Training material for extension advisors in irrigation water management

Volume 2: Technical Learner Guide
Part 2: Assessing of soil resources

JB Stevens & MC Laker

TT 540/2/12

WATER RESEARCH COMMISSION

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Report to the

Water Research Commission

University of Pretoria

NQF
Level 5

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Volume 2: Technical learner guide
Volume 3: Extension learner guide

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Before we start...............

Dear Learner ....this learner Guide contains information to acquire the basic knowledge and skills leading to the unit standard:

Title: Manage and control resources in sustainable manner

US No: 116384 NQF Level: 5

Title: Manage soil systems

US No: 116371 NQF Level: 5

Title: Implement soil fertility and plant nutrition practices

US No: 116371 NQF Level: 4

The full unit standards are available and can be cited on the SAQA website. Read the unit standards at your own time and if there are any questions or aspects that you do not understand, discuss it with your facilitator.

The unit standards are some of the building blocks in the qualification listed below:

Title	ID no	NQF Level	Credits
National Diploma: Plant Production	49010	5	120
National Certificate: Plant Production	49009	4	120
National Certificate: Animal Production	49011	5	120

Assessment.........

You will be assessed during the course of the study (formative assessment) through the expected activities that you are expected to do during the course of the study. At the completion of the unit standard, you will be assessed again (summative assessment).

Assessment therefore takes place at different intervals of the learning process and includes various activities - some will be done before commencement of the program, others during the delivery of the program and others after completion of the program.

How to attend to the activities.......

The activities included in the module should be handed in from time to time on request of the facilitator for the following purposes:

- The activities that are included are designed to help gain the necessary skills, knowledge and attitudes that you as the learner needs in order to become competent in this learning module.
- It is important that you complete all the activities and worksheets, as directed in the learner guide and at the time indicated by the facilitator.
- It is important that you ask questions and participate as much as possible in order to be actively involved in the learning experience.
- When you have completed the activities and worksheets, hand it in so that the assessor can mark it and guide you in areas where additional learning might be required.
- Please do not move to the next activity or step in the assessment process until you have received feedback from the assessor.
- The facilitator will identify from time to time additional information to complete. Please complete these activities.
- Important is that all activities, tasks, worksheets which were assessed must be kept as it becomes part of your ***Portfolio of Evidence*** for final assessment.

Check your progress.......

Use the following checklist to determine your competency regarding this specific learning module.

Confidence level	I am sure	Still unsure	Do not understand and need help	Motivate your answer
Can you identify problems and troubleshoot correctly?				
Are you able to work well in a team?				
Are you able to collect the correct and appropriate information required for decision making?				
Will you be able to perform the observation expected in an organised and systematic way while performing your task as an extensionist?				
Are you able to communicate the information and newly gained knowledge well to experts?				
Can you base your tasks and answers on scientific knowledge that you have learned?				
Are you able to show and perform the activities required in this learning module correctly				
Are you able to link the knowledge, skills and competencies you have learned in this module of learning to specific duties in your job?				

How to use this guide ....

Throughout the learner Guide you will come across certain re-occurring notifications. These notifications each presents a certain aspect of the learning process, containing information, which would help you with the identification and understanding of these aspects. The following will be found in the learning material:

Study objective	What are the study objectives for a specific module? This provides an idea of the knowledge, skills and competencies that are envisaged to be
Activity	You will be requested to complete activities, which could either be group or individual activities. Please remember that the completion of these activities is important for the facilitator to assess, as it will become part of your ***Portfolio of Evidence.***
Definition	What does it mean? Each learning field is characterised by unique terminology and concepts. Definitions help to understand these terminology and concepts and to use it correctly. These terminology and concepts are highlighted throughout the learner guide in this manner.

My notes...................................

You can use this box to jot down some questions or notes you might have, concepts or words you do not understand, explanations by facilitators or any other remark that will help you to understand the work better.

What are we going to learn?

For each of the learning modules included in this learning area specific learning outcomes were set, which you need to be able to demonstrate a basic knowledge and understanding of:

Contents

Module 1
Introduction to soil

Study objective

After studying this module, the learner should be able to have a basic understanding of:

- The different soil components
- The different soil forming factors and their influence in the determining of soil properties
- To examine a soil profile and use the information with the development of an irrigation management plan

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1. IMPORTANCE OF SOIL IN IRRIGATED AGRICULTURE

Irrigated agriculture is very intensive agriculture. Since capital input costs are high, it is important that profitable irrigated agriculture must be sustainable for a long time. This means that careful selection of suitable soils must be made.

The following soil physical factors are the most important soil properties to evaluate. These include factors such as:

(a) soil depth, specifically effective rooting depth,

(b) soil water factors such as infiltration (getting water into the soil), storage of plant-available water and drainage of excess water,

(c) soil aeration and

d) suitability of the soil for effective root development and functioning.

e) the vulnerability of a soil to crusting (surface sealing) and/or subsurface compaction. Some soils that have been irrigated before and some virgin (natural) soils in arid areas have high salt and/or sodium contents that make them unsuitable for irrigated agriculture.

The inherent fertility of a soil is not a critical factor, since nutrient deficiencies can be overcome relatively easily with appropriate fertilization management. Several irrigation projects in South Africa have experienced serious problems or failed because they have been established or rehabilitated essentially on the basis of civil engineering and crop technology criteria, without adequate knowledge of soil parameters or incorrect soil suitability evaluation. These include both commercial and small-scale irrigation schemes. An Institute of Soil Climate and Water (ISCW) study, for example, found that only 41% of the area investigated on 30 irrigation schemes for small-scale farmers forming part of the Revitalization of Small Scale Irrigation (RESIS) project in the Limpopo Province can be regarded as irrigable. They described this as a *"very alarming percentage, because the surveys were done on existing irrigation schemes"*.

It is important to keep in mind that different crops (even different cultivars and rootstocks) have different soil requirements and tolerances. What is highly suitable for one may be totally unsuitable for another? Likewise different irrigation technologies have different soil requirements and tolerances.

Three things need to be kept in mind regarding South Africa's irrigable soil resources:

- South Africa has very limited areas with irrigable land. This is mainly because South Africa does not have any big alluvial plains, which is where irrigation is usually developed. South Africa's rivers are small and have very narrow alluvial terraces. Consequently the individual irrigation schemes are very small, compared with international standards, making irrigation development expensive.
- The quality of South Africa's irrigable soils is generally quite poor. Large proportions of the soils have severe physical limitations.
  - Less than 10% of the soils at Vaalharts Irrigation Scheme are rated as having high suitability for irrigation.
  - Examples of irrigation schemes dominated by soils with very serious limitations include small-scale irrigation schemes in the Eastern Cape like Qamata and Tyefu (Eastern Cape).
  - A small number of irrigation schemes have high proportions of high quality soils, examples including Dzindi and Middle Letaba (Limpopo) and Keiskammahoek and Ncora (Eastern Cape).

- South Africa falls within the major soil region of the world that is dominated by poor quality soils and unfavourable climate, namely the mid-latitudes. These soils differ widely from the deep, fertile soils of the high latitudes (as found in North America and Europe) and the highly weathered soils of the humid tropics (as for example in Brazil and the central parts of Africa). ***From local research and field experience is has been found that criteria that are, for example, used to classify soils in North America and Europe as irrigable cannot be used in South Africa.***

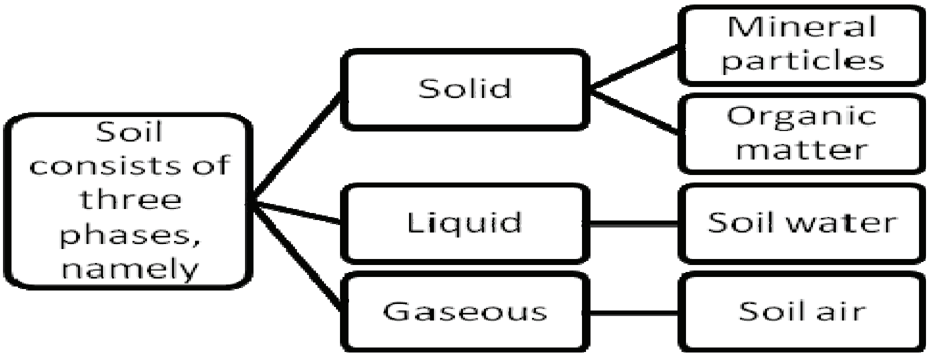
Notes for Facilitator

Soil science terminology: *It is impossible to define or explain all soil science terms that students will come across in publications in these lecture notes. It is thus essential that students should during their studies and in their career have access to or own a copy of the following publication giving definitions and explanations of these terms: Van der Watt, H.v.H. & Van Rooyen, T.H. 1995. A Glossary of Soil Science (2nd Ed.). Soil Sci. Soc. S. Afr., Pretoria.*

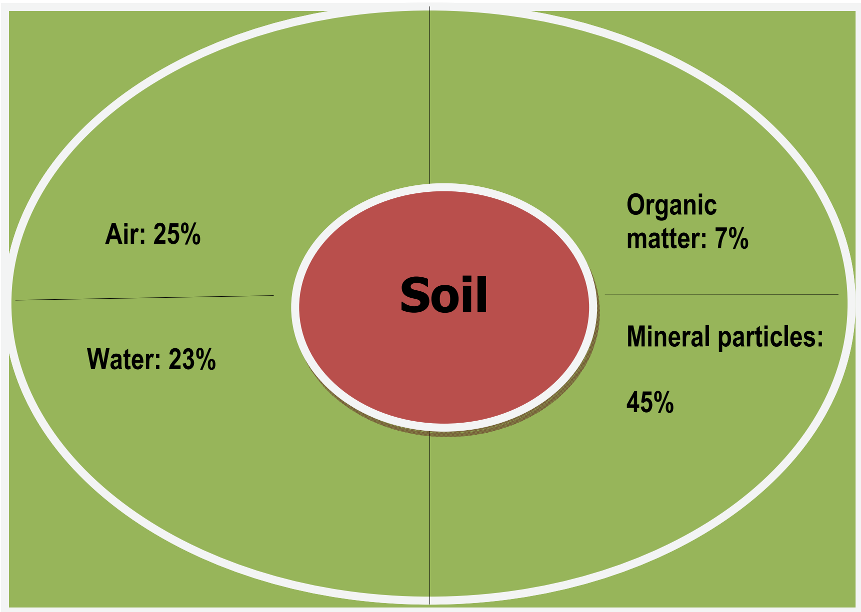
2. WHAT IS SOIL?

Soil is the thin loose outer layer of the earth's crust, consisting of weathered mineral material that has been changed under the influence of the genetic and environmental factors of the parent material, climate, topography and living organisms. Thus, soil is not just simply weathered geological material[1]

3. COMPONENTS OF SOIL



Soil consists of four components namely:



The amount of each component varies with the specific soil type and with increase in depth. At a greater depth the soil air and organic matter will decrease while the soil water and inorganic component will increase.

a. Inorganic or mineral composition of soil

Soils differ in their ability to provide the necessary plant nutrients, and the main reason for this is the inorganic fraction that is formed from different parent rocks. The inorganic material could include stone, gravel, sand, silt and clay. The parent rocks determine the chemical and physical composition of the inorganic fraction. The size fractions of the inorganic material are displayed in Table 1.

Table 1. The size fraction of inorganic material[1,2)]

Inorganic material	Size fraction	Composition
Stone	>75 mm	Rock fragments
Gravel	2-75 mm	Rock fragments, quartz
Sand	0.02-2 mm	Quartz mainly and varying quantities of fieldspars and mica,
Silt	0.002-0.02 mm	Quartz, fieldspars, mica and other silicate minerals which have weathered
Clay	< 0.002 mm	Quartz, oxides, hydrates of iron and aluminum, such as sesquioxides and allophone plus secondary clay minerals (kaolinite and smectite)

Soil also consists of different proportions of fine and coarse size factions. The physical nature of soil, such as aeration, drainage, infiltration and water retention capacity, is again determined by these various size fraction ratios.

b. Organic material

The organic constituent consists of residues of plant, animal and micro-organisms that have decomposed and transformed to a greater or lesser extent. This product is referred to as humus, which normally is present in small quantities (less than 7%). The contribution of humus or organic matter to the physical and chemical properties of soils is considerable. Under tropical and subtropical climate like in Mpumalanga the climatic conditions for the oxidation of organic matter proceeds rapidly and the build –up of it is limited.

c. Soil air

Soil air occurs particularly in the macro pores of the soil, while soil water is usually held in the micro pores. The speed of gaseous exchange is mainly determined by a favourable micro/macro pore ratio. If the micro pores predominate, the soil water retention may be good but perhaps the aeration could be poor, or conversely, the soil may be well aerated but have a poor water retention capacity.

Soil compaction, soil crusting and structural conditions may have a considerable influence on the micro/macro soil pore ratio, and therefore on the soil air content and composition. The oxygen content of soil is very important for root activities, and also for the microorganism activities. Therefore it is important to replenish the oxygen level of soils constantly and to ensure that the carbon dioxide formed as a result of respiration of roots and organisms and the decomposition of organic matter is moved away into the atmosphere.

d. Soil water

The manner in which soil water is stored when it is added through rain or irrigation and how it is becoming available for the growing of plants, is extremely important. Soil is like a sponge – it can only retain a certain amount of water and it can only do it at a certain rate (infiltration rate). Factors that influence these aspects include soil texture, soil structure and the salts present in the soil. This will be discussed in more detail in later modules. When soil is saturated there is no benefit in applying more water, as excess water only results in plant stress, waterlogging, drainage to watertables below the rootzone, run-off and the leaching of fertilizers.

Soil water is held in soil pores (spaces between soil particles). There are two forms of soil water (Figure 1):

- water held tightly to soil particles (also referred to as adsorbed water)
- water held in the pores between the soil particles (capillary water)

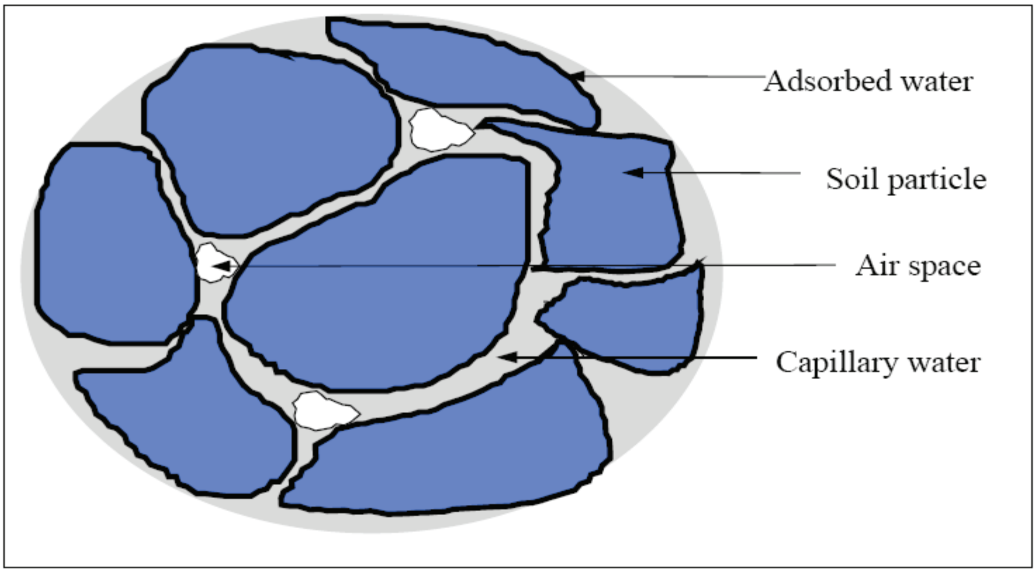


Figure 1. Forms of soil water

Roots remove water from soil pores by the creation of suction. Plants use water from large soil pores first because the energy required is less than to remove water held by small pores. Some plants have the ability to extract water from drier soil more easily than others. The efficient irrigator should aim to minimize the time soil is in a saturated or dry state, and maximize the time that water is readily available to the plant.

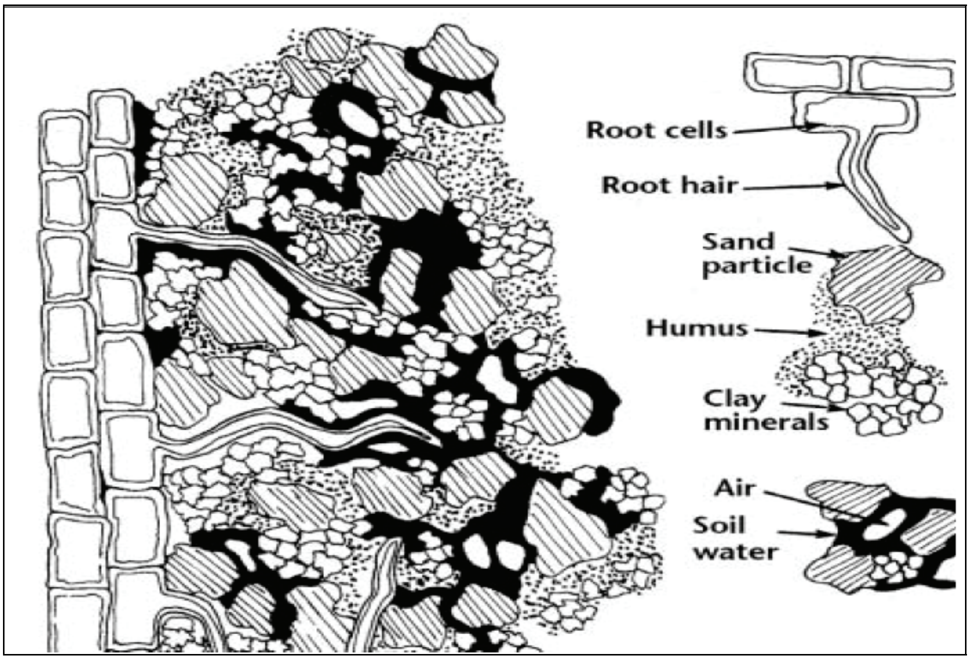


Figure 2: Major soil components

Activity

Group activity

1. Make use of a soil profile to identify the various soil components illustrated in Figure 2. Important is to observe if the root hairs and roots in general are actively growing. Try to answer the following questions:
   a. What colour is it?
   b. How well does it retain water?

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References

1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

My notes...........

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Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

Module 2

Soil formation

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- The effects of parent material,climate,time and topography on soil formation
- How the position of soil in the landscape influence it properties
- To describe each soil layer according to its characteristics such as texture, structure, depth and colour

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A basic understanding of soil formation is essential in order to understand what kinds and qualities of soils are found where and why. Many factors have an influence on the formation of soil, and the more important factors and processes that occur in South Africa will be discussed. Before the process which influences the soil formation can start the parent material must first be broken down to smaller fragments (also referred to as mechanical weathering), after which the chemical weathering (changing the composition of the constituents) can become the dominant process. In this process the following products are formed:

- Soluble salts: ca and Mg – bicarbonates, NaCl, etc.
- Colloidal substances such as clay, silica, iron oxide, etc.

- Chemical resistant minerals such as quartz, muscovite, which is released, unchanged from the weathering rock to form sand and silt particles.

These products are then available to form sediments, which are later consolidated to yield sedimentary rocks.

1. Soil forming factors

The combination of the following soil forming factors result in a particular soil characteristic:

- **Parent material**

  The minerals that constitute the parent material contribute greatly to the properties of different soils. A basic knowledge of the mineralogical composition of prominent potential parent materials is therefore important to understand soil forming.

  South Africa has very complex geological patterns. This means that parent materials that give rise to soils with widely different properties and qualities are often found in patches over short distances. It is impossible to give a comprehensive discussion on the soil parent materials found in South Africa here. Anyone working as an extension officer in a specific area should at the start liaise with experts to get information on the geology/soil parent materials in that area and their implications regarding the properties and qualities of different soils in that area. Only a few of the most important ones with regard to irrigation will be touched on briefly here:

  a. Sedimentary rocks of the Beaufort Group underlie large areas in the north-western parts of the Eastern Cape, eastern Free State and north-western KwaZulu-Natal. Large areas of these are mudstones and shales, which produce fine-grained soils. These rocks also contain high quantities of sodium and magnesium, which, together with the fine-grained nature of the soils, give very unfavourable conditions for irrigation. Some are purple mudstones, which produce red soils. Traditionally red soils are considered to be good soils, but the red soils developed from these rocks have extremely poor qualities, especially for irrigation. Rating such soils as suitable for irrigation has made serious mistakes. This is especially the case in some of the small-farmer schemes in the Eastern Cape.
  b. In the Lowveld of Mpumalanga and Limpopo, as well as other areas in Limpopo, granite is a widespread parent material. It gives deep sandy soils on the middle slopes of hills and very poor quality, non-irrigable soils on the foot slopes.
  c. In the areas dominated by Beaufort mudstones as well as shales and granite (a and b above), relatively small dolerite outcrops occur. Dolerite is a basic igneous rock from which very high quality red soils develop. Where these good red soils occur side-by-side with the poor quality red soils from purple mudstones and shales (as, for example, along the White Kei River below the Xonxa dam) correct identification of the different soils is critically important.

