WATERWISE ON THE FARM

Irrigation Efficiency
Principles to Practice

Assessing your soil & water resources

Perth Region NRM

CARING
FOR
OUR
COUNTRY

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These materials are part of the WaterWise on the Farm education program Introduction to Irrigation Management. They were developed by NSW Agriculture staff from the Water Management subprogram with major input from Lindsay Evans.

CONTENTS

INTRODUCTION

The aim of the Irrigation Efficiency course is to give you skills and knowledge to assist you to manage your irrigation system more effectively, and improve your water use efficiency.

This workshop introduces you to techniques for assessing the irrigation characteristics of soil and water quality. These techniques will help you to manage irrigation water more efficiently.

To manage your irrigation system effectively and achieve good yields, it is vital that you have a clear understanding of the variation that may occur in soil and their water holding capacity across your property.

Soil is a fundamental resource on which your production as an irrigator depends. The most important functions of your soil are to store water and nutrients and to supply this to the plants between rainfall and irrigation. How much water the soil stores can differ greatly within very short horizontal and vertical distances.

With the skills learned in this workshop, you will be able to determine your own soil characteristics and apply the results on your own property.

The quality of the water used for irrigation is also important. Water quality does vary and it is important to understand the effects of this on plant growth and the efficiency of your irrigation system. The final part of this workbook covers water quality.

LEARNING OUTCOMES

When you have completed this workshop you will be able to:

- Define the terms *field capacity, refill point, permanent wilting point* and *readily available water (RAW)*
- Identify soil layers
- Identify effective rootzone
- Identify soil texture
- Calculate the soil's RAW to indicate how much water is available to the plant
- Discuss how water is held by soil
- Sample soil and water to check their suitability for irrigation
- Discuss irrigation water quality

Workshop Activities

To assist you achieve these learning outcomes there are a number of workshop activities for you to complete. These activities are outlined in your workbook and may include:

- Hand texturing soils
- Calculations on rootzone RAW
- Examining the soil profile in a soil pit
- Conducting an infiltration test
- Collecting a water sample from an irrigation system.

Assessment

This course is competency based. By completing Workshop activities during the course, you will demonstrate that you have met the learning outcomes. This method of training and education benefits both you and the trainer as any topics that have not been clearly covered may be quickly reviewed.

*Workshop Program**

This workshop is made up of six topics:

Topic 1. All about soils

Topic 2. Soil Water

Topic 3. Practical session in soil pits ('Down Pit')

Topic 4. Infiltration

Topic 5. Water quality and how to collect and interpret water samples

Topic 6. Special soil features of Your Local Area

* *The order of the Program may vary to accommodate participants and local conditions*

The topics include workshop activities, notes, practical application of material and assessment tasks. Together, the topics cover the Learning Outcomes for this workshop.

ALL ABOUT SOILS

What is Soil?

Soil is formed from rocks, sediment, and organic matter that are broken down over time. It consists of a complex structure of five components:

1. **Mineral particles** derived from weathered ‘parent’ rocks
2. **Humus (organic matter)**, the remains of plants and animals
3. **Water** containing dissolved nutrients
4. **Air** supplying oxygen to plants
5. **Living organisms** including bacteria, fungi, worms etc.

The amount of each component varies with the soil type.

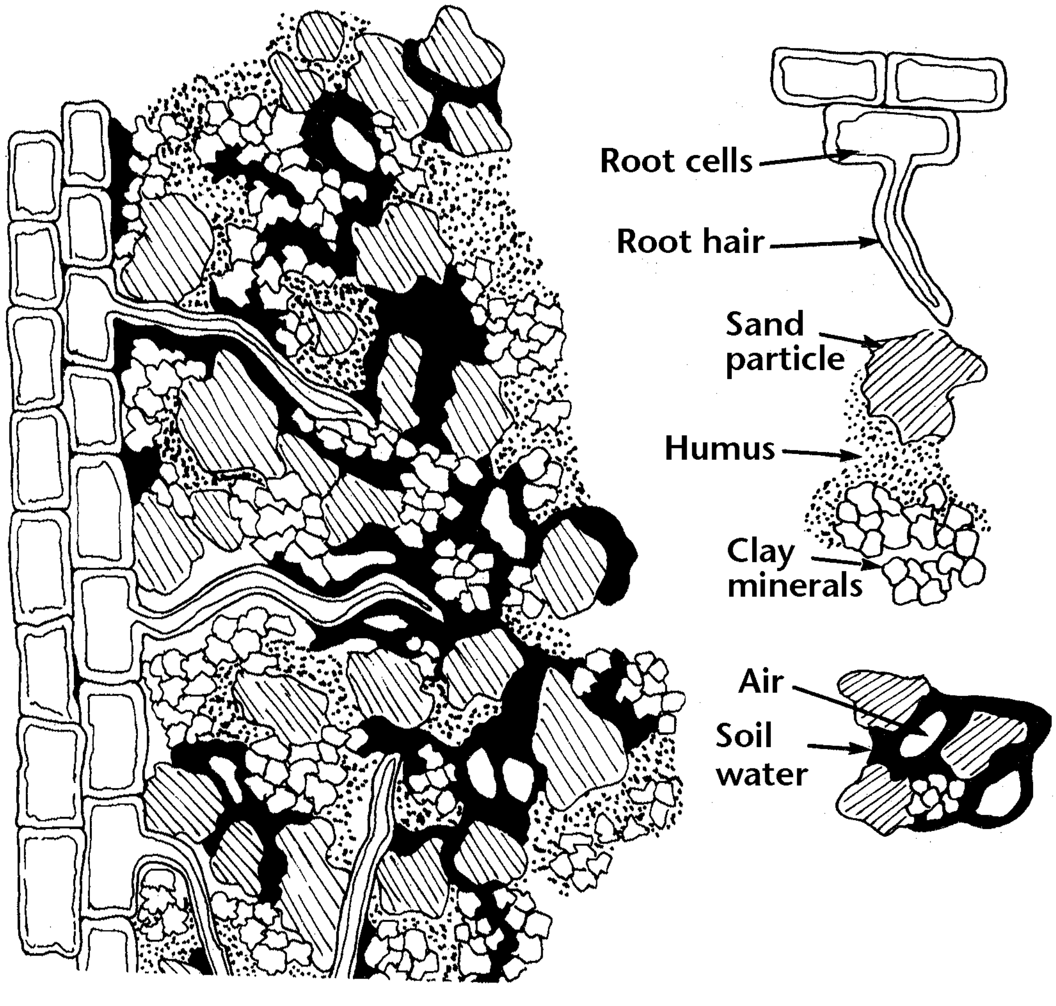


Figure 1. Major soil components

Mineral particles

The mineral particles of the soil come from the breakdown of rocks. They vary in shape and size and are broadly divided into three categories:

- **SAND** the largest soil particles (0.02 to 2 mm)
- **SILT** smaller particles of parent rock (0.002 to 0.02 mm)
- **CLAY** very small particles of parent rock, important in soil structure and fertility (smaller than 0.002 mm)

The type and amount of mineral particles vary greatly between soils, resulting in a large number of soil types. The names of soil types usually refer to their texture and colour.

Texture is the relative amount of sand, silt, and clay in the soil.

For example, a sandy loam has a greater amount of sand than other components, while heavy clay is predominantly composed of clay particles.

Sand and silt particles are often bound together by clay and organic matter to form aggregates. How the aggregates are arranged is called the soil structure.

Soil Structure refers to the way Sand, Silt, Clay, and Organic matter is arranged into crumbs (or aggregates).

In between these aggregates are spaces called ‘Pores’. Within the pore spaces are water, air and micro organisms.

How well these aggregates fit together, together with how the pore spaces are arranged within and between aggregates, influences the soil’s water holding characteristics. Soils with good structure hold more water than those with poor structure.

Understanding your soils, and knowing how much water they can hold, makes irrigation planning easier and can improve water use efficiency.

There are many other benefits to be gained through assessing your soil resources. If you can minimise the time that soil is too dry or too wet, the benefits of the organic matter in the soil, and the activity of the living organisms in it, can be maximised. Organic matter and living organisms are essential for good soil health, fertility, and structure.

ASSESSING SOIL TEXTURE

The amount of water held by the soil and available to plants varies with the individual soil type. As we discussed earlier, soil type depends on the relative proportions of sand, silt, and clay.

Soil texture may be assessed in the field by the feel of a sample of moist soil when worked between the finger and thumb. This field test is referred to as 'the Ribbon Test'. The ribbon test uses thumb pressure against the middle joint of the index finger to produce a ribbon about 2 mm thick. The length of the unbroken ribbon that you produce will indicate the soil type (Table 1).

The soil must be moist (near field capacity) and pliable. The feel and behaviour of the soil as you moisten and knead it will assist you in identifying the soil texture. Scan through Table 1 so you have an idea of how the soil will behave and feel as you are assessing your soil texture.

