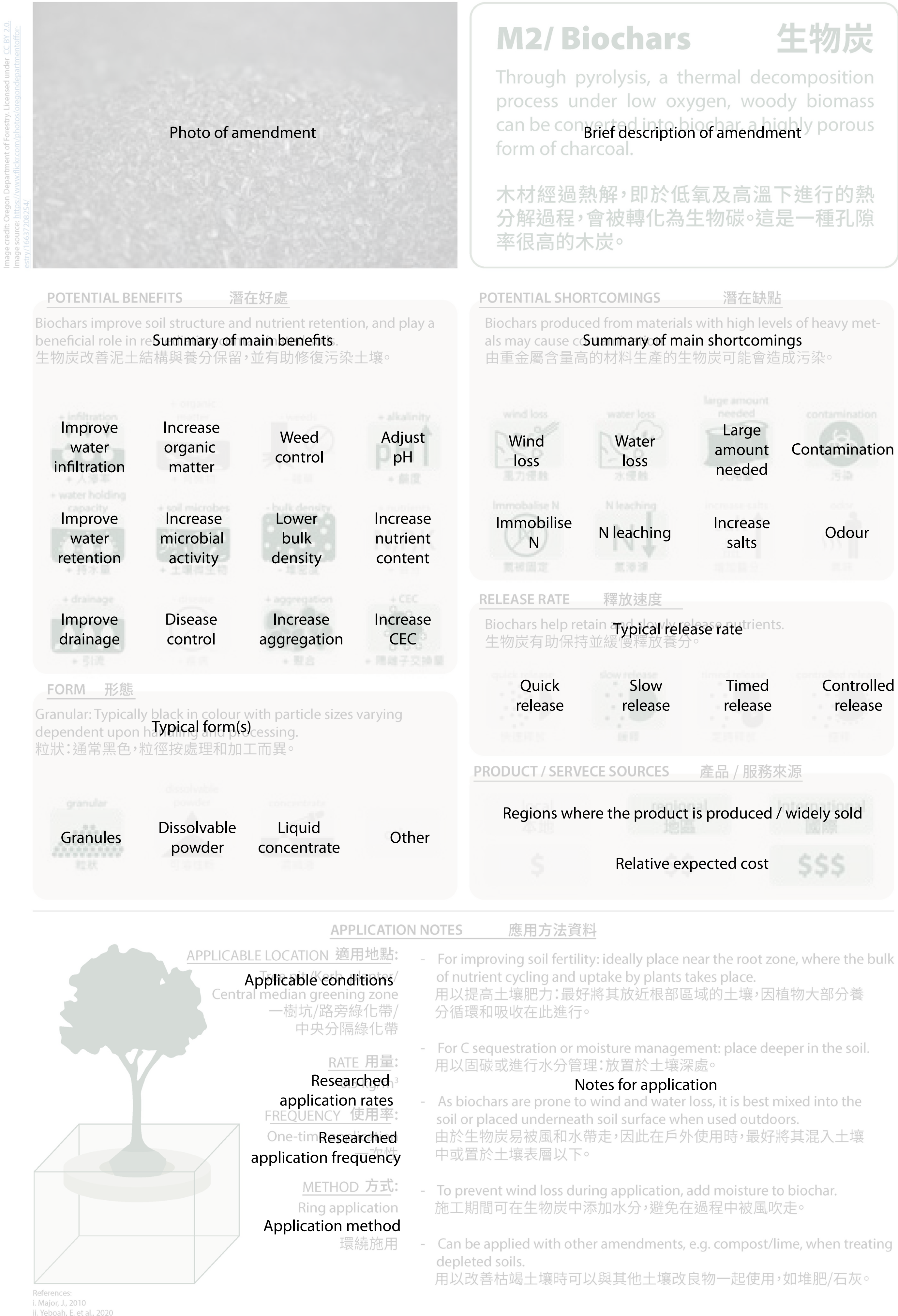
● = strong effect ◐ = moderate effect ○ = weak effect * may damage roots and utilities ** creates noise / raises dust



APPX A - INFOSHEETS

This section contains information on the benefits, shortcomings and basic application notes on different recommended soil improvement measures.

HOW TO READ THE INFOSHEET



ORGANIC AMENDMENT 有機改良物

M1/ Peat Moss 泥炭土

Peat moss is the product created from organic matters submerged and slowly decomposed in bogs. It is typically formed from sphagnum moss and other plants.

泥炭土是浸沒在沼澤中並緩慢分解的有機物，通常由泥炭蘚和其他植物形成。

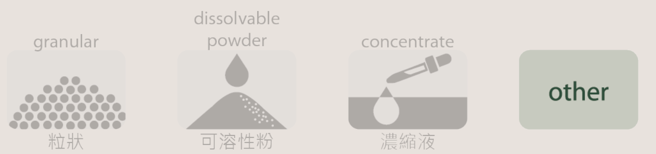
POTENTIAL BENEFITS 潛在好處

Good quality peat moss is clean and sterile, lightweight, and retains water while preventing compaction.
優質的泥炭土乾淨、無菌、輕身，有助防止土壤緻密同時保留水分。

FORM 形態

Peat moss appears as a dark brown fibrous material, similar to soil.

泥炭土為暗褐色的纖維狀物質，形似泥土。



POTENTIAL SHORTCOMINGS 潛在缺點

Peat moss can be difficult to re-wet once dry, and has received criticism for being unsustainable. [i]
泥炭土一旦乾透比較難再潤濕，而其不可持續的生產特性亦備受批評。

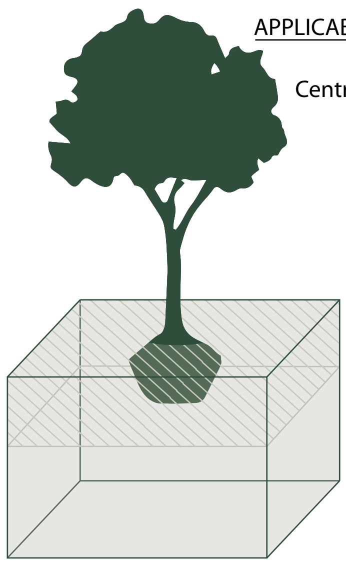
RELEASE RATE 釋放速度

Peat moss decomposes very slowly.
泥炭土的分解速度非常緩慢。

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Tree pit /Kerb planter/ Central median greening zone
一樹坑/路旁綠化帶/ 中央分隔綠化帶

RATE 用量:
a 5-8 cm layer

FREQUENCY 使用率:
Once every few years
數年一次

METHOD 方式:
Mix into top 300mm
混入泥土表層 300mm

- Peat moss is generally recommended more for seed-starting and container use rather than as landscape amendment.
  通常建議將泥炭土用於種子起苗和盆栽，多於作為園景改良劑。
- To prevent wind loss during application, pre-soak peat moss in water.
  為防在施工過程中被風吹走，可將泥炭土預先浸泡在水中。
- For plants that are adapted to alkaline soil, composts are a possible alternative to acidic peat moss.
  如果植物適應鹼性土壤，可考慮以堆肥替代泥酸性的炭土。
- Can be applied with other amendments, e.g. compost, when treating depleted soils.
  用於改善枯竭的土壤時可以與其他土壤改良物例如堆肥一起使用。

References:
i. Higgings, 2017.
ii. Trees.com, 2021
iii. Grow Organic, 2018

M2/ Biochars 生物炭

Through pyrolysis, a thermal decomposition process under low oxygen, woody biomass can be converted into biochar, a highly porous form of charcoal.

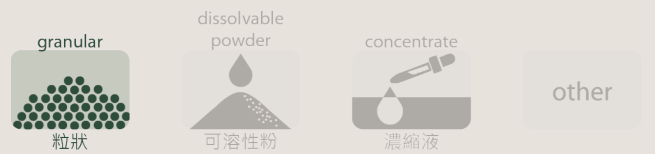
木材經過熱解，即於低氧及高溫下進行的熱分解過程，會轉化為生物碳。這是一種孔隙率很高的木炭。

POTENTIAL BENEFITS 潛在好處

Biochars improve soil structure and nutrient retention, and play a beneficial role in remediating contaminated soils.
生物炭改善泥土結構與養分保留，並有助修復污染土壤。

FORM 形態

Granular: Typically black in colour with particle sizes varying dependent upon handling and processing.
粒狀：通常黑色，粒徑按處理和加工而異。



POTENTIAL SHORTCOMINGS 潛在缺點

Biochars produced from materials with high levels of heavy metals may cause contamination.
由重金屬含量高的材料生產的生物炭可能會造成污染。

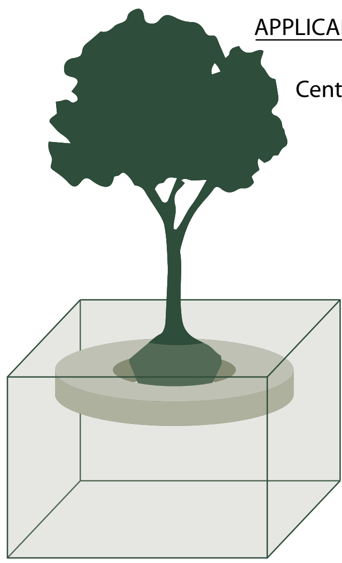
RELEASE RATE 釋放速度

Biochars help retain and slowly release nutrients.
生物炭有助保持並緩慢釋放養分。

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Tree pit /Kerb planter/ Central median greening zone
一樹坑/路旁綠化帶/ 中央分隔綠化帶

RATE 用量:
~0.5 kg/m^3

FREQUENCY 使用率:
One-time application
一次性

METHOD 方式:
Ring application
環繞施用

- For improving soil fertility: ideally place near the root zone, where the bulk of nutrient cycling and uptake by plants takes place.
  用以提高土壤肥力：最好將其放近根部區域的土壤，因植物大部分養分循環和吸收在此進行。
- For C sequestration or moisture management: place deeper in the soil.
  用以固碳或進行水分管理：放置於土壤深處。
- As biochars are prone to wind and water loss, it is best mixed into the soil or placed underneath soil surface when used outdoors.
  由於生物炭易被風和水帶走，因此在戶外使用時，最好將其混入土壤中或置於土壤表層以下。
- To prevent wind loss during application, add moisture to biochar.
  施工期間可在生物炭中添加水分，避免在過程中被風吹走。
- Can be applied with other amendments, e.g. compost/lime, when treating depleted soils.
  用以改善枯竭土壤時可以與其他土壤改良物一起使用，如堆肥/石灰。

References:
i. Major, J., 2010
ii. Yeboah, E. et al., 2020
iii. Biochar currently trialled in Tuen Mun by HK Government. See: HK Government Press Releases. (2020)
iv. Rawat et al., 2019

BIOCHAR 生物炭

M3/ Green Manure 綠肥

Fast growing plants, typically legumes and grasses, are grown and then turned into the soil to build organic matter and nitrogen levels.

快速生長的植物（通常是豆類和草）可以種於樹旁，然後翻進土壤裏，以提升土壤的氮水平和有機物質。

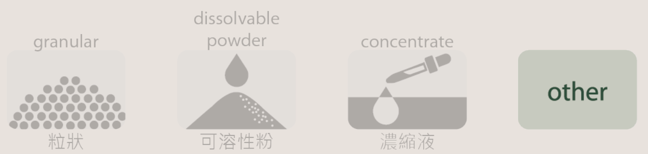
POTENTIAL BENEFITS 潛在好處

Green manures increase biodiversity and improves soil aggregation. When decomposing, it boosts nutrients and organic matter.
綠肥可增加生物多樣性，同時改善土壤的聚合力。分解時，它亦會增加土壤養分和有機物質。

FORM 形態

Typicallly, fast growing annuals are selected.