Table 1. Examples of parent materials and possible associated soil properties[1,2)]

Parent material (rock)	Minerals	Characteristics	Possible soil characteristics
Quartzite	Quartz	Usually white or colourless, very hard	Gravel-sand and silt fractions consists predominantly of quartz particles
Granite	Quartz Potash feldspar Biotite Muscovite	Granites are light pink, greyish white or reddish in colour, and always coarse grained. Physically very hard, but chemical weathering occurs fairly easily.	Two main granite types in South Africa, namely older Basement Complex granite occurring in many places, and the younger Bushveld Complex granite. Coarse sand and the potential for clay minerals.
Shale	Clay fraction	Fairly soft and undergo rapid mechanical weathering.	Common in the Highveld Plains and valleys develop on such rocks, as observed on the shales and slates between Potchefstroom and Parys (Free State) Clay minerals
Andesite	Quartz Amygdales Silica	Fine textured rock which weathers slower than diabase or dolerite, and tends to form undulating low hills and plains	Soils are usually shallow red and yellow-brown soils, and the clay minerals are relatively high (25-35%) Sand grade is fine

Dolerite, diabase and norite	Plagioclase Pyroxene	Physically very hard rock but readily undergo chemical weathering. When these rocks weather chemically iron dioxides are released from the pyroxene.	Soils usually high clay content, vertic black turf or red structured clayey soils. Where drainage and permeability of the clay is poor, vertic black clay soils very high in smectite clay are formed. In cases with better drainage and permeability red structured clayey soils, carrying both smectite and kaolinite, are developed.
Basalt	Ca rich plagioclase Pyroxene Magnetite Olivine	Highlands of Lesotho as well as mountain peaks in the eastern Free State consist of basalt (very thick and hundreds of square kilometres), Springbok Flats.	Shallow, mainly melanic black soils with clay and smaller proportions of smectite occur. In the Eastern Free State and the Drakensberg the chemical weathering is much slower than on the Springbok Flats, where the climate is hot. Deep vertic soils occur in this area.
Dolomite and chert	Dolomite Calcite	Physically hard and the dolomite undergoes rapid chemical weathering while the chert weathers very slowly. The chert weathers physically to smaller fragments, which eventually form gravel and sand.	Stony and very shallow soil are formed

- **Climate**

The effects of climate on both the soil forming factors and the process are often difficult to isolate. The influence of climate on soil formation (e.g. chemical and mechanical weathering) gave rise to the so-called great soil groups. In the tropics for instance the warm, humid conditions stimulate chemical weathering, while physical weathering is more dominant in cold and dry climate, like the deserts.

Soils in areas with high temperatures and low rainfall are generally very shallow. The deep alluvial deposits along rivers in such areas often contain free lime. This is often the case in the alluvial soils in the deep narrow valleys of the rivers along the east coast of South Africa, especially in the central and south-western parts of the Eastern Cape. The rainfall in these valleys is very low (in several below 400 mm per annum) and the temperatures very high. Their rainfall is much lower and the temperatures much higher than on the surrounding plateau and hills. Some soils along these rivers even contain high amounts of free salts under natural conditions.

Under high rainfall highly weathered, infertile acid soils develop, which need different soil fertility management from those in the dry areas. Where the rainfall is strongly seasonal, irrigation is often required during the non-rain season in high rainfall areas, especially under intensive production of high value crops. Some of the deciduous fruit producing areas in the Western Cape are examples of such situations.

- **Topography**

Steep slopes cause a rapid removal of the products of weathering and fresh rock is regularly exposed. The higher up, and the steeper the slope, the greater the chances to find shallow soils, which are leached. Physical weathering will be promoted in preference to chemical weathering. The position of soil in the landscape will have an important effect on its properties

During soil surveys, for irrigation purposes excluding these areas beforehand from the surveys can save a lot of money, time and manpower. The soils on middle slopes are usually deep and of relatively good quality, while those on foot slopes often have severe limitations for irrigation. The soils on valley bottoms (for example on the terraces next to rivers) are usually deep, but their quality for irrigation can vary over short distances. The lowest terrace next to a river may be subject to relatively frequent and sometimes severe flooding. This factor must be studied for each case.

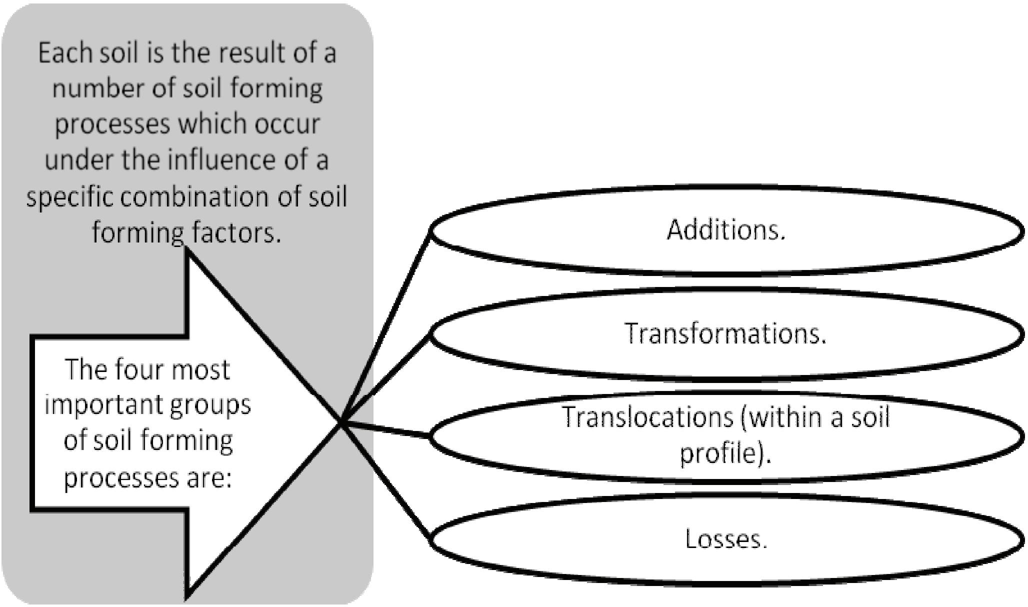
- **Organisms**

The biofactor is another soil forming factor because they are intimately connected to climate. The influence of different vegetation, for example, could have an important effect.

- **Time**

Soil formation is a very slow process and thus time is an important factor in soil formation. In South Africa this is an important factor for irrigated agriculture on the important terraces along rivers. Each river has two or more terraces of different ages. The lowest terrace is always the youngest one and the higher the terrace, the older it is. In the youngest terrace no real soil formation has occurred and the soil is characterised by strong alluvial stratification – alternating sandy layers and clayey or silty layers. These have negative implications for water movement and root penetration, as will be discussed later. On the second terrace the stratifications have been obliterated, but no strong downward movement of clay has taken place. Thus the deep soil profile is uniform throughout. The soil on the third terrace can have strong clay increase in the subsoil, making it unfavourable for irrigation (as in places along the Tyumie River in the Eastern Cape). Or it could have undergone oxidation of the iron in it, giving a high quality red soil (as in places along the Pongola River on the Makatini Flats in northern KwaZulu-Natal).

2. Soil forming process



In all soils processes representing all four groups occur simultaneously. However, specific processes and their relative intensities differ widely (a) between different localities and (b) between different parts of any particular soil profile. The former causes the occurrence of different soils at different localities, while the latter causes the development of different horizons in a specific soil profile. Irrigation often causes drastic changes to the soil forming processes operating in a soil and thus also to the properties, characteristics and qualities of the soil.

The soil forming processes are schematically illustrated in Figure 1.

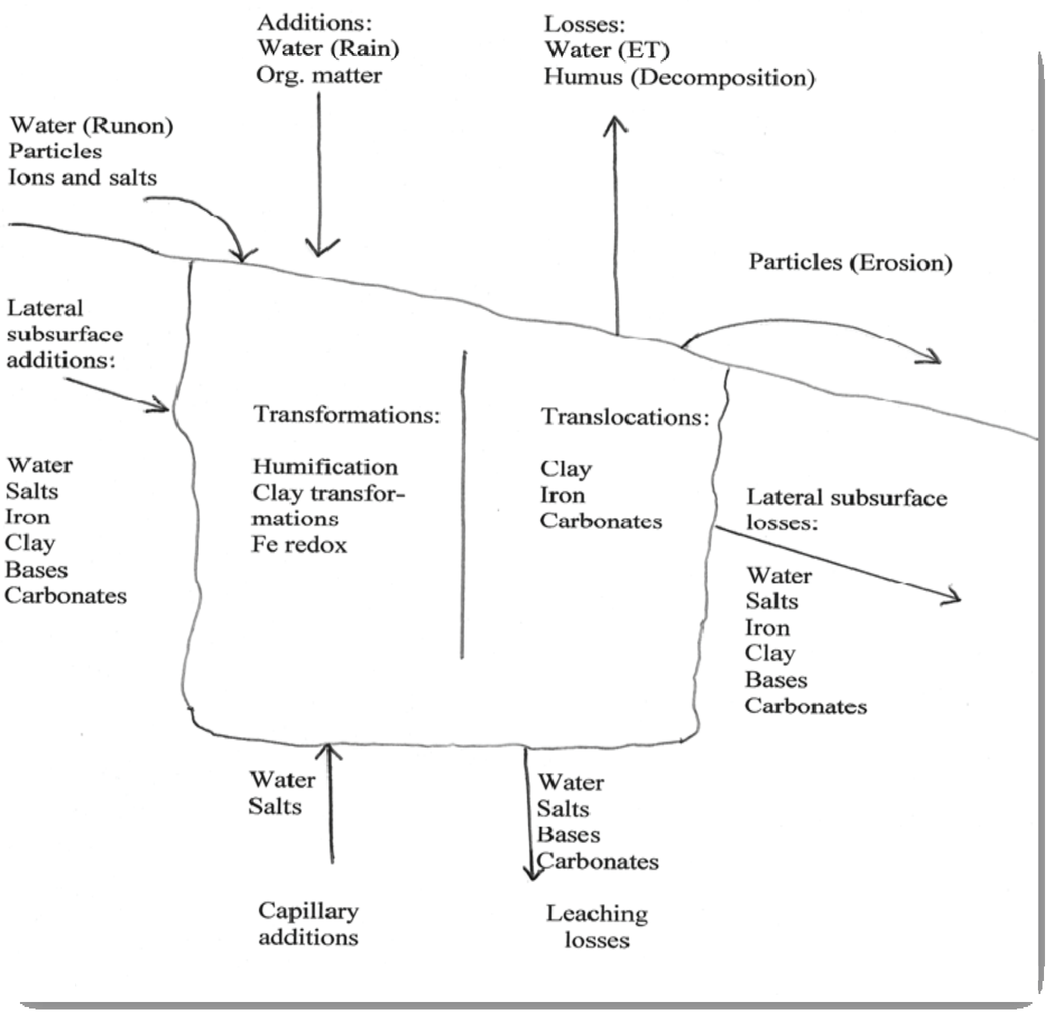


Figure 1. Schematic illustration of soil forming

2.1 Additions

Additions do not occur only at the soil surface. Lateral subsurface additions are important in soils in lower landscape positions. In some cases additions from the bottom are important. Some important additions are:

a. *Addition of water by rain, run-on from higher lying slopes and/or lateral subsurface seepage:*
   Due to the effects of run-on and seepage soils on lower lying slopes are wetter than those on upper slopes. Due to a combination of this and other processes soils on lower slopes are usually also deeper. Addition of water is an important process in irrigated soils.

b. *Addition of organic matter:*

It consists mainly of addition of plant material. This is mainly in the form of above ground materials dropping on the ground when dying and then being decomposed by soil organisms and mixed with the topsoil. Under irrigation addition of organic matter can be strongly increased or strongly decreased, as will be discussed in the module on soil organic matter.

c. *Addition of mineral materials (soil; partly weathered geological material):*

There are two types of this kind of addition, which are both important in regard to irrigation. The main type is addition in the form of surface deposits of transported materials. It occurs mainly in lower lying position in landscapes, such as river terraces and foot slopes of hilly terrain. In the process deep soils are produced in lower position, mainly close to rivers, making it relatively easy to deliver irrigation water to them. Transportation of the material is by means of water, wind, or gravity and deposited material is classified according the means of transportation:

- Alluvial material has been transported and deposited by water. It is found almost exclusively on river terraces. Thus much irrigation is practised on this type of material. Examples of the many South African irrigation schemes developed on soils formed from alluvium are Lower Orange River (Upington area), Olifants river (Western Cape) and Loskop.
- Aeolian material has been transported and deposited by wind. More than 80% of Vaalharts has been developed on aeolian sandy soils.
- Colluvial material has been transported and deposited under the force of gravity (although water is often a co-factor). Colluvial deposits are mainly on the middle slopes of steep hills and the foothills of mountains. The higher potential soils in the eastern side of the Vaalharts irrigation scheme have developed in colluvium from the hills bordering the eastern side of the scheme. Other examples of South African irrigation schemes developed on high quality colluvial material are Dzindi and Keiskammahoek irrigation schemes.

The second type of addition of mineral material that is important to understand for irrigation development is much less visible and often poorly understood. It entails the lateral subsurface addition of clay to subsoil horizons in areas with sandy soils on hill slopes. This type of addition occurs mainly in soils on the foot slopes of hills. The clay is transported by lateral subsurface moving water. It is usually associated with addition of the very unfavourable cation sodium. The result is soils that are ***extremely*** unfavourable for irrigation and highly erodible.

Example

Such soils are, for example, found widely on foot slopes in the Lowveld areas of Mpumalanga and Limpopo, associated with granite parent material. It is also common in sandstone areas, like the Waterberg area in Limpopo. Erroneous irrigation development on such soils has been disastrous in more than one case in South Africa, for example in the Eastern Cape.

d. *Addition of salts:*
Water that is added to soil by run-on or lateral subsurface movement contains different amounts of soluble salts. In arid and semi-arid areas, where leaching of water through the soil profile is minimal, these salts accumulate in the soil, causing several serious problems. These are discussed in the module on salinity and sodicity.

The problems are most severe in low lying areas. Large amounts of salts are added in irrigation water. Where free water tables occur in a soil salts can be added from salt-rich rocks at the bottom of the profile. Water tables often develop under irrigation, leading to accumulation of salts in the soil.

2.2 Transformations (Changes)

The following are a few transformations in soils that are relevant to irrigated agriculture:

a. *Humification of organic matter:*
Organic matter is decomposed by microbes. From the decomposition products an amorphous dark-coloured product called humus is synthesized. The degree to which humification occurs and the nature of the product that is formed has an important influence on soil properties and qualities. This is discussed in the module on soil organic matter.

b. *Transformation of primary minerals to secondary clay minerals:*
Some primary minerals in the original geological materials from which soils develop are decomposed and from these secondary clay minerals (soil clays) are synthesized. The type of clay that is formed is determined by the soil forming factors and has a large influence on the chemical, fertility and physical properties of a soil. This is very important for irrigated agriculture. It will be discussed under 2.2 and other modules.

c. *Simple chemical reactions:*
The most important chemical reaction is the reduction of ferric iron (Fe^{+3}) to ferrous iron (Fe^{+2}) under conditions of poor aeration (usually water logging). The soil colour changes associated with the reduction and oxidation of iron are very important indicator of possible problem conditions in a soil for irrigated agriculture. This is discussed in the module on soil aeration and soil colour.

2.3 Translocations

With translocation is meant the moving of material from one position in a soil profile to another position within that same profile. Translocations are mainly in the solution or suspension in water and are mainly vertically downwards. Removal of material from a certain part of a profile, usually topsoil (A-horizon), is called eluviation. The most intense eluviation is from E-horizons. The importation of material into a certain part of a profile, usually subsoil (B-horizon), is called illuviation. A few important translocations in soils in arid, semi-arid and sub-humid areas are:

a. *Translocation of clay:*
Clay particles are transported in suspension. In a well-developed profile the most important characteristic is an increase in clay content in the subsoil relative to the topsoil. The magnitude of the difference in clay content between the topsoil and subsoil and how sharp the increase is over distance are important in the evaluation of soils for irrigation.

b. *Translocation of salts and carbonates:*
Under extremely dry (hyper arid) conditions soluble salts like sodium salts and gypsum accumulate in the topsoil. Under arid conditions such salts are translocated from the topsoil to the subsoil, where they still create problems for irrigated agriculture. This is especially in soils with poor water percolation properties (discussed in a later module). Where there is any degree of leaching, these salts are removed from the soil profile. Under the latter conditions calcium and/or magnesium carbonates can still accumulate at different depths in the subsoil. It can occur in the form of powdery lime, round lime nodules (concretions) or lime pans. Sub soils containing lime are found in all South African provinces. The presence of powdery lime or lime nodules in a soil is not a major problem for irrigation. It does, however, lead to deficiencies of some trace elements, such as zinc, iron and copper, in crops. Lime pans can restrict drainage and lead to water logging under irrigation.

2.4 Losses

With losses is meant the total removal of something from a soil profile. Losses occur vertically upwards (at the surface), vertically downward (at the bottom) and laterally. A few of the most important losses in arid to sub-humid areas include:

a. *Losses of water through evaporation:*
This is very important in hot, dry areas. The high evaporation greatly reduces the efficiency of the little amounts of rain that fall. Soil formation is restricted, leading to vast areas of shallow soils. Leaching is restricted and salts and/or carbonates accumulate in the soil. Natural vegetation is sparse and addition of organic matter is limited. Intense drying leads to the development of hard pans, like dorbanks, in the soil. Under irrigation the high evaporation leads to the accumulation of salts in the soil.

b. *Losses of organic matter:*
The humus formed from organic matter can be decomposed to volatile substances and lost completely from the soil, particularly under very hot conditions. In dry areas, where organic matter production is low due to the limited rainfall, this leads to top soils with very low organic matter contents and various serious physical problems. Under irrigation the organic matter content of soils can increase or decrease, depending on the management system.

c. *Losses of soil by means of erosion:*
Under natural conditions erosion removes soil especially from steep upper slopes and from highly erodible soils that are often found in low-lying areas. The result is

shallow soils that are too shallow for irrigation. Such soils have been put under irrigation, for example recently at Qamata, with very bad outcomes. Erosion is also caused under irrigation where highly erodible soils are put under irrigation, especially under aggressive overhead sprinkler systems.

3. The soil profile and soil horizons

The study of the soil genesis includes a wide range of soil morphology, chemical and physical properties. Soil usually varies spatially and also vertically. A vertical section through a soil is called a soil profile. A soil profile is usually studied in a so-called profile pit that is dug to a depth of about two meters or until solid rock or other hard layer or water is reached – if these are found at depths less than two meters.

The top layer (also referred to as the topsoil) has the most organic matter and therefore contains the most nutrients. Plant roots usually occur throughout the topsoil. It is important to examine the soil profile so that one knows the different soil textures it contains. A soil survey will describe each soil layer according to its characteristics such as texture, structure, depth and colour. This information will assist the extensionists in determining soil water characteristics and development of an irrigation and drainage management plan.

Figure 2. Soil profile

A soil profile reveals different layers that have developed in the process of soil formation which are called soil horizons (Figures 2 and 3). Soils of young alluvial terraces next to rivers contain many layers that were formed by deposition of material during successive floods and not by soil profile development. These are not called soil horizons, but alluvial stratifications. To promote effective communication and minimize misunderstandings about soils, different types of horizons have been defined.

Definition

Soil horizon: a layer that has developed in the soil profile through certain soil forming processes, such as accumulation of clay and organic materials, as well structural development.

Master horizon: A number of horizons formed in the soil profile through the organization and reorganization of material as a result of the soil forming process.

We never encounter all of these horizons in a soil, and deep soils may have more than one A and/or more than one B horizon. C horizons consist of unconsolidated (loose) weathered geological material underlying the real soil. R indicates hard (unweathered) rock underlying the soil.

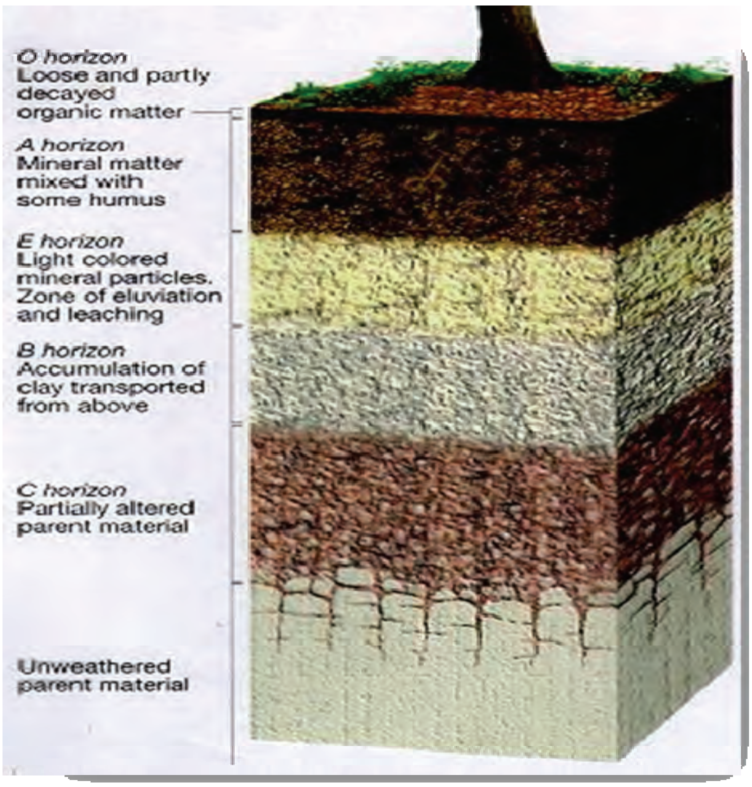


Figure 3. Example of a diagnostic soil profile with various soil horizons

The different master horizons (Figure 3), which can be found in soils are briefly described in Table 2.