Table 1. Quick Guide to Common Soil Textures

Soil texture	Ribbon length	How the soil behaves or feels	% Clay
Sand (S)	Nil	Coherence nil to very slight, cannot be moulded; sand grains adhere to fingers	Less than 5%
Sandy loam (SL)	15–25 mm	Coherent bolus but very sandy to the touch dominant sand grains are of medium size and readily visible	10–20%
Loam (L)	About 25 mm	Loams may form a thick ribbon. Soil ball is easy to manipulate and has a smooth spongy feel with no obvious sand. Greasy to touch if organic matter present	About 25 %
Clay loam (CL)	40–50 mm	Strongly coherent, plastic bolus, smooth to manipulate	30–35%
Light clay (LC)	50–75 mm	Plastic behaviour, smooth feel, easily worked, moulded and rolled into rod. Rod forms a ring without cracking	35–40 %
Medium clay (MC)	Greater than 75mm	Smooth plastic bolus; handles like plasticine, can be moulded into rods without cracking, resistant to shearing	45–55%
Heavy clay (HC)	Greater than 75mm	Smooth, very plastic bolus, firm resistance to shearing Will mould into rods. Handles like stiff plasticine. Very sticky and strongly coherent. Rods form a ring without cracking	Over 50%

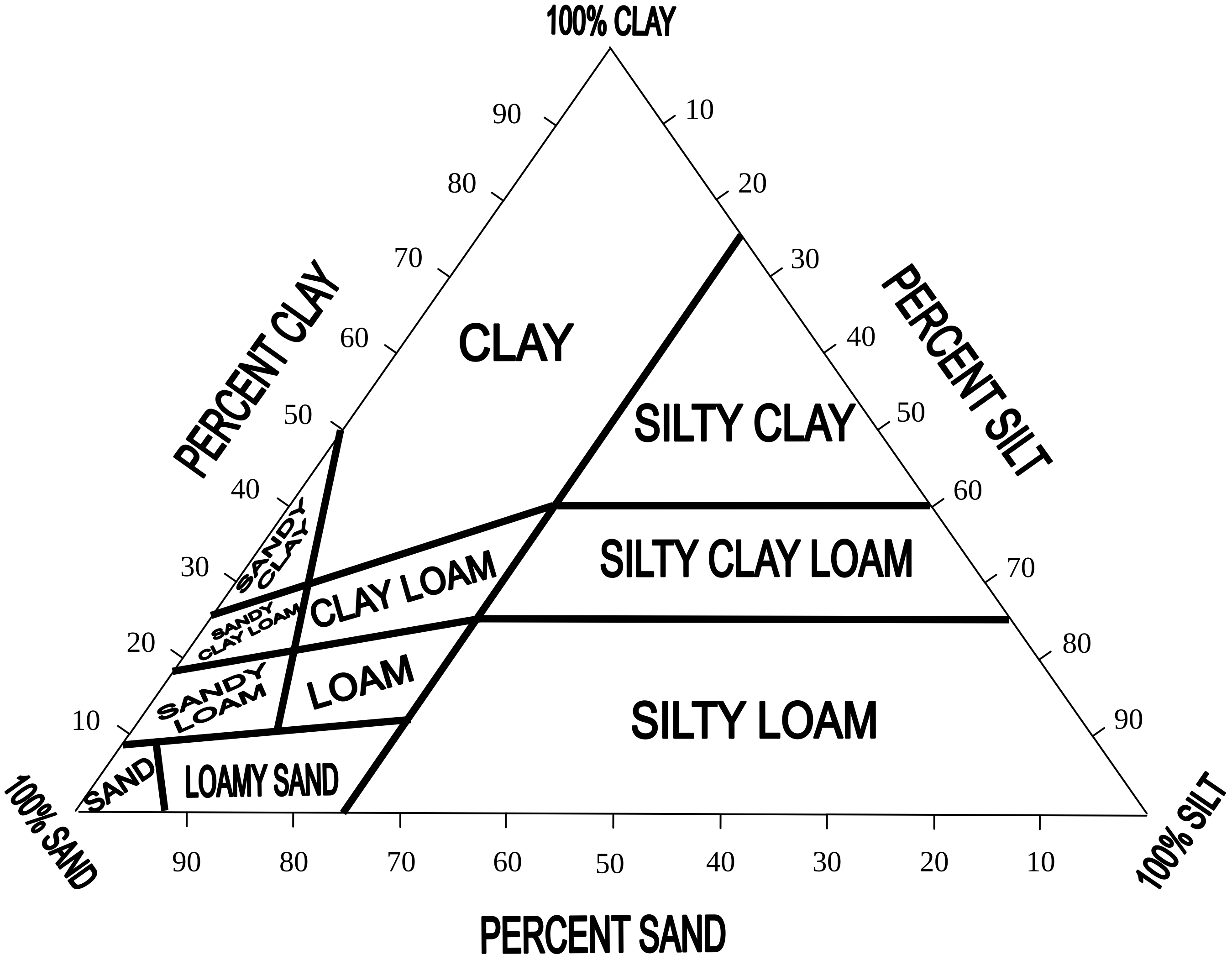


Figure 2. The soils triangle

Activity 1: Hand texturing

Complete the activity in your workbook by assessing the texture of several soil types by hand texturing them

The soil profile

A cross-sectional view of a soil, called the soil profile (Figure 3), shows several layers. The top layer, referred to as the topsoil, has most of the organic matter and therefore contains the most nutrients. Plant roots usually occur throughout the topsoil. The organic matter usually makes this layer dark.

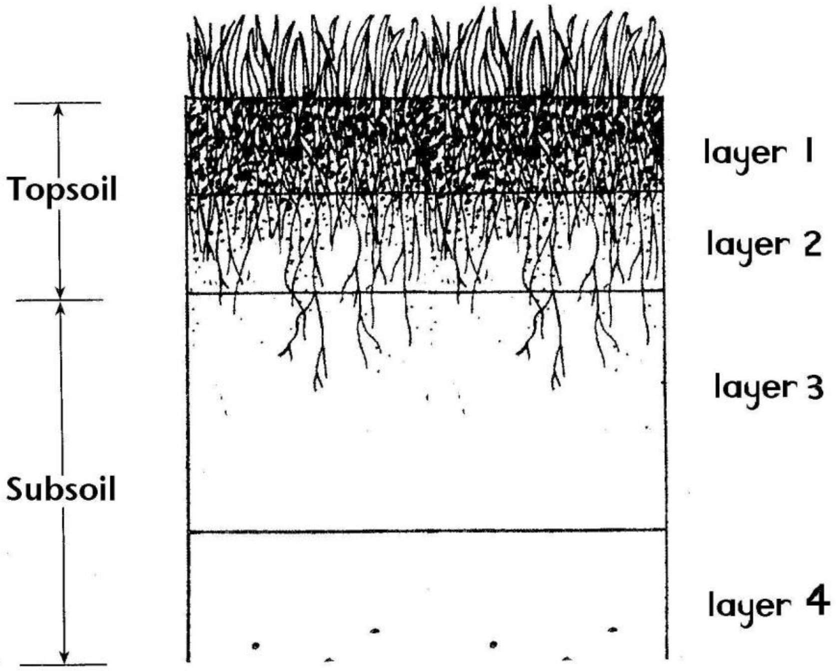


Figure 3: Layers in a Soil Profile.

It is important to examine your soil profile so you know the different soil textures it contains. A soil survey will describe each soil layer according to its characteristics such as texture, colour, and depth. This information will assist in determining your soil water characteristics and develop an irrigation and drainage management plan.

Soil layers may also be referred to as Horizons.

Clay at depth

Most Australian soil is ancient and weathered, with a tendency to have more clay at depth in the profile. This means that a typical Australian soil profile will have lighter topsoil above heavier or more clayey subsoil, although it is also possible to have sand and clay throughout the profile.

Soil Colour

Looking at colour variations in the soil profile can often assist you to identify the different layers of soil within the profile. Soil colour can also indicate the amount of leaching, aeration, and organic matter.

To determine the soil colour, you need to examine the surface of a freshly turned sod of moist soil.

Here are some of the properties that soil colour may indicate:

Organic matter content: The darker the surface soil, the higher the organic matter content.

Leaching: Light-coloured (near-white) subsurface soil indicates leaching of nutrients.

Waterlogging: Mottled subsoil (showing blotches of different colours or shades) indicates that soil has periods of waterlogging.

Permeability: The permeability decreases as subsoils change from red to yellow to blue/green-grey.

Strong colours: Generally indicate good fertility.

Weak colours: Generally indicate poor fertility and leaching.

Soil colour is only an indication of possible soil properties. Further soil tests must be conducted to confirm or disprove these indications.

Effective rootzone

The effective rootzone is that part of the plant's rootzone where the main mass of a plant’s roots that contribute to crop growth are found. Below the effective rootzone there may be a few roots, but the water they extract is not significant for the plant’s growth.

The effective rootzone is typically one third to two-thirds the depth of the deepest roots. Some crops, such as irrigated pasture, citrus, bananas, avocados and low chill stone fruit, develop a mass of shallow roots with only a few roots penetrating into deeper soil layers (see Figure 4).

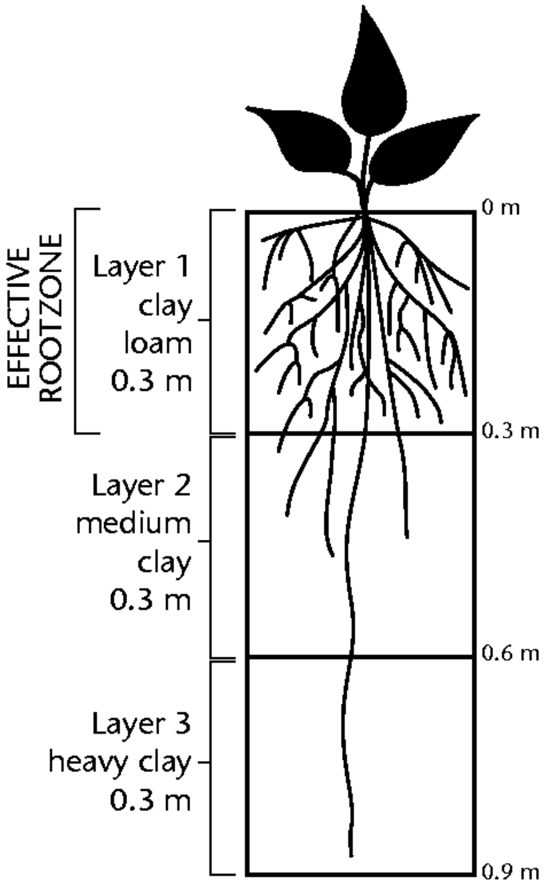


Figure 4: Typical rootzone for a shallow-rooted crop

When you examine your soil profile, look for healthy, living roots within each soil layer. This will enable you to estimate the depth of your crop’s effective rootzone and the depth of each layer of different soil.