通常選擇快速生長的年生植物。



POTENTIAL SHORTCOMINGS 潛在缺點

Green manures do not add much organic matter to the soil in the long term.
長遠來說，綠肥不會為土壤添加很多有機物。

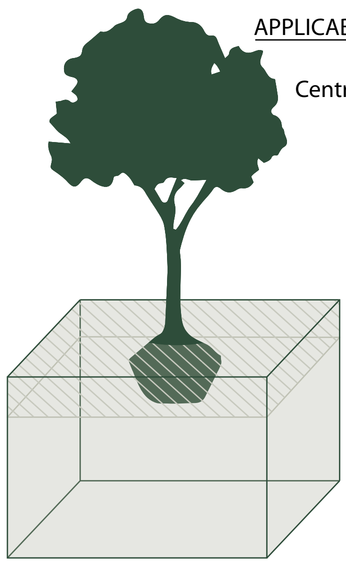
RELEASE RATE 釋放速度

When turned, green manure generally decomposes over 6 weeks.[i]
被翻進土壤的植物常會在6週內分解。[i]

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Tree pit /Kerb planter/ Central median greening zone
樹坑/路旁綠化帶/ 中央分隔綠化帶

RATE 用量:
-

FREQUENCY 使用率:
Seasonally, twice a year
季節性，每年兩次

METHOD 方式:
Mix into top 150mm
混入泥土表面150毫米

- Any nutrient deficiencies (except nitrogen) are best corrected before sowing.[ii]
  播種前建議先糾正任何營養缺乏（氮元素除外）。[ii]
- Example nitrogen-fixing legumes for green mulches: *Chamaecrista mimosoides* (L.), *Desmodium microphyllum* (Thunb.) DC., *Tephrosia candida* DC etc.
  固氮豆科植物示例：山扁豆、小葉三點金、白花鐵富豆等。
- Green mulches can be especially useful in bare soils awaiting tree planting, to control weeds, prevent erosion and improve soil.
  綠肥植物特別在待植樹的裸土上有助於控制雜草、防止水土流失和改善土壤。
- Green mulches are recommended to be harvested and left on soil as mulch or turned into the top 150 mm of soil. This can be done before flowering to retain more nutrient content.
  建議收割綠肥時，將其當作覆蓋物留在土壤表面，或者混入泥土表面150毫米。這在開花前完成可以保留更多的營養成分。

References:
i. Michaels, F., n.d.
ii. Green Harvest, n.d.

M4/ Composts 堆肥

Composting speeds up decomposition of organic matter to produce a variety of composts. Vermicomposts contain greater nutrient profile and microbial activities, an excellent peat substitute.
堆肥過程加速有機物的分解，產生各種堆肥。蚯蚓肥含有特別多的養分和微生物活性，可作優良的泥炭替代品。

POTENTIAL BENEFITS 潛在好處

Composts affect soil structure, water retention and drainage while adding organic matter and nutrients.
堆肥改善泥土結構，增加保水和排水，亦同時添加有機物和養分。

FORM 形態

Composts can look similar to good, rich soil, or can be made into a tea, a dark brown liquid.
堆肥看似優質的肥沃土壤，也可以製成深棕色的液體堆肥茶。

POTENTIAL SHORTCOMINGS 潛在缺點

Composts may turn anaerobic if stored in dry, airtight containers.

如果將堆肥儲存在乾燥及氣密的容器中，則可能出現厭氧情況。

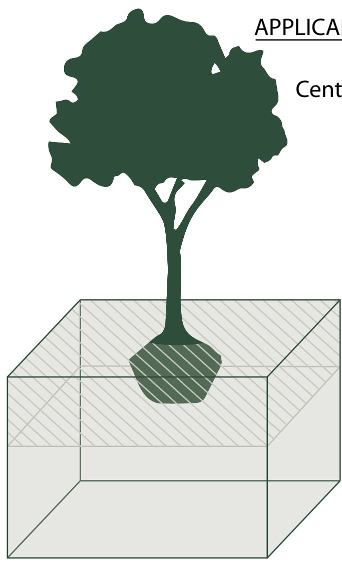
RELEASE RATE 釋放速度

Water gradually dissolves compost particles into the soil.
堆肥的粒子逐漸被水溶解到土壤中。

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Tree pit /Kerb planter/ Central median greening zone
一樹坑/路旁綠化帶/ 中央分隔綠化帶

RATE 用量:
0.5-1 kg/m^2

FREQUENCY 使用率:
At planting
種植時

METHOD 方式:
Mix into top 300mm
混入泥面300毫米

- As a follow-up alternative to chemical fertiliser: Apply solid compost to soil surface and water, mix compost tea into irrigation water, or use diluted compost tea as foliage spray.
  作為化肥的替代品進行追肥：將固體堆肥撒於土壤表面再灌水，或將堆肥茶混入灌溉水中，或稀釋後作葉面噴霧劑使用。
- Compost properties very greatly depending on materials used for composting, application amount should be adjusted accordingly.
  堆肥的性能很大程度上取決於堆肥過程所用的原料，運用時應相應地調整施用量。

References:
i. NYCsanitation, n.d.

ORGANIC FERTILISER 有機肥料

M5/ Woodchip / Bark Mulches 木片、樹皮覆蓋料

Chipped up pieces of wood that are organic and biodegradable can be spread on soil surfaces as mulch.

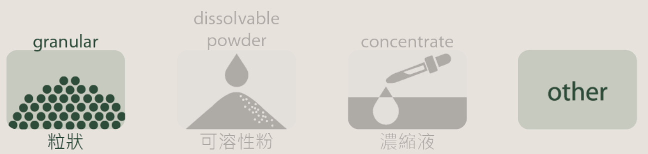
有機、可生物降解的木材經切碎後可以作為覆蓋物散佈在土壤表面。

POTENTIAL BENEFITS 潛在好處

Mulching suppresses weed growth, modifies root zone microclimate and insulates the soil as well as protects tree trunks.
覆蓋物可以抑制雜草的生長、改變根區的微氣候、為土壤隔溫以及保護樹幹。

FORM 形態

Woodchip mulches are often inner wood blocks from trees, while bark mulches are made from the outer coverings of trees.
木片覆蓋物通常是樹木的內部木塊，而樹皮覆蓋物則由樹木的表面製成。



POTENTIAL SHORTCOMINGS 潛在缺點

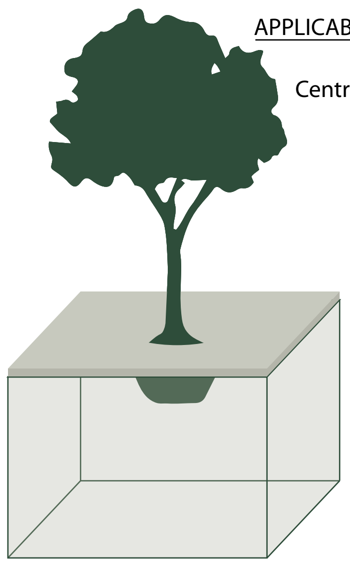
Overmulching can prevent water and air infiltration. It may create breeding sites for insect pests such as biting midges.
覆蓋過度可阻礙水和空氣滲透，也可能成為小螫蚊等害蟲的繁殖地。

DEGRADATION RATE 生物降解速度

Wood mulches decompose over years and need replenishment.
木覆蓋物會經數年分解，並需要補充。

PRODUCT / SERVICE SOURCES 產品 / 服務來源

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Tree pit /Kerb planter/ Central median greening zone
一樹坑/路旁綠化帶/ 中央分隔綠化帶

RATE 用量:
5-8 cm

FREQUENCY 使用率:
Once every few years
數年一次

METHOD 方式:
Surface application
表面放置

- Bark mulches by nature often contain a waxy substance that repels water, thus have lower water holding capacity than woodchip mulch and are more likely to float away in rain.
樹皮覆蓋物通常自然含有疏水的蠟狀物質，因此比木片覆蓋物具有較低的持水量，並且更有可能在雨水中漂走。
- Woodchip mulches retain more water. They are generally easier to source and cheaper.
木片覆蓋物可保留更多水分。它們通常更容易採購且比較便宜。
- Keep mulch away from trunks to prevent causing rot.
覆蓋物需與樹幹底部保持距離，以免引起腐爛。

Reference standard drawing(s): HYD Standard Drawings H5145, H5146
考標準圖：路政署標準圖則 H5145，H5146

References:
i. Iles J.K. and Dosmann M.S., 1999
ii. Chalker-Scott L., 2007
iii. Dahiya R. et al., 2007
iv. Shi L.et al., 2010
v. NYCsanitation, n.d.

M6/ Sawdust Mulches 鋸末覆蓋料

Powdery particles of wood that are organic and biodegradable can be spread on soil surfaces as mulch.

有機、可生物降解的沫狀木屑可以作為覆蓋物散佈在土壤表面。

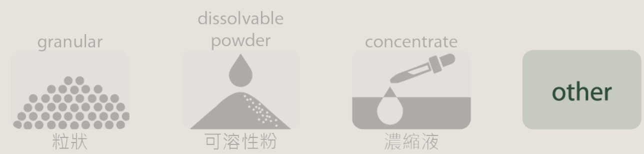
POTENTIAL BENEFITS 潛在好處

Mulching suppresses weed growth, modifies root zone microclimate and insulates the soil as well as protects tree trunks.
覆蓋物可以抑制雜草的生長、改變根區的微氣候、為土壤隔溫以及保護樹幹。

FORM 形態

Light brown / yellow powder in the form of shavings or flakes.

淺褐色/黃色粉末，呈刨花或薄片狀。



POTENTIAL SHORTCOMINGS 潛在缺點

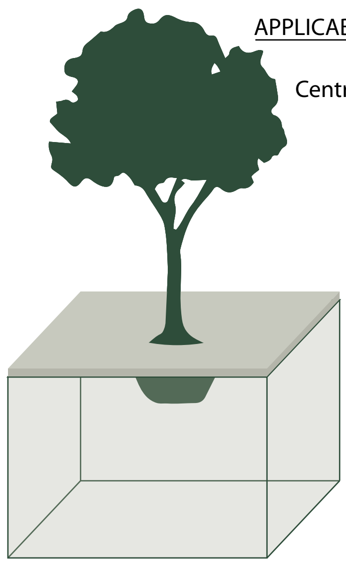
Overmulching can prevent water and air infiltration. It may create breeding sites for insect pests such as biting midges.
覆蓋過度可阻礙水和空氣滲透，也可能造成小螫蚊等害蟲的繁殖地。

DEGRADATION RATE 生物降解速度

Sawdust mulches decompose over years and need replenishment.
木覆蓋物會經數年分解，並需要補充。

PRODUCT / SERVICE SOURCES 產品 / 服務來源

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Tree pit /Kerb planter/ Central median greening zone
一樹坑/路旁綠化帶/ 中央分隔綠化帶

RATE 用量:
5-8 cm

FREQUENCY 使用率:
Yearly
每年一次

METHOD 方式:
Surface application
表面放置

- Sawdust can decompose quickly and compact, so replenishment and fluffing is recommended each year.
木屑分解速度比較快且容易被壓實，因此建議每年補充木屑和翻鬆泥土。
- Keep mulch away from trunks to prevent causing rot.
覆蓋物需與樹幹底部保持距離，以免使樹幹底部腐爛。

Reference standard drawing(s): HYD Standard Drawings H5145, H5146
考標準圖：路政署標準圖則 H5145，H5146

References:
i. Iles J.K. and Dosmann M.S., 1999
ii. Chalker-Scott L., 2007
iii. Dahiya et al., 2007
iv. Shi L.et al., 2010

MULCH 覆蓋物

M7/ Hydrogels 水凝膠

Hydrogels are formed from three-dimensional networks of crosslinked polymer gels developed as an additive to soil to combat drought.