Table 2. Soil master horizons[2)]

Master horizon designation	General description
O	Surface layer of undecomposed or partly decomposed organic matter on top of the mineral soil profile. Found mainly in forests and swamps.
A	The normal topsoil horizon. The surface mineral soil horizon, which normally contains more organic matter than the underlying horizons and is thus normally darker coloured than the underlying horizons. In dry parts of South Africa light coloured (“bleached”) A horizons are found. These are severely crusting, presenting a problem for irrigated agriculture. Sometimes the A horizon has been removed by sheet erosion.
E	A mineral horizon underlying the O or A horizon that has undergone strong eluviations, i.e. removal of materials likes clay and iron oxides. A light grey (bleached) horizon. Very infertile and usually with very poor soil physical properties. Not found in most soils. Sometimes occupies the whole subsoil.
B	The typical subsoil horizon below the A, O or E horizon. Usually an illuvial horizon, i.e. a horizon into which materials like clay and iron oxides have moved from overlying Characterized by Fe, Al, humus, carbonate, gypsum or Si or the development of a structure
G	A special type of subsoil horizon indicating a zone of extreme permanent wetness. Grey and blue-green colours, clayey and sticky. Absent in most soils.
C	Unconsolidated material that has not undergone horizon differentiation. Varies from weathered rock to stratified alluvial materials and wind-blown sand.
R	Hard, unweathered rock such as basalt, sandstone or granite

Diagnostic horizon deals with the definition of soil horizons according to strict criteria. The diagnostic horizon sequence in a soil profile is used for the taxonomic classification (naming) of soils. This promotes better communication about soils and easier evaluation of the quality of a soil for any specific use. For the users of soil information, such as extension officers, it is not necessary to know the precise definitions of diagnostic horizons. It is more important that a basic understanding is exists of the concept of each diagnostic horizon and what it entails in terms of soil properties, characteristics and especially qualities, so as to be able to understand the information that soil experts and soil survey reports convey to in these regards.

It must be understood that taxonomic soil classification is absolutely essential for effective communication. However, the information contained in taxonomic classification alone is not adequate for effective land suitability evaluation, especially for irrigation. Additional soil information, not included in taxonomic soil classification, must be collected. The latter is used in the mapping of so-called soil phases. It is not possible to give comprehensive discussions on diagnostic horizons and taxonomic soil classification here. It is imperative that extension officers should attend short courses on the basics of soil classification.

Soil does not only vary over the vertical plane, but also along the horizontal plane. The reason for that is mainly the variation in landscape and the influence of it on soil forming process and the soil properties.

Additional reading:

Students should also obtain copies of the South African soil classification system. The reference of the publication is: Soil Classification Working Group 1991. Soil Classification: A Taxonomic System for South Africa. Dept. Agric. Dev., Pretoria. (Obtainable from the ARC-Institute for Soil, Climate and Water.)

Activity 1

Small group activity

1. What do you understand underneath "soil classification"?
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   ....

2. Describe the role that climate and parent material play in the forming of soil.
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3. Explain how soil is formed.

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4. List four types of diagnostic topsoil horizons and explain the typical characteristics of each horizon.

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References

1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

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Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

References

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My notes............

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Module 3
Soil texture
(Particle size distribution)

Study objective

After completion of this module, the learner should be able to:

- Identify different soil textural classes
- Differentiate between different clay minerals
- Discuss the influence of texture on the physical soil properties
- Apply the hand texturing method in the field
- Identify major characteristics of different texture classes

Table of contents

The basic knowledge gained so far on the formation of soil and the various factors causing various types of soils to develop in nature will help us to determine the irrigation potential of the soil. In this module the soil property soil texture will be discussed.

Soil consists mainly of mineral particles of different sizes, and only particles smaller than 2mm in diameter are considered to be soil. Those that are larger are called coarse fragments and are classified as gravel, cobbles and stones, depending on their size.

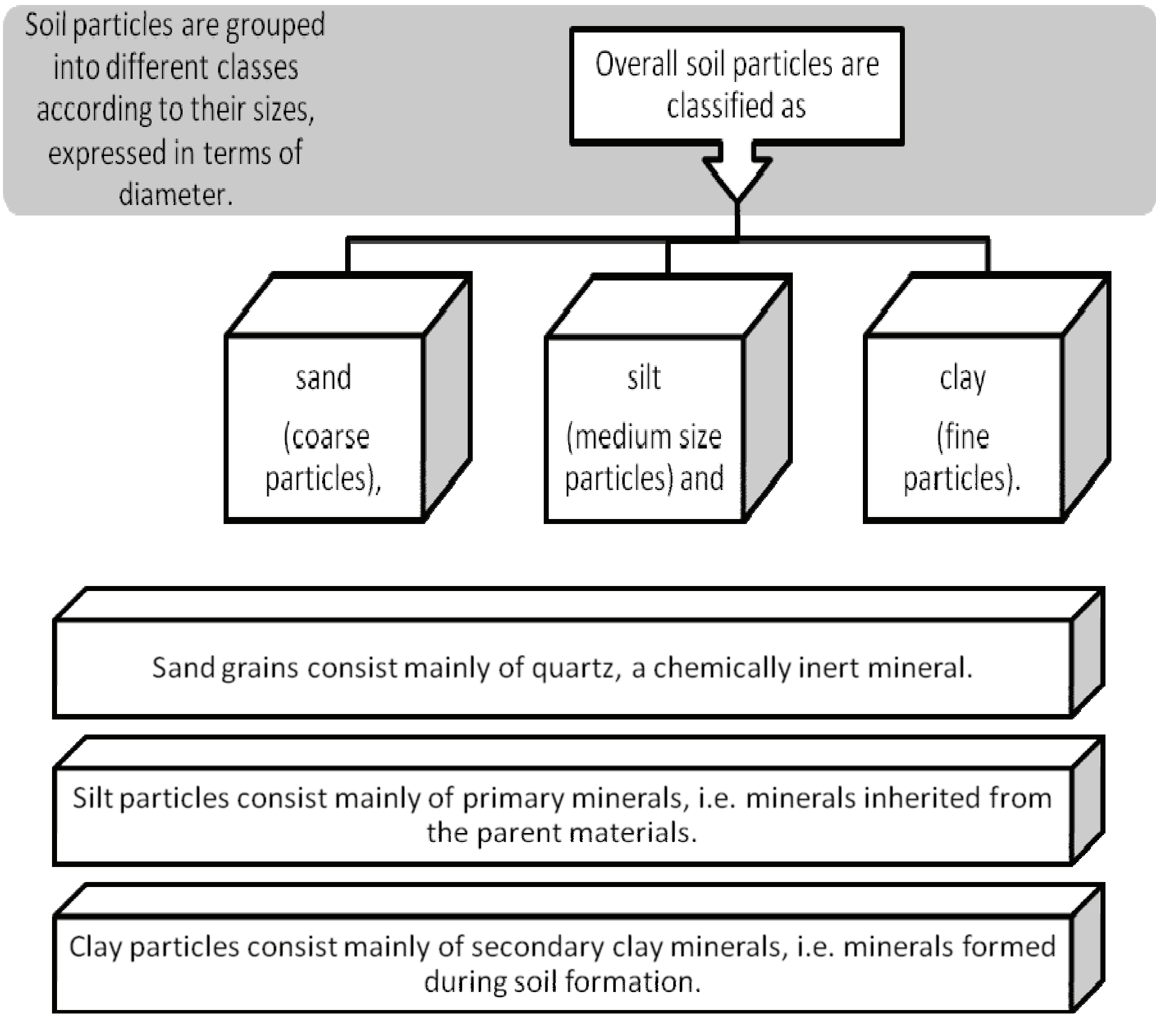
Although the coarse fragments are not considered to be soil, it is important to determine the amount of coarse fragments in a soil - especially on a volume basis- when it is evaluated for irrigation purposes. The presence of coarse fragments reduces the amount of actual soil, and thus reduces the capacity of the soil to store water and plant nutrients.

1. What is soil texture?

Definition

Soil texture is defined as the relative proportions of particles of different size groups (sand, silt and clay) in the soil, determined on a mass basis and expressed as percentages[2)].

The texture of the soil depends on the type of particle of which it consists. Very seldom will you encounter a soil, which is 100% clay or 100% sand. Most soils are a combination of sand, clay and silt.



The higher the sand percentage in the soil the greater the pore space is between soil particles. These pores are important for aeration and water drainage. The higher the clay contents of a soil the stronger the adsorption of nutrients and water by soil particles. Sand is sub-divided into five sub-classes and silt into two sub-classes (Table 1).

Table 1. Soil particle size classes

Collective name	Class name	Class limits (mm diameter)
Sand	Very coarse sand	2.0 to 1.0
	Coarse sand	1.0 to 0.5
	Medium sand	0.5 to 0.25
	Fine sand	0.25 to 0.1
	Very fine sand	0.1 to 0.05
Silt	Coarse silt	0.05 to 0.02
	Fine silt	0.02 to 0.002
Clay	Clay	<0.002

Different types of clay minerals dominate the clay fractions of different soils.

- The clay fractions of soils in semi-arid to sub-humid areas are dominated by so-called **smectite** clay minerals, mainly **montmorillonite.** This clay mineral is favourable in terms of soil fertility, but unfavourable in regard to soil physical properties if present in large proportions. These aspects are discussed in later modules.
- The clay fractions of fairly highly weathered soils are dominated by **kaolinite clay.** This type of clay mineral is relatively poor in terms of soil fertility, but favourable in terms of soil physical properties.

Table 2. Some major characteristics of the different soil texture classes

Soil properties	Soil texture class		
	Sand	**Loam**	**Clay**
Aeration	Good	Medium	Poor
Water retention capacity	Limited	Medium	Large
Infiltration (water)	Rapid	Medium	Slow
Cohesion	None	Medium	Limited
Adsorption of nutrients	Limited	Medium	Large
Other properties	High rainfall areas: usually acidic and poor in nutrients	Most favourable for production purposes	Poorly aerated, easily waterlogged and drain slowly
	Windy areas: susceptible to wind erosion		

2. SOIL TEXTURE CLASSES

Many properties of soils are very closely linked to their soil texture and therefore soil texture serves as a means of classification. To facilitate easier communication different textural class groups have been defined, which can be determined from a texture triangle diagram (Figure 1). Many properties of soils are very closely linked to their soil texture and therefore soil texture serves as a means of classification. To facilitate easier communication different textural class groups have been defined, which can be determined from a texture triangle diagram (Figure 1).

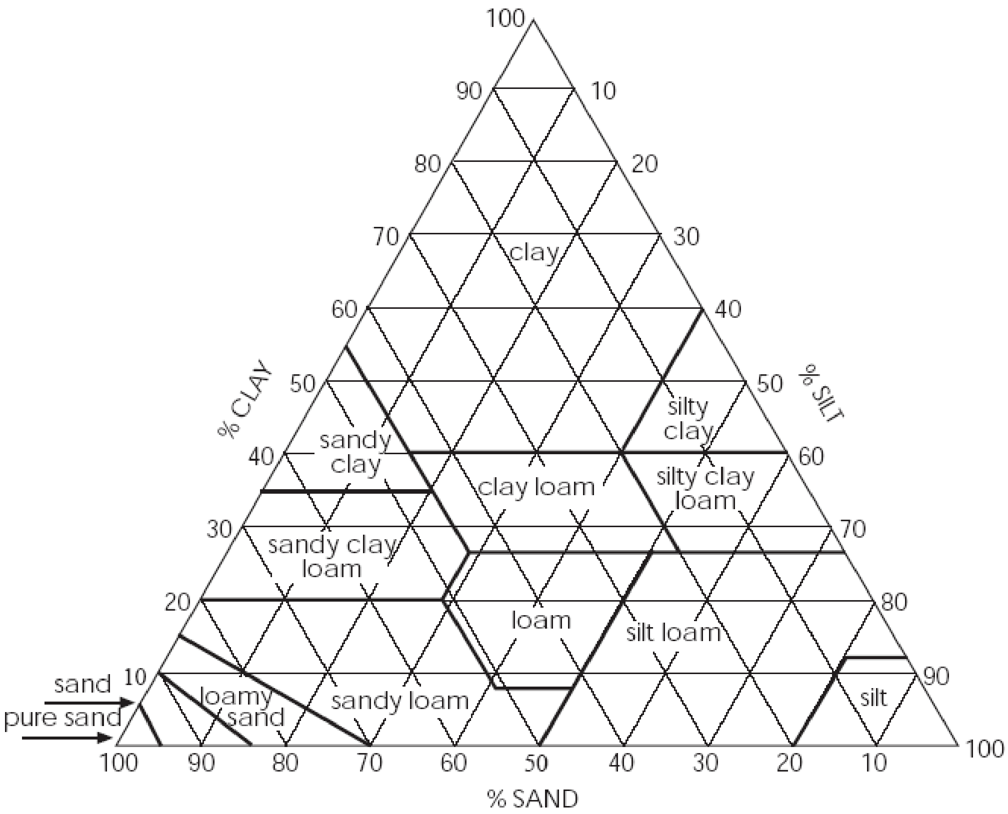


Figure 1. Soil texture triangle [1)]

The soil texture triangle defines the limits for the percentages of clay, silt and sand for each textural class, and could be easily used by irrigation extensionists.

- Sandy soils: usually contain at least 80% sand fraction and a maximum of 20% clay
- Clay soils: usually contains at least 35% clay fraction
- Loamy soils: are more difficult to describe but contain silt and the balance is roughly half sand and half clay.

The soil texture classes of sand, loamy sand, sandy loam and sandy clay loam are further subdivided according to the percentage of coarse, medium and fine sand in the sand fraction.

The sand grade is determined by the relative proportions of coarse, medium and fine sand and is read off from a sand grade triangle diagram (Figure 2).

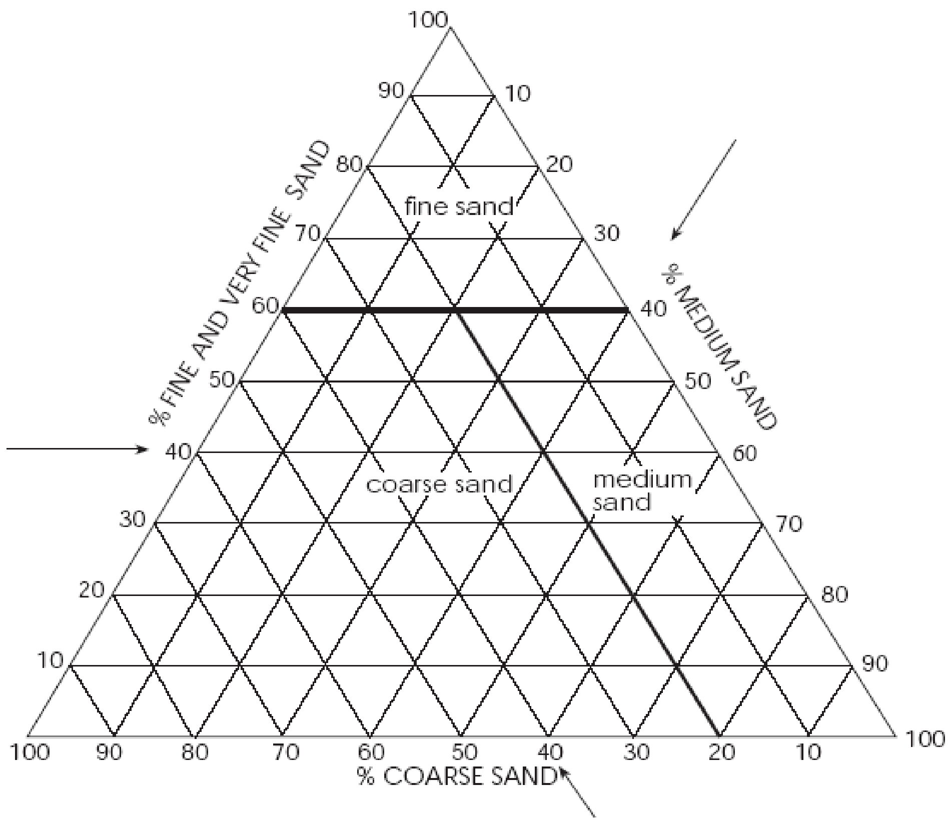


Figure 2. Sand grade triangle [1)]

Activity

Activity 1

Small group activity

1. Determine the textural class and sand grade from the diagrams by looking at two examples:

- ✓ Clay = 35%   Sand = 62%
  Soil texture class = …………………???

- ✓ Fine sand = 25%   Medium sand = 30%
  Soil texture class =……………….??

3. Importance of soil texture

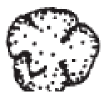
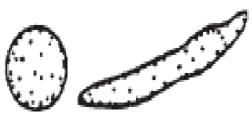
The particle size distribution (texture) of a soil and its clay mineralogy are the over-riding factor determining most of the physical and chemical properties of a soil, and consequently also its qualities for irrigated agriculture:

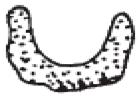
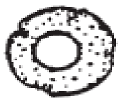
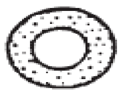
- It *inter alia* determines the water holding capacity of the soil,
- Determines its susceptibility to crusting and compaction
- Influences the fertility of soil
- It also largely determines soil aeration, drainage, etc.

3.1 Determine soil texture

Soil texture can be accurately determined in a laboratory or it can be estimated reasonably accurately in the field by the "ribbon or sausage method" as described below. Hand texturing is the cheapest and most convenient method of determining soil texture in the field.

Table 3. Ribbon or sausage test and soil characteristics

	Soil texture	% Clay	How the soil behaves or feel
	Sand	<10% clay	Non-coherent; does not form a "sausage", when clay is present to the maximum permissible percentage, a stable ball can be formed.
	Loamy sand	10-15% clay	Slight coherence, sand grains of medium size, can be sheared between thumb and forefinger
	Sandy Loam	15-20% clay	Forms a stable ball without difficulty; soil coheres sufficiently to form a thick "sausage" if carefully rolled, but when slight pressure applied during the rolling, the sausage breaks into pieces or falls apart.
	Sandy clay loam	20-35% clay	Rolls into a stable 'sausage", when the one end is carefully lifted and waved in a circular movement to form a U, the sausage breaks in the middle, which indicates that it is clearly grittier than clay loam. Rolling it carefully between the thumb and the forefinger can roll thick thread.

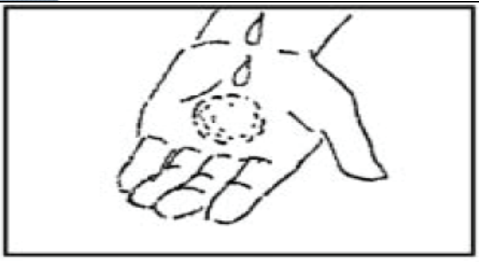
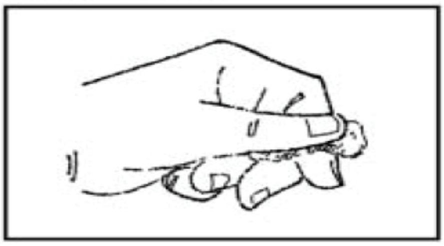
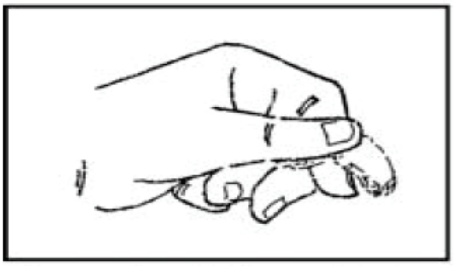
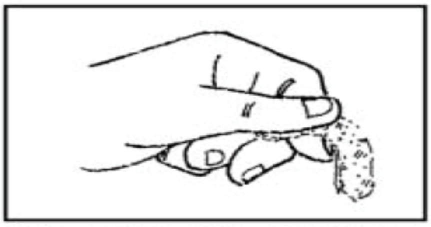
	Clay loam	±27-40% clay	With careful handling, it forms a “stable sausage” and a stable U, but breaks when formed into a ring by swinging one end in a circular movement to join it to the other end.
	Sandy clay	35-50% clay	Shows the properties of clay, but tends to split when a ring is formed, a clear grittiness when rubbed or smeared firmly between the thumb and the forefinger is an indication of sandy clay.
	Clay	>50% clay	Forms a stable ring without cracking; rolls easily to a thin stable thread, absence of grittiness, smooth plastic consistency.