This is very important for determining how much water will be available to your crop. It is essential to estimate the depth of the crop’s effective rootzone as accurately as you can.

Unhealthy plant roots, or the absence of plant roots, may also indicate structural problems in the soil profile such as plough pans, impermeable layers, sodic subsoils, or perched watertable.

SOIL WATER

Soil is like a big sponge—it can only soak up a certain amount of water and it can only do so at a certain rate (see infiltration rates later). Water infiltrates the soil and is held in the spaces between soil particles. These spaces are referred to as soil pores.

Once the soil has ‘soaked up’ enough water to fill all the pore spaces, the soil is said to be saturated. There is no benefit in applying more water to the effective rootzone once the soil is saturated. Excess water causes plant stress from water logging, drainage to water tables below the rootzone, run-off, and loss of fertilisers.

There are two forms of soil water (Figure 5):

- Water held tightly to the soil particles (adsorbed water)
- Water held in the pores between the soil particles (capillary water)

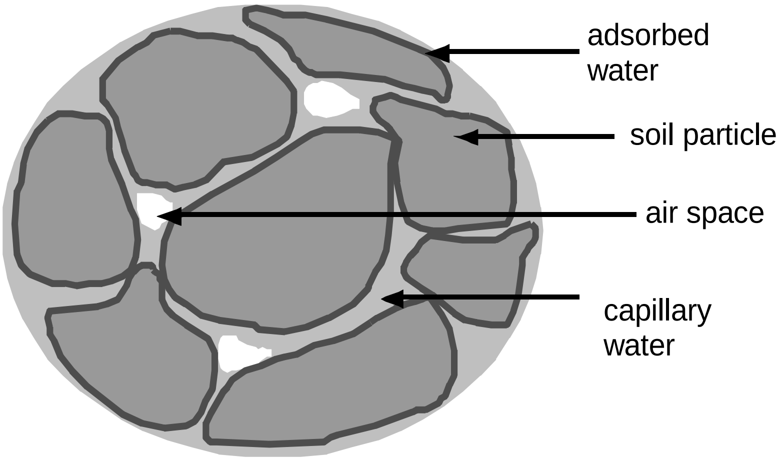


Figure 5. The two forms of soil water (microscopic view)

Roots remove water from the soil pores by creating suction. Water from large soil pores (macropores) drain from the soil due to gravity.

The remaining water is held more tightly in the smaller pores (capillaries) or adhering to the particles’ surface. Plants use water from the capillary pores first.

As the capillary water is used up, the water is held more tightly by the soil particles. It is very difficult for the roots to remove this water (adsorbed water). However, some plants can extract water from drier soil more easily than others.

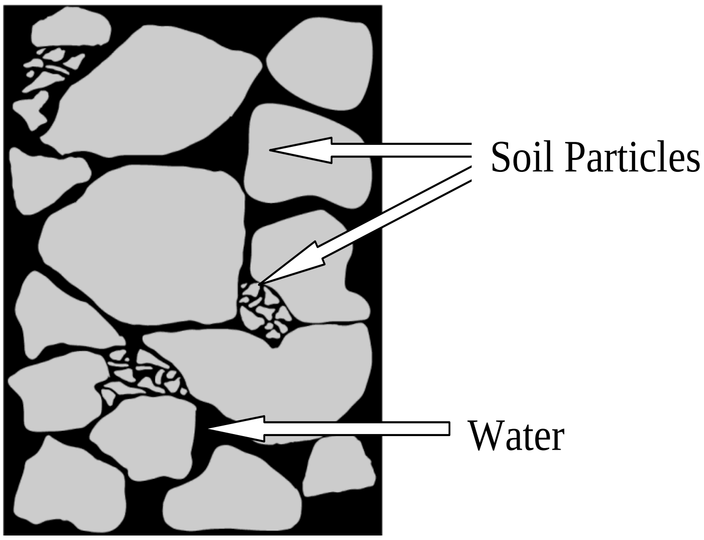
As efficient irrigators, we should aim to minimise the time soil is in a saturated or dry state, and maximise the time when water is readily available to the plant.

Describing soil water content

How ‘tightly’ the soil holds onto its water, and how much effort the plant has to make to extract this water, can be described as 'soil moisture tension'. We use a negative pressure in kPa to describe this tension. By measuring soil water, we can describe the condition of the soil at each stage of irrigation and crop use: from ‘saturation point’ to ‘permanent wilting point’, and the stages in between: ‘field capacity’ and ‘refill point’.

Saturation point

After heavy rain, during surface irrigation, or over-irrigation, soil may become saturated. This is when even the largest pores are filled with water (Figure 6).



Applying more water causes ponding on the surface, leading to run-off and/or deep drainage. When the soil is saturated, there is no air for the plant roots. This will stress many plants.

Figure 6: Saturated soil

The total water holding capacity of saturated soils is generally from 400 to 480 mm of water per metre of soil depth. However, only a small amount of this is actually used by the plant.

This is because saturated soil freely drains due to the pull of Gravity. A saturated soil will drain until a point is reached where the pull of gravity matches the soil’s ability to hold onto the water.

Field capacity

Once rain or irrigation stops, large soil pores (macropores) drain due to gravity. Depending on the type of soil, this drainage may take from a few hours up to several days.

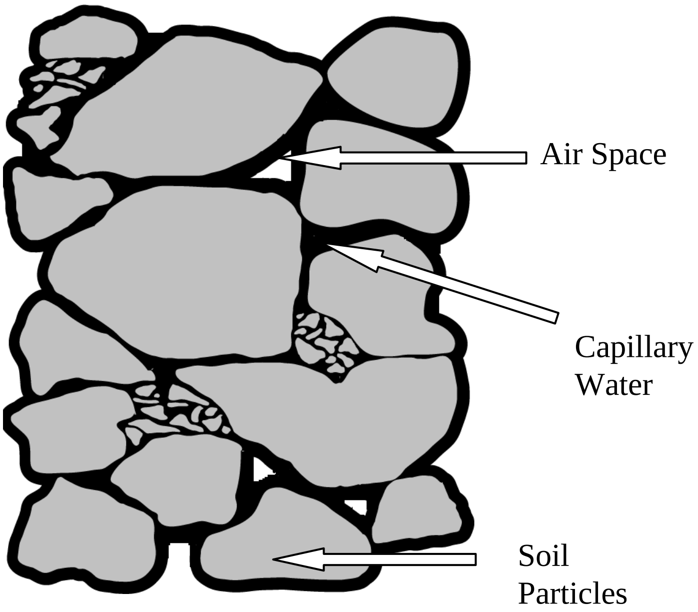


Figure 7: Soil at field capacity

When the large pores have drained, the soil is still wet, but not saturated. The soil is said to be at field capacity (Figure 7). Field capacity in most soils is at a soil-water tension of about –8 kPa.

The small pores resist gravity and hold onto their water through capillary force. The water they hold provides the main source of readily available water for the plant. It is easy for plants to extract water when the soil is at or near field capacity.

Permanent wilting point

As the capillary soil moisture is used by a plant or lost to evaporation, the greater the soil water tension becomes. This means that the plant has to work harder to overcome the tension and extract water. If a plant has to work too hard, it may start to stress (wilt) reducing growth and yield.

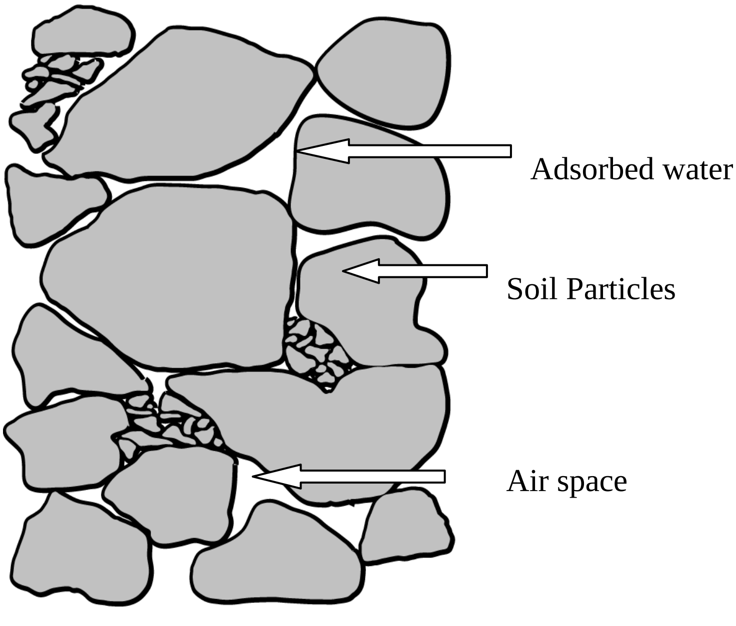


Figure 8: Soil at permanent wilting point

Eventually the soil reaches a point when the plant can no longer extract moisture. This is called the permanent wilting point (Figure 8).