水凝膠是為抗旱而研發的土壤添加劑，是由三維網絡形成的交聯聚合物凝膠。

POTENTIAL BENEFITS 潛在好處

Hydrogels can absorb and retain water for plant use, though they do not work when water is far from sufficient.
水凝膠可以吸收和保留水分以供植物使用，但當極度缺水時不會起作用。

+ infiltration / + 入滲率
+ organic matter / + 有機物
- weeds / - 雜草
+ alkalinity / + 碱度
+ water holding capacity / + 持水量
+ soil microbes / + 土壤微生物
- bulk density / - 堆密度
+ nutrients / + 養分
+ drainage / + 引流
- disease / - 疾病
+ aggregation / + 聚合
+ CEC / + 陽離子交換量

POTENTIAL SHORTCOMINGS 潛在缺點

Traditional polyacrylate hydrogels which do not biodegrade readily are considered potential soil pollutants.
不輕易生物降解的傳統聚丙烯酸酯水凝膠被認有可能造成土壤污染。

wind loss / 風力侵蝕
water loss / 水侵蝕
large amount needed / 大用量
contamination / 污染
Immobalise N / 氮被固定
N leaching / 氮滲濾
increase salts / 增加鹽分
odour / 氣味

RELEASE RATE 釋放速度

Hydrogels can entrap and release fertilisers in a controlled way.
水凝膠可以保存並以持續控制的方式釋放肥料。

quick release / 快速釋放
slow release / 緩釋
timed release / 定時釋放
controlled release / 控釋

FORM 形態

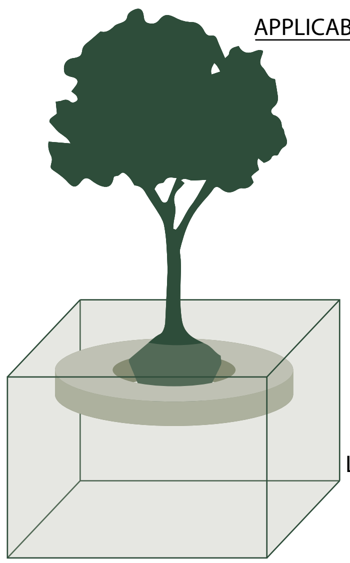
Hydrogels can come as granules that swell after absorbing water, or solutions that can be sprayed onto topsoil.
水凝膠可以造成遇水膨脹的顆粒狀，也可以製成噴在土壤表面的溶液。

granular / 粒狀
dissolvable powder / 可溶性粉
concentrate / 濃縮液
other

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Areas prone to drought, especially in sandy soils [i]
容易乾旱的地區
特別適用於沙質土壤 [i]

RATE 用量:
2 kg/m²

FREQUENCY 使用率:
One-time / as needed
一次性 / 需要時

METHOD 方式:
Granules: Ring application [ii]
Liquid: Spray on soil surface
顆粒：環繞施用 [ii]
液體：噴灑在土壤表面

- To prevent bare root dessication: root dips made with dry hydrogel of particle sizes 0.2-0.3 mm can be used to coat roots and prevent drying while transplanting.[ii]
用以防止裸露的根部乾燥：可用粒徑約 0.2-0.3 mm 的水凝膠製成的根部浸膠在移植樹木時用於覆蓋根部，以防止乾燥。[ii]
- To amend planting soil : mix larger hydrogel granules near root zone. [ii]
用以修改土壤：於根部附近混合較大粒徑的水凝膠顆粒。[ii]
- To improve soil surface resistance to erosion: spray hydrogel solution onto initially wetted soil, followed by drying. [iii,iv]
用以提高土壤表面的抗侵蝕能力：將水凝膠溶液噴灑到潤濕的土壤上然後讓其風乾。[iii,iv]

References:
i. Orikiriza, L.J.B. et al., 2013
ii. Hasse, D. & Landis, T.D., 2012
iii. Reddy, J. 2018
iv. Mandal, Uttam & K.L. et al., 2015

HYDROGEL 水凝膠

M8/ Expanded Perlite/ Exfoliated Vermiculite 珍珠岩/ 蛭石

Lightweight minerals are often formed from expanded rock which have low density and high porosity.

輕質礦物通常由密度低，孔隙率高的膨脹岩石形成。

POTENTIAL BENEFITS 潛在好處

Lightweight minerals modify soil texture, increasing soil aeration and drainage.
輕質礦物會改變土壤質地、增加土壤通氣和排水能力。

+ infiltration / + 入滲率
+ organic matter / + 有機物
- weeds / - 雜草
+ alkalinity / + 碱度
+ water holding capacity / + 持水量
+ soil microbes / + 土壤微生物
- bulk density / - 堆密度
+ nutrients / + 養分
+ drainage / + 引流
- disease / - 疾病
+ aggregation / + 聚合
+ CEC / + 陽離子交換量

POTENTIAL SHORTCOMINGS 潛在缺點

Lightweight minerals are prone to water and wind loss.
Contaminated vermiculite can cause adverse health effects.
輕質礦物容易流失。被污染的蛭石可對健康造成不良影響。

wind loss / 風力侵蝕
water loss / 水侵蝕
large amount needed / 大用量
contamination / 污染
Immobalise N / 氮被固定
N leaching / 氮滲濾
increase salts / 增加鹽分
odour / 氣味

RELEASE RATE 釋放速度

quick release / 快速釋放
slow release / 緩釋
timed release / 定時釋放
controlled release / 控釋

FORM 形態

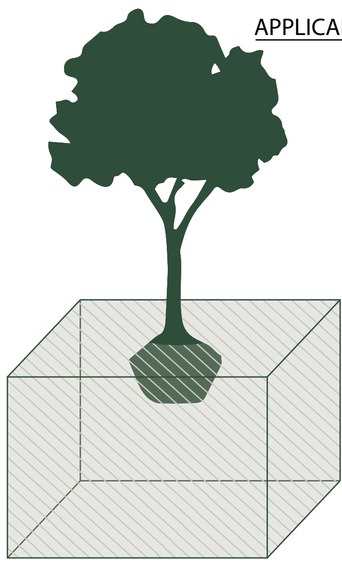
Perlite appears like hard styrofoam, while vermiculite is brown with a layered structure. Particle size for both are 5-10 mm or more.
珍珠岩形似堅硬的泡沫塑料，而蛭石是棕色，具有分層結構。兩者的粒徑均為 5-10 mm 或以上。

granular / 粒狀
dissolvable powder / 可溶性粉
concentrate / 濃縮液
other

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Roof planters, pot planters
屋頂花壇
盆栽

RATE 用量:
Varies 按情況

FREQUENCY 使用率:
One-time application
一次性

METHOD 方式:
Mix throughout soil
與土壤混合

- For more drainage and aeration but weaker water retention effect: use (a larger proportion of) expanded perlite. [i]
若用於增加排水和曝氣多於增加儲水效果：使用 (佔更大比例的) 膨脹珍珠岩。[i]
- For plants that require damp soil: use (a larger proportion of) exfoliated vermiculite, which retains more water.[i]
若用於需要更多水分的植物：使用 (較大比例的) 層脹蛭石增加儲水量。[i]
- While health effects from exposure to perlite and vermiculite dusts are found to be minimal, goggles and masks are recommended when working with them to prevent respiratory and eye irritation.[iii, iv]
雖然接觸珍珠岩和層脹蛭石粉對健康不造成任何嚴重影響，使用時建議佩戴護目鏡和口罩以避免刺激呼吸道和眼睛。[iii, iv]

References:
i. Ramsey, K., 2015.
ii. Buechel, T., 2021.
iii. Maxim, L. D. et al., 2014.
iv. Gibson, M. & Erin, M.R., n.d.

INORGANIC AMENDMENT 無機改良物

M9/ Lime / Calcite 石膏粉/方解石

Agricultural lime is made from limestone, a carbonate sedimentary rock composed mostly of the minerals calcite and aragonite.

農業石灰是由石灰石製成的，石灰石是一種碳酸鹽沉積岩，主要由方解石和文石等礦物組成。

POTENTIAL BENEFITS 潛在好處

Liming agents modifies soil texture and neutralises acidity, and supplies some calcium. Dolomitic lime releases some magnesium.
石灰劑可改變土壤質地及中和酸度，並提供一些鈣質。含鎂石灰更會釋放一些鎂質。

- + infiltration / + 入滲率
- + organic matter / + 有機物
- - weeds / - 雜草
- **+ alkalinity / + 鹼度**
- **+ water holding capacity / + 持水量**
- + soil microbes / + 土壤微生物
- - bulk density / - 堆密度
- + nutrients / + 養分
- **+ drainage / + 引流**
- - disease / - 疾病
- **+ aggregation / + 聚合**
- + CEC / + 陽離子交換量

POTENTIAL SHORTCOMINGS 潛在缺點

Liming dust may cause respiratory tract irritation.

塵土粉塵有機會刺激呼吸道。

- **wind loss / 風力侵蝕**
- **water loss / 水侵蝕**
- large amount needed / 大用量
- contamination / 污染
- Immobalise N / 氮被固定
- N leaching / 氮滲濾
- increase salts / 增加鹽分
- odour / 氣味

RELEASE RATE 釋放速度

The rate of release depends on particle size.
釋放率取決於粒徑。

- quick release / 快速釋放
- **slow release / 緩釋**
- timed release / 定時釋放
- controlled release / 控釋

FORM 形態

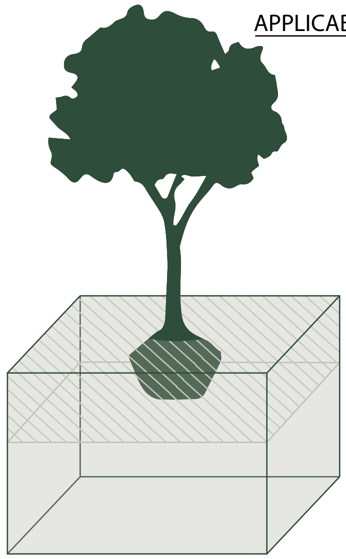
Lime can come in powder, (powder-encapslating) pill or granule form.
石灰可以製成粉狀，丸狀或顆粒狀。

- **granular / 粒狀**
- **dissolvable powder / 可溶性粉**
- concentrate / 濃縮液
- other

PRODUCT / SERVICE SOURCES 產品 / 服務來源

- **local 本地**
- **regional 地區**
- International 國際
- $
- $$
- **$$$**

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
Acidic soils with high proportion of DG
含有高比例風化花崗岩的酸性土壤

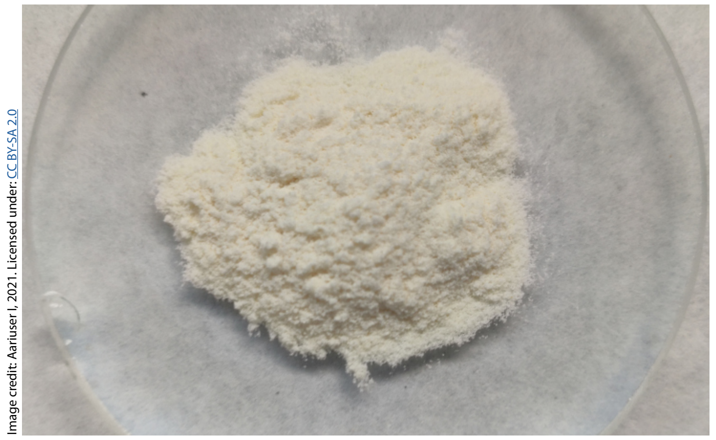
RATE 用量:
0.2~2 kg/m²

FREQUENCY 使用率:
Varies
按情況

METHOD 方式:
mix in to top 300 mm of soil
混入泥土表層300mm

- Dolomitic lime can be used where soil is also deficient in magnesium, though liming is not a replacement for fertiliser.
若土壤同時缺乏鎂質可以使用含鎂石灰，但石灰仍不能完全代替肥料。
- To determine how much lime to apply when pH of soil is noted to be overly low, the SMP lime requirement test is recommended. [iii]
當土壤的pH值過低時建議進行SMP石灰要求測試以確定石灰用量。[iii]
- Goggles and masks are recommended when working to prevent respiratory and eye irritation.
為了預防呼吸和眼睛受到刺激，運用時建議佩戴護目鏡和口罩。

References:
i. Jason. 2014.
ii. Ball, J. 2002.
iii. Marx, E.S. & Hart, J. Stevens, R. G., 1999.



M10/ Chitosan 殼聚醣

Chitosan is a polysaccharide derived from shells of shrimp and other crustaceans with a wide range of commercial and biomedical uses.