Activity 2

Group activity: Field method

Use a small sample of soil that is wet and rubbed it between the thumb and forefinger to estimate its grittiness and whether the soil will roll out in a thin thread. Then try to form a ribbon or sausage of 10 cm long and approximately 1 cm in diameter. The soil must be damp and plastic to approximate field capacity. The feel and behaviour of the soil as you moisten and knead it will assist in identifying the soil texture.

Step 1: Take a handful of soil	

Step 2: Add enough water to make a ball. If you cannot make a ball, the soil is very sandy.	
Step 3: Feel the ball with your fingers to find out if it is gritty (sand), silky (silt) or plastic (clay)	
Step 4: Reroll the ball and with your thumb gently press it out over your forefinger to make a hanging ribbon.	
Step 5: If you can make a short ribbon your soil texture is loamy, a mixture of sand and clay.	
Step 6: The longer the ribbon the more clay is in the soil	

Each learner should carry out their own textural evaluation by using Table 3.

Assess the soil samples provided:

Sample 1:

- Ribbon length…………………………………………………….
- Texture…………………………………………………………..

Discuss the findings and observations in the small group.

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References

1. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.
2. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.

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- Mr D Haarhoff

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Module 4

Soil organic matter and soil organisms

Study objective

After completion of this module, the learner should be able to:

- Explain the various factors that affect the forming of organic matter
- Explain the role of micro-organisms in the biological breakdown of organic matter and the formation of humus
- Explain the decomposition of organic matter

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Soil organic matter comprises only a small fraction of the solid part of normal soils, usually between about 2-5% expressed on a mass basis. Despite this it plays several very important roles in soils. These are especially important in irrigated agriculture. Soil organic matter consists mainly of plant material (soil flora) in different stages of decomposition material called humus. Soil organisms (soil fauna) like soil microbes (bacteria and fungi) and earthworms decompose organic matter. There is an incorrect perception that humus consists of plant material that is difficult to decompose, such as lignin. Even the most resistant compounds in organic matter are decomposed and humus is synthesized from the decomposition products by microbes.

1. Factors affecting the organic matter content of soils

Factors affecting the organic matter content of soil	Amount of organic matter added to soil
	Temperature
	Aeration
	Texture
	Soil moisture

A few of the most important factors affecting the organic matter content of soils that are relevant to irrigated agriculture include:

a. Amount of organic matter added to the soil

It is logical to expect that the organic matter content of a soil will be higher the higher the amount of organic material that is added under otherwise identical conditions. It has been found that under South African conditions addition of three to four tons of plant material per hectare at a time does not make a difference to the organic matter content of the soil. At least about 20 to 30 tons per hectare need to be applied. Application of so much fresh, undecomposed plant material (green or dry) at a time can have very negative effects. Application of such quantities of decomposed organic matter (compost) is a feasible option under intensive irrigated farming systems, such as small-scale vegetable or cut flower production. It is very important that the compost must be produced by means of correct methods.

The organic matter content of a soil is almost always drastically reduced when natural vegetation is converted to rainfed cropland. When land is put under irrigated agriculture the organic matter content of the soil can be either reduced or increased, depending on the farming system and the management system. Where large amounts of compost are applied the soil organic matter content will usually increase up to an equilibrium level. Under irrigated pastures, especially grass pastures, it will usually also increase. This will usually also be the case where a permanent (perennial) grass cover crop is grown in orchards or vineyards. The opposite, i.e. drastic reduction in the soil organic matter level, happens where clean cultivation is practised in orchards or vineyards. The soil is kept bare and organic matter additions are minimal. Often bare strips are kept in the rows of trees or vines in orchards or vineyards. This is usually done by means of herbicide applications. The reason for clean cultivation is usually to avoid water being used by grasses and other non-productive vegetation. Where bare soil strips are maintained in the rows as wide as the drip lines of the trees it is done for this purpose or to avoid interference with water distribution patterns of micro-sprinkler irrigation by vegetation which intercepts it. In many cases the maintenance of bare soil surfaces, and consequent low organic matter levels, leads to very poor soil physical conditions that cause poor irrigation water use efficiencies. This will be discussed in the modules on soil crusting and soil compaction.

b. Temperature

Decomposition of organic matter is very rapid and very intense at high temperatures. South Africa is a hot country and therefore it is virtually impossible to maintain high organic matter levels in the country's soils, except where a dense permanent grass cover is maintained. This is why a grass ley crop in a crop rotation is not effective for building up soil organic matter levels under South African conditions. Nearly all of South Africa's irrigated areas are in the hottest parts of the country and thus decomposition of organic matter incorporated into the soil in these areas is very fast. This needs to be kept in mind when designing irrigation management systems.

c. Aeration

The soil microbes involved in the decomposition of organic matter are aerobic, i.e. they need oxygen to conduct this function. Any action that improves soil aeration will thus accelerate and intensify organic matter decomposition. Cultivation is one such action. From the point of maintenance of the highest possible organic matter level in soils, conservation tillage practices such as minimum tillage or zero tillage would therefore be advantageous. In some soils the latter practices however have negative effects that may outweigh their positive effect on soil organic matter level, as shown also by some South African research. These are discussed in later modules. Each case must thus be considered on its own merit before deciding whether to implement such practices or not.

In waterlogged areas (wetlands, vleis, marshes) aeration is poor and this is why soil organic matter levels in such areas are very high. Normally such areas should not be drained or cultivated since they have very important ecological functions. When such soils are drained and/or cultivated the organic matter is decomposed very fast and the areas lose their ability to perform their ecological functions.

d. Texture

Sandy soils virtually always have considerably lower organic matter levels than medium-textured or especially clayey soils and it is much more difficult to maintain fairly high organic matter levels in sandy soils. A few of the reasons for this are:

- Sandy soils are generally less fertile than clay soils and consequently less plant material is produced to add to the soil.
- Sandy soils are better aerated than clay soils.
- Sandy top soils are drier and warmer than clay soils.
- Humus binds to clay particles, in which form it is more stable against decomposition. Sandy soils lack this protection.

2. Soil organisms

There is a close relationship between soil organic matter and soil organisms, because organic matter is the energy source for these organisms – and to some extent also provides their mineral nutrition. The various types of living organisms in and above the soil are depending on each other. The plant is using nutrients from the soil and carbon dioxide from the atmosphere to produce plant tissues. The plant tissue is serving as food for living organisms in or above the soil. Plant and animal residues return to soil where it is decomposed by insects, earthworms, fungi, bacteria and other organisms. This decomposition process eventually yields carbon dioxide and plant nutrients, which are then again available for consumption by plants.

Table 1. Categories of soil organisms [1)]

Animal organisms (Fauna)	Macro	Earthworms, ants, beetles, millipedes, woodlice, snails, mice and other small organisms
	Micro	Predators like nematodes and parasites that live on rotted matter
Plant organisms (Flora)	Macro	Roots and trunks /branches of higher plants
	Micro	Bacteria (aerobic and anaerobic) that plays an important role in nitrogen fixation
		Fungi like mushrooming fungi, yeasting fungi.
		Algae (green, blue and diatoms)

The biological activities in the soil promote:

- Soil structure – the secrete products produced by micro and macro organisms contribute to the binding of silt and clay particles into a crumb or granular structure.
- Pore volume of soil
- Permeability

Both favourable and unfavourable organisms are found in soils:

- **Favourable organisms** are usually aerobic organisms, i.e. they need good soil aeration.
- **Unfavourable organisms** are usually anaerobic organisms, i.e. they operate under conditions of poor aeration, for example waterlogged conditions.
- **Soil-borne diseases**, e.g. root rot organisms, are also unfavourable organisms. Several of these can be curbed or eliminated by good soil and/or irrigation management.

Example

- In Mpumalanga and Swaziland it was at one stage found that application of fungicide was no longer effective to combat phytophtera root rot in various irrigated citrus orchards. It was found that these orchards had serious management-induced compaction and water logging problems. It was found that this combination seriously predisposed the trees to phytophtera damage (and death). The problem could be overcome by eliminating the combination of compaction and water logging by good soil and irrigation management. It led to the concept of "root care", i.e. creating favourable conditions for healthy root growth in the soil.

- Nematode (eelworm) infestation is a serious problem, leading to great losses under intensive crop production, such as irrigated agriculture. Some crops are particularly vulnerable to it and it is a much bigger problem in sandy soils than in finer textured soils. Nematodes can be controlled by measures such as fumigation of soil. Several decades ago grape farmers in the Lower Orange River (Upington) irrigation scheme found that nematodes can be controlled by planting *Eragrostis curvula* (oulandsgras) as cover crop in the vineyards. Likewise, tobacco farmers near Nelspruit plant *Eragrostis curvula* as a grass ley crop in their crop rotation for the same purpose. The grass ley does not have significant benefit in terms of increasing organic matter levels in the soil, but is effective in terms of disease control.

Several other types of problems can be overcome simply by appropriate management, such as breaking disease cycles by appropriate crop rotations, appropriate soil and irrigation management, manipulating soil pH levels, etc.
The effectiveness of a specific group of microbes is determined by:

- The numbers in the soil
- The mass per volume of the soil (also known as the biomass)
- Metabolic activity

3. Decomposition of organic matter

The following three reactions take place when organic matter is applied to the soil:

- *Microbiological breakdown of the organic matter*
  The decomposition of organic matter is usually an enzymatic oxidation process, which can occur under aerobic and anaerobic conditions. The products are mainly carbon dioxide, water, and energy. Under anaerobic conditions, incomplete oxidation occurs and some of these intermediary products can even be toxic.
- *Release of plant nutrients*
  Essential plant nutrients, namely nitrogen, phosphorous and sulphur are released from complex organic compounds and changed into plant absorbable forms of the elements by the process of mineralization.
- *Formation of humus*
  After the decomposition process, the following compounds remain in the soil namely:
  - Compounds resistant to decomposition
  - Compounds formed during decomposition

Table 2. Composition of humus and plant material[1)]

Component	Plant residue (%)	Humus (%)
Carbohydrates	30-60	3-14
Proteins	1-15	30-35
Lignins	10-30	40-50
Lipids, waxes, etc.	1-8	1-8

The following factors are influential on the rate of decomposition:

- *Carbon content[2]*

The carbon content in the soil is very important because it serves as a source for energy and the carbon is essential for the formation of new cell matter. Microflaura use up to 20-40% of the carbon source, while the residue is collects as waste and /or is released as CO_2.While the carbon is absorbed to form new protoplasm, other nutrient elements like nitrogen, phosphorous and sulphur are absorbed simultaneously. These elements are important for plant growth.

- *Nitrogen content[2]*

Nitrogen is a key ingredient for microbic growth and thus for the degradation process. In decomposition of plant residues, organic nitrogen is released as ammonium. Some of this nitrogen that is released can be absorbed immediately to form new microbic tissues. The processes of nitrogen mineralisation and immobilisation are therefore simultaneous processes.

If the nitrogen content of the organic matter in the soil is high	Not enough nitrogen to meet the needs of microbes and they may use mineralized nitrogen, creating a negative nitrogen period
If the nitrogen content of the organic matter is high	Enough nitrogen for the basic needs of microbes, and the excess released as ammonium

- *C/N ratio of organic matter[3]*

45% of the plant tissue is made up of carbon, while the nitrogen content will differ with plant types and also according to the age of the plant.

Nitrogen level relatively low in organic matter, and therefore C/N ratio high	Microflaura exhaust inorganic reserves and application of inorganic nitrogen required to avoid negative nitrogen period
Nitrogen content relatively high in organic matter, and therefore C/N ratio low	Increase in inorganic nitrogen that serves the needs of microflara, and seldom-additional application of nitrogen required.

- *Chemical and physical environmental factors* like aeration, texture of the soil, optimum temperature and adequate soil water

Activity

Activity 1

Small group activity

The most accurate method of determining the organic matter content of the soil is by laboratory analysis **OR** to dig a soil pit with a soil auger or a shovel. This pit is dug to at least 0.3 m below the effective root zone (preferably 1.5 m). The soil pit will help you to get up close and observe the life forms that are working the soil. Describe the type of life form, number and activity of the microbes discussed earlier in this module**.** Make drawings of the different life forms, or take some pictures. This should form part of the Soil Pit Survey that is required for irrigation.

What practices will you recommend to the farmer if the organic matter content is very low, and the microbes' activity and numbers are proving your observation?

References

1. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.
2. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
3. Singer MJ & Munns DN, 1992. 2nd Ed Soils. An introduction. New York: McMillan

My notes............

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Technical Learner Guide

Assessing of soil resources

Level 5

Module 5

Soil structure

Study objective

After completion of this module, the learner should be able to:

- Define soil structure, aggregates and soil peds
- Identify and understand the prominent factors that determine soil structure
- Identify different soil structure types
- Identify factors which contribute to the weakening of soil structure
- Carry out structural evaluation (macro structure) of a soil profile and describe a soil profile in terms of structure degree, size and type
- Explain the stabilization process of soil structure
- Explain how ploughing and other cultivation practices weaken structure

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1. What is soil structure?

Some soils have fairly uniform structure throughout the soil profile. More often the types of structure of different horizons in a profile are quite different and in some cases drastically different.

Soil structure is a very important factor in evaluation of the suitability of a soil for irrigated agriculture, in regard to both irrigability and crop growth and production. In South Africa this evaluation must be based on research findings and experience in South Africa and neigbouring countries like Swaziland and Zimbabwe. European and North American criteria are not applicable and should not be used.

Description of soil structure for classification purposes refers only to macro structure. This is important in land suitability evaluation. Soil structure includes macro and microstructure. Microstructure occurs where soil particles form such peds that they are not visible to the naked eye. Some soils have stable microstructure, which has important impacts on soil physical properties – usually favourable. It is important to record such microstructure during soil surveys for irrigation purposes

Definition

Soil structure refers to the grouping or arrangement of primary soil particles (sand, silt and clay) into larger units called aggregates or peds.

Aggregate: individual sand, silt and clay particles grouped together into a larger lump. An aggregate can be spherical, prismatic, blocky, plate-like or columnar.

Peds: This is an alternative term for aggregate. It is a natural unit of soil structure[3]

Structure stability is important regarding the suitability of a soil for irrigated agriculture. With structure stability is meant the resistance of aggregates against disintegration by water and implements.

2. Classification and description of soil structure

Soil structure is morphologically described according to three criteria:		
The type of structure, i.e. the form of the structural units.	The size of the structural units.	The degree (grade) of structure development.

2.1 Types of soil structure

Different types of soil structure are illustrated in Figure 1.

a. *Structureless:* No aggregation has occurred. Two types of structures soil are distinguished:
   i. Single grained: when the soil is dry all particles are loose from each other (i.e. they occur as single grains) as in loose sand.
   ii. Massive: the soil forms a hard mass when it is dry. It breaks into hard clods with no clear pressure or cleavage planes. This condition is found in compacted

plough pans or traffic pans that form under intensive cultivation. It also occurs in the naturally occurring dense sub soils that are found in many parts of South Africa. They are typically sub soils with high fine sand and/or silt contents.

b. *Blocky:* The aggregates have a more-or-less cubic form. Two types of blocky structure are distinguished, viz. (i) angular blocky structure, which has sharp corners, and (ii) sub angular blocky, where the corners are rounded off. Blocky structure is characteristic of many medium-textured to clayey sub soils in sub-humid to semi-arid areas. Soil with moderate to strongly developed medium to coarse angular blocky structure has poor physical conditions. Soils with such sub soils cannot be recommended for irrigation. Subsoil with sub angular blocky or fine angular blocky structure are somewhat better, but should still be evaluated very carefully, taking into account local experiences with them. An exception is the very stable “Red structured B horizon” of the South African soil classification system. It has very favourable “nutty” type sub angular blocky structure. It is a good soil for irrigation – provided that careful crop selection is made.

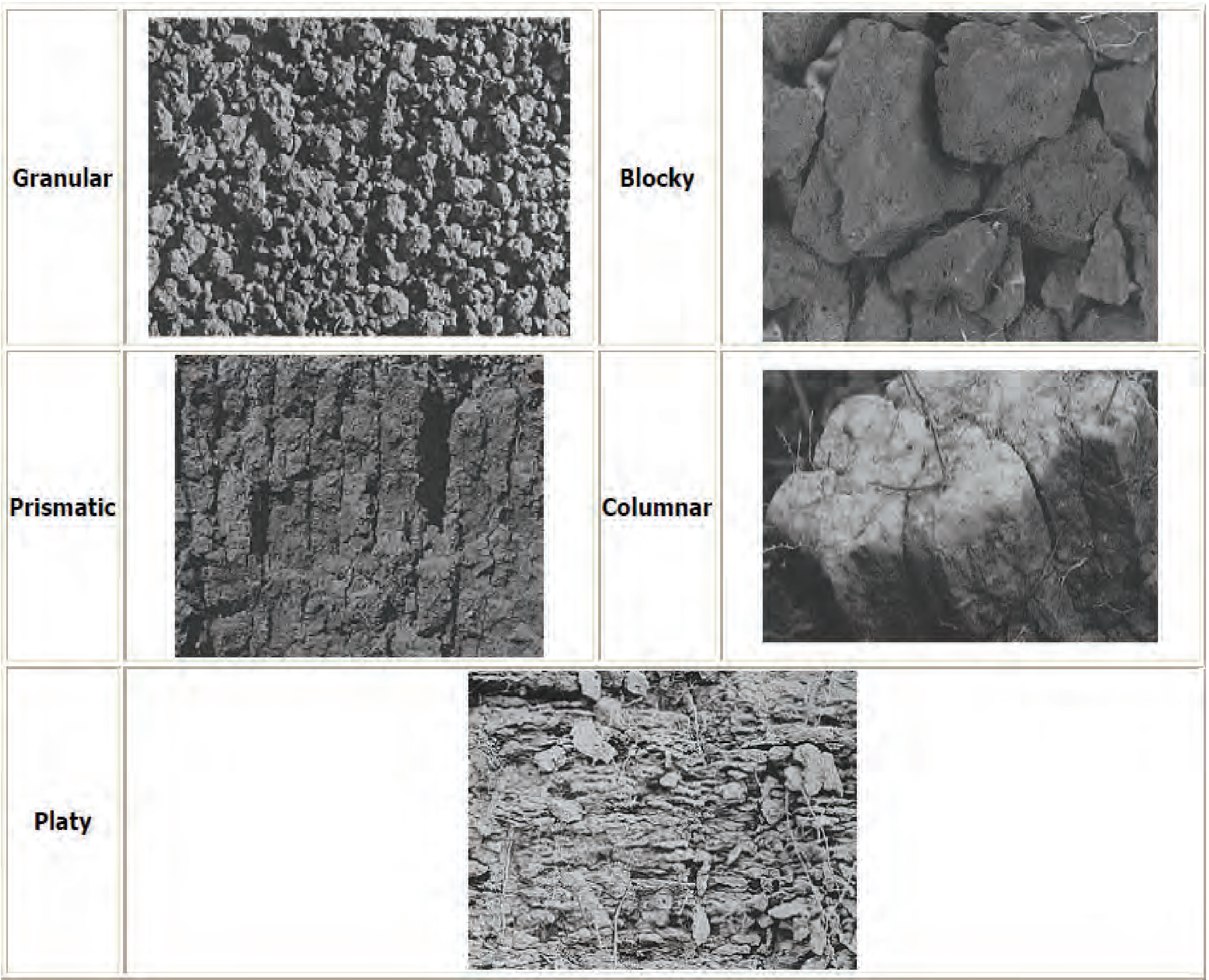

Figure 1. Types of soil structure

c. *Prism-like:* These aggregates have much longer vertical axes than horizontal axes. In farmer language it is sometimes called "beer can structure", because it resembles beer cans stacked next to each other. Two types of prism-like structure are distinguished, *viz*. (i) prismatic, where the tops of the aggregates are flat, and (ii) columnar, where the tops of the aggregates are rounded off. Prism-like structure is characteristic of sub soils in sub-humid to semi-arid areas with high swelling clay contents and unfavourably high sodium and/or magnesium contents. Such structure is extremely unstable. The soils are highly erodible (also under irrigation) and have very poor conditions for root penetration and water movement into the subsoil. Soils with such sub soils are absolutely not suitable for irrigation. Unfortunately South Africa has large areas covered by such soils, due to the influence of parent material. The most extensive areas are in the central, western and north-western parts of the Eastern Cape, the southern and south-eastern parts of the Free State and the north-western parts of KwaZulu-Natal. Serious errors have been made, e.g. in the White Kei-Qamata-Occupation Post area of the Eastern Cape, by developing irrigation on such soils, with disastrous consequences.

d. *Spheroidal:* This type of structure consists of small stable aggregates of which the shape resembles small blocky structure units. Two types of spheroidal structure are distinguished, *viz*. (i) granular structure, and (ii) crumb structure, consisting of soft aggregates that are porous. Granular and crumb structure represent soils with very good physical conditions. They are characteristic of top soils (usually medium-textured) under a dense grass cover. This condition is destroyed very quickly when the organic matter content of the soil decreases due to intensive cultivation. Conversely it can be created by addition of large quantities of organic matter, e.g. in the form of compost.