Once the soil has passed this point, water is held by the soil so tightly that the plant cannot extract it and will start to die from lack of water.

Total Water Holding Capacity of soil

The total water holding capacity of saturated soils is generally 400–480 mm of water per metre of soil depth. The approximate volume of water held at **saturation point** in seven soil textures is shown in Figure 9.

Although most soils have similar total water holding capacities, the amount of water actually available for use by the plant varies greatly. The variation is due to the different soil textures and their influence on soil moisture.

The shaded section in the middle of each column shows the average amount of total water available to plants. Water held below permanent wilting point is shown by the bottom section of each column, and free-draining water (above field capacity) is shown in the top section.

For example:

- Sand holds about 70 mm of water per metre of soil depth below permanent wilting point, 60 mm (the shaded section) is the total water available to plants, and the remaining 270 mm is the free-draining water between field capacity and saturation.
- Medium to heavy clay holds slightly more water, but 250 mm is held below permanent wilting point, 140 mm is available to plants, and only about 20 mm is free draining above field capacity.
- Sandy loams, loams, clay loams, and self-mulching clays hold a similar total volume of water. Self-mulching clays have the greatest total available water that plants can use, followed by the loams, clay loams, and light clays.

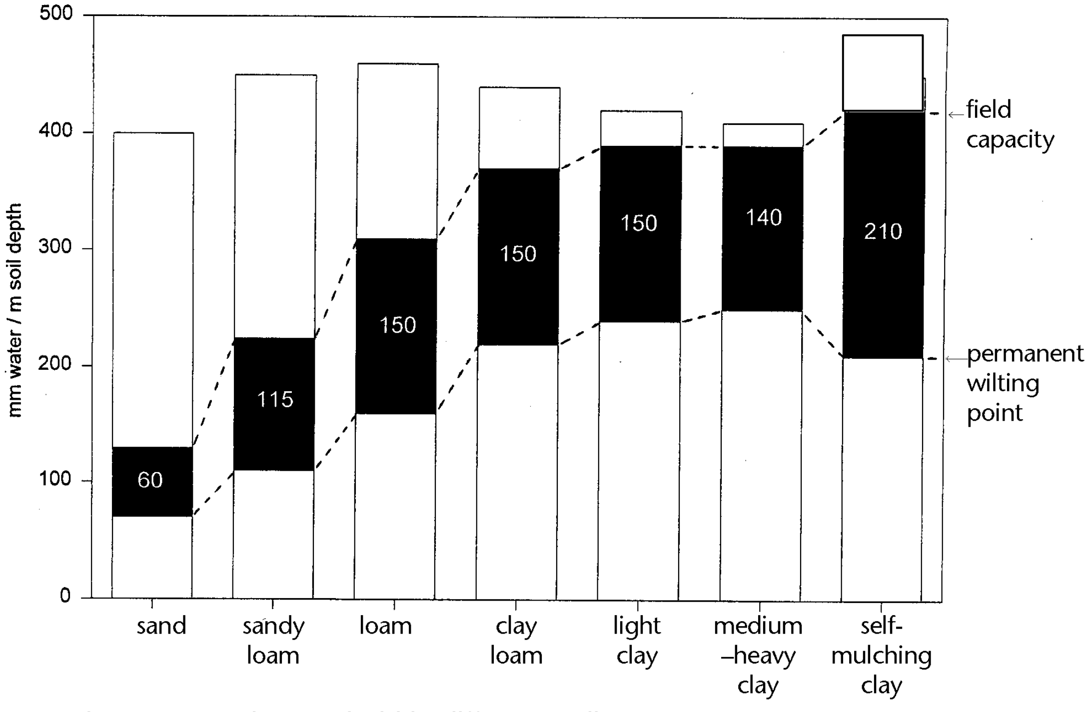


Figure 9: Total water held in different soils

Readily available water (RAW)

A plant cannot use all of the water held in the soil. Only the water between field capacity and permanent wilting point is available to the plant. However, as level of soil water approaches the permanent wilting point the plant has to work harder to obtain the water. This may cause unnecessary stress for the plant. To improve water use efficiency, irrigators must work with the water that can be readily removed from the soil by the plant. That is, the readily available water, or RAW.

RAW is expressed in millimetres per metre (mm/m) and indicates the depth of water (mm) held in every metre (m) of soil depth that can be readily removed by the plant. RAW can be calculated for the total depth of soil examined. However, for irrigation management it is more useful to only calculate the RAW of the plant's effective rootzone. In the following examples, we work out RAW for the full soil profile and then determine the effective rootzone RAW of a particular crop.

To achieve high yields without creating excess drainage you need to know the RAW for each crop and block.

When to irrigate (refill point)

After the readily available water has been used, plant roots cannot as easily extract water from the soil. This point is referred to as the refill point (Figure 10). As its name suggests, refill point is the time to irrigate. Once the RAW has been used, the plant has to use its energy to extract water rather than putting that energy into growth and reproduction.

The drier the soil is, the more water it needs to return to field capacity.

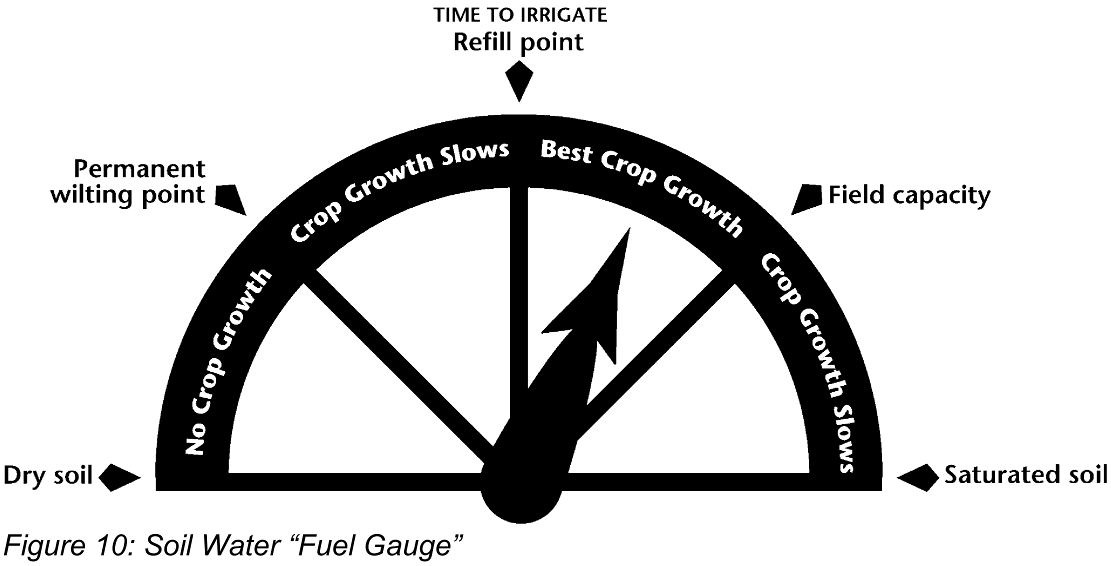


Figure 10: Soil Water "Fuel Gauge"

Calculating Rootzone RAW

The best way to determine the RAW for a particular situation is dig some holes and get your hands dirty. The RAW stored within the effective rootzone can be calculated by measuring the thickness of each soil layer (in metres or parts of a metre), determining the soil texture of each layer, and then multiplying the thickness by the appropriate RAW value as shown in Table 2.

Table 2 shows the approximate amount of RAW stored in six soils for a range of tension levels. You need to use the appropriate column (A to D) in the table to calculate your RAW.

In general, soft leafy crops wilt very quickly, therefore to calculate likely RAWs for these crops choose values from column A (‘sensitive’ crops). You should also use this range for plants that are susceptible to water stress or that have underdeveloped root systems.

Trees and vines that have a well-developed root system can exert a moderate to strong tension on the soil. Figures from columns B or C can be used for these. When calculating the RAW for crops it is important to only use the effective rootzone.

For hardy crops and those that require managed water deficits, choose column D (–8 to –100 kPa). To simplify the calculations in the rootzone RAW examples in these notes, we use RAW values from column C (most pastures, Summer crops and wine grapes).

Table 2: RAW and AW values for different soil textures

Water Tension *	**To –20 kPa**	**To –40 kPa**	**To – 60 kPa**	**To –100kPa**	**To –1500 kPa**
	A	**B**	**C**	**D**	**E**
	Water-sensitive crops such as vegetables and some tropical fruits should be irrigated.	Most fruit crops and table grapes, most tropical fruits.	Lucerne, most pasture, crops such as maize and soybeans, and grapes**	Annual pastures and hardy crops such as cotton, sorghum and winter crops	AW is the total water available in the soil. Plants stress well before this level is reached
Soil texture	**Readily Available Water RAW (mm/m)**				**AW (mm/m)**
Sand	*35*	*35*	*35*	*40*	*60*
Sandy loam	*45*	*60*	*65*	*70*	*115*
Loam	*50*	*70*	*85*	*90*	*150*
Clay loam	*30*	*55*	*65*	*80*	*150*
Light clay	*25*	*45*	*55*	*70*	*150*
Medium to heavy clay	*25*	*45*	*55*	*65*	*140*

Tension is 0 kPa at saturation point. The figures are only approximate.