殼聚醣是由蝦殼和其他甲殼類動物殼製造的多醣，具有廣泛的商業和生物醫學用途。

POTENTIAL BENEFITS 潛在好處

Chitosan is a biopesticide against fungal and insect infections. It stimules growth, abiotic stress tolerance and pathogen resistance.
殼聚醣是一種針對真菌和昆蟲感染的生物農藥。它刺激植物生長、增強非生物耐逆性和病原體抵抗力。

- + infiltration / + 入滲率
- + organic matter / + 有機物
- - weeds / - 雜草
- + alkalinity / + 鹼度
- + water holding capacity / + 持水量
- + soil microbes / + 土壤微生物
- - bulk density / - 堆密度
- + nutrients / + 養分
- + drainage / + 引流
- **- disease / - 疾病**
- + aggregation / + 聚合
- + CEC / + 陽離子交換量

POTENTIAL SHORTCOMINGS 潛在缺點

- wind loss / 風力侵蝕
- water loss / 水侵蝕
- large amount needed / 大用量
- contamination / 污染
- Immobalise N / 氮被固定
- N leaching / 氮滲濾
- increase salts / 增加鹽分
- odour / 氣味

RELEASE RATE 釋放速度

Observed to degrade more quickly in silty soil than in sandy soil. [iv]
殼聚醣的降解速度在粉質土壤中比在沙質土壤中更快。[iv]

- quick release / 快速釋放
- slow release / 緩釋
- timed release / 定時釋放
- controlled release / 控釋

FORM 形態

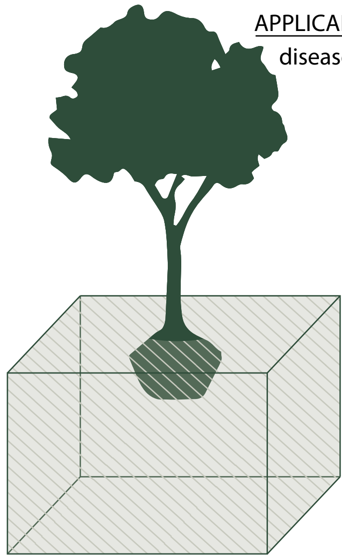
呈白色或微黃色粉末。亦可能以液體溶液的形式售賣。
White or yellowish powder. May also be sold as liquid solutions.

- granular / 粒狀
- dissolvable powder / 可溶性粉
- concentrate / 濃縮液
- **other**

PRODUCT / SERVICE SOURCES 產品 / 服務來源

- local 本地
- **regional 地區**
- **International 國際**
- $
- $$
- **$$$**

APPLICATION NOTES 應用方法資料



APPLICABLE LOCATION 適用地點:
disease-prone / diseased plants; bioremediation locations
易病/患病植物;
生物修復地點

RATE 用量:
1 L/m³ [ii]

FREQUENCY 使用率:
At planting / as needed
種植時 / 需要時

METHOD 方式:
Mix throughout soil
與土壤混合

- Chitosan is noted to increase plant absorption of essential minerals, thus it is also proposed that it would help bioremediation planting take up higher concentrations of toxic elements. [i]
殼聚醣被認為會增加植物對必需礦物質的吸收，因此也有人認為殼聚醣有助於生物修復種植吸收更高濃度的有毒元素。
- As a basic soil amendment: mix into planting soil.
作為基本土壤改良劑：混入種植土壤中。
- As a follow-up additive: spray a solution on the leaves or apply with irrigation, as advised by provider.
作為後續添加劑：在葉子上噴灑溶液或根據供應方建議進行灌溉。

Reference:
i. Orzali, L. et al.,. 2017.
ii. EZ-Grow Chitosan, n.d.
iii. Maluin, F. N., & Hussein, M. Z., 2020
iv. Sawaguchi, A. et al. 2015.

INORGANIC AMENDMENT 無機改良物

Image credit: Texas A&M Forest Service, unspecified

M11/ Vertical Mulching 垂直覆蓋

Vertical mulching is a root-zone treatment technique carried out by digging vertical trenches into the soil then placing mulches like straw, corn cobs, and grass clippings in them.

垂直覆蓋是一種根域處理技術。先在土壤中挖掘垂直溝槽，然後在其中放置秸稈、玉米芯和草屑等覆蓋物。

POTENTIAL BENEFITS 潛在好處

Vertical mulching can be used to decompact soil and control erosion with minimal disturbance to other plants in shared soil.
垂直覆蓋能在對附近的植物造成最小干擾的情況下增加緻密土壤的透氣和透水度，並控制泥土流失。

POTENTIAL SHORTCOMINGS 潛在缺點

There is a limited area of effect and risk of root damage which may be minimised by using pneumatic technology.
作用範圍有限，並且可能傷害根部。這可以通過使用氣動技術將根部受損的風險降至最低。

EQUIPMENT NEEDED 需要工具

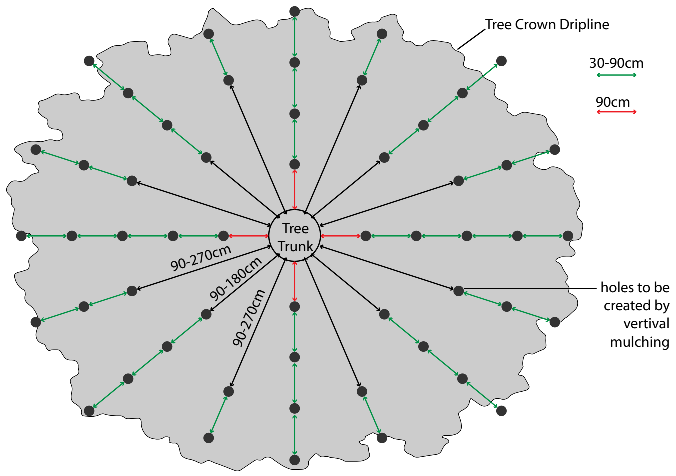
- Electric / gasoline powered drill or other vertical mulching tool
  電動/汽油動電力鑽或其他垂直覆蓋工具
- Desired mulch / amendment material
  所需的覆蓋物/土壤改良物
- ⚠ Suitable personal protective equipment (PPE)*
  合適的個人防護設備*

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

*Please refer to 請參考: Safety Handbook for Construction Site Workers (Labour Department) 地盤工友安全手冊（勞工處）& Guidelines on Arboriculture Occupational Safety and Health (Development Bureau) 樹藝工作的職業安全及健康指引（發展局）

APPLICATION NOTES 應用方法資料



⚠ It is recommended to consult an expert before excavation to avoid damaging tree roots.
建議在開挖前諮詢專家以免損壞樹根。

- For nutrient deficient soils: Trenches can be filled with composts e.g. vermicompost.
  針對營養不足的土壤：可以加入堆肥，如蚯蚓肥。
- To improve air and water permeability: Trenches can be filled with amendments that increase soil porosity e.g. expanded perlite and exfoliated vermiculite.
  改善透氣和透水度：可以加入增加土壤孔隙度的土壤改善物，例如珍珠岩或蛭石。

APPLICABLE LOCATION 適用地點:
Large tree pits/kerb planters open to foot traffic
人流量大的種植區

FREQUENCY 使用率:
once every 2-3 years, as needed
按需要，可每2-3年一次

METHOD 方式:
drilling 2-5 cm diameter holes, 20-25 cm deep
鑽2-5厘米寬，20-25厘米深的孔

TIMING 適用時間:
Spring / fall
春天、秋天

Suggested vertical mulching pattern image modified from: Texas A&M Forest Service
Image source: Technical Tree Solutions: Vertical Mulching / Composting

Image credit: AirSpade, 2021

M12/ Air Spading 空氣噴射開挖

Air spading is a pneumatic technology which has become widely employed in the arboricultural industry as a nondestructive diagnostic and excavation tool for tree roots.

空氣鏟是一種氣動技術，已廣泛作為無損樹木的診斷和挖掘工具，並應用於樹木栽培行業。

POTENTIAL BENEFITS 潛在好處

Air spading is a less invasive way of breaking up soil from tree bases. It is especially useful for transplanting trees.
空氣鏟是一種侵入性較小的，用以移除樹根上土壤的方法。它對於移植樹木特別有用。

POTENTIAL SHORTCOMINGS 潛在缺點

There are concerns about noise and dirt blown up by the air spade, a nuisance to the operator and nearby residents.
空氣鏟吹起的泥土和造成的噪音可能對操作員和附近居民造成滋擾。

EQUIPMENT NEEDED 需要工具

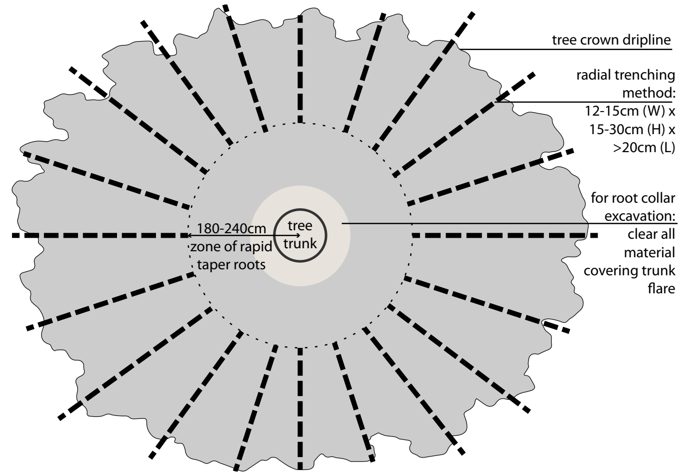
- Compressed air-powered tool (e.g. air spade) & air compressor
  壓縮氣動工具（例如氣鏟）及空氣壓縮機
- Desired replacement soil / soil amendment (optional)
  所需的替代土壤/土壤改良物（如有需要）
- ⚠ Suitable PPE against dust, noise and flying debris*
  防止噪音、灰塵和飛散的碎片的個人防護設備*

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

*Please refer to 請參考: Safety Handbook for Construction Site Workers (Labour Department) 地盤工友安全手冊（勞工處）& Guidelines on Arboriculture Occupational Safety and Health (Development Bureau) 樹藝工作的職業安全及健康指引（發展局）

APPLICATION NOTES 應用方法資料



⚠ It is recommended to consult an expert before excavation to avoid damaging tree roots or causing collapse.
建議在開挖前諮詢專家以免損壞樹根或導致倒塌。

- To expose buried root flare / girdling roots: Excavate root collar. Root pruning to be carried out by arborist as needed.
  以暴露根頸: 圍繞根頸開挖。如需要可由樹藝師進行根部修剪。
- To decompact soil: Carry out vertical mulching (see p.A-xiii) or radial trenching with air spade . Amendments can be applied and mixed into loosened soil, then 5-10cm of mulch applied.
  以減低土壤壓實: 使用工具進行垂直覆蓋（請參閱第xi頁）或徑向挖溝. 開挖後，可以在疏鬆的土壤上施用土壤改良劑並混合到其中，然後蓋上5-10厘米的覆蓋層。
- To replace soil: Working on one section at a time, remove a portion of soil and immediately replace with desired soil. Keep exposed roots moist by misting or other methods.[i]
  替換土壤：去除一部分土壤，然後立即用所需的土壤替換。可使用噴霧或其他方法使露出的根部保持濕潤。[i]
- Other possible uses: to safely extract and transplant trees, or preemptively expose and prune roots before construction work.
  其他用途：安全提取和移植樹木，或在施工前暴露根部進行修剪。
- Do not use under heavy rain and when soil is too wet or too dry. Pre-wetting dry soil can improve excavation efficiency.
  不宜在大雨或土壤太濕或太乾的情況下使用，可預先濕潤乾燥的土壤提高開挖效率。
- It is suggested to wrap tree trunks to prevent injury.
  可以在操作過程中將樹幹包裹起來，以免造成傷害。

APPLICABLE LOCATION 適用地點:
Flush tree pits/kerb planters open to foot traffic; girdling roots
人流量大的種植區; 盤根

FREQUENCY 使用率:
once a year / as needed [i]
每年一次/按需要 [i]

METHOD 方式:
Root collar excavation / radial trenching / vertical mulching
根頸開挖/徑向開溝/垂直覆蓋

TIMING 適用時間:
Spring / fall
春天、秋天

References:
i. Urban, J., 2008.

ROOT INVIGORATION 根部開挖

Image credit: AirSpade, 2021

M13/ Air Vacuum 氣動抽吸式開挖

This pneumatic technology requires the operator to use the vacuum wand or other methods to mechanically break up soil to be vacuumed up.