2.2 Degree of structure

The degree of structure is the degree of aggregation or the strength with which the peds are joined together. The degree of structure refers to:

- How easily the structure can be seen in the ped
- How many primary particles have been aggregated
- How firmly the particles are bonded together in the aggregate

This classification is then used to define the degree of structure, i.e. either unstructured where no perceptible peds are observed, or structured. The structured soil can then be classified according to the size of soil structural units.

2.3 Soil structural classes

Soil structure is classified as fine, medium or coarse, according to the size of the aggregates. Generally fine to medium structure is considered to be the most favourable, while coarse structure is seen as an indication of unfavourable soil conditions. According to the degree of structural development, soil structure is described as weak, moderate or strong.

Soil structure classified	**Fine**	**Weak, moderate, strong**
	Medium	**Weak, moderate, strong**
	Coarse	**Weak, moderate, strong**

Structure grade is described according to:

- How clear the cleavage planes are at which aggregates break from each other. In the case of weak structure the planes or vague, whereas in the case of strong structure they are very clear.
- A second criterion is the difficulty with which a ped can be broken. The latter, of course, does not apply to massive structure. The grade of soil structure is influenced strongly by the moisture content of the soil. Structure appears much weaker in moist soil than in dry soil. Prism-like structure can often not even be seen in moist soil, while in the same soil it can be very strong when the soil is dry. For such soils it is recommended to describe soil structure 24 to 48 hours after a profile pit has been opened. During soil surveys it is imperative to annotate the moisture content of the soil at which structure was described. (Just qualitatively, either “moist” or “dry”. This is in any case required for soil colour description also.)

Note: *Structure strength must not be confused with structure stability. Strong structure is not necessarily stable structure. In reality strong structure is usually unstable and thus unfavourable, while weak structure is often stable.*

Soil structure is described in the order: grade-class-type, i.e. clarity-size-form. For example: moderate coarse angular blocky. In profile descriptions abbreviations are usually used.

Degree	Size	Type
Moderate	Coarse	Angular blocky

3. Soil structure formation

An adequate quantity of flocculated clay is a prerequisite for structure formation. It is usually considered that soil must contain more than 15% clay to enable structure formation. Sandy soils (sand, sandy loam and loamy sand texture classes) are thus structureless or have at the best very weak structure. In soils with more than 15% clay, structure formation increases with increasing clay content. Conditions conducive for clay flocculation are needed to initiate structure formation.

Van der Waals forces bind flocculated clay particles into domains (packets of orientated crystals). The domains are bound to each other and larger sand and silt particles by different types of bonds in which soil organic matter plays a key role.

3.1 Stabilization of soil structure

Although flocculated clay and conditions conducive for clay flocculation are prerequisites for structure formation, none of these can stabilize soil structure against disintegration by water or implements. For the stabilization of soil structure adequate amounts of "cementing" materials are required. By far the most important cementing materials are (i) organic colloids, in the form of humus, and (ii) so-called sesquioxides, i.e. free iron and aluminium oxides. In the vast majority of soils organic colloids are by far the most important (or only) cementing materials. A special case in South Africa is the soils of the so-called "Shortlands" soil form. In these soils the "nutty" blocky structure aggregates of both the topsoil and subsoil are stabilized by iron oxides by which they have been impregnated. These stabilize their structure to such an extent that the structural stability is maintained even if their organic matter content is drastically reduced under intensive cultivation. These soils occupy only small areas, but are very important from a crop production point (both dry land and irrigated).

Soil fauna, especially earthworms, make important contributions to structure formation and stabilization by means of promoting intimate mixing of organic matter with soil particles. Earthworms also ingest soil particles and bind them into stable micro aggregates in their intestines. These are then excreted as earthworm casts. They can make meaningful contributions in soils that are fertile and have adequate organic matter contents.

Activity 1

Small group activity

1. Describe the soil structure of a soil profile in terms of the degree, size and type of structure observed.
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2. Explain the difference between soil texture and soil structure as well as the important role both properties are playing for irrigation development.

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References

1. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.
2. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York: John Wiley.
3. Singer MJ & Munns DN, 1992. 2nd Ed Soils. An introduction. New York: McMillan

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Module 6

Additional soil physical properties

Study objective

After completion of this module, the learner should be able to:

- Understand the processes of dispersion and flocculation
- Understand the process of swelling and forming of crusts at the surface
- Explain the roles of macro and micropores in the soil and their influence on porosity
- Discuss the importance of good soil aeration for plant growth and irrigation efficiency
- Identify factors promoting good soil aeration
- Explain the relationship between bulk density and porosity
- Identify the factors that affect soil aeration
- Identify the symptoms that cause poor soil aeration
- Provide appropriate support in the selecting of crops suitable for specific soil aeration conditions
- Use soil colour as an indirect indicator of soil aeration
- Identify effective root zone

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1. Flocculation and dispersion[1,2)]

Definition

Dispersion is when soil breaks into individual particles of sand, silt and clay when wet. A dispersive soil is structurally unstable and forms crusts when it dries. In dispersive sub soils, the clay particles clog pore spaces, forming a barrier to water and air movement, and to the root growth. In a dispersed condition clay occurs as single particles, which repel each other.

In the **flocculated state** several clay particles cling together to form larger units. Soils which are in a dispersed condition have very poor physical properties, leading to serious problems in irrigated agriculture: Water infiltration and conductivity is poor, aeration is poor, root development is inhibited, etc. Such soils are also highly erodible, which can be a problem under overhead sprinkler irrigation.

Adsorbed cations do not occur as a single layer around soil colloids, but as a positively charged diffuse double layer surrounding the clay particles. Similar charges always repel each other. Similarly charged particles can be attracted to each other if they can get close enough to each other to allow the Van der Waals physical attraction forces to overcome the repelling forces. **Van der Waals forces** are very strong, but they operate only over extremely short distances. If the diffuse double layer is thick, then the particles cannot get close enough to each other for the Van der Waals forces to come into operation. Consequently they repel each other and remain in a dispersed state. If the double layer is thin enough and the particles come close enough to each other, then Van der Waals forces can bring about attraction between clay particles. The particles are then flocculated.

The thickness of the double layer is determined by

- the charge density, which is related to CEC, on the colloid,
- the type of adsorbed cation and
- the electrolyte (dissolved salt) concentration in the soil solution.

A thin double layer, and thus flocculation, is promoted by:

a. A low charge density (low CEC).

b. Poli-valent cations, mainly Ca^{++}.

c. A high electrolyte concentration.

A thick double layer, and thus dispersion, is caused by:

a. High charge density (high CEC).

b. Large mono-valent cations, mainly Na^{+}.

c. A low electrolyte concentration.

Soils susceptible to dispersion[1,2)]:

- Smectite clay minerals have high charge densities and are very susceptible to dispersion.
- Kaolinite has a low charge density and is much less susceptible to dispersion.
- In the case of a mono-valent cation, like Na^{+}, a lot more ions must fit into the double layer to neutralize the negative charges than in the case of a small divalent ion like Ca^{++}. Furthermore, Na^{+} occurs as a very large hydrated ion. Thus, sodium is highly dispersive, because it causes a very thick double layer. This is a big problem in irrigated agriculture.

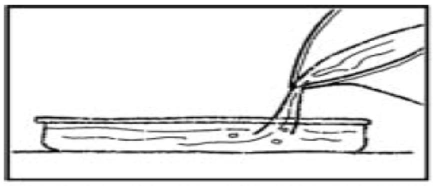
Each specific situation (type of clay mineral; nature of adsorbed cations) has a minimum electrolyte concentration, which is required to compress the double layer enough to bring about flocculation. This is called the *threshold concentration*. The practical implications of all of these for irrigation are discussed in later modules.

Activity

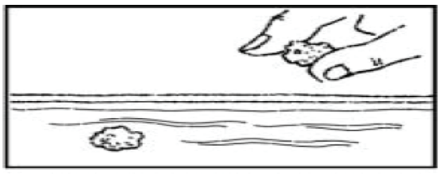
Activity 1: Testing of soil for dispersion

Small group activity

1. Pour some rainwater or distilled water into a dish.

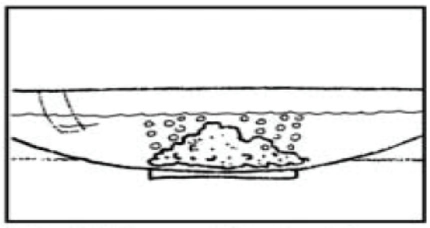


2. Drop several small lumps of dry soil into the water one at a time

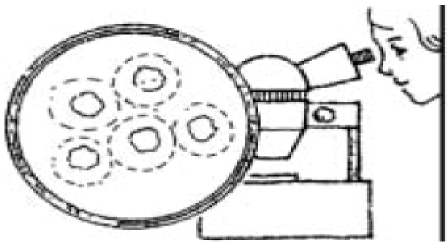


3. Check after 10 minutes and again after 30 minutes whether the water around the soil has started to become cloudy. If this happens, then it means that the soil has started to disperse.

4. Check the cloudiness of the soil as it develops after further30 minutes.



5. Sodic soil has sodium attached to the clay. When the clay is wet, the sodium attracts a water shell around the clay particle presenting the particles from joining together.



2. Swell-shrink phenomena in soils

Some clay minerals (like smectites) are subject to tremendous swelling upon wetting. Others (like kaolinite) have no swelling properties. Swelling is determined mainly by the same factors, which affect dispersion. Swelling causes a large reduction in the macro porosity of soils and thus inhibits water conductivity, aeration and root growth. On the other hand it is very useful to make soil impenetrable for water; such as in earth dams (especially for wall cores) and canal linings. When swelling clays dry out they shrink and large cracks develop in the soil, accompanied by great forces. Various problems are caused by the development of deep, wide cracks in such soils, such as:

a. Plant roots are torn or broken. This is called "root pruning" and causes serious stunting of trees on such soils.
b. Intense drying of the soil occurs to great depths.
c. During rain or irrigation much water initially moves right through these cracks without actually wetting the soil. This is called "short circuiting".
d. Structures in or on the soil get seriously cracked and damaged (houses, stores, concrete canals, concrete storage dams, pipes, etc.)

3. Bulk density

Definition

Bulk density is defined as the mass of a unit volume of oven-dry soil. This volume includes both solids and the spaces between them (pores). The bulk density of a soil is used in the calculation of volumetric water contents and volumetric water holding capacities of soils. These are used to calculate how much water needs to be applied during irrigation[1,2].

The average particle densities of different soils are assumed to be approximately the same. Thus bulk density is determined by the total porosity of a soil. The higher the porosity, the lower is the bulk density. Fine-textured soils such as clays, clay loams and silt loams generally have lower bulk densities than sandy soils.

Table 1. Bulk density of different soil texture classes

Texture of soil	Bulk density ($kg.m^{-3}$)
Fine textured	1000-1600
Sand Loamy sand Sandy loam	1200-1800
Fine sand	Very high (>1800)

Under natural conditions the bulk densities of the fine sandy soils which are, for example, found widespread in the western Free State and at the Vaalharts and Taung irrigation schemes have bulk densities in the order of 1 650 $kg.m^{-3}$ to 1 750 $kg.m^{-3}$. These high bulk densities explain why research has shown that practices such as zero tillage and minimum tillage do not give good results on these soils, compared with well-managed conventional tillage.

On the other hand poorly managed conventional tillage on these soils causes compacted layers with bulk densities of up to 1 800 $kg.m^{-3}$. In extremely compacted soils bulk densities can reach 2 000 $kg.m^{-3}$ or even higher. Bulk densities in excess of 2 000 $kg.m^{-3}$ have been found in reclaimed soils on opencast coal mining areas in Mpumalanga. Inhibition of the root growth of most crops by high bulk densities starts at a bulk density of about 1 650 $kg.m^{-3}$. Root growth of most crops stops when the bulk density goes over 1 800 $kg.m^{-3}$.

4. Soil porosity

Definition

The porosity (pore space) of a soil is the open spaces between the soil particles. These spaces are filled by air and water. The porosity of a soil is determined by the arrangement of the soil particles. If the particles are packed close together, for example in sandy soils or compact sub soils, the total porosity of the soil is low. Well-structured medium-textured to clay soils, especially those with porous aggregates and high organic matter levels, have high total porosity[1,2)].

Soil pores are classified into two types, viz. (i) macropores and (ii) micropores. As their names indicate, macropores are large pores and micropores are small pores. No real limit has been defined to distinguish between macropores and micropores, but it is tentatively assumed that macropores have diameters larger than 0.06 mm and micropores diameters smaller than this.

- ***Macropores***
  Sandy soils have high macroporosity. Clayey soils have low macroporosity, especially if they (i) are not well-structured and/or (ii) contain swelling type clay minerals. Macropores have three main functions in soils:
  - *a. Downward movement of water through the soil under the force of gravity takes place only in macropores*. Thus soils with inadequate macroporosity have slow and inadequate movement of water into subsoils, which is an important storage place of plant-available water. Soils with inadequate macroporosity in the deeper layers are poorly drained. This can cause serious problems under irrigation. Despite the fact that they have high total porosity, clayey soils thus have low hydraulic conductivities and are often poorly drained, because of their low macroporosity. In contrast sandy soils have, despite their low total porosities, high hydraulic conductivities and are often excessively drained if there are no limiting layers within the bottom of the profile.
  - *b. Soil aeration takes place in macropores.* Soils with inadequate macroporosity, such as poorly structured clay soils and swelling clays are

poorly aerated. Plant roots cannot function properly without enough oxygen. The same is true for favourable soil organisms.

c. Root growth takes place in macropores.

- ***Micropores***

  Medium-textured and clayey soils have high microporosity. Sandy soils have low microporosity. Downward movement of water under the force of gravity, soil aeration and root growth, do not take place in micropores. The function of micropores is to retain water in the soil against the force of gravity. Thus the microporosity of a soil determines its plant-available water storage capacity. This is why medium-textured and clayey soils have high water storage capacities, while sandy soils have low water storage capacities. (The latter statement is not quite true for fine sandy soils, such as those found at Vaalharts. This is discussed in a later Module.)

Pore space depends on:

- Texture and structure: extent of pore space varies between different soil types, e.g. sandy soils *versus* heavier clay soils
- Depth of soil: pore space varies with depth of soils, can drop as low as 25-30%
- Cultivation: soil under permanent pasture cover generally have a larger pore space *versus* a soil which is under intensive cultivation

Rule of thumb

Total porosity of an average soil is approximately 50%. Sandy soils have lower values while clay soils display higher values.

5. Effective soil depth

Definition

The effective depth of the soil is that part of the soil to which normal root development can take place. This effective root zone is where the main mass of a plant's root system is found, and below the effective root zone only a few roots may occur[1,2)].

Figure 1. Effective soil depth of a soil profile-illustrated through active root development

When you examine a soil profile, look for healthy, living roots within each soil layer. This will enable you to estimate the depth of the crop's effective rootzone and the depth of each layer of different soil. This is very important for the determining of how much water will be available to a crop. It is essential to estimate the depth of the crop's effective rootzone as accurately as one 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 subsoil's or imbalanced water table.

The following are general aspects, which determine the effective depth of a soil:

a. *Clay layer in soil*
   Clay layers inside soils usually limit both water and air penetration. Different types of clay layers are found in different soil horizons (discussed earlier). When a horizon, with high clay content is found in the soil, the soil's effective depth is regarded as the depth to where this layer begins.

b. *Stony layer in soil*
   Stone layers are limiting as far as air, moisture and nutrients are concerned and are also a physical limitation for roots. Common stone layers are, for example, ferricrete ("ouklip") , a rock formation which forms in the soil profile.

c. *High water table layers*
   In wet low lying areas the water table may at times be reasonably close to the soil surface. Air is then a limiting factor for root development in such layers.

d. *Weathered rocks*

Rock formation that is weathering under the soil may be limiting for various reasons. These weathering rock layers in soils are classified as C-horizons.

Activity

Activity
Group activity

The only way to determine the effective soil depth for a particular situation is to dig a profile hole (or a couple if possible) and get your hands dirty.

1. The soil profile usually shows a change in texture, and it is important to determine how deep the effective rootzone is and also measure the thickness of the different soil within the effective rootzone layers.
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2. Use this exercise also to reflect on the various soil texture and soil colour.
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6. Soil aeration and soil colour

Good soil aeration is essential for good crop production. Irrigated agriculture particularly requires highly efficient management of several factors to ensure that good soil aeration and high production levels are maintained. Almost all-favourable process in soil is aerobic, i.e. they require adequate oxygen (O_2) levels. With good soil aeration high O_2 levels are maintained in the soil and that at the same time carbon dioxide (CO_2) in the soil air must be kept at the lowest possible level.

Table 2. Composition of soil air and atmosphere[1)]

Gas	Atmosphere (%)	Soil air (%)
Oxygen (O_2)	20.95	20
Nitrogen (N_2)	79.02	79.1
Carbon dioxide (CO_2)	0.03	0.3-1.0

6.1 Basic factors regarding soil aeration

There are three basic factors regarding soil aeration, viz.:

- The volume of air in the soil.
- The rate of gas exchange into and out of the soil.
- The aeration requirement of the soil (or rather of plants growing in the soil).

a. *Soil air volume:* The volume of air in a soil is determined by the total soil porosity (total pore volume) and the water content of the soil. The total pore volume determines that maximum volume potentially available to be filled by air. Some of the pores are filled with water and not actually available to be filled with air. Thus the actual volume of air in a soil at any specific time is determined by the water content of the soil. Since the water content of a soil changes continuously (except when it is permanently waterlogged), the volume of air in the soil also changes continuously. Because of these continuous changes characteristic water content must be used at which to compare the air content of soils. The “field water capacity”, or just called “field capacity” (FC) of soils is used as this reference point. The volume of air in a soil at this point is called the “field air capacity” of the soil. At this point all the macropores are filled with air and all micropores with water, which is the ideal situation. The field air capacity of a soil is determined mainly by soil texture and structure. It can range from more than 25% in uncompacted sandy soils to less than 5% in compacted medium-textured and clayey soils with poor structure. It is generally considered that if the soil air porosity drops below 10-12% soil oxygen replenishment is too slow to maintain adequate crop growth.

Major problems of inadequate soil aeration occur when the macropores in a soil (usually a subsoil layer) remain filled with water for extended periods. The worst scenario is where they remain filled with water permanently. This is called waterlogging. Waterlogging is the general cause of poor soil aeration. It is a major problem in irrigated agriculture due to poor irrigation management involving injudicious over-irrigation and/or inadequate provision for drainage of excess water. Floods can also cause temporary waterlogging.

b. *Gas exchange in soils:* The major processes root respiration, microbial respiration and organic matter decomposition that take place in soil all consume O_2 and produce CO_2. Thus the main gas exchanges required in soils are replenishment of O_2 in the soil atmosphere and release of CO_2 from the soil. Several other essential favourable reactions and processes in soils, like nitrification of nitrogen compounds, also consume O_2. The rate of gas exchange must be sufficiently rapid to prevent the O_2 in the soil air dropping below a critical level and the CO_2 content rising excessively high. A rough generalization is that functioning of the roots of many plants are inhibited when the O_2 content of the soil air is less than 10%.

Gas exchange takes place mainly in air filled macropores. Diffusion of gasses is ten thousand times slower in water than in air. Thus gas movement in water filled micropores and in waterlogged conditions is too slow to satisfy the oxygen requirements of plant roots and soil microbes. Gas exchange in macropores is greatly related to soil texture and structure. In well-structured clayey soils with adequate macroporosity poor soil aeration may be found inside aggregates due to too slow gas exchange into the central parts of aggregates. This is often the case in sub soils with coarse strong blocky structure. Sometimes these aggregates are also coated with dense thin clay layers, called clay skins or cutans that inhibit gas movement into and out of the aggregate. This is one of the reasons why soils with such sub soils have such poor qualities that they are not recommended for irrigated agriculture.

Soil crusting (surface sealing) is a serious widespread problem in irrigated areas throughout South Africa, as will be discussed later. A serious negative effect of soil crusts is that they severely inhibit gas exchange between the soil and the air above it, leading to poor soil aeration and all the negative effects associated with it.