**(Except when partial rootzone drying is being practised on wine grapes) should be irrigated before –60 kPa is reached.

The steps involved in calculating RAW are:

Step 1: Identify and measure the thickness (depth) of the soil layers

Step 2: Determine the soil texture of each layer

Step 3: Select the crop water tension group from table 2 and identify the RAW value for each soil layer

Step 4: Multiply the thickness of each soil layer by its RAW value to determine the RAW for the soil layer

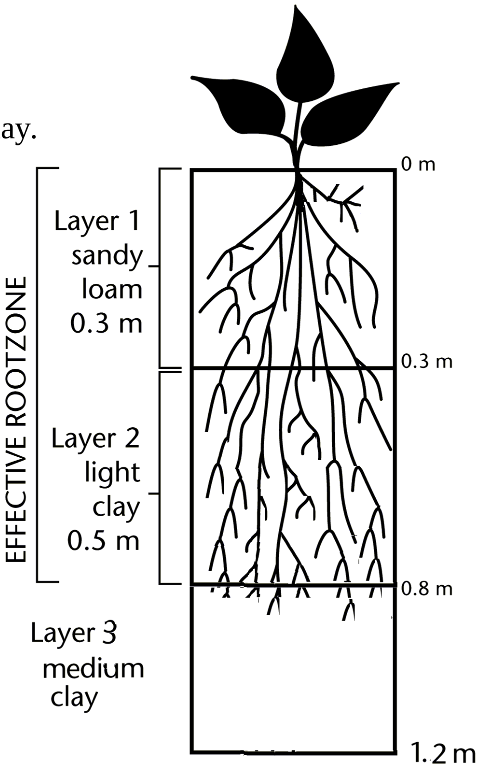
Step 5: Add up the RAW for each soil layer to obtain the total soil profile RAW

Step 6: Identify the effective rootzone

Step 7: Determine the RAW within the crop's effective rootzone by adding the RAW of each layer (or part layer) within the rootzone

Calculating rootzone RAW: Example 1

Lucerne is growing in 0.3 m of sandy loam over 0.5 m of light clay.
For a soil pit at this site the calculations would be:



STEP 1: Identify and measure the soil layers.

Layer 1: 0 to 0.3 m = 0.3 m

Layer 2: 0.3 to 0.8 m = 0.5 m

Layer 3: 0.8 to 1.2 m = 0.4 m

STEP 2: Determine the soil texture of each layer

Layer 1: Sandy loam

Layer 2: Light clay

Layer 3: Medium clay

STEP 3: Select the crop water tension using table 2 and identify the RAW for each soil layer.

RAW values for each layer in column C (for lucerne) water tensions are:

Layer 1: Sandy loam = 65 mm/m

Layer 2: Light clay = 55 mm/m

Layer 3: Medium Clay = 55 mm/m

STEP 4: Multiply the thickness of each soil layer by its RAW value.

Layer 1: 0.3 m x 65 mm/m = 19.5 mm

Layer 2: 0.5 m x 55 mm/m = 27.5 mm

Layer 3: 0.4 m x 55 mm/m = 22 mm

STEP 5: Add up the results of step 5 to obtain the total **Soil Profile RAW**

Soil Profile RAW = Layer 1 RAW + Layer 2 RAW + Layer 3 RAW

= 19.5 + 27 .5 + 22

= 69 mm

STEP 6: Identify the effective rootzone

Effective rootzone = 0.8 m (Layer 1 and Layer 2 only)

STEP 7: Add up the RAW stored within the crop's effective rootzone.

Layer 1 RAW + Layer 2 RAW

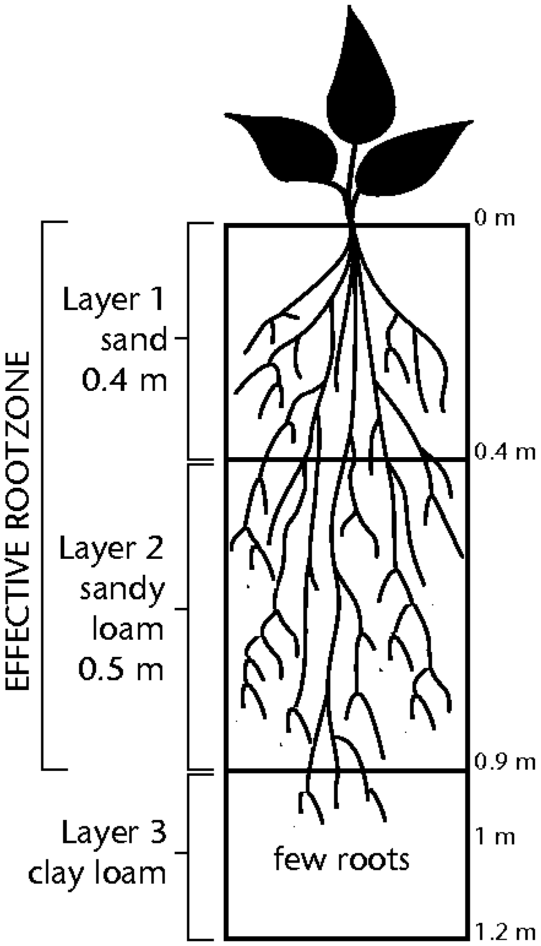
19.5 mm + 27.5 mm

Rootzone RAW = 47 mm

In this example, 47 mm of water is readily available in the soil for this plant's use. That is, 47 mm of water is required to refill the plant's effective rootzone when the suction reads -60 kPa.

Calculating Rootzone RAW: Example 2

Wine Grapes are growing in 0.4 m of sand over 0.5 m of sandy loam and 0.1 metres of clay loam. The effective rootzone for the plant extends through the top two layers only.



Layer 1: sand from 0 m to 0.4 m = 0.4 m

RAW of layer 1 = 0.4 m x 35 mm/m

= **14 mm**

Layer 2: sandy loam from 0.4 m to 0.9 m

= 0.9 - 0.4

= 0.5 m

RAW of layer 2 = 0.5 m x 65 mm/m

= **32.5 mm**

Layer 3: clay loam from 0.9 m to 1.2 m
= 1.2 - 0.9
= 0.3 m

RAW of layer 3 = 0.3 m x 65 mm/m
= **19.5 mm**

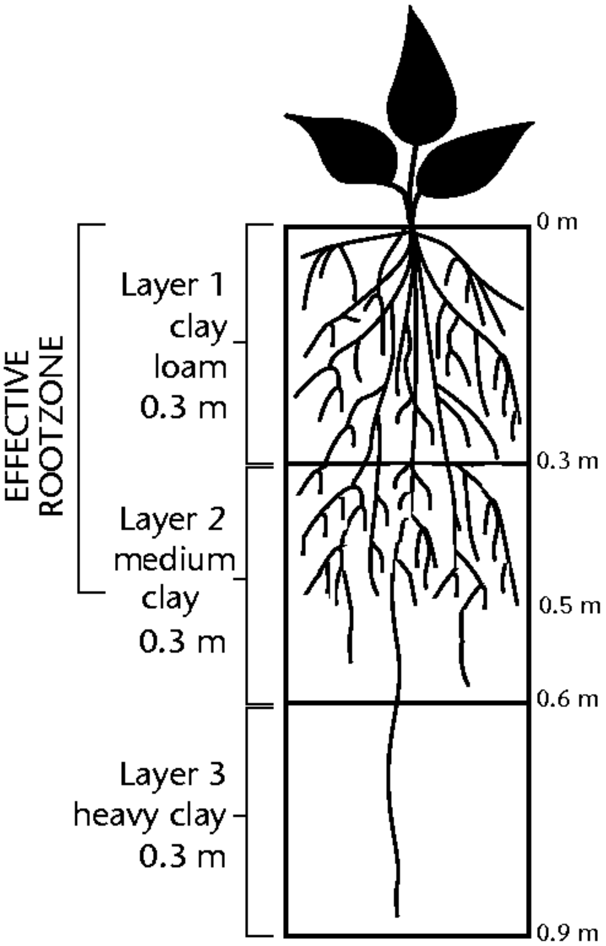
Total Profile RAW
(all three layers to 1.2 m)
14 + 32.5 +19.5
= 66 mm

⚠ **NOTE**

Layer 3 is deeper than the effective rootzone. Therefore we do not include it in the sum for the **Rootzone RAW** (step 7)

Calculating rootzone RAW: example 3

A soybean crop is growing in 0.3 m of clay loam over a layer of medium and heavy clay. Each soil layer is about 0.3 m thick. Although some roots extend to 0.9 m, the effective rootzone is only 0.3 m.



Layer 1: Clay loam from 0 m to 0.3 m

RAW of layer 1 = 0.3 m x 65 mm/m
= 19.5 mm

Layer 2: Medium clay from 0.3 m to 0.6 m

RAW of layer 2 = 0.3 m x 55 mm/m
= 16.5 mm

Layer 3: Heavy clay from 0.6 m to 0.9 m

RAW of layer 3 = 0.3 m x 55 mm/m
= 16.5 mm

The total RAW for the soil profile to 0.9 m is the total of all three figures, however the **rootzone is layer 1 and only part of Layer 2 (where most roots are)**

Layer 2 Rootzone RAW therefore is

RAW 2 x Layer 2 Rootzone
55 x 0.2
= 11 mm

Thus, the Rootzone RAW for this example is

RAW 1 + RAW 2 (part)

19.5 mm + 11 mm

= 30.5 mm

Activity 2: Calculating RAW

Complete the RAW calculations for the exercises in your workbook.

DOWN PIT

A good way to determine the significant features of your soils and determine their RAW is to dig a **soil pit**. This is a pit dug by a backhoe to at least 0.3 metres below the rootzone of the crop. Do not dig pits greater than 1.5 metres deep without shoring and always remember safety first. A soil pit allows you to ‘get up close and personal’ with your soils. It will also give you an appreciation and practical reality of the topics discussed earlier in this Workshop.