這項氣動技術需要操作員使用真空棒弄碎土壤，讓機器吸入泥塊。

POTENTIAL BENEFITS 潛在好處

Air vacuum excavation allows excavated material to be stored and reused, minimising dust generated and need for disposal.
抽吸式開挖出來的的物料可以存儲和重複使用，能減低產生的灰塵和無需處理廢物。

POTENTIAL SHORTCOMINGS 潛在缺點

Air vacuums also generate noise though dust is minimal. The tool itself has lower digging power.
真空吸塵器製造的灰塵很少，但仍會產生噪音。該工具亦具有較低的挖掘力。

EQUIPMENT NEEDED 需要工具

- Compressed air-powered tool (e.g. air spade) & air compressor
  壓縮氣動工具 (例如氣鏟) 及空氣壓縮機
- Desired replacement soil / soil amendment (optional)
  所需的替代土壤/土壤改良物 (如有需要)

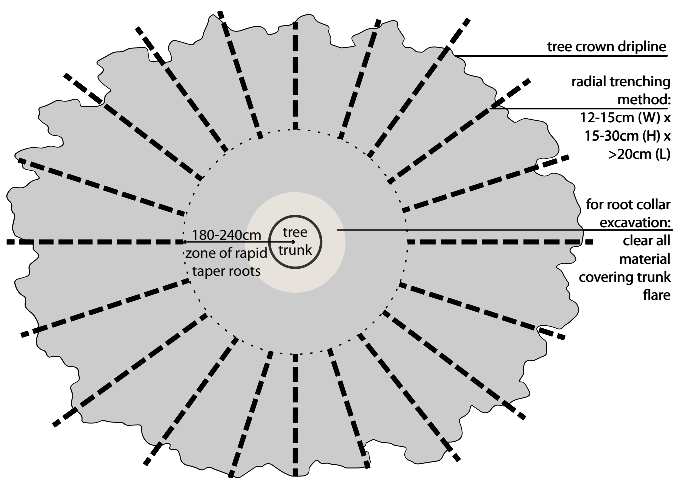
⚠ Suitable PPE against dust, noise and flying debris*
防止噪音、灰塵和飛散的碎片的個人防護設備*

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
$	$$	$$$

*Please refer to 請參考: Safety Handbook for Construction Site Workers (Labour Department) 地盤工友安全手冊 (勞工處) & Guidelines on Arboriculture Occupational Safety and Health (Development Bureau) 樹藝工作的職業安全及健康指引 (發展局)

APPLICATION NOTES 應用方法資料



⚠ It is recommended to consult an expert before excavation to avoid damaging tree roots or causing collapse.
建議在開挖前諮詢專家以免損壞樹根或導致倒塌。

- More effective for looser materials e.g. dirt, sand, gravel etc. or sludge/slurry materials. [i]
  用於較鬆散的物料更有效，例如 污垢，沙子，礫石等；或污泥/泥漿物料。[i]
- An air spade may be used in combination with air vacuum to break up and reuse harder, compact soils.
  可以將氣鏟與真空結合使用，以分解和重用較硬和緻密的土壤。
- It is suggested to wrap tree trunks during operation to prevent injury.
  可以在操作過程中將樹幹包裹起來，以免造成傷害。
- After airspading, soil amendment can mix with collected soil to be reused as backfill, then a 5-10 cm layer of mulch applied.
  噴水後，可以將土壤改良劑與收集的土壤混合，以用作回填，然後施加5-10厘米的覆蓋層。

APPLICABLE LOCATION 適用地點:
Large tree pits/kerb planters open to foot traffic; girdling roots
人流量大的大型樹穴或石壆花槽旁; 有盤根症狀的樹木

TIMING 適用時間:
Spring / fall
春天、秋天

FREQUENCY 使用率:
once a years, as needed
按需要，可每年一次

METHOD 方式:
Root collar excavation / radial trenching / vertical mulching
根頸開挖/徑向開溝/垂直覆蓋

References:
i. Airspade, n.d.

Image credit: Ditch Witch, 2008

M14/ Hydro Excavation 水力開挖

In hydro-excavation, pressurized water is injected into soil. The resulting slurry is sucked up by a vacuum operated by a fan or blower.

在水力開挖的過程中，加壓水被注入土壤中。風扇或鼓風機操作機器將產生的漿液吸起。

POTENTIAL BENEFITS 潛在好處

Pressurised water is more efficient than air excavation in heavy, clayey or rocky soils. It generates minimal dust.
在厚重、黏土或多岩石的土壤中，加壓水比空氣挖掘更有效。它產生的灰塵很少。

POTENTIAL SHORTCOMINGS 潛在缺點

A water source is needed, and the mud slurry cannot be used to backfill the hole. High water pressure may damage fragile utilities.
水裏開挖需要水源，並且泥漿不能重用於回填。高水壓有機會損壞脆弱的管綫。

EQUIPMENT NEEDED 需要工具

- Hydro-excavation truck
  水力開挖車
- Desired replacement soil / soil amendment (optional)
  所需的替代土壤/土壤改良物 (如有需要)

⚠ Suitable PPE against dust, noise and flying debris*
防止噪音、灰塵和飛散的碎片的個人防護設備*

PRODUCT / SERVICE SOURCES 產品 / 服務來源

local 本地	regional 地區	International 國際
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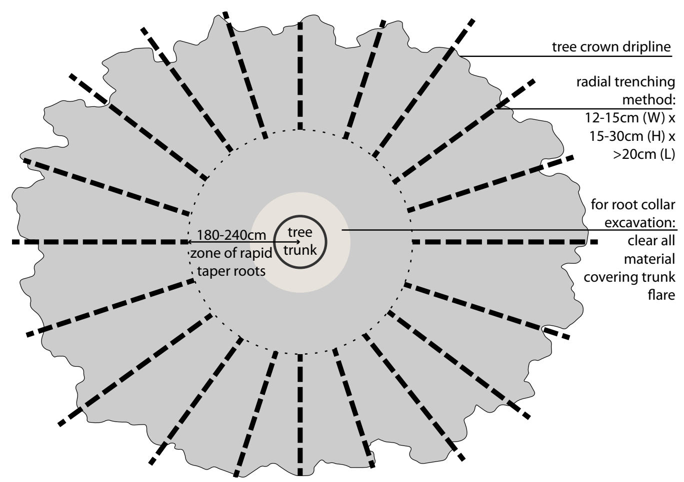
APPLICATION NOTES 應用方法資料



⚠ It is recommended to consult an expert before excavation to avoid damaging tree roots or causing collapse.
建議在開挖前諮詢專家以免損壞樹根或導致倒塌。

- Most effective in extremely compacted, fine grained soil, and for removing large amount of material. [i]
  在非常壓實的細粒土壤中以及需去除大量物料的情況最有效。[i]
- To expose buried root flare / girdling roots: Excavate root collar for diagnosis and root pruning by arborist as needed.
  用以暴露根頸:圍繞根頸開挖並由樹藝師進行診斷及根部修剪。
- To replace soil: Working on one section at a time, remove a portion of soil and immediately replace with desired soil. Keep exposed roots moist by misting or other methods. [i]
  用以替換土壤：去除一部分土壤，然後立即用所需的土壤替換。可使用噴霧或其他方法使暴露出的根部保持濕潤。[i]
- Other possible uses: to safely extract and transplant trees, or preemptively expose and prune roots before construction work.
  其他用途：安全地提取和移植樹木，或在施工前先暴露根部進行修剪。
- Do not use under heavy rain and when soil is too wet or too dry.
  不宜在大雨或土壤太濕或太乾的情況下使用。
- It is suggested to wrap tree trunks to prevent injury.
  可以在操作過程中將樹幹包裹起來，以免造成傷害。

APPLICABLE LOCATION 適用地點:
Large tree pits/kerb planters open to foot traffic; girdling roots
人流量大的大型樹穴或石壆花槽旁; 有盤根症狀的樹木

TIMING 適用時間:
Spring / fall
春天、秋天

FREQUENCY 使用率:
as needed
按需要，可每年一次

METHOD 方式:
Root collar excavation / radial trenching / vertical mulching
根頸開挖/徑向開溝/垂直覆蓋

References:
i. Urban, J., 2008.
ii. Fite, K. & Smiley, T., n.d.

ROOT INVIGORATION 根部開挖

APPX B - SOIL TESTING CHECKLIST FOR LABORATORY TESTS

A checklist may be used after eliminating possible issues from past amendments and self-testing to request a limited number of soil tests from a soil laboratory. They are mostly chemical analyses and may occasionally include physical tests. Microbiological or biological analyses are only occasionally done.

Table 28. Laboratory analyses for various soil parameters.

Soil parameters	Methods	References
Moisture content	Oven drying method	Klute, 1986
Texture	Hydrometer method	
Bulk density	Soil core method and laboratory volumetric and gravimetric analyses	
Particle size distribution (soil texture)	Sieve analysis	
Porosity	Water saturation method or Imbibition method	
Aggregate stability	Wet sieving	
Infiltration rate	Double-ring infiltrometer method (in-situ test)	ASTM, 2018
pH	pH meter	Page et al., 1982
Electrical conductivity / salinity	Conductivity meter	
Organic C	Dichromate oxidation or CHN analyzer	
N (total)	Kjeldahl digestion and colorimetric/electrode determination	
N (extractable)	KCl extraction and colorimetric/electrode determination	
P (total)	Kjeldahl / Nitric acid digestion and colorimetric/electrode determination	
P (extractable)	Olsen or Bray I extraction and colorimetric/electrode determination	
K (total)	Nitric acid digestion and atomic absorption spectrophotometry / flame photometry	
K (extractable)	Ammonium acetate extraction and atomic absorption spectrophotometry / flame photometry	
Cation exchange capacity	Extraction at pH 7 with NH_4OAc or $BaCl_2$ (for acidic soil) and atomic absorption spectrophotometry / inductively coupled plasma spectroscopy	
Other macronutrients (S, Ca, Mg)	Digestion or extraction followed by atomic absorption spectrophotometry / inductively coupled plasma spectroscopy; turbidimetry (for S)	
Micronutrients	Digestion or extraction followed by atomic absorption spectrophotometry / inductively coupled plasma spectroscopy	

REFERENCES

ASTM D3385-18. 2018 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer. ASTM International, West Conshohocken, PA

Klute A. (ed). 1986 Method of Soil Analysis, Part 1, Physical and Mineralogical Methods, Second edition. American Society of Agronomy, Soil Science Society of America and Crop Science Society of America, Madison, Wisconsin, USA

Page A.L., Miller R.H. & Keeney D.R. (eds). 1982 Methods of Soil Analysis. Part 2 Chemical and Microbiological Properties, Second edition. American Society of Agronomy, Soil Science Society of America and Crop Science Society of America, Madison, Wisconsin, USA

APPX C - GLOSSARY

Abiotic factor
A physical, meteorological, geological, or chemical aspect of the environment.

Adsorption
The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surfaces of solids by chemical or physical binding.

Aeration, soil
The process by which air in the soil is replaced by air from the atmosphere. In a well-aerated soil, the soil air is very similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher content of CO_2 and a lower content of O_2 than the atmosphere above the soil. The rate of aeration depends largely on the volume and continuity of air-filled pores within the soil.

Aerobic
(i) Having molecular oxygen as a part of the environment. (ii) Growing only in the presence of molecular oxygen, such as aerobic organisms. (iii) Occurring only in the presence of molecular oxygen (said of chemical or biochemical processes such as aerobic decomposition).

Aggregate
A group of primary soil particles that cohere to each other more strongly than to surrounding particles.

Aggregate stability
A measure of the proportion of the aggregates in a soil which do not easily slake, crumble, or disintegrate.

Aggregation
The process whereby primary soil particles (sand, silt, clay) are bound together, usually by natural forces and substances derived from root exudates and microbial activity.

Air dry
(i) The state of dryness at equilibrium with the water content in the surrounding atmosphere. The actual water content will depend upon the relative humidity and temperature of the surrounding atmosphere. (ii) To allow to reach equilibrium in water content with the surrounding atmosphere.

Anaerobic
(i) The absence of molecular oxygen. (ii) Growing in the absence of molecular oxygen (such as anaerobic bacteria). (iii) Occurring in the absence of molecular oxygen (as a biochemical process).

Anion
An atom or atomic group that is negatively charged because of a gain in electrons.

Anion exchange capacity
The sum of exchangeable anions that a soil can adsorb. Usually expressed as centimoles, or millimoles, of charge per kilogram of soil (or of other adsorbing material such as clay).

Application rate
(i) Weight or volume of a fertiliser, soil amendment or pesticide applied per unit area, (ii) (irrigation) rate at which water is applied per unit area; usually in mm per hour.

Available nutrients
(i) The amount of soil nutrient in chemical forms accessible to plant roots or compounds likely to be convertible to such forms during the growing season. and (ii) The contents of legally designated "available" nutrients in fertilisers determined by specified laboratory procedures which in most states constitute the legal basis for guarantees.

Available water (capacity)
The amount of water released between in situ field capacity and the permanent wilting point (usually estimated by water content at soil matric potential of -1.5 MPa). It is not the portion of water that can be absorbed by plant roots, which is plant specific. See also nonlimiting water range.