Several mechanisms can bring about gas exchange in soils. Only one that is of special significance for irrigated agriculture is discussed here, viz. the influence of water that infiltrates into the soils and then drains to field capacity: During infiltration the water displaces "foul" soil air having low oxygen and high CO_2 levels. Displacement is downward and upward. When watering a dry soil with a hosepipe this is seen as air bubbles coming through the thin water layer on the soil as infiltration takes place. During subsequent drainage to field capacity a "suction pump" action is created which sucks air from the atmosphere above the soil into the soil. The suction sound can actually be heard clearly. The effect of this type of gas exchange is considerable, especially for aeration of sub soils. This is an advantage of irrigation scheduling strategies based on allowing soil to dry out as much between irrigations as can be tolerated without harming the crop.

c. *Aeration requirement:* The overall respiration rate due to all biological activities in the soil (mainly plant root and microbial respiration) determines the amount of O_2 consumed and CO_2 produced per unit volume soil per unit time. This determines the aeration requirement of the soil, i.e. how much O_2 must be replenished per unit volume soil per unit time to satisfy the needs of the respiration processes. The aeration requirement of any specific soil is not a constant value, but varies over time. Several factors affect aeration requirement, the following being the most important two:

   i. Soil temperature: The higher the soil temperature, the higher the respiration rates of plant roots and soil microbes – and thus the higher is the aeration requirements. This temperature related differences are huge. The hazards associated with water logging are thus much greater during summer than during winter. Under very hot conditions, such as found in most of South Africa's irrigation areas, less than 24 hours of inadequate aeration (e.g. through temporary water logging) can kill plants.

ii. Microbial activity: Incorporation of large quantities of energy rich fresh (undecomposed) organic material strongly stimulates microbial activity in the soil. This temporarily increases the aeration requirement of the soil sharply, especially under hot conditions. It can lead to temporary anaerobic (oxygen deficient) conditions – to the detriment of plant root activity and plant growth. The timing of the incorporation of such organic matter is thus very important.

6.2 Consequences of poor soil aeration

Poor soil aeration has several very negative effects that have serious consequences in irrigated agriculture. Some of the most important ones are:

a. *Poor root respiration, leading to:*
   i. Inhibited root elongation. Thus the root system is very small. In the Sundays River Valley root development of irrigated citrus trees was changed from very poor and shallow to very good by simply alleviating a dense surface crust by means of application of an organic soil conditioner less than 5 cm deep.

   ii. Poor nutrient uptake. Nutrient absorption is strongly dependent on effective root respiration.

   iii. Poor water uptake. Water uptake from waterlogged soil is very poor. One of the symptoms of plants on waterlogged soils is that they are wilted. This is often interpreted as a sign of drought and more water is added to the soil, aggravating the situation further.

b. *Poor germination of seed:* Poor aeration due to a dense surface crust is often responsible for this.

c. *Reduced activity of favourable micro organisms, including:*
   i. Reduced rate of decomposition of organic material applied as fertilizer to supply plant nutrients. Organic materials that are applied to supply plant nutrients must be decomposed and the nutrients released into inorganic forms that can be utilized by plants. This process is conducted by aerobic microbes and is called “mineralization”.
   ii. Reduced rate of oxidation of certain major plant nutrients into forms in which they are utilized most effectively by plants. Most important of these is so-called “nitrification” of nitrogen. This consists of microbial oxidation of nitrogen compounds in the soil to nitrate (NO_3^-), the form in which nitrogen is most efficiently absorbed by plants.
   iii. Reduced fixation of nitrogen gas (N_2) from the air into plant-available forms by symbiotic organisms living in the nodules on the roots of legumes or free-living

microbes in the soil. This limits the ability of legumes to bind nitrogen for themselves and for crops succeeding them in a crop rotation.

d. *Enhancement of negative or harmful microbial activities, including:*

i. "Denitrification" of nitrogen compounds, especially nitrates, into forms in which cannot be utilized by plants, such as nitrite (NO_2^-) or gaseous forms, such as N_2O or N_2, in which they are completely lost from the soil. Thus nitrogen deficiency, seen as intense yellowing of the leaves of plants, is characteristic of waterlogged soils.

ii. Production of harmful chemicals that becomes toxic when accumulating in high concentrations in soils. These include products of incomplete decomposition of organic matter and products of various anaerobic microbial processes.

iii. Increased incidence and activity of soil borne root pathogens (disease organisms) that prosper in anaerobic conditions, for example *Phytophtera* root rot.

6.3 Sensitivities of different crops to poor soil aeration

Different crops, and in the case of tree crops different rootstocks, differ widely in regard to their sensitivity or tolerance to poor soil aeration – especially to water logging. This must be taken into account when land use planning is done for irrigation development on soils with potential water logging hazards. It is impossible to give complete information on all crops here.

A few important examples are discussed here:

a. *Fruit crops and related crops:* Under conditions of poor aeration fruit crops differ very widely in regard to their (i) sensitivity to suffocation, (ii) tendency to produce toxins in the plants themselves and (iii) vulnerability to root pathogens. South African publications indicate that the kernel fruits (pears and apples) are resistant to water logging, i.e. they can tolerate high water tables.

- Pears are, in fact, very resistant.
- Grapes are also resistant.
- Stone fruits such as apricots and peaches are much more sensitive to water logging than kernel fruits and grapes. Peaches specifically are very sensitive. Prunes are intermediate, mainly because Marianna plum rootstock performs moderately well under unfavourable conditions.
- Citrus and several subtropical fruit crops are also sensitive to poor aeration, because of their susceptibility to *Phytophtera* infestation under such conditions. Since water logging is such a major problem in irrigated agriculture due to poor land use planning and/or irrigation management, these ramifications need to be understood very well.

b. *Vegetable and field crops:* Vegetable and field crops also have different sensitivities to water logging. Potatoes and sorghum are amongst the most tolerant, being able to produce well even with a water table (top of the waterlogged layer) as close as 50 cm to the soil surface. For crops like maize, tomato, peas and beans the water table must be at least 75 cm from the surface. For successful production of green beans and dry beans even a non-waterlogged strongly structured clay layer must be at least 75 cm from the surface. At Occupation Post, field beans (for dry beans) were in the early 1980s planted under irrigation on a soil with such clay layer only 30 cm from the surface, resulting in a total crop failure. The small grain cereals wheat, oats and barley are described as moderately sensitive to very sensitive for water logging and needing a water table to be no closer than 100 cm to the soil surface.

6.4 Soil colour as indicator of soil aeration

Soil aeration can be determined directly by monitoring O_2 and CO_2 levels and their fluxes in the soil by means of various kinds of probes. Such measurements are complicated and tedious and need to be maintained for a long time – for a number of years if meaningful results are to be obtained.

Fortunately soil colour can be used as indirect indicator of soil aeration. It is associated with the oxidation status of iron (Fe). The colour of the iron compounds in a soil absolutely dominates the colour of a soil, except where high organic matter levels give an overriding dark colour or few rare exceptions.

- Under well-aerated conditions iron is oxidized to the ferric (Fe^{+3}) form. Under poor aeration it is reduced to the ferrous (Fe^{+2}) form. Ferric oxides have bright red (if not hydrated) or bright yellow (if hydrated) colours, with sometimes a reddish brown colour. Some people erroneously interpret a bright yellow soil colour as an indication that the iron is in the reduced form and thus that it indicates poor aeration. This is absolutely wrong. Thus, if a soil horizon has a uniform bright red, yellow or reddish brown colour it indicates that the horizon is well aerated and well drained. Note the words “uniform” and “bright”.

- If the colour of a horizon is predominantly bright red, yellow or reddish brown, but with some colour variation, it indicates that aeration is imperfect. This indicates that good irrigation management and drainage will be required.

- If a soil horizon at or near the bottom of a soil profile has abundant bright red or yellow mottles (specks) in a matrix (soil body) that has at least some light gray areas in it, it is an indication that the horizon is a zone in which there is a fluctuating water table. This is an indication of poor drainage. During rain seasons the water table rises to the top of the horizon. During dry seasons the water table subsides to the bottom of the horizon. Very good irrigation management and very effective drainage will be required if irrigation is developed on such soils, otherwise a permanent water table will develop in this horizon and eventually also in horizons above it.

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- Dominance of ferrous iron in a soil horizon indicates strong permanent reduction of iron. This indicates permanent anaerobic (very poorly aerated) conditions in such horizon. This is an indication of virtually permanent water logging in the horizon, which in turn indicates extremely poor drainage. Ferrous iron compounds have blue or green colours. The colours are usually not uniform and usually also include dull (not bright) yellow and light grey streaks. Sometimes a mixture of light gray and dull yellow colours dominates the horizon. Because of their inherently extremely poor drainage, soils with such horizons are normally not recommended for irrigation. Very often these horizons consist of very dense sticky clay. Installation of drainage at the bottom of such horizon will be useless, because excess water will not move effectively to the drain. If the soil above this horizon is deep, and irrigated, a high level of management together with an effective drainage system must be installed above this horizon.

Activity

Activity 3: Soil aeration

Group activity

In pairs or in a group, examine a soil pit of approximately 1 meter deep and wide enough to get into to observe the features of soil aeration of the different soil layers by making use of the knowledge gained in this module.

If features of soil aeration problems occur, identify the causes for the symptom and also present some recommendations how to manage this problem to the rest of the group.

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7. Cation adsorption and exchange

Cations (positively charged ions) play important roles in soils. With few exceptions the essential plant nutrients are present as cations in soils, from where plants absorb them. Animals and humans also obtain their essential mineral nutrients also *via* the soil –plant system. The ratios between the macro cations calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}) and sodium (Na^{+}) are also important in determining the physical condition of soils. These are called macro cations because they are present in large quantities in soils and the first three also needed in large quantities by plants.

7.1 Cation adsorption and the cation exchange capacity (CEC) of soils

Definition

Soil colloids (clay minerals and humus) have negative charges. These negative charges attract cations, which are then attached to the surface of the colloid by the negative charges. This process is called **cation adsorption** *(Note the "d")* This process is fortunate, in that the adsorbed cations are available for absorption (uptake) by plants, but are also protected against leaching from the soil.

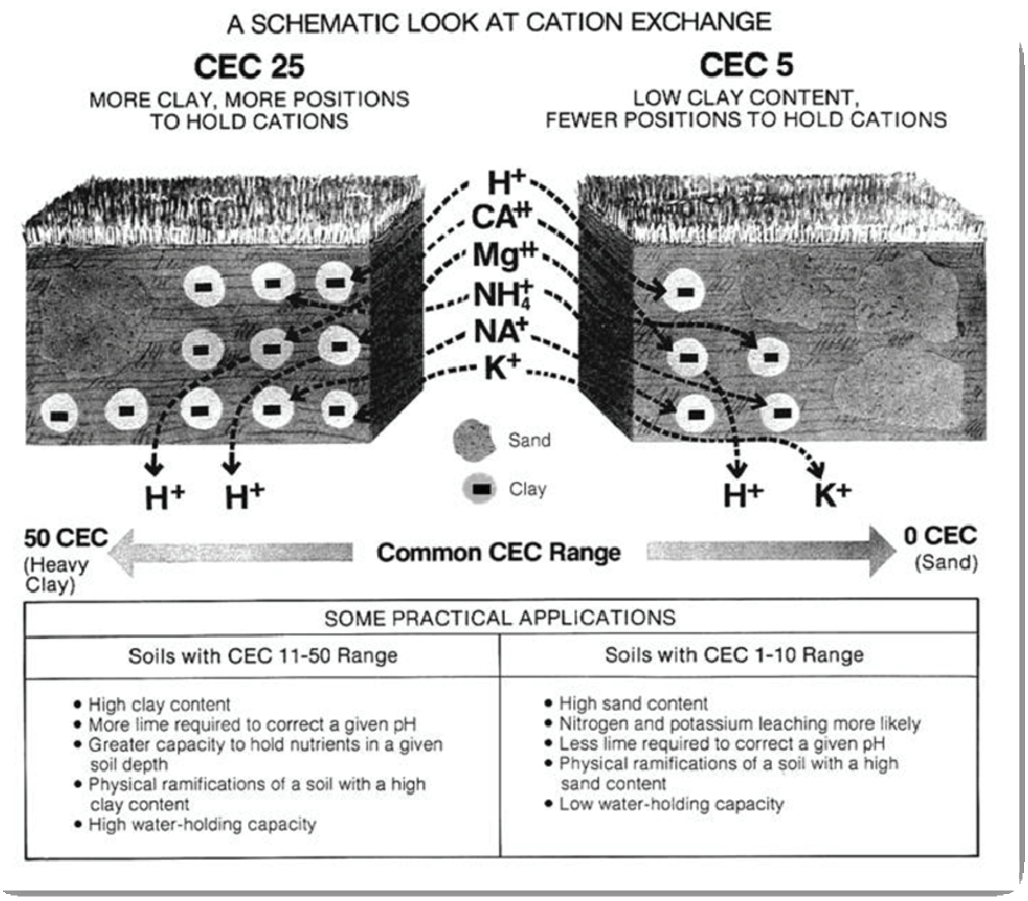
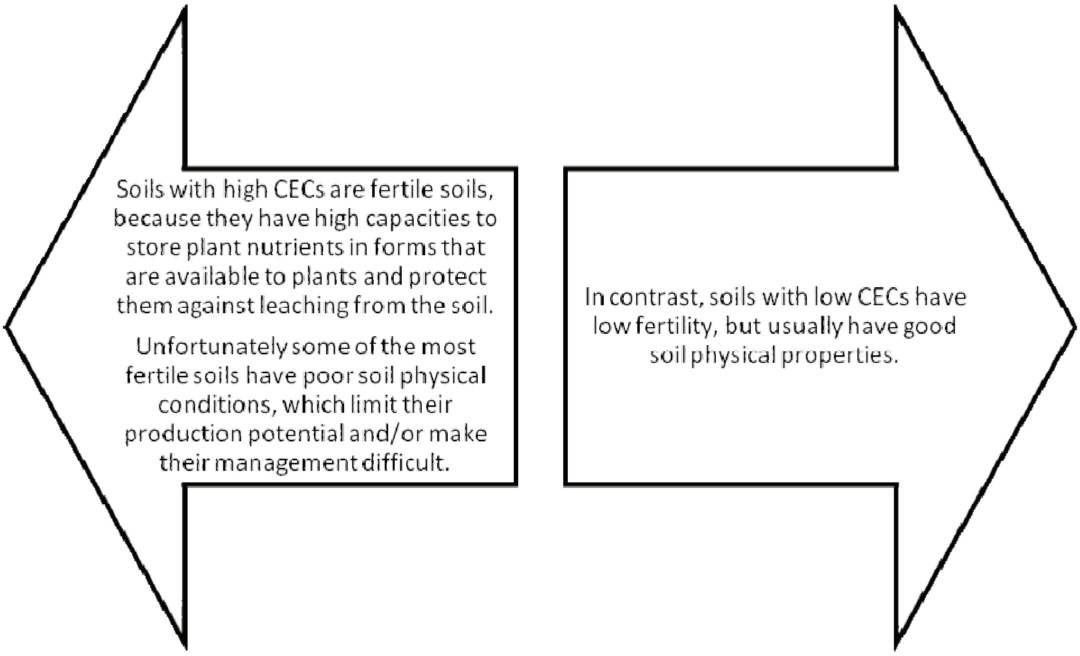


Figure 2. Schematic look at cation exchange

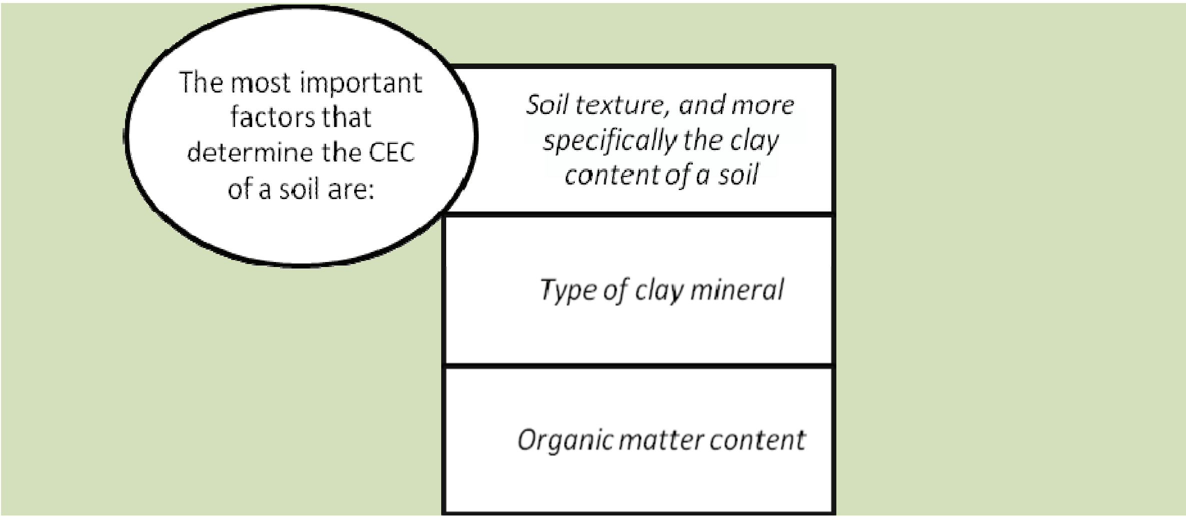
Adsorbed cations can be replaced by other cations. This process is called **cation exchange.** The number of negative charges in a soil or on a soil colloid is called the cation exchange capacity (CEC) of the soil or colloid. It is expressed on a mass basis, usually per kilogram soil or colloid (clay or organic matter). Soil organic matter has a very high CEC (Table 3). Humus is specifically relevant here. Undecomposed organic matter makes very little, if any, contribution. Different types of clay mineral have widely different CECs.

Table 3. Cation exchange capacities (CEC) of soil colloids

Colloid	CEC (cmol/kg)
Humus (Organic matter)	100-300
Montmorillonite clay	60-100
Illite clay	20-40
Kaolinite clay	3-15



7.2 Factors determining the CEC of a soil



The most important factors that determine the CEC of a soil are:

a. *Soil texture, and more specifically the clay content of a soil:* Sand particles have practically no CEC and silt very little. Thus the CEC of a soil depends on its clay content. The higher the clay content of a soil, the higher is its CEC.

b. *Type of clay mineral:* As seen in Table 3 the CECs of different clay minerals have widely different CECs. Thus, two soils with the same clay contents will have different CECs if their clay fractions are dominated by different clay minerals. The clay fractions of soils in sub-humid to semi-arid areas, where most irrigation is practised in South Africa are dominated by smectites, which have high CECs. In some areas, for example parts of the Eastern Cape, illite, which still has a fair CEC, is an important clay mineral. Highly weathered soils are dominated by kaolinite clay, which has low CEC.

c. *Organic matter content:* As shown in Table 3, soil organic matter has a very high CEC, compared with the clay minerals. Thus, even a small amount organic matter will make a big difference to the CEC of the soil. This is especially important in sandy soils.

What is the difference between soils with high *versus* low CECs?	
Soils with high CEC	**Soils with low CEC**
Soils with high CECs are more fertile soils because they have high capacities to store plant nutrients in forms that are available to plants and protect them against leaching from the soil. Unfortunately some of the most fertile soils have very poor soil physical conditions, which limit their production potential and /or make their management difficult.	In contrast, soils with low CECs have low fertility, but usually have good soil physical properties

Activity

Activity 4

Individual activity

1. Define CEC

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2. What is the difference between soils with a high CEC versus soils with a low CEC?

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My notes............

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Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

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Module 7

Soil compaction

Study objective

After completion of this module, the learner should be able to:

- Identify soil compaction
- Identify the cause for soil compaction
- Identify the factors that cause soil compaction
- Discuss how to manage soil compaction effectively
- Understand the impact of soil compaction

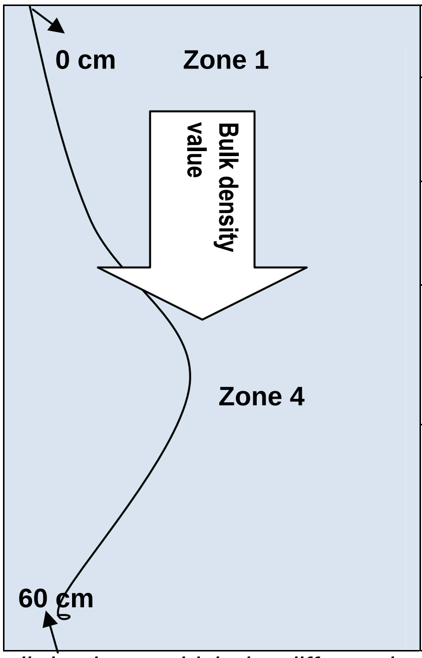
Table of contents

Extremely severe soil compaction is a widespread problem throughout the whole of South Africa under intensive mechanised cropping – both dry land and irrigated. It is even more serious in irrigated agriculture than in dry land cropping. It is found in commercial irrigated agriculture and in mechanised small-farmer irrigation. It is found under all kinds of crops, from crops like sugarcane, cotton or tobacco on the one hand, right through the whole spectrum to fruit orchards and vineyards on the other hand. The reason is that South African soils are extremely susceptible to soil compaction. No matter where in the country an irrigation extensionist is going to work, he/she will have to be able to identify this problem and recommend appropriate measures to combat it. There are large volumes of South African data available on the susceptibilities of different soils to soil compaction, where such soils are found and effective management systems to combat soil compaction under intensive irrigated agriculture. These should be used to identify potential problems and ways to prevent or overcome them. Unfortunately there is a tendency to use irrelevant overseas data – sometimes even, which are obsolete. This tendency must be avoided.