In the soil pit, you will clearly see the layers that make up the soil profile. The layers may be identified by changes in colour and/or appearance. Once you have identified the layers, you will be able to measure them and determine their texture and other characteristics.

The soil pit should also reveal the extent of the root system so that you can determine the effective root zone. The root zone will vary with the age of the crop, crop type, and other soil features. It is important to record accurate details such as the date, crop, crop age (for permanent plantings), and other significant features.

A sample soil pit survey sheet is included in this guide. Blank soil pit survey forms will be found in your workbooks. The soil pit survey sheet is designed to help you record and calculate the important aspects of your soils.

A soil pit will form part of your soil survey. A soil survey must be conducted over a series of sites selected based on topography (landforms, slopes, rises, crests, flats), crop type and irrigation system. At each site, a vertical picture of your soil is obtained by recording details of the soil from the surface down to approximately 1.5 metres.

Methods of surveying soil

Step 1: Dig your “Observation Hole”

Dig a series of holes with a hand auger, post-hole digger, backhoe, or pick and shovel to a depth of at least 0.3 metres below the rootzone of the crop, and preferably to 1.5 metres.

Ensure that you follow all the relevant work safe practices when digging and examining your soil pit

If using an auger or post hole digger:

- Make sure when you are extracting the soil that you lay it out in the same order that it comes from the hole. It is also important to only go down 5 to 10 cm at a time. This way you avoid mixing the soil and get greater accuracy when you measure the depth of each layer. Note any changes in the colour or feel of the soil as you dig down the profile.
- (Hint: When it gets more or less difficult to turn a soil auger, this often indicates a change in soil texture.)
- Use a shovel to enlarge the hole. Clearly separate soils from different layers using a knife or screwdriver.

Step 2: Identify and measure the depth of the effective rootzone.

There are blank soil survey sheets for you to complete in your workbook.

Step 3: Measure and record the layers of the soil

Record each change in colour as well as the presence of healthy crop roots within each soil layer.

Step 4: Identify the soil textures

Take a small sample of soil from each layer and identify the soil texture (use the hand method).

- Complete any other tests appropriate for your area, e.g. pH or fine carbonates.
- Record the results on a soil survey sheet.

Step 5: Move onto the next survey site

Repeat the same procedure for every site surveyed.

Locating soil survey sites

Sites are chosen that represent all apparent variations in your irrigation area as indicated by topography, colour change, workability, and production differences. In hilly country, select sites on crests, mid-slopes, and lower areas. Ensure sites are located in both poor and good production areas to allow comparisons.

Sites must be representative of the larger areas, so avoid drainage depressions, headlands, eroded areas, old stock camps, fertiliser dumps and so on.

The scale of grid used in your soil survey depends on the area to be surveyed and the topographic variation of the land.

- Generally, where the land use is crops or pastures and soil and landform variations are not great, a 200 m x 200 m grid is adequate.
- Alternatively, sampling sites can be closer along a line at right angles to changes in topography and expected changes in soil type.
- For permanent horticulture, a grid of 75 m x 75 m should be used. This is the grid size professional soil surveyor's use.

Soil survey holes are generally dug to a depth of 1.5 metres, preferably with a backhoe.

In land where rice is to be grown, an electro-magnetic (EM) soil survey should be completed before soil texture and depth are assessed. An EM survey will reveal 'hot spots' and areas that require more detailed soil surveying.

Information from soil surveys is recorded in a variety of formats. In general, each site will record soil textures, RAWs, and other significant features. The soil survey report will also indicate where on your property the survey sites were conducted.

You should discuss with your local soil surveyor about what type of survey is necessary for your particular country and enterprise. It is important that you are able to interpret and use the data from your soil survey in your irrigation and drainage management plan.

In addition to soil texture and the plant rootzone depth, your soil survey map should also show any features listed below that are relevant:

- Acid soils
- Acid sulphate soils
- Hard setting or crusting
- Hardpans
- Compacted soils
- Saline patches
- Results of any electromagnetic surveys
- Rocky soils
- Soil erosion
- Shallow watertable
- Flood-susceptible
- Leaking channels
- Awkward paddock shape or size
- Difficult slopes (too steep, too flat)
- Access problems
- Distance from water source
- Lack of shelter
- Weed infestation
- Herbicide resistance and residues
- Plant diseases
- Trees and windbreaks
- Watercourses

Activity 3: Conduct a soil pit survey

Complete the Soil Pit Survey Activity outline in your workbook.

WATER INFILTRATION INTO SOIL

Water can only infiltrate into the soil at a certain rate, and the longer that water is applied, the slower this rate becomes. The rate that water can enter the soil is called the **infiltration rate** of a soil.

- With pressurised irrigation systems the rate water is applied must not exceed the soil's infiltration rate.
- With surface irrigation systems, the application at any one point must be long enough to allow enough water to enter the soil profile.

Exceeding the infiltration rate can (depending on the situation) result in soil damage and run-off. It can also cause erosion, loss of fertilisers, and excessive waterlogging of the rootzone in low-lying areas.

Infiltration rates can vary within a field as well as between fields. Infiltration mainly depends on soil texture, structure, porosity, and bulk density, but groundcover, slope, and dispersion also influence it. Infiltration usually decreases with soil depth so application rates may need to be adjusted if the water movement through the subsoil is slower than through the topsoil.

Table 3 shows the range expected for the six main texture classes.

Table 3: Average infiltration rates for some soil types

	Application rate (mm/h)		Infiltration rate range (mm/h)
Texture group	Average soil structure	Well-structured soil	
Sands	50		50-700
Sandy loam	30	45	50–700
Loam	30	45	5–300
Clay loam	10	25	2.5–300
Light clay	2.5	5	0.5–40
Medium-heavy clay	2.5	5	0.1–40

Adapted from Charman, P.E.V. and B. W. Murphy (eds) 2000, *Soils: their Properties and Management*, in association with the NSW Department of Land and Water Conservation, 2nd edn, Oxford University Press, Melbourne.

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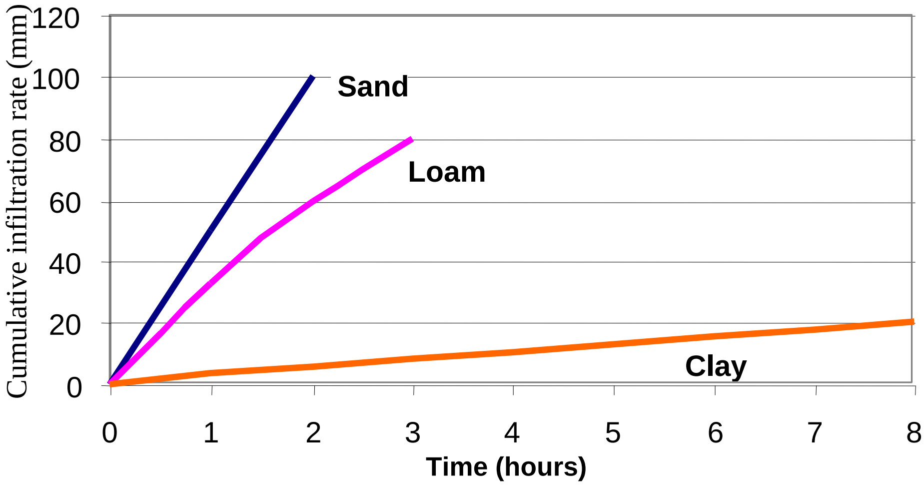


Figure 11: Cumulative infiltration of water

Figure 11 illustrates how water infiltrates in different soils over time. For example, if 30 mm/h is being applied to a loam (see Table 3), and the application continues for 3 hours, the total amount applied would be 90 mm. This is above the cumulative rate for loam (80 mm at 3 hours), so run-off will occur.

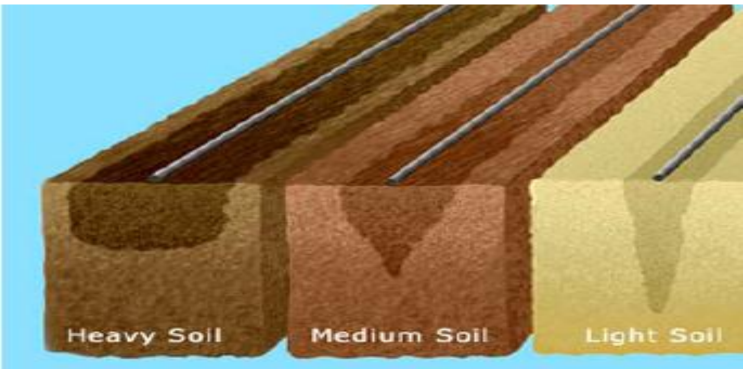


Figure 12: Water movement through different soil types

Figure 12 illustrates how water moves in different soil types. Typically, the more free draining the soil type the greater the downward movement of water and the narrower the horizontal wetted area.