Biomass
(i) The total mass of living organisms in a given volume or mass of soil. (ii) The total weight of all organisms in a particular environment. See also microbial biomass.

Bulk density
The mass of dry soil per unit bulk volume.

Bulk volume
The volume, including the solids and the pores, of an arbitrary soil mass. The bulk volume is determined before drying to constant weight at 105°C.

Calcareous soil
Soil containing sufficient free $CaCO_3$ and other carbonates to effervesce visibly or audibly when treated with cold 0.1M HCl. These soils usually contain 10 to almost 1000 g/kg $CaCO_3$ equivalent.

Carbon-nitrogen (C:N) ratio
The ratio of the mass of organic carbon to the mass of organic nitrogen in soil, organic material, plants or microbial cells.

Cation
An atom or atomic group that is positively charged because of a loss in electrons.

Cation exchange
The interchange between a cation in solution and another cation in the boundary layer between the solution and surface of negatively charged material such as clay or organic matter.

Cation exchange capacity (CEC)
The sum of exchangeable bases plus total soil acidity at a specific pH, values, usually 7.0 or 8.0. When acidity is expressed as salt extractable acidity, the cation exchange capacity is called the effective cation exchange capacity (ECEC) because this is considered to be the CEC of the exchanger at the native pH value. It is usually expressed in centimoles of charge per kilogram of exchanger (cmolc/kg) or millimoles of charge per kilogram of exchanger. See also acidity, total.

Chelates
Organic chemicals with two or more functional groups that can bind with metals to form a ring structure. Soil organic matter can form chelate structures with some metals, especially transition metals, but, much metal ion binding in soil organic matter probably does not involve chelation. Artificial chelating compounds are sometimes added to soil to increases the soluble fraction of some metals.

Clay
(i) A soil separate consisting of particles <0.002 mm in equivalent diameter. See also soil separates. (ii) A textural class. See also soil texture. (iii) (In reference to clay mineralogy) A naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when dried or fired. Although clay usually contains phyllosilicates, it may contain other materials that impart plasticity and harden when dried or fired. Associated phases in clay may include materials that do not impart plasticity and organic matter.

Clay loam
A soil textural class. See also soil texture.

Clayey
(i) Texture group consisting of sandy clay, silty clay, and clay soil textures. See also soil texture. (ii) Family particle-size class for soils with 35% or more clay and <35% rock fragments in upper subsoil horizons.

Clod
A compact, coherent mass of soil varying in size, usually produced by ploughing, digging, etc., especially when these operations are performed on soils that are either too wet or too dry and usually formed by compression, or breaking off from a larger unit, as opposed to a building-up action as in aggregation.

Coarse textured
Texture group consisting of sand and loamy sand textures. See also soil texture.

Colloid
A particle, which may be a molecular aggregate, with a diameter of 0.1 to 0.001 µm. Soil clays and soil organic matter are often called soil colloids because they have particle sizes that are within, or approach colloidal dimensions.

Community
All of the organisms that occupy a common habitat and that interact with one another.

Compaction
(i) To unite firmly; the act or process of becoming compact. (ii) (geology) The changing of loose sediment into hard, firm rock. (iii) (soil engineering) The process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density. (iv) (solid waste disposal) The reducing of the bulk of solid waste by rolling and tamping.

Competition
A rivalry between two or more species for a limiting factor in the environment.

Compost
Organic residues or a mixture of organic residues and soil, that have been mixed, piled and moistened, with or without addition of fertiliser and lime, and generally allowed to undergo thermophilic decomposition until the original organic materials have been substantially altered or decomposed. Sometimes called "artificial manure" or "synthetic manure."

Composting
A controlled biological process which converts organic constituents, usually biological wastes, into humus-like material suitable for use as a soil amendment or organic fertiliser.

Cone penetrometer
An instrument in the form of a cylindrical rod with a cone-shaped tip designed for penetrating soil and for measuring the end-bearing component of penetration resistance. The resistance to penetration developed by the cone equals the vertical force applied to the cone divided by its horizontally projected area.

Consistency
The manifestations of the forces of cohesion and adhesion acting within the soil at various water contents, as expressed by the relative ease with which a soil can be deformed or ruptured. Engineering descriptions include: (i) the designation of five inplace categories (soft, firm or medium, stiff, very stiff, and hard) as assessed by thumb and thumbnail penetrability and indentability; and (ii) characterization by the Atterberg limits (i.e., liquid limit, plastic limit, and plasticity number). See also Atterberg limits, liquid limit, plastic limit, and plasticity number.

Cover crop
Close-growing plant, that provides soil protection, seeding protection, and soil improvement between trees. When ploughed under and incorporated into the soil, cover crops may be referred to as green manure plants.

Denitrification
Reduction of nitrogen oxides (usually nitrate and nitrite) to molecular nitrogen or nitrogen oxides with a lower oxidation state of nitrogen by bacterial activity (denitrification) or by chemical reactions involving nitrite (chemodenitrification). Nitrogen oxides are used by bacteria as terminal electron acceptors in place of oxygen in anaerobic or microaerophilic respiratory metabolism.

Detritus
Dissolved and particulate dead organic matter.

Dinitrogen fixation
Conversion of molecular nitrogen (N2) to ammonia and subsequently to organic nitrogen utilisable in biological processes.

Disintegration
See mechanical weathering.

Dispersion
The break-down of soil aggregates into individual component particles. See also deflocculate.

Dolomitic lime
A naturally occurring liming material composed chiefly of carbonates of Mg and Ca in approximately equimolar proportions.

Drainage
Movement of water out of the soil profile.

Dry-mass content or ratio
The ratio of the mass of any component (of a soil) to the oven-dry mass of the soil. See also oven-dry soil.

Dry-weight percentage
See dry-mass content or ratio.

Electrical conductivity (EC)
(i) Conductivity of electricity through water or an extract of soil. Commonly used to estimate the soluble salt content in solution. (ii) The ability of the soil to conduct electricity.

Eluviation
The removal of soil material in suspension (or in solution) from a layer or layers of a soil. Usually, the loss of material in solution is described by the term "leaching." See also illuviation and leaching.

Enzyme
Any of numerous proteins that are produced in the cells of living organisms and function as catalysts in the chemical processes of those organisms.

Equilibrium
The state of being physically or chemically balanced, when forces (energy, concentration,..) equalize such that mass or energy transfer ceases.

Erosion
(i) The wearing away of the land surface by rain or irrigation water, wind, ice, or other natural or anthropogenic agents that abrade, detach and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere; (ii) The detachment and movement of soil or rock by water, wind, ice, or gravity.

Essential elements
Elements required by plants to complete their normal life cycles which includes C, H, O, P, K, N, S, Ca, Fe, Mg, Mn, Cu, B, Zn, Co, Mo, Cl, and Na.

Evaporation
The process by which liquid water from soil vaporizes near the soil surface and is lost to the atmosphere.

Exchangeable anion
A negatively charged ion held on or near the surface of a solid particle by a positive surface charge and which may be easily replaced by other negatively charged ions (e.g. with a Cl- salt).

Exchangeable bases
Charge sites on the surface of soil particles that can be readily replaces with a salt solution. In most soils, Ca^{2+}, Mg^{2+}, K^+ and Na^+ predominate. Historically, these are called bases because they are cations of strong bases. Many soil chemists object to this term because these cations are not bases by any modern definition of the term. See also base saturation and exchangeable cation.

Exchangeable cation
A positively charged ion held on or near the surface of a solid particle by a negative surface and which may be replaced by other positively charged ions in the soil solution. Usually expressed in centimoles or millimoles of charge per kilogram.

Exchangeable nutrient
A plant nutrient that is held by the adsorption complex of the soil and is easily exchanged with the anion or cation of neutral salt solutions.

Fertility, soil
The relative ability of a soil to supply the nutrients essential to plant growth.

Fertiliser
Any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to a soil to supply one or more plant nutrients essential to the growth of plants.

- *Controlled-release* - A fertiliser term used interchangeably with delayed release, slow release, controlled availability, slow acting, and metered release to designate a controlled dissolution of fertiliser at a lower rate than conventional water-soluble fertilisers. Controlled-release properties may result from coatings on water-soluble fertilisers or from low dissolution and/or mineralization rates of fertiliser materials in soil.
- *Granular* - Fertiliser particles sized usually within the range of 1 to 4 mm and often more closely sized. The desired size may be obtained by agglomerating smaller particles, crushing and screening larger particles, controlling size in crystallization processes, or prilling.
- *Inorganic* - A fertiliser material in which carbon is not an essential component of its basic chemical structure.
- *Liquid* - Fertiliser wholly or partially in solution that can be handled as a liquid, including clear liquids and liquids containing solids in suspension
- *Organic* - A material containing carbon and one or more plant nutrients in addition to hydrogen and/or oxygen.
- *Slow-release* - See fertiliser, controlled-release.

Fine sand
(i) A soil separate. See also soil separates. (ii) A soil textural class. See also soil texture.

Fine texture
(i) A broad group of textures consisting of or containing large quantities of the fine fractions, particularly of silt and clay. (Includes all sandy clay, silty clay, and clay textural classes). (ii) When used in reference to family particle-size classes in U.S. soil taxonomy, is specifically defined as having 35 to 60 percent clay. See also soil texture.

Flocculation
The coagulation of colloidal soil particles due to the ions in solution. In most soils the clays and humic substances remain flocculated due to the presence of doubly and triply charged cations.

Flooding
Accumulation of large amounts of runoff on the landscape as a result of rainfall in excess of the soil's ability to drain water from the landscape before extensive inundation and ponding occurs. See also irrigation.

Food web
Diagram of interconnections of nutrient flow in soil ecosystems through food chains.

Goethite
FeOOH. A yellow-brown iron oxide mineral. Goethite occurs in almost every soil type and climatic region, and is responsible for the yellowish-brown colour in many soils and weathered materials.

Granite
A coarse-grained, acid igneous rock containing chiefly alkali feldspar, quartz and some mica and/or hornblende.

Green manure
Plant material incorporated into soil while green or at maturity, for soil improvement.

Ground water
That portion of the water below the surface of the ground at a pressure equal to or greater than atmospheric. See also water table.

Gypsum
CaSO4·2H2O. The common name for calcium sulfate, used to supply calcium to ameliorate soils with a high exchangeable sodium fraction.

Habitat
The place where a given organism lives.

Heavy metal
A metal which has density >5.0 Mg m^3. In soils these include the elements Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, and Zn.

Heavy soil
(colloquial) A soil with a high content of the fine separates, particularly clay, or one with a high drawbar pull and hence difficult to cultivate, especially when wet. See also fine texture.

Humus
The well decomposed, more or less stable part of the organic matter in mineral soils. Humus is an organic soil material which is also one of the USDA textures of muck (sapric soil material), mucky peat (hemic soil material), or peat (fibric soil material.) Most likely it is muck.

Hydrometer
A sealed cylinder with weighted bulb and graduated stem used to measure the density of soil suspensions.

Hygroscopic water
Water adsorbed by a dry soil from an atmosphere of high relative humidity, water remaining in the soil after "air-drying," or water held by the soil when it is in equilibrium with an atmosphere of a specified relative humidity at a specified temperature, usually 98% relative humidity at 25°C.

Hypha (pl. hyphae)
Filament of fungal cells. Many hyphal filaments (hyphae) constitute a mycelium. Bacteria of the order Actinomycetales also produce branched mycelium.

Illuviation
The process of deposition of soil material removed from one horizon to another in the soil; usually from an upper to a lower horizon in the soil profile. See also eluviation.

Imbibition
Absorption of water into dry soil.

Immobilisation
The conversion of an element from the inorganic to the organic form in microbial or plant tissues.

Impedance
The total opposition of a material (e.g., soil, copper wire) to items (e.g. roots, coleoptiles, water, electrons) moving through it.

Indicator plants
Plants characteristically associated with specific soil or site conditions, such as soil acidity, alkalinity, wetness, or a chemical element.

Infiltration
The entry of water into soil.

Infiltrometer
A device for measuring the volume or flux (or rate) of liquid (usually water) entry downward into the soil.

Inoculate
To treat, usually seeds, with microorganisms to create a favourable response. Most often refers to the treatment of legume seeds with Rhizobium or Bradyrhizobium to stimulate dinitrogen fixation but also refers to the introduction of microbial cultures into sterile growth medium.