High susceptibility to compaction is seldom, if ever, used to rate a soil unsuitable for irrigated agriculture. It is important to evaluate the sensitivity of a specific crop to soil compaction and the susceptibility of the soil to compaction in order to establish whether strict management practices to combat soil compaction will have to be implemented. Land suitability evaluation for irrigated agriculture involves evaluation regarding (i) crop requirements, (ii) management requirements (very important in this case) and (iii) environmental impact.

1. Typical compacted zones in irrigated soils

Figure 1 illustrates the typical compacted zones found in irrigated soils under intensive annual cropping in South Africa. Similar patterns are found under perennial crops like orchards and vineyards.



ZONE 1 (0-2 cm)	Compacted crust
ZONE 2 (2-15 cm)	Relatively loose cultivated layer
ZONE 3 (15-25 cm)	Plough layer compaction
ZONE 4 (25-45 cm)	Sub-plough layer compaction
ZONE 5 (>45 cm)	Naturally compacted subsoil

**The soil depths at which the different layers occur vary according to type of soil and type of implement used.*

Figure 1. Types of compacted layers found in cultivated soils at various depths (0-60cm)

Figure 1 illustrates various bulk density values at different soil depths actually found at the Vaalharts irrigation scheme. Similar patterns and values are found widespread at other irrigation schemes in the country. The following aspects need to be noted in this figure:

a. The high bulk density of the undisturbed subsoil indicates the inherent tendency of the soil towards compaction.

b. There are two compacted layers that formed due to intensive cultivation and/or traffic, viz. (i) plough layer compaction (zone 3) and (ii) sub-plough layer compaction(zone 4).

c. The depth of the plough layer (25 cm in the table) is the depth of the primary cultivation. Plough layer compaction takes place in the bottom part of the plough layer. Its upper limit, which is usually the depth of root penetration, is between only 10 and 15 cm from the soil surface.

   The root restricting effect of this compaction is aggravated by the abrupt (sharp) transition from the loose surface layer to this layer. Roots (i) cannot adapt quickly enough to this sharp change in density and (ii) take the route of least resistance by growing horizontally above this transition. Sub-plough layer compaction is immediately below the plough layer. The two compacted layers are usually difficult to distinguish and in practice it is not necessary to do so.

Human-induced subsurface compaction is classified as (i) traffic pans and (ii) plough pans. In South Africa traffic pans occur much more widely than plough pans. This is fortunate, because they are easier to overcome with appropriate management. Traffic pans are caused by the wheels of in-field traffic and occur mainly in sandy soils. Plough pans are less common and occur in clayey soils, where the tillage implements smear and compact the soil just below plough depth. Severe compaction can be caused by treading by livestock under intensive farming systems, e.g. by dairy cattle on irrigated pastures. Worst of the latter compaction is by “pugging”, plastic flow around the hoof in wet soil.

2. Criteria for measuring degree of compaction

Bulk density is the direct measure of the density of a soil layer. Bulk density is, however, not the best indicator of the degree of inhibition of root growth by a compacted subsurface soil layer. It has been found that so-called “soil strength”, i.e. the mechanical resistance of the soil to root penetration, is the best measure of it. Soil strength is measured by means of instruments called penetrometers. They work on the principle that a probe, connected to either a proving ring or spring, is pushed into the soil. The pressure at which the probe enters (breaks into) the soil is recorded. Penetrometers vary from sophisticated constant rate electronic digital ones to simple pocket penetrometers.

Figure 2. Penetrometer used for determination of soil compaction

A comprehensive comparative study at Vaalharts showed that a pocket penetrometer, barely the size of a fountain pen, is as accurate and reliable as sophisticated penetrometers if used correctly. Most of the time it is not necessary to obtain quantitative soil strength values by means of a penetrometer. Qualitative manual testing with a steel rod to simply identify the presence or absence of a compacted layer is usually adequate.

3. Soil factors affecting the susceptibility of a soil to compaction

The most important soil factors affecting the susceptibility of a soil to compaction are:

a. *Particle size distribution (texture):* Particle size distribution and related factors such as sorting and the shape and smoothness of particles are by far the most important soil factors affecting the susceptibility of a soil to compaction. The terms “sorting”, “shape” and “smoothness” are used in the description of sand size particles. Particles that have been transported over long distances, especially by wind, are round and smooth and moderately to well sorted.

   The aeolian (wind blown) soils at Vaalharts irrigation scheme are characterised by a very high fine sand fraction (often >70%), low clay (usually <10%) and organic matter content and single grain to weakly massive structure. The fine sand particles are smooth, moderately to well sorted and rounded. In contrast to the rounded (spherical) nature of the severely compacting fine sandy soils of the central part of South Africa, the silt and fine sand fractions of the extreme compacting soils from the Southern Cape area are platy (flat). The latter soils contain as much as 65% coarse silt. It was found that so-called “hard setting soils”, found especially widely in the Eastern Cape, are soils with massive structure (a type of structureless soil), generally with the following properties:

- More than 50% (fine sand + silt), with usually more than 20% fine silt ***and***
- Less than 35% clay.

The most extreme ones of the above are bleached (light gray) horizons, either bleached A horizons (topsoils) or E horizons. Around Nelspruit severe compaction under intensive irrigated agriculture was even found on medium to coarse sandy E horizons.

A common problem is that researchers almost always group silt together with clay when relationships between particle size classes and soil physical parameters are studied. In the case of soil compaction this is obviously incorrect. Silt should be grouped together with fine sand.

b. *Soil organic matter content:* Very little South African data are available on relationships between organic matter content and soil compaction. As indicated earlier, organic matter contents of South African soils, especially subsoils, are very low and effects of grass leys in rotations are of very short duration. Since organic matter is in most soils the only structure stabilising material, any practice that will maintain a high organic matter content will reduce soil compaction. If correct management practices are applied, maintenance of a dense permanent grass ley (cover crop) in an orchard or vineyard will minimize compaction by the wheels of tractors, spray carts or loaded trailers moving between the rows.

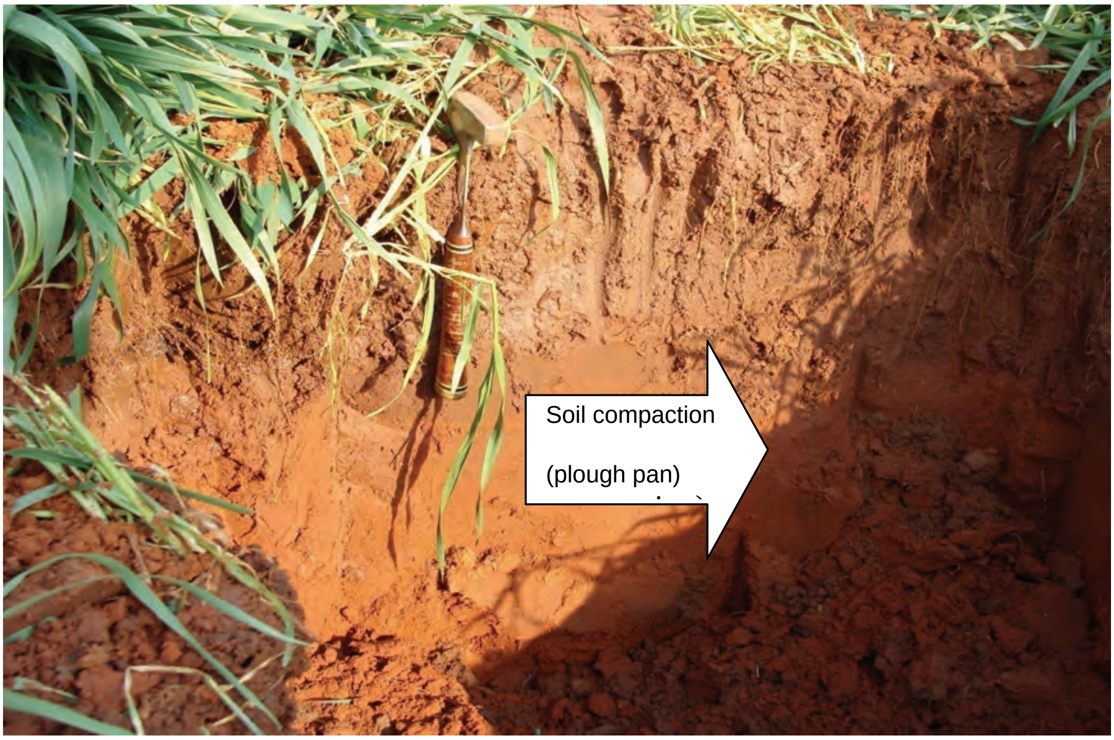


Figure 3. Plough pan soil compaction (Source: D Haarhoff)

4. Management systems affecting soil compaction

In several parts of South Africa a large amount of excellent research has been done on the effects of management systems on soil compaction, especially in irrigated agriculture. Any extension officer should avail him-/herself of these.

a. Wheel traffic and secondary cultivation: In South Africa in-field vehicular traffic has been described as the primary source of forces, which lead to soil compaction. Tractors, with their great mass and concentrated pressure under the wheels, are often described as the most important vehicles involved in soil compaction. Tractor factors causing increased soil compaction include *inter alia* the following:

i. Increased load on the drawbar.
ii. Travelling at lower speeds.
iii. Wheel slip. This is caused mainly when a tractor is too small and not powerful enough to pull an implement, often a problem on small-farmer irrigation schemes.
iv. Wide tyres or dual wheels increase the area that is compacted during a pass over the field and do not reduce compaction. Single big narrow tyres give the least compaction – provided that controlled traffic is applied. (See later.)

Other related factors affecting compaction include:

i. Tyre pressure (of tractor wheels and wheels of all other vehicles traversing the field), determines the degree of compaction. The higher the tyre pressure is, the more severe is compaction. The ideal is to work at the lowest tyre pressure that can carry the load, making it important to select the type of tyre that can operate at the lowest pressure.
ii. Working with the tractor wheel in an open plough furrow, especially during mould board ploughing, causes more severe compaction and to greater depth.
iii. By far the biggest part of compaction (up to 90%) takes place during the first pass of wheels over an area. This effect is biggest on loose soil, e.g. during the first secondary cultivation of soil that has undergone primary cultivation like ploughing or ripping. This is the cause of the severe compaction found at shallow depth within the plough layer. The solution is controlled traffic i.e. driving in the same tracks from primary cultivation to harvest. This does not reduce the degree of compaction under the tracks, but greatly reduces the compacted area.
iv. In controlled traffic it is important to position vehicular tracks as far as possible from the plant rows. For example, in the sugarcane industry 1.5 meter row spacing has very bad impacts due to compaction, because wheels of tractors and implements run on the side of rows. In contrast very high yields are obtained with 1.8 meter row spacing, with wheels running in the middle of the inter-row areas.

b. Ripping: Compacted layers, natural or man-made, can be broken up by tined implements (rippers). In many cases ripping is not successful in combating compaction. This is where it is not implemented correctly. Important aspects include:

i. The relative positions of the crop row rip line and vehicle tracks must be correct. If the tractor wheel runs between the rip line and the plant row during a secondary cultivation after ripping, compaction under the wheel track will “box in” the plant roots, preventing them from reaching the rip the line to penetrate into the subsoil.

For annual crops this has led to the highly successful practice of "rip-under-row", i.e. where the rip line is directly beneath where the crop row is subsequently planted.

ii. Uncontrolled secondary cultivations can nullify any positive effects of ripping and even create situations that are worse than if no ripping was done. This includes land preparation for annual crops or for the establishment of orchards or vineyards.

iii. Farmers are sometimes under the false impression that they have done ripping, while the ripper has just run on top of the compacted layer, instead of breaking it up. A tine does not penetrate under a compacted layer if the angle of the tine is not correct.

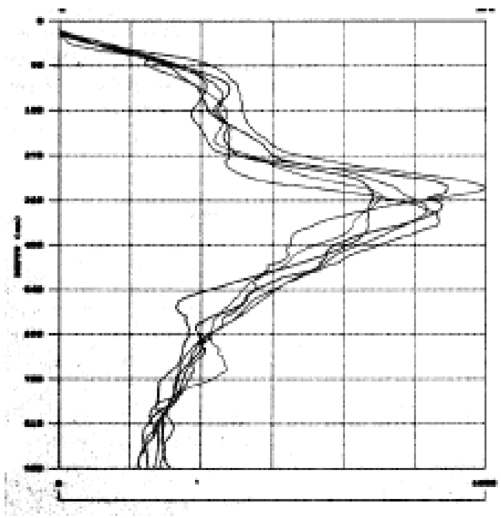


Figure 4.a.Compaction layer at 270-630 mm

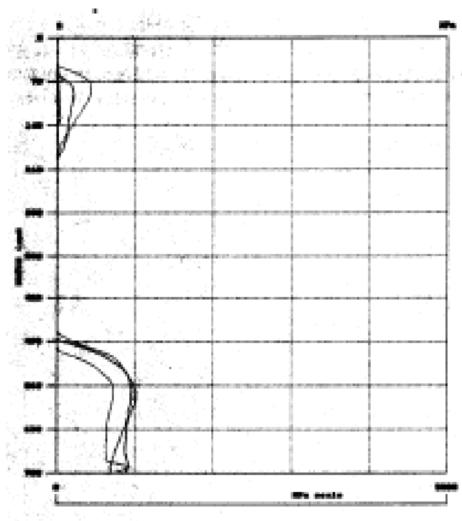


Figure 4b Compaction layer broken up with ripper*(Source: D Haarhoff, GWK)*

c. Soil water content at which cultivation is done: Each soil has specific soil water content at which it is most susceptible to compaction when pressure is applied to it. Maximum compaction occurs at fairly high soil water contents – just below field capacity. Cultivating soil that is too wet is an important factor aggravating soil compaction in irrigated agriculture. This is probably an important reason why the length of period under no-till before cultivation is required again is shorter under irrigation than under dryland cropping (Table 1).

Soil compaction is also aggravated when heavy harvesting or haulage vehicles operate in a field when the soil is too wet. This poses big challenges in regard to the harvesting of sugarcane, for example. Putting livestock in irrigated pastures when the soil is too wet will also aggravate soil compaction due to pugging.

Table 1. Length of permissible period under no-till

Clay content of tilled layer (%)	Permissible number of seasons without tillage		
	Dryland grain crops	Irrigated grain crops	Silage crops
1-8	1	1	1
9-16	2	2	2
17-24	4	3	2
25-32	8	5	3
33-40	16	8	5
>40	32	11	7

5. Impact of soil compaction

Soil compaction has several impacts that have large negative effects on plant growth and production. Comprehensive research on this has been done in South Africa. Some of the most important ones are discussed here:

a. *Soil strength and root development:* The effects of soil compaction on soil strength and of soil strength on root development (and other plant parameters) have been studied comprehensively in South Africa, especially in irrigated agriculture. High soil strengths in compacted layers limit roots to very shallow depths. This is the case for both annual crops and perennial crops like fruit trees and grapevines. There are big differences between different crops in regard to the degree to which their root development is restricted by high soil strengths. The root systems of plants with taproots are more seriously affected than other plants. Cotton, groundnuts and sunflowers are amongst crops of which root development is very seriously affected by high soil strengths. Amongst the grain crops it was found that maize root development was restricted four times more than wheat root development by high soil strength. Wheat has an exceptionally robust root system that is able to penetrate quite dense soil layers.

b. *Hydraulic conductivity and aeration:* Reduced hydraulic conductivity (rate of water movement in the soil) is a consequence of soil compaction. In sandy soils this is not a problem, since water still moves fast enough through the compacted layer. In medium-textured to clayey soils this can under irrigation result in water logging in and/or above the compacted layers. Such water logging is called “perched” water table, i.e. a water table that is not at the bottom of a soil profile. Thus, a water logged layer is caused close to the soil surface with negative effects :

- It enhances the possibility that field operations will be done under too wet conditions, further aggravating compaction.
- Root respiration is impaired, negatively affecting uptake of both plant nutrients and water.
- The activities of favourable micro organisms are restricted and negative organisms are promoted.

- Root rot diseases are enhanced.

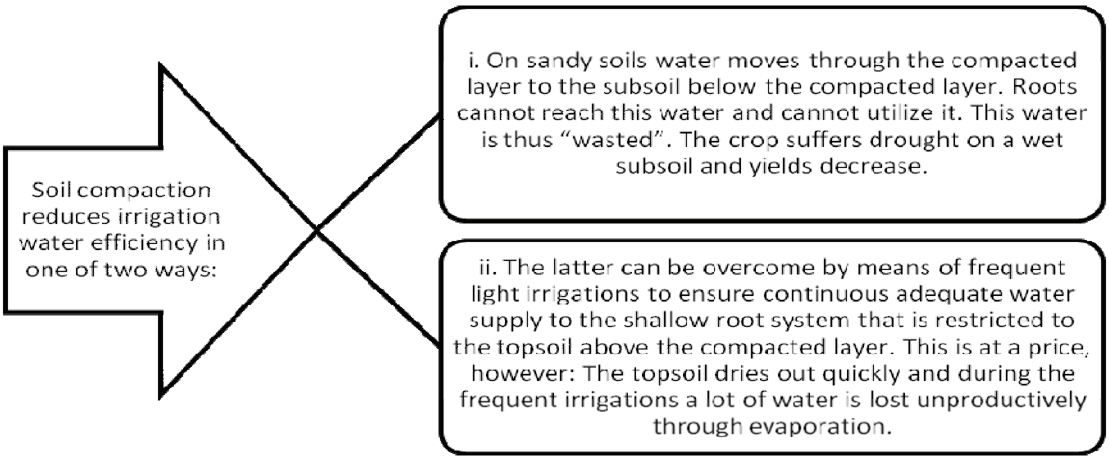
c. Plant nutrient uptake: South African studies have shown that uptake of plant nutrients, especially P and K and the micro-nutrients Fe, Mn and Zn, is strongly reduced by soil compaction. Uptake of both potassium (K) and phosphorus (P) was reduced by about 40%. These were not even at high bulk densities or high soil strengths (according to South African standards) and were not related to water logging. To what extent reductions in nutrient uptake will reduce plant growth and yield will depend on the inherent fertility of the soil and/or level of fertilizer application. I.e. fertility factors can mask the effects of soil compaction on plant growth and yield and of measures to alleviate it. If the fertility level of the soil is very high, the crop may perform well even in the presence of severe soil compaction. If the fertility level of the soil is very low, alleviating compaction can often not give a significant growth response, because the low soil fertility can be a more limiting factor.

The degree to which compaction reduces nutrient uptake differs between different crops. For Vaalharts soils it was found that reduction is in the order :

1. Cotton
2. Groundnuts
3. Maize
4. Wheat

This was the same order in which root growth of the different crops was restricted by soil compaction.

d. Water use efficiency:
In irrigated agriculture an important parameter is irrigation water use efficiency (WUEi), which is the production per unit irrigation water applied.



Activity

Activity
Individual activity

1. *What do you understand* underneath "soil compaction"?
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2. Name **TWO** examples of human induced subsurface compaction.
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3. Which soil factors are most important for affecting the susceptibility of soil to compaction?

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4. Discuss **THREE** possible management systems that may cause soil compaction. How can the farmer address it?

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5. Discuss the impact of soil compaction on crop production
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1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

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Authenticators:

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WATER RESEARCH COMMISSION

agriculture, forestry & fisheries

Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Technical Learner Guide

Assessing of soil resources

Level 5

Module 8
Soil crusting
(Surface sealing)

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Defining soil crusting
- The mechanisms of crust formation
- Soil factors affecting soil crusting
- The effects of soil crusting

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Soil crusting is a serious and widespread problem in South Africa and neighbouring countries like Swaziland, especially in irrigated agriculture. Soil crusting in South Africa was really only identified as a problem relatively recently upon the changeover from flood irrigation (flood beds and furrows) to overhead systems, ranging from centre pivots to drip and micro-sprinkler systems.

1. What is soil crusting?

Definition

A **soil crust** is a dense layer at the soil surface. In some cases it is extremely thin, virtually only a thumb nail thick (<1 mm), and is often overlooked. In many cases the crust is so dense that it literally seals the soil, from there the term "surface sealing". Internationally various types of crusts have been identified. In South Africa crusts are mainly thin dense mineral soil layers right at the soil surface. Sometimes it is in the form of a series of thin layers stacked upon each other, with the total thickness still being small. In rare cases biological crusts are formed, consisting of thin dense green algal layers on the soil surface.

Figure 1. Example of soil crusting

2. Mechanisms of crust formation

There are mainly three mechanisms for the formation of the main types of crusts found in South Africa and neighbouring countries. It is very difficult to distinguish between crusts formed due to the first two mechanisms listed below. The two mechanisms usually operate together and the key is then to identify the dominant one:

a. *Chemical dispersion of the surface soil layer:* This mechanism leads to crust formation even under very low to zero water drop energy. It leads to crust formation even under drip and micro-sprinkler irrigation and include areas under the canopy areas of orchards, which are protected against raindrop impact. Extreme cases of this are found widespread in the Eastern Cape and other areas. Two of the most extreme examples were seen in a citrus orchard in the Sundays river valley (under micro-sprinklers) and a citrus orchard in Swaziland (under drip)

b. *Physical (mechanical) disaggregation by the impact of water drops:* This refers to the breaking up (disaggregation) of aggregates or clods at the soil surface due to the impact of water drops from rain or overhead irrigation. This is often incorrectly called dispersion of aggregates by the impact of water drops.

c. *Algae growth in areas with continuous or prolonged excessive soil surface wetness:* This has been described as: "A surface organic crust usually developed upon repeated (more or less daily) surface-applied irrigation. It consists of a dense mat of algae and fungi, and sometimes mosses.