Application rates can safely be increased if:

- Soil is well structured (especially self-mulching clays)
- Soil aggregates are stable when wet
- Soil is resistant to erosion
- Moderate soil salinity is present (where structure is improved by the flocculating effect of salinity)

Application rates should be reduced if:

- Soil has weak or unstable structure (including single grain size and massive structure)
- Soil is bare
- Slope is more than 5% (a commonly used maximum infiltration rate on steeper slopes is 10 mm/h)
- Soil is sodic (above ESP 6%)

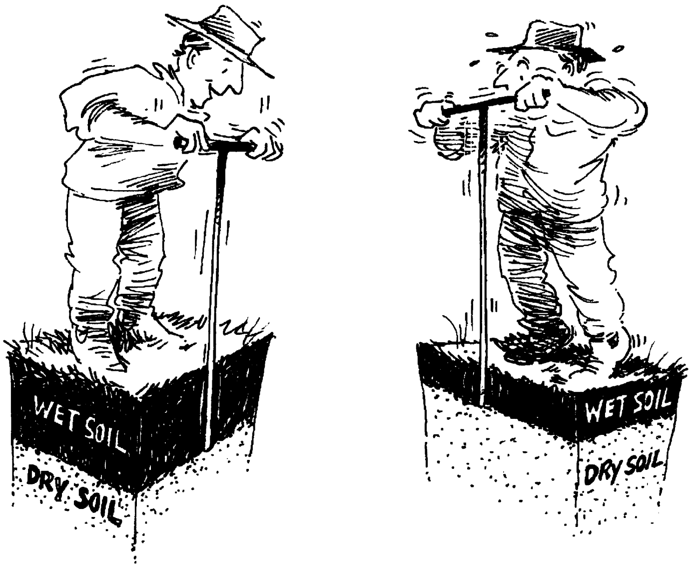
The infiltration rate of a soil may be increased by management techniques such as:

- Opening up the surface (breaking up crusts, hardpans and hard-set layers, adding gypsum to sodic soils)
- Relieving compaction (cultivating, coring, spiking, splitting)
- Improve soil structure (increasing organic matter, including a pasture phase in rotation, growing deep-rooting plants such as lucerne)
- Breaking up impermeable layers
- Retaining more surface cover (stubbles, pastures)
- Overcoming water repellence by the methods above, especially organic matter in the topsoil

Activity 4: Infiltration test

In this activity, you measure the infiltration rate at a particular point.

Note that an infiltration test at the surface is only an indicator of what is happening in the top layer of soil. It is also helpful to use a soil probe to 'feel' the depth that water has reached, especially in duplex soils.



Judging the infiltration depth using a soil moisture probe

OTHER SOIL TESTS

There are many other features of soil that are important for irrigation. However due to the diverse range of soil types and irrigation enterprises the importance and value of these features will vary.

In addition to the soil features and tests we have already mentioned, there are other tests that may be used to classify soil and determine its limiting factors or weaknesses. On the next pages, we have described some simple soil tests to enable you to further assess your soil.

Not all the tests will be applicable to your soil, but many of them will assist you in managing your soil and improving productivity.

NOTE: The following tests are not essential to fulfil the learning outcomes of this workshop, but the section that follows them on water quality, **is** required.

Structure

Soil structure refers to the way soil particles and organic matter are arranged to form aggregates and pore spaces. With the exception of loose sands, soil particles are held together in lumps known as **aggregates**.

In a well-structured soil, roots can readily penetrate the aggregates and water and air can move freely through the pores in the aggregate. This means that the soil is rarely saturated with water or starved of oxygen. A well-structured soil will also:

- Resist erosion
- Allow crop seedlings to emerge easily
- Have ideal drainage, infiltration and water holding capacity

The strength of the aggregate is important. A soil with good structure has aggregates that may be broken between thumb and forefinger. The aggregates generally form a loose, soft, friable soil. Aggregates that cannot be broken or shatter into dust when forced have a poor structure.

How to assess soil structure:

1. Take a spadeful of soil and turn it onto the ground.
2. Note the proportion of soil that has remained as individual soil aggregates.
3. Note the soil structure and record your result in the ‘comments’ section of the soil pit survey sheet of your Workbook.

Soils within each texture class that have good soil structure are able to hold more readily available water than those with poor to moderate structure. The figures in Table 2 are therefore low for soils that are naturally well structured (such as self-mulching clays) or where structure is good due to high organic matter content.

Testing for slaking

Slaking and dispersion describe processes where soil structure breaks down. If a soil is not stable, it slakes and disperses quickly when it is wet. Slaking is commonly caused by over-cultivation or occurs in soil with little organic matter.

Slaking is the breakdown of aggregates into smaller aggregates as air in the soil pores is forced out by water. Soils that slake form hard-set layers at the surface when they dry out. Increasing the organic matter content of a soil may reduce slaking, as this helps to form more aggregates that are stable when wet.

Activity 5: Slaking soils

Complete the slaking activity outlined in your workbook.

Testing for sodicity and dispersion

Sodicity

If a soil is 'sodic', it has a higher than usual proportion of sodium ions (electrically charged atoms) held on the clay particles. These sodium ions are easily loosened by water. The result of the dislodging of sodium ions is that sodic soils easily break down and disperse upon wetting. Soils with exchangeable sodium (ESP) above 6% are called 'sodic'.

A way of reducing sodicity is to replace some of the sodium with calcium, commonly applied in lime or gypsum. The calcium forms a stronger bond between the clay particles, making them less susceptible to dispersion. Other possible solutions are to alter farming practices to retain organic matter in the topsoil and to use non-inversion tillage to prevent the more sodic subsoils from being brought to the surface.

Dispersion

Dispersion is when soil slakes when wet, then further breaks down into individual particles of sand, silt and clay. A dispersive soil is structurally unstable and forms crusts when it dries. In dispersive subsoils the clay particles clog pore spaces, forming a barrier to water, air, and root movement.

Highly dispersive soils erode easily and are likely to cause problems through poor seedling emergence and workability. Dispersion can be managed by applying gypsum to keep the clay particles bonded together as aggregates, and to increase the level of calcium on the clay particles, which displaces some of the sodium.

Activity 6: Sodicity and dispersion

If you suspect that may have sodicity or dispersion problems with your soils, complete this activity in your workbook.

Testing soil pH

Soil pH is a measure of how acidic or alkaline the soil is. If a soil is too acidic or too alkaline then plants will not grow.

pH is measured on a scale of 1–14, with highly acidic at 1 and highly alkaline at 14. pH 7 is neither acid nor alkaline, it is neutral. Distilled water has a pH of 7. Lemon juice has a pH of around 3, while caustic soda has a pH of around 12.

pH is important as the further the pH moves from neutral, the more nutrients are locked into the soil and become unavailable to plants. The growth and yield of most plants is reduced in soils with pH below 5 (acidic) or above 8 (alkaline).

Acid sulphate soils have severe problems with low pH and must be avoided.

Toxicities of aluminium and manganese are common problems in most soils where pH drops below 5.

Soil acidification is increased by many agricultural practices, including the use of some fertilisers. Lime is generally added to make soils less acidic.

You can measure soil pH with a simple test kit available from rural suppliers. It consists of an indicator dye, barium sulphate powder, mixing board, and colour chart.

What you need

- One spoonful of soil from each layer
- The pH test kit including spoon or spatula (such as a paddle-pop stick)
- Soil survey sheet for recording results

Activity 7: Determining soil pH

Testing for fine soil carbonates

Note: this test is only relevant in the Mallee soil areas or in areas where high levels of limestone are present. It is also useful to determine where not to grow lime-sensitive plants.

The amount of carbonate (lime) contained within your soil affects your crop's ability to obtain nutrients from the soil. You can usually see from the soil colour that carbonate is present, but the acid test can be used to give a measure of its strength. To test for carbonates, take a sample of soil and apply a drop of hydrochloric acid (3%) and record the reaction.

Warning: Always add acid to the water. Never add water to acids.

Activity 8: Soil carbonates

Complete the Soil Carbonates Activities if you suspect that your soils may have a problem with Limestone.

Testing for soil salinity

Salts occur naturally in the environment. All water has some salt in it, and as plants use water from the soil, the salt is left. In areas where evaporation greatly exceeds rainfall it is likely that there will be a build-up of salt: in these cases, additional irrigation water (a leaching fraction) is required to flush excessive salts and maintain the level below that harmful to plants.

Depending on the soil type, if groundwater is within 2 metres of the surface, capillary action may elevate the groundwater into the rootzone. If the ground water is saline, this may cause the salt level the soil to build up. The result will be that roots will *lose* water through salt dehydration. In such cases, it is important to reduce the groundwater level.

Soil salinity can be measured using a simple field test. This will give an indication of the salts in the soil of your farm. The test is reasonably accurate in indicating whether salts may cause yield losses or soil problems, but, to be certain, we strongly recommend that you send soil samples away for laboratory testing. (Soil laboratories are listed in the Yellow Pages.)

Activity 9: Soil salinity

Complete the Soil Salinity Activity in your workbook if you suspect that you have a soil salinity problem.

IRRIGATION WATER QUALITY

As an irrigator you need to be familiar with water quality issues, and be able to take water quality samples, interpret the results, and put any changes recommended into practice.

The quality of the water used for irrigation is extremely important. Depending on your locality and source of water, you may have a problem with irrigation water quality. Water quality can vary over time and by degree. If any of the issues covered below are common in your locality, you must monitor the quality of your irrigation water. Simple tests can be performed that will indicate the quality and effect of water on a particular crop and your irrigation equipment.

Growers have been known to irrigate more frequently on seeing a problem in their crop, when, in fact, it was the poor quality of the water that was the cause of the problem.

How often should water be tested?

How often you test your water depends on the source, flow rates and previous water quality problems. Iron levels, for instance, do not change often, so only infrequent testing is required, but salinity and pH levels can fluctuate rapidly with changes in flow rates. Similarly, levels of nutrients and pesticides are not constant. Of course, certain crops are more tolerant than others of water quality and tolerance can change at different stages of growth.