Ion selective electrode
An electrochemical sensor, the potential of which (in conjunction with a suitable reference electrode) depends on the logarithm of the activity of a given ion in aqueous solution (e.g. pH, copper, nitrate, and sodium electrodes).

Ionic strength
A parameter that estimates the interaction between ions in solution. It is calculated as one-half the sum of the products of ionic concentration and the square of ionic charge for all the charged species in a solution. It is needed for calculation of single ion activity.

Ions
Atoms, groups of atoms, or compounds, which are electrically charged as a result of the loss of electrons (cations) or the gain of electrons (anions).

Iron oxides
Group name for the oxides and hydroxides of iron. Includes the minerals goethite, haematite, lepidocrocite, ferrihydrite, maghemite, and magnetite. Sometimes referred to as "sesquioxides," or "iron hydrous oxides.

Irrigation
The intentional application of water to the soil, usually for the purpose of crop production.

Labile
Readily transformed by microorganisms or readily available to plants.

Landscape
A collection of related landforms; usually the land surface which the eye can comprehend in a single view.

Leaching
The removal of soluble materials from one zone in soil to another via water movement in the profile. See also eluviation.

Light soil
(colloquial) A coarse-textured soil; a soil with a low drawbar pull and hence easy to cultivate. See also coarse textured and soil texture. Contrast to heavy soil.

Litter
The surface layer of the forest floor which is not in an advanced stage of decomposition, usually consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits.

Loam
A soil textural class. See also soil texture.

Loamy
(i) Texture group consisting of coarse sandy loam, sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam, silt, clay loam, sandy clay loam, and silty clay loam soil textures. See also soil texture. (ii) Family particle-size class for soils with textures finer than very fine sandy loam but <35% clay and <35% rock fragments in upper subsoil horizons.

Loamy sand
A soil textural class. See also soil texture.

Macronutrient
A plant nutrient found at relatively high concentrations (>500 mg/kg) in plants. Usually refers to N, P, and K, but may include Ca, Mg, and S.

Macropore
Large pores responsible for preferential flow and rapid, far-reaching transport (See pore-size classification).

Manure
The excreta of animals, with or without an admixture of bedding or litter, fresh or at various stages of decomposition or composting. May denote any fertiliser material in some countries.

Mass
The property of a material that describes the quantity of matter in it; the ratio of the weight of a body and the acceleration due to gravity.

Mechanical weathering
The process of weathering by which frost action, salt-crystal growth, absorption of water, and other physical processes break down a rock into smaller fragments; no chemical change is involved.

Medium-textured
Texture group consisting of very fine sandy loam, loam, silt loam, and silt textures. See also soil texture

Mesofauna
Nematodes, oligochaete worms, smaller insect larvae and microarthropods.

Mesopore
A secondary pore class between macropores and micropores that contributes to water flow and solute movement by advection and diffusion (see Pore-size classification).

Mica
A layer-structured aluminosilicate mineral group of the 2:1 type that is characterised by its non expandability and high layer charge, which is usually satisfied by potassium. The major types are muscovite, biotite, and phlogopite.

Microbial biomass
(i) The total mass of living microorganisms in a given volume or mass of soil. (ii) The total weight of all microorganisms in a particular environment.

Microbial population
The sum of living microorganisms in a given volume or mass of soil.

Microbiota
Microflora and protozoa.

Microclimate
(i) The climatic condition of a small area resulting from the modification of the general climatic conditions by local differences in elevation or exposure or other local phenomena. (ii) The sequence of atmospheric changes within a very small region.

Microfauna
Protozoa, nematodes, and arthropods of microscopic size.

Microflora
Bacteria (including actinomycetes), fungi, algae, and viruses.

Micronutrient
A plant nutrient found in relatively small amounts(<100 mg/kg) in plants. These are usually B, Cl, Cu, Fe, Mn, Mo, Ni, Co, and Zn.

Micropore
A class of pores that are sufficiently small that water within these pores is considered immobile, but available for plant extraction, and solute transport is by diffusion only (see Pore-size classification).

Microsite
A small volume of soil where biological or chemical processes differ from those of the soil as a whole, such as an anaerobic microsite of a soil aggregate or the surface of decaying organic residues.

Mineral
A naturally occurring homogeneous solid, inorganically formed, with a definite chemical composition and an ordered atomic arrangement.

Mineral soil
A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter. Usually contains <200 g/kg organic carbon (< 120-180 g/kg if saturated with water), but may contain an organic surface layer up to 30 cm thick.

Mineralization
The conversion of an element from an organic form to an inorganic state as a result of microbial activity.

Mulch
(i) Any material such as straw, sawdust, leaves, plastic film, loose soil, etc., that is spread or formed upon the surface of the soil to protect the soil and/or plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc. (ii) To apply mulch to the soil surface.

Munsell colour system
A colour designation system that specifies the relative degree of the three simple variables of colour: hue, value and chroma. For example: 10YR 6/4 is a colour (of soil) with a hue = 10YR, value = 6, and chroma = 4.

Mycelium
A mass of interwoven filamentous hyphae, such as that of the vegetative portion of the thallus of a fungus.

Mycorrhiza (pl. mycorrhizae)
Literally "fungus root". The association, usually symbiotic, of specific fungi with the roots of higher plants. See also endomycorrhiza and ectomycorrhiza.

Neutral soil
A soil in which the surface layer, at least in the tillage zone, is in the pH 6.6 to 7.3 range.

Niche
(i) The particular role that a given species plays in the ecosystem; (ii) The physical space occupied by an organism.

Nitrification
Biological oxidation of ammonium to nitrite and nitrate, or a biologically induced increase in the oxidation state of nitrogen.

Nitrogen fixation
See dinitrogen fixation.

Nodule
(i) A cemented concentration of a chemical compound, such as calcium carbonate or iron oxide, that can be removed from the soil intact and that has no orderly internal organisation. (ii) [micromorphological] A glaebule with undifferentiated fabric. (iii) Specialized tissue enlargements, or swellings, on the roots, stems, or leaves of plants, such as are caused by nitrogen-fixing microorganisms.

No-tillage (no-till / zero tillage) system
A procedure whereby a crop is planted directly into the soil with no primary or secondary tillage since harvest of the previous crop; usually a special planter is necessary to prepare a narrow, shallow seedbed immediately surrounding the seed being planted. No-till is sometimes practiced in combination with subsoiling to facilitate seeding and early root growth, whereby the surface residue is left virtually undisturbed except for a small slot in the path of the subsoil shank.

Nutrient
Elements or compounds essential as raw materials for organism growth and development.

Nutrient concentration vs. content
Concentration is usually expressed in grams per kilogram (g/kg) or milligrams per kilogram (mg/kg) of dry or fresh weight; content is usually expressed as weight per unit area (e.g. kg/ha). These terms should not be used interchangeably with regard to nutrients in plants.

Nutrient deficiency
A low concentration of an essential element that reduces plant growth and prevents completion of the normal plant life cycle.

Osmotic potential, pressure
The potential energy acting upon soil water due to the effect of solutes. Solution in contact with pure water will draw water from the reservoir of pure water due to the decrease in potential energy, i.e., osmotic potential, of the solution relative to the pure water. Osmotic potential equals the product of the universal gas constant, R, the temperature, T, and the total molar concentration of solutes, C(=RTC).

Oven-dry soil
Soil that has been dried at 105°C until it reaches constant mass.

P_2O_5
Phosphorus pentoxide; designation on the fertiliser label that denotes the percentage of available phosphorus reported as phosphorus pentoxide.

Parent material
The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic processes.

Particle density
The density of the soil particles, the dry mass of the particles being divided by the solid (not bulk) volume of the particles, in contrast with bulk density. Units are Mg/m.

Particle size
The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

Parts per million (ppm)
(i) The concentration of solutions expressed in weight or mass units of solute (dissolved substance) per million weight or mass units of solution. (ii) A concentration in solids expressed in weight or mass units of a substance contained per million weight or mass units of solid, such as soil.

Polymerase chain reaction (PCR)
An in vitro method for amplifying defined segments of DNA. PCR involves a repeated cycle of oligonucleotide hybridization and extension on single-stranded DNA templates.

Peat
Organic soil material which is the least decomposed. See fibric soil material.

Peat soil
An organic soil in which the plant residues are recognisable. The sum of the thicknesses of the organic layers are usually greater than the sum of the thicknesses of the mineral layers. See also peat, muck, muck soil, and Histosol.

Penetrability
The ease with which a probe can be pushed into the soil. (May be expressed in units of distance, speed, force, or work depending on the type of penetrometer used.)

Penetration resistance
The force per unit area on a standard ASAE cone necessary for penetration by the cone. See also cone index.

Penetrometer
See cone penetrometer.

Percolation, soil water
The downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

Permanent wilting point
The largest water content of a soil at which indicator plants, growing in that soil, wilt and fail to recover when placed in a humid chamber. Often estimated by the water content at -1.5 MPa soil matric potential.

Permeability, soil
(i) The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different soil horizons vary in permeability, the particular horizon under question should be designated. (ii) The property of a porous medium itself that expresses the ease with which gases, liquids or other substances can flow through it, and is the same as intrinsic permeability k.

pH, soil
The pH of a solution in equilibrium with soil. It is determined by means of a glass, quinhydrone or other suitable electrode or indicator at a specified soil-solution ratio in a specified solution, usually distilled water, 0.01 M $CaCl_2$, or 1 M KCl.

Phosphate
In fertiliser trade terminology, phosphate is used to express the sum of the water-soluble and the citrate-soluble phosphoric acid (P_2O_5); also referred to as the available phosphoric acid (P_2O_5).

Physical properties (of soils)
Those characteristics, processes, or reactions of a soil which are caused by physical forces and which can be described by, or expressed in, physical terms or equations. Examples of physical properties are bulk density, hydraulic conductivity, porosity, pore-size distribution, etc.

Physical weathering
The breakdown of rock and mineral particles into smaller particles by physical forces such as frost action. See also weathering.

Phytotoxic
The property of a substance at a specified concentration that restricts or constrains plant growth.

Plant nutrient
An element which is absorbed by plants and is necessary for completion of the normal life cycle. These include C, H, O, N, P, K, Ca, Mg, S, Cu, Fe, Zn, Mn, B, Cl, Ni and Mo.

Pollution
The presence or introduction of a pollutant into the environment.

Ponding
Process through which water stands on the soil surface.

Poorly drained
A drainage class referring to soils which have evidence (e.g., mottles) of seasonal water tables at depths between 0 and 200 mm.

Pore space
The portion of soil bulk volume occupied by soil pores.

Pore volume
See pore space.

Pore-size distribution
The volume fractions of the various size ranges of pores in a soil, expressed as percentages of the soil bulk volume (soil particles plus pores). See also *Table 8*.

Porosity
The volume of pores in a soil sample (nonsolid volume) divided by the bulk volume of the sample.

Potash
Term used to refer to potassium or potassium fertilisers and usually designated as K_2O.

Predation
A relationship between two organisms whereby one organism (predator) engulfs and digests the second organism (prey).

Productivity, soil
The output of a specified plant or group of plants under a defined set of management practices.

Remote sensing
Refers to the full range of activities that collects information from a distance, e.g., the utilisation at a distance (as from aircraft, spacecraft, or ship) of any device for measuring electromagnetic radiation, force fields, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, and scintillation counters.

Root penetration
The process by which plant roots elongate through soil.

Root zone
The portion of the soil profile from which plants absorb water and nutrients.

Runoff
That portion of precipitation or irrigation on an area which does not infiltrate, but instead is discharged from the area. That which is lost without entering the soil is called surface runoff. That which enters the soil before reaching a stream channel is called ground water runoff or seepage flow from ground water. (In soil science runoff usually refers to the water lost by surface flow; in geology and hydraulics runoff usually includes both surface and subsurface flow.)

Saline soil
A nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS/m(at 25 °C). Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.

Salinity, soil
The amount of soluble salts in a soil. The conventional measure of soil salinity is the electrical conductivity of a saturation extract.

Sand
(i) A soil separate. See also soil separates. (ii) A soil textural class. See also soil texture.

Sandy
(i) Texture group consisting of sand and loamy sand textures. See also soil texture. (ii) Family particle-size class for soils with sand or loamy sand textures and <35% rock fragments in upper subsoil horizons.

Sandy clay
A soil textural class. See also soil texture.

Sandy clay loam
A soil textural class. See also soil texture.