Common water quality problems are:

- Salinity And Electrical Conductivity
- The pH Levels (Acidity Or Alkalinity)
- Sodicity
- Chloride
- Calcium Carbonate Saturation Index
- Soluble Iron
- Turbidity
- Nutrients
- Pesticides

Salinity

The biggest problem with water quality is salinity. Testing the salinity of the water indicates whether the water is suitable for irrigation or if dilution (shandying) with fresh water is necessary (or feasible) before use. Groundwater and reuse surface water should be tested regularly before being used on crops.

Water salinity can be measured using a pocket-sized salinity meter or by sending samples to a laboratory for analysis. The salinity is measured by reading the electrical conductivity of the water. As the salt level increases, so does the conductivity. Water salinity measurements are expressed in ‘micro siemens per centimetre’ (μS/cm) or sometimes as ‘decisiemens per metre’ (dS/m).

The old units for measuring salinity were milligrams of salt in one litre of water, often expressed as parts per million (ppm). This was a measure of the total soluble salts. Conductivity is a more accurate indication of salinity than total soluble salts. As a rough approximation, you can convert your salinity readings to parts per million (ppm) as follows:

- Micro siemens per centimetre multiplied by 0.64 = ppm
- Decisiemens per metre multiplied by 640 = ppm

How salinity affects plants

Salts in irrigation water affect crop performance in several ways.

- Dissolved salts in the rootzone can affect the availability of water. Salts out-compete plant roots for moisture, reducing growth and yield.
- Salts reduce shoot growth and yield.
- There are toxic effects of certain elements such as chloride, sodium, or boron.

Other factors, such as the soil’s ability to drain, the method of irrigation, the level of rainfall, and the plant’s natural tolerance to salinity, affect the ability of plants to cope with salinity. Some crops can accept much higher salinity levels than others.

General recommendations regarding the salinity of water used for irrigation:

- If salinity is less than 0.8 dS/m, the water is suitable for most crops and pastures on moderately to well-drained soils.
- If salinity is more than 2.3 dS/m, the water is not suitable for continuous use for most crops and pastures.

pH

pH is a measure of the acidity, neutrality or alkalinity of the water. It is measured on a scale of 0 to 14 with 7 being neutral. Readings below 7 are acidic and those above are alkaline. Water with a pH reading between 6.0 and 8.5 is generally suitable for irrigation.

Highly alkaline water with high carbonate and bicarbonate levels can affect plant uptake of calcium, magnesium, and some trace elements. It also tends to precipitate calcium carbonate. Carbonate and bicarbonate levels of up to 150 mg/L should be acceptable, while 350 mg/L would be a level for concern.

This loss of calcium causes an imbalance of ions in favour of sodium, causing problems associated with sodicity. Water lower than pH 6.0 or higher than pH 8.5, when used in spray mixes, can reduce the effectiveness of some pesticides. Check with your pesticide supplier.

Sodicity

Another water quality problem facing irrigators is the concentration of sodium ions (Na+) in the water. An imbalance of sodium ions relative to calcium and magnesium ions is referred to as the Sodium Adsorption Ratio (SAR).

High SAR levels cause poor water penetration through the soil, poor drainage, and low aeration levels. Soils affected often have a hard, blocky structure and surface crusting.

A high proportion of Australian irrigated soils is sodic and has a degraded structure that limits the movement of water and air and the growth of roots. Continued irrigation with saline sodic water will lead to further sodification of soil layers and concentration of salt in the rootzone. Usually gypsum is applied to combat high sodium levels.

Using sodic water

The following are general guidelines for the use of sodic water for irrigation:

- Low sodicity water (SAR <3) can be used for irrigation on all soil types with little risk of developing or aggravating a soil sodicity problem.
- Medium sodicity water (SAR 3–12) may cause problems in both sodic and non-sodic clay soils. Water in this category can be used on coarse-textured soils (sands and loams) or organic soils. Applications of gypsum promote the leaching of sodium in clay soils.
- High sodicity water (SAR >12) is generally unsatisfactory for irrigation except at medium salinity levels. However, the salinity level needed to counteract the high SAR would affect the yields of most crop and pasture species. The addition of gypsum reduces the impact of the large concentration of sodium.

Chloride

High chloride levels in water may cause poor growth and death to sensitive plants, particularly if sprayed onto the leaves. If chloride is applied by drip irrigation and not on the plant, levels below 140 mg/L (140 ppm) are generally acceptable. Readings between 140 to 350 mg/L should be treated with caution, and any above 350 mg/L should not be used.

Calcium carbonate saturation index

This is an index determined from the relationship between pH, salinity, alkalinity, and hardness. It indicates if water is likely to cause corrosion of metal components, or blockages.

Figures between –0.5 and +0.5 are usually acceptable, but a figure of –0.5 indicates possible corrosion problems. Above +0.5 indicates possible blockages.

Iron

Soluble and bacterial iron can cause blockages to irrigation components. If water with high soluble iron levels is applied by spray, it can discolour leaves and reduce the efficiency of transpiration and photosynthesis. Iron levels as low as 0.1 mg/L (0.1 ppm) can cause problems with blockages in micro-irrigation systems. In such cases, the water supply may benefit from aeration or filtration.

Turbidity

Turbidity is a measure of water clarity and an indicator of the amount of solids in the water. Turbidity is usually high in western NSW streams and rivers.

The major cause of turbidity is human activity, particularly on sodic soils. Removal of vegetation and depletion of organic matter exposes sodic soil. This readily disperses on wetting and the dispersed clay particles stay suspended in water for long periods, causing a build-up of sludge in irrigation components.

Odour may indicate decaying organic material, and this can cause a build-up of slime in pipes and drippers. Algae can also cause rapid blockages of filters and drippers.

Turbidity is measured in the field by submerging small white discs in the water until they are no longer visible. The depth at which this occurs is then recorded. The scientifically accepted measurement units are NTU (nephelometric turbidity units).

Nutrients

An excessive level of nutrients such as nitrates and phosphates in drainage water encourages algal blooms and the growth of aquatic weeds.

Blue-green algae occurs on bodies such as lakes, channels, and farm dams, and relies on sufficient nutrients (particularly phosphorus), still, warm conditions, sunlight and relatively low turbidity for outbreaks to occur.

Excessive nutrients in water result in prolific growth of aquatic weeds and algae, restricting water flows and reducing water quality due to the production of algae and bacterial toxins. Blue-green algae can be toxic to animals and humans through body contact and ingestion.

Pesticides

Irrigation communities must be aware of the problem of pesticide contamination of water supplies. Some chemicals can cause environmental damage at very low concentrations. Pesticides can contaminate irrigation water by direct application, spillage, drift, careless disposal, and run-off.

All landholders need to follow best management practice in pesticide use and disposal to minimise the chance of this type of contamination.

Activity 10: Measuring water quality

Complete the water quality activity in your workbook.

Your soil survey

Your soil survey is an essential part of the irrigation and drainage management plan (IDMP).

Map soil details onto your plan so you can easily see where soil types change, and develop your irrigation layout to suit. For example, areas with similar soil types and RAW need similar irrigation management.

There are three essential pieces of information that should be noted. These are:

- Soil texture (for example, shallow sandy clay loam, red clay)
- Soil Profile RAW (for a depth of 1.2 meters)
- Rootzone RAW (your estimate)

In addition, your soil survey will indicate any other significant soil and water features.

In sample IDMPs and other farm plans, you may see maps with soil survey overlays. On these overlays, the soil survey results have been mapped to the test locations within the area.

Activity 11: Basic soil survey

Describe each soil type you identify on your property. Use the blank soil survey sheets from your workbook.

Appendix 1 More detailed Soil texture table

Table 1. Guide to common soil textures

Soil texture	Ribbon length	How the soil behaves or feels	% Clay
Sand (S)	Nil	Coherence nil to very slight, cannot be moulded; sand grains adhere to fingers	Less than 5%
Loamy sand (LS)	5 mm	Slight coherence; sand grains of medium size can be sheared between thumb and forefinger.	5–10%
Clayey sand (CS)	5–15 mm	Slight coherence, sticky when wet, sand grains stick to fingers, discolours fingers. Little or no organic matter	5–10%
Sandy loam (SL)	15–25 mm	Coherent bolus but very sandy to the touch dominant sand grains are of medium size and readily visible	10–20%
Light sandy clay loam	20–25 mm	Coherent bolus, sandy to the touch, dominant sand grains are of medium size and readily visible	15–20%
Loam (L)	About 25 mm	Loams may form a thick ribbon. Soil ball is easy to manipulate and has a smooth spongy feel with no obvious sandiness. Greasy to touch if organic matter present	
Sandy clay loam (SCL)	25–40 mm	Strongly coherent bolus, sandy to touch medium sand grains visible in a finer matrix	20–30%
Clay loam (CL)	40–50 mm	Strongly coherent and plastic bolus, smooth to manipulate	30–35%
Sandy clay (SC)	50–75 mm	Plastic bolus, sand grains can be seen and felt	35–40%
Light clay (LC)	50–75 mm	Plastic behaviour evident, smooth feel easily worked, moulded and rolled into rod. Rod forms a ring without cracking	35–40 %
Light medium clay (LMC)	75–85 mm	Plastic bolus; smooth to touch, slight to moderate resistance to shearing	40–45%
Medium clay(MC)	Greater than 75 mm	Smooth plastic bolus; handles like plasticine, can be moulded into rods without cracking, resistant to shearing	45–55%
Heavy clay (HC)	Greater than 75 mm	Smooth, very plastic bolus; firm resistance to shearing Will mould into rods. Handles like stiff plasticine. Very sticky and strongly coherent. Rods form a ring without cracking	Over 50%