Sandy loam
A soil textural class. See also soil texture.

Saturate
(i) To fill all the voids between soil particles with a liquid. (ii) To form the most concentrated solution possible under a given set of physical conditions in the presence of an excess of the solute. (iii) To fill to capacity, as the adsorption complex with a cation species; e.g., H^+-saturated, etc.

Secondary nutrients
Refers to Ca, Mg, and S in fertilisers.

Sediment
Transported and deposited particles or aggregates derived from rocks, soil, or biological material.

Semipermeable
A thin layer of animal or plant tissue which allows some substances to move through them more than others.

Silt
(i) A soil separate. See also soil separates. (ii) A soil textural class. See also soil texture.

Silt loam
A soil textural class. See also soil texture.

Silty clay
A soil textural class. See also soil texture.

Silty clay loam
A soil textural class. See also soil texture.

Site
A volume defined by the abiotic factors (i.e. climate, soil, physiography) that influence vegetation growth and development.

Slow release
A fertiliser term used interchangeably with delayed release, controlled release, controlled availability, slow acting, and metered release to designate a rate of dissolution (usually in water) much less than is obtained for completely water-soluble compounds. Slow release may involve either compounds that dissolve slowly or soluble compounds coated with substances relatively impermeable to water.

Soil
The layer(s) of generally loose mineral and/or organic material that are affected by physical, chemical, and/or biological processes at or near the planetary surface, and usually hold liquids, gases and biota and support plants.

Soil aeration
The condition, and sum of all processes affecting, soil pore-space gaseous composition, particularly with respect to the amount and availability of oxygen for use by soil biota and/or soil chemical oxidation reactions.

Soil amendment
Any material such as lime, gypsum, sawdust, compost, animal manures, crop residue or synthetic soil conditioners that is worked into the soil or applied on the surface to enhance plant growth. Amendments may contain important fertiliser elements but the term commonly refers to added materials other than those used primarily as fertilisers. See also soil conditioner.

Soil auger
A tool for boring into the soil and withdrawing a small sample for field or laboratory observation. Soil augers may be classified into several types as follows: (i) those with worm-type bits, unenclosed; (ii) those with worm-type bits enclosed in a hollow cylinder; and (iii) those with a hollow cylinder with a cutting edge at the lower end.

Soil characteristics
Soil properties which can be described or measured by field or laboratory observations, e.g., colour, temperature, water content, structure, pH, and exchangeable cations.

Soil compaction
Increasing the soil bulk density, and concomitantly decreasing the soil porosity, by the application of mechanical forces to the soil.

Soil conditioner
A material which measurably improves specific soil physical characteristics or physical processes for a given use or as a plant growth medium. Examples include sawdust, peat, compost, synthetic polymers, and various inert materials. See also soil amendment.

Soil management
The combination of all tillage operations, cropping practices, fertiliser, lime, and other treatments conducted on or applied to the soil for the production of plants.

Soil microbial diversity
Expression of the variety of soil microorganisms and activities at the genetic, species, and soil ecosystem levels; measurements based on communities rather than species.

Soil mineral
(i) Any mineral that occurs as a part of or in the soil. (ii) A natural inorganic compound with definite physical, chemical, and crystalline properties (within the limits of isomorphism), that occurs in the soil. See also clay mineral.

Soil order
A group of soils in the broadest category. For example, in the 1938 classification system. The three soil orders were zonal soil, intrazonal soil, and azonal soil. In the 1975 there were 10 orders, whereas in the current USDA classification scheme (Soil Survey Staff. 1994. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. SCS-USDA. U.S. Gov. Print. Office, Washington, DC) there are 11 orders, differentiated by the presence or absence of diagnostic horizons: Alfisols, Andisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, Vertisols. Orders are divided into Suborders and the Suborders are further divided into Great Groups.

Soil organic matter
The organic fraction of the soil exclusive of undecayed plant and animal residues. See also humus.

Soil population
(i) All the organisms living in the soil, including plants and animals. (ii) Members of the same taxa. (iii) Delineations of the same map unit - a grouping of like things in a statistical sense.

Soil productivity
The capacity of a soil to produce a certain yield of crops or other plants with a specified system of management.

Soil quality
The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.

Soil sample
A representative sample taken from an area, a field, or portion of a field from which the physical, biological, and chemical properties can be determined.

Soil separates
Mineral particles, <2.0 mm in equivalent diameter, ranging between specified size limits. The names and size limits of separates recognised in the USA are: very coarse sand (Prior to 1947 this separate was called “fine gravel;” now fine gravel includes particles between 2.0 mm and about 12.5 mm in diameter), 2.0 to 1.0 mm; coarse sand, 1.0 to 0.5 mm; medium sand, 0.5 to 0.25 mm; fine sand, 0.25 to 0.10 mm; very fine sand, 0.10 to 0.05 mm; silt, 0.05 to 0.002 mm; and clay (Prior to 1937, “clay” included particles <0.005 mm in diameter, and “silt,” those particles from 0.05 to 0.005 mm) <0.002 mm. The separates recognised by the International Society of Soil Science are: (i) coarse sand, 2.0 to 0.2 mm; (ii) fine sand, 0.2 to 0.02 mm; (iii) silt, 0.02 to 0.002 mm; and (iv) clay, <0.002 mm.

Soil solution
The aqueous liquid phase of the soil and its solutes.

Soil test
A chemical, physical, or biological procedure that estimates the suitability of the soil to support plant growth. (Sometimes used as an adjective to define fractions of soil components, e.g., “soil test phosphorus”.)

Soil texture
The relative proportions of the various soil separates in a soil as described by the classes of soil texture shown in *Figure 4*. The textural classes may be modified by the addition of suitable adjectives when rock fragments are present in substantial amounts; for example, “stony silt loam.” (For other modifiers see also rock fragments.) The sand, loamy sand, and sandy loam are further subdivided on the basis of the proportions of the various sand separates present. The limits of the various classes and subclasses are as follows: clay - Soil material that contains 40% or more clay, <45% sand, and <40% silt.

- *Clay loam* - Soil material that contains 27 to 40% clay and 20 to 45% sand.
- *Loam* - Soil material that contains 7 to 27% clay, 28 to 50% silt, and <52% sand.
- *Loamy sand* - Soil material that contains between 70 and 91% sand and the percentage of silt plus 1.5 times the percentage of clay is 15 or more; and the percentage of silt plus twice the percentage of clay is less than 30.
- *Loamy coarse sand* - Soil material that contains 25% or more very coarse and coarse sand, and <50% any other one grade of sand.
- *Loamy sand* - Soil material that contains 25% or more very coarse, coarse, and medium sand, <25% very coarse and coarse sand, and <50% fine or very fine sand.
- *Loamy fine sand* - Soil material that contains 50% or more fine sand (or) <25% very coarse, coarse, and medium sand and <50% very fine sand.
- *Loamy very fine sand* - Soil material that contains 50% or more very fine sand.
- *Sand* - Soil material that contains 85% or more of sand; percentage of silt, plus 1.5 times the percentage of clay, shall not exceed 15.
- *Coarse sand* - Soil material that contains 25% or more very coarse and coarse sand, and <50% any other one grade of sand.
- *Sand* - Soil material that contains 25% or more very coarse, coarse, and medium sand, <25% very coarse and coarse sand, and <50% fine or very fine sand.
- *Fine sand* - Soil material that contains 50% or more fine sand (or) <25% very coarse, coarse, and medium sand and <50% very fine sand.
- *Very fine sand* - Soil material that contains 50% or more very fine sand.
- *Sandy clay* - Soil material that contains 35% or more clay and 45% or more sand.
- *Sandy clay loam* - Soil material that contains 20 to 35% clay, <28% silt, and >45% sand.

- *Sandy loam* - Soil material that contains 7 to 20% clay, more than 52% sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7% clay, less than 50% silt, and more than 43% sand.
- *Coarse sandy 1oam* - Soil material that contains 25% or more very coarse and coarse sand and <50% any other one grade of sand.
- *Sandy loam* - Soil material that contains 30% or more very coarse, coarse, and medium sand, but <25% very coarse and coarse sand, and <30% very fine or fine sand, or <15% very coarse, coarse, and medium sand and <30% either fine sand or very fine sand and 40% or less fine plus very fine sand.
- *Fine sandy loam* - Soil material that contains 30% or more fine sand and <30% very fine sand (or) between 15 and 30% very coarse, coarse, and medium sand, or >40% fine and very fine sand, at least half of which is fine sand, and <15% very coarse, coarse, and medium sand.
- *Very fine sandy loam* - Soil material that contains 30% or more very fine sand and <15% very coarse, coarse, and medium sand (or) >40% fine and very fine sand, more than half of which is very fine sand and <15% very coarse, coarse, and medium sand.
- *Silt* - Soil material that contains 80% or more silt and <12% clay.
- *Silty clay* - Soil material that contains 40% or more clay and 40% or more silt.
- *Silty clay loam* - Soil material that contains 27 to 40% clay and <20% sand.
- *Silt loam* - Soil material that contains 50% or more silt and 12 to 27% clay (or) 50 to 80% silt and <12% clay.

Coarseness and fineness refers to the particle sizes of soil separates:

Soil separate	Diameter limits (mm) (USDA classification)
Clay	< 0.002
Silt	0.002 – 0.05
Very fine sand	0.05 – 0.10
Fine sand	0.10 – 0.25
Medium sand	0.25 – 0.50
Coarse sand	0.50 – 1.00
Very coarse sand	1.00 – 2.00

Sorption
The removal of an ion or molecule from solution by adsorption and absorption. It is often used when the exact nature of the mechanism of removal is not known.

Surface runoff
See runoff.

Surface sealing
The deposition by water, orientation and/or packing of a thin layer of fine soil particles on the immediate surface of the soil, greatly reducing its water permeability.

Suspension
The state in which particles of a solid are mixed with a fluid but are not dissolved.

Sustainability
Managing soil and crop cultural practices so as not to degrade or impair environmental quality on or off site, and without eventually reducing yield potential as a result of the chosen practice through exhaustion of either on-site resources or non-renewable inputs.

Swelling
The process which occurs when interacting clay platelets move apart.

Textural class
See soil texture.

Textural triangle
A classification of earth materials with equivalent particle diameters less than 2.0 mm based solely on particle-size distribution.

Texture
See soil texture.

Topsoil
(i) The layer of soil moved in cultivation. Frequently designated as the Ap layer or Ap horizon. See also surface soil. (ii) Presumably fertile soil material used to topdress roadbanks, gardens, and lawns.

Toxicity
Quality, state, or degree of the harmful effect from alteration of an environmental factor.

Trace element
(i) It is no longer used in SSSA publications in reference to plant nutrition. See also micronutrient. (ii) In environmental applications it is those elements exclusive of the eight abundant rock-forming elements: oxygen, aluminum, silicon, iron, calcium, sodium, potassium, and magnesium.

Trophic level
The presence of nutrients and energy within a stage, represented by a group of organisms, of the food chain, ranging from primary nutrient assimilating autotrophs to the predatory organotrophs.

Vermiculite
A highly charged, averages about 159 cmolc/kg for soil vermiculites but has a very wide range, layer silicate of the 2:1 type that is formed from mica. It is characterised by adsorption preference for potassium, ammonium, and cesium over smaller exchange cations. It may be di- or trioctahedral.

Vertical mulching
A subsoiling operation in which a vertical band of mulching material is placed into vertical slits in the soil made by the soil-opening implement.

Water content
The water lost from the soil upon drying to constant mass at 105°C; expressed either as the mass of water per unit mass of dry soil or as the volume of water per unit bulk volume of soil.

Water retention
A property of soil which results from the attraction of the soil matrix for water.

Water table
The upper surface of ground water or that level in the ground where the water is at atmospheric pressure.

Waterlogged
Saturated or nearly saturated with water.

Water-stable aggregate
A soil aggregate which is stable to the action of water such as falling drops, or agitation as in wet-sieving analysis.

Weathering
The breakdown and changes in rocks and sediments at or near the Earth's surface produced by biological, chemical and physical agents or their combinations. See also chemical weathering and physical weathering.

Well drained
A soil drainage class characterised by the lack of any evidence of seasonal high water tables in the top 900 mm of the soil profile.

Wilting point
Water content of a soil when indicator plants growing in that soilwilt and fail to recover when placed in a humid chamber.

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APPX E - INDEX