   An example was observed in Swaziland under the shaded canopy area of a citrus orchard under drip irrigation, where a continuous dense thin green layer of algae upon which irrigation water remained ponded covered a large proportion of the area under the canopy. This type of crust is actually a secondary crust, which forms upon a mineral crust that severely limits water infiltration and thus causes ponding of water on the soil surface. In the Swaziland example there was also severe ponding of water on the drip irrigated soil surface in less shaded areas where there was no algal growth. At Tyefu small-farmer irrigation scheme in the Eastern Cape the algal growth found in micro-depressions on strongly crusting soils was seen as a consequence of slow infiltration, causing water to remain ponded on the soil surface for considerable time.

3. Soil factors affecting soil crusting in South Africa

The relationships between various soil factors and crusting have been studied intensively in South Africa.

a. Clay mineralogy

Clay mineralogy is one of the most dominant soil factors affecting soil crusting in South Africa. This effect is so strong that soils have to be grouped according to their clay mineralogy before meaningful equations for the calculation of parameters important for irrigation management can be derived. Soils from the Eastern and Western Cape, with illite dominated clay fractions are particularly prone to crusting. Red soils with koalinite dominated clay mineralogy are normally very stable against dispersion and crusting. However, in South Africa some of these soils are highly susceptible to crusting if they also contain smectite clay.

b. Particle size distribution

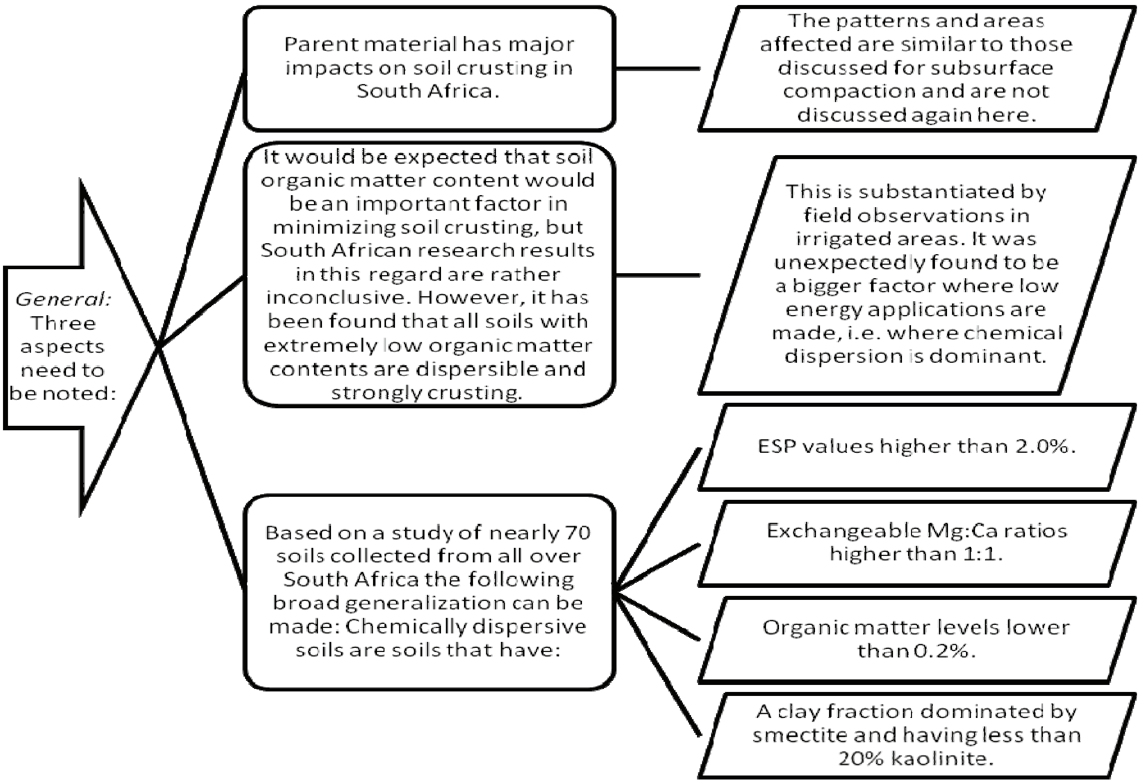
Severe soil crusting under irrigation has in South Africa been reported for soils ranging from structureless red fine sands to black swelling clay soils (black turf soils). It seems that the most severe crusting is found where top soils have high (fine sand + silt) contents and low clay contents – similar to soils that are most susceptible to subsurface soil compaction.

c. Exchangeable sodium percentage (ESP)

Exchangeable Sodium Percentage (ESP) is worldwide probably considered to be the most important factor affecting dispersion in soils and consequently also soil crusting. In North America and Western Europe there is a very simplistic view that serious negative effects of sodium on soil physical conditions, such as crusting and reduction in infiltration rate, due to clay dispersion occur when the ESP exceeds 15%. In countries like Russia, Australia, Zimbabwe and South Africa it has been found that there is no such single "magical" threshold ESP value. The critical ESP differs widely for different soils and conditions. The big concern in South Africa is the very low critical ESP values above which serious dispersion and crusting occur in many of our soils, especially soils on which irrigated agriculture is developed. In most of these soils it was found that at ESP values higher than 2.0% the soil could be classified as dispersive and strongly crusting. This is also not a "magical" value and there are big differences between soils.

d. Exchangeable magnesium and Mg:Ca ratio

High exchangeable Mg levels and lopsided Mg:Ca ratios are well-known as important widespread factors contributing to dispersion and crusting of soils in South Africa. The threshold Mg:Ca ratio above which clay dispersion increases notably and crusting is aggravated, is generally somewhere between 1.5:1 to 3:1. (The ideal Mg:Ca ratio in soils is normally considered to be 1:2 or lower – more Ca relative to Mg.) At the Riet River Irrigation Scheme Mg:Ca ratios of as high as 20:1 have been found in some of the irrigated soils. The effects of lopsided Mg:Ca ratios are aggravated in the presence of problematic ESPs.



4. Effects of soil crusting

Soil crusting has a number of serious negative consequences in irrigated agriculture

1. ***Reduced infiltration of water***
2. ***Reduced soil aeration***
3. ***Seedling emergence***

4.1 Reduced infiltration of water

Soil crusting causes serious reduction in the infiltration capacity of soils, i.e. in the maximum rate at which water can enter the soil. This rate is often much lower than the rate at which water is applied by overhead irrigation, including even drip and micro-sprinkler irrigation. The consequence is ponding of water on the soil surface and/or increased runoff under irrigation.

Ponding leads to high evaporation losses of the ponded water. These losses are particularly high in the very hot and dry climates of most of South Africa's irrigated areas, especially the river valleys along the east coast. In the already mentioned citrus orchard in the Sunday's river valley, ponding under micro-sprinkler irrigation was so severe that oranges were floating in the ponded water. According to the farmer it would take about 24 hours for all the ponded water to "infiltrate". The fact is that in that time about all the ponded water would have evaporated in that very hot, dry area. In the nearby Gamtoos Valley a potato farmer limited his irrigation applications by centre pivot to less than 7 mm per application to avoid ponding. Such frequent light applications lead to a big unproductive evaporation loss of applied water. In other cases subsoils just simply remain bone dry in crusted irrigated soils, without farmers or their advisors realizing it.

Depending on the surface condition and slope of the irrigated area, ponding can be followed by increased runoff. Any runoff from an irrigated area is a waste of irrigation water. Even worse is that cases have been found in South Africa where the increased runoff has caused soil erosion in irrigated areas, especially under centre pivots, in some cases very serious. Another consequence of increased runoff was found where patches of very poor seed maize growth were observed in a specific irrigated area on a sandy soil on a plain. It was found that the poor patches were on the little "hills" in this slightly uneven field. This was caused by runoff from these very slightly higher areas due to soil crusting. The plants on the hills were simply suffering from drought. The plants in the slight depressions received both irrigation water and this runoff water and grew well. On a medium-textured or clayey soil the situation usually is the other way round, with the poor patches being in the depressions, due to excessive water.

4.2 Reduced soil aeration

A dense crust seriously inhibits soil aeration, i.e. gas exchange between the soil and atmosphere. The occurrence of this effect is sometimes seen in the form of "bubbles" in the soil below the crust. It resembles an Aero chocolate, with its dense smooth surface and bubbles inside. The bubbles indicate that air replaced by infiltrating water could not escape through the crust.

A perfect example of this was found in an irrigated soil in the northwest of Limpopo Province, where an extremely dense very thin (<1 mm) crust was underlain by a layer filled with air bubbles. Again this was completely overlooked by farmers and advisors who could not understand why crop performance was so poor.

Reduced soil aeration due to crusting has all the negative effects caused by poor soil aeration discussed earlier. The importance of the effects of soil crusting is that they occur in soil layers where this would normally not be expected, i.e. layers that are not waterlogged and are close to the soil surface.

Two particularly important consequences of reduced soil aeration due specifically to crusting are:

- Inhibition of seed germination
- Inhibition of root development

4.3 Seedling emergence

Seedling emergence is restricted by the high mechanical strength of a soil crust, resisting breaking of the coleoptile through the soil surface. This is particularly severe for dicotyledons, such as the various types of beans. Small seeded crops are also severely affected. An important crop that is known to be very vulnerable to soil crusting in this regard is wheat.

5. Management factors and soil crusting

Various management practices have major impacts on soil crusting. Only a few of the most important ones are discussed here.

a. Irrigation system selection and planning and irrigation management

Due to the drastic increases in energy costs for overhead irrigation and increasing demands for improved water use efficiencies in irrigated agriculture, efficient irrigation system selection and design and irrigation management is becoming increasingly more important.

In view of the big differences between different soils in regard to crusting, and especially that such a large proportion of the irrigated and potentially irrigable soils in South Africa are very prone to crusting, it is for each case important to:

- Select an appropriate irrigation system that is suitable for the specific case.
- Adapt the design of the selected system to the requirements of the specific soil.
- Adapt irrigation management to the requirements of the crop and the soil.

Soil crusting potentially poses problems for all types of overhead irrigation systems, depending on the vulnerability of the soil to crusting and the causes of crusting (physical/ mechanical disaggregation and/or chemical dispersion). Overhead irrigation systems should be selected, designed and managed such as to minimize crusting and always ensuring that the water application rate remains lower than the infiltration rate of the soil – so as to avoid ponding and/or runoff. South African studies have shown that the determining factor is what is described as the "energy flux" during overhead irrigation. Energy flux is the combined effect of droplet size (median drop diameter), droplet velocity (affected by falling height) and application rate. Energy flux is sometimes called "energy flux density", breaking the factors up into energy flux (in this case seen as determined by drop size and drop velocity) and intensity (application rate). The important point is that one should not look at droplet size or droplet velocity (falling height) or application rate in isolation, but at the combined effect of the three. It is very important to reduce the energy flux (energy flux density) of water applied by sprinkler irrigation systems to the absolute minimum that can practically be achieved. In many crusting soils the minimum that can be achieved with a specific system may be higher than can be tolerated on that soil, making that system unsuitable for that soil.

High-energy fluxes are particularly generated by floppy and centre pivot irrigation systems. In floppy systems the large drop size and great falling height cause the high-energy flux. In the case of centre pivots the falling height and drop size can be reduced, but the high application rate that perforce has to be maintained in the outer parts of the circle causes a high-energy flux density in those outer parts. A study under two centre pivots in KwaZulu-Natal showed that runoff from areas near the centre of the pivots was between about 5 and 10%. Near the outside of the laterals runoff was between about 36 and 46%. Runoff from control plots was insignificant (<1%). The high runoff at the end of the laterals was attributed to the high-energy flux density there, resulting in a less permeable crust.

Criteria and equations have been developed for the adaptation of the design and management of overhead irrigation systems to the infiltration rates of South African soils. An implicit key element was to minimize crusting and its negative effects. Two sets of equations are provided for different groups of soils, one set for each of the following scenarios:

i. Where the energy flux delivered by the system is fixed and cannot be changed: Calculation of the maximum amount of water that can be applied per irrigation without causing ponding and/or runoff. This is the so-called "cumulative application before ponding" (CABP).
ii. Where the energy flux can be changed and the aim is to apply a certain pre-determined amount of water per irrigation: Calculation of the maximum permissible energy flux that the system can be allowed to deliver. This is the so-called "maximum allowable energy flux" (MAEF).

b. Management of the soil surface condition

In soils that are prone to crusting effective management of the soil surface is very important. Appropriate irrigation management, as outlined above, is important. Some other management practices are also important, however, including:

i. Maintaining a dense basal vegetation cover as far as possible. This will both dissipate water drop energy and stabilize the surface soil structure.
ii. Application of organic mulch (e.g. straw), where enough material is available and it is feasible to apply it, is highly effective. The high effectiveness of mulch is ascribed to:
    - Dissipation of raindrop impact by the mulch, thus reducing the physical disaggregation of aggregates.
    - Prevention of the "stirring" effects of raindrops, thus inhibiting chemical dispersion processes.
    - Keeping the soil surface in seedbeds moist, thus preventing a crust to harden and limit seedling emergence.
iii. Application of so-called "soil conditioners" is highly effective, as shown in several South African studies. Soil conditioners are organic compounds that create very stable soil structure and thus prevent crusting. In the 1950s and 1960s there was great interest in these products to combat soil compaction. They were effective, but too expensive in view of the large quantities needed to ameliorate a soil to considerable depths. In the 1980s new interest in them emerged because it was realised that small, affordable quantities could be effective to combat soil crusting. The one product most widely studied during this time, also in South Africa, is poly-acryl amide (PAM). Applied just to the top few centimetres of the soil as little as 20 kg PAM per hectare was found to be highly effective in various South African studies. In the already mentioned citrus orchard with the extreme crusting in the Sundays river valley very shallow (1-2 cm deep) application of a coal-derived humic product brought about big increases in root development

(without any deep cultivation) and orange yields. The effect of a once-off application lasted for a number of years.

iv. Application of agricultural gypsum or phosphogypsum is often used to alleviate soil crusting because these are relatively cheap products. South African studies show that it is effective in some cases, but always much less effective than soil conditioners or mulching. In some cases it has no effect or even negative effects, as for example found in different studies in the Sundays River Valley.

v. Management to improve seedling emergence in crusted soils can be done in a few ways, such as:
   - Using organic (e.g. straw) mulch, as indicated above.
   - Keeping the soil surface moist during the emergence period to keep the crust strength as low as possible.
   - Using very high sowing densities (especially in the case of vegetables) so that the large number of densely spaced seedlings can help each other to break through the crust. Once the seedlings are well established, they are thinned out to give an appropriate final plant density.

vi. Where overhead sprinkler, micro-sprinkler or drip irrigation are all-impractical due to soil crusting, furrow or flood irrigation can in most cases be used very successfully. The dynamic water flow situation under furrow or flood irrigation breaks up crusts and gives much higher infiltration rates than under the other irrigation systems. This was shown very clearly in a comparative study in the Eastern Cape, for example. Under furrow irrigation the situation can be improved further by planting seedlings in the sidewalls or on the crests of the ridges between furrows. These are the zones with least crusting. This technique is (also for other reasons) applied very successfully by small-scale farmers using the highly efficient indigenous short furrow irrigation system – e.g. at Dzindi Irrigation Scheme.

Activity

Activity

Small group activity

1. What do you understand underneath “soil crusting”?
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2. Discuss the **THREE** mechanisms responsible for soil crusting in South Africa.
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3. Name **TWO** soil factors that cause soil crusting.

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4. Soil crusting has serious negative effects on irrigation agriculture. Discuss **TWO** of these effects and how can the irrigation farmer minimise these effects?

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References

1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

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Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

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Technical Learner Guide

Assessing of soil resources

Level 5

Module 9

Salt affected soils

Study objective

After completion of this module, the learner should be able to:

- Define saline, sodic and saline-sodic soils
- Identify factors causing saline, sodic and saline-sodic soils
- Define leaching fraction
- Discuss the role of irrigation water quality related to salinity and sodicity
- Discuss the management of sodic and saline soils

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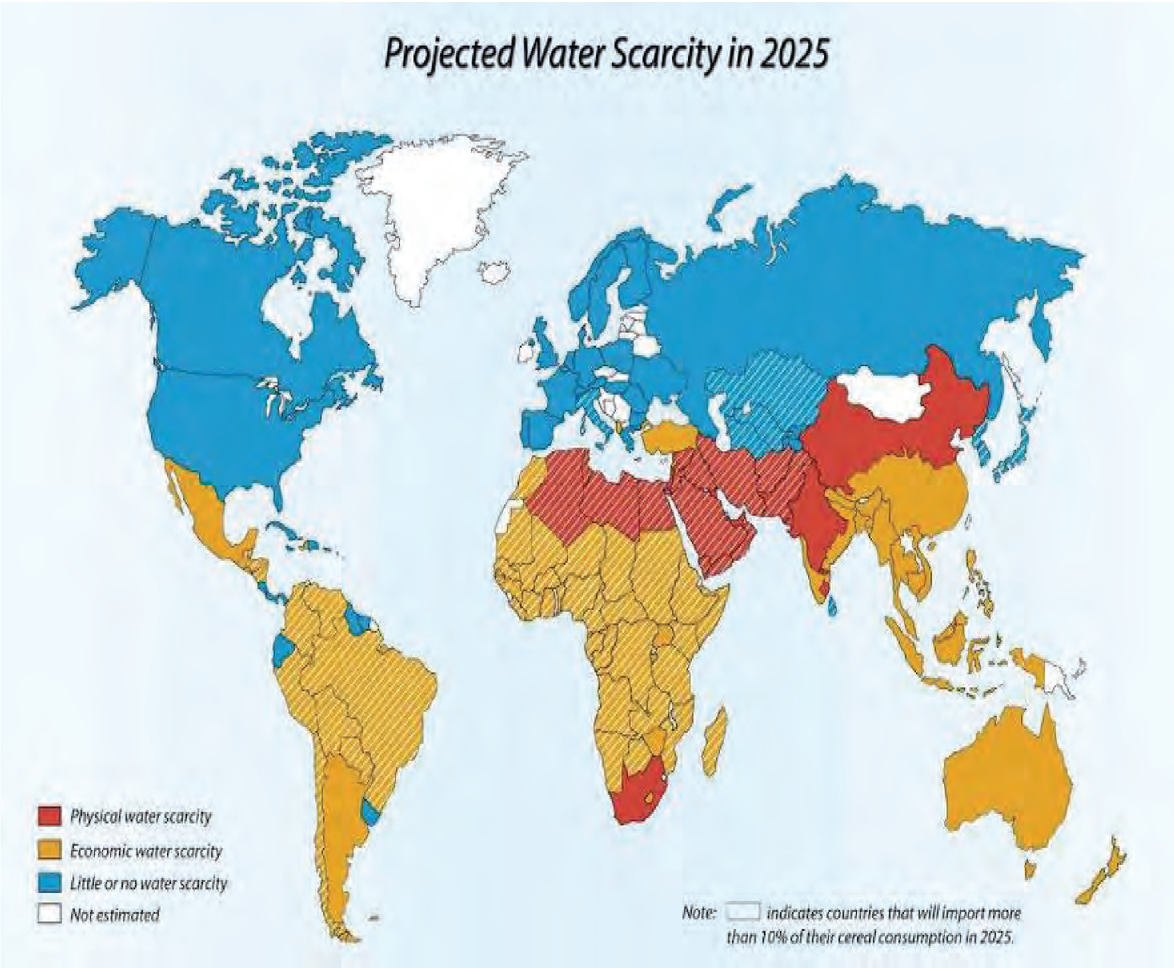
Accumulation of high levels of soluble salts and/or high exchangeable sodium levels under irrigation in soils has been called the "cancer" of irrigation schemes. It has led to the total collapse of many irrigation schemes in the world, including some very big ones. Sodicity, salinity and water logging seriously affect 40-50% of the arable land in the world.

Thus far South Africa has been lucky that only a little more than 10% of the total irrigated area has become saline or sodic. The present overall relatively good situation in South Africa is ascribed to the fact that (i) South Africa has had relatively good quality irrigation water in most areas and (ii) high quality soil surveys and rigid selection of soils were done in the past. Both these situations have in some areas changed for the worst in more recent years. In some areas or cases the situation is serious. Best known is the Golden Valley irrigation scheme in the Eastern Cape, which has become totally saline.



Salt-affected soils can be of natural origin or human-induced. The latter is usually due to poor irrigation planning and/or poor irrigation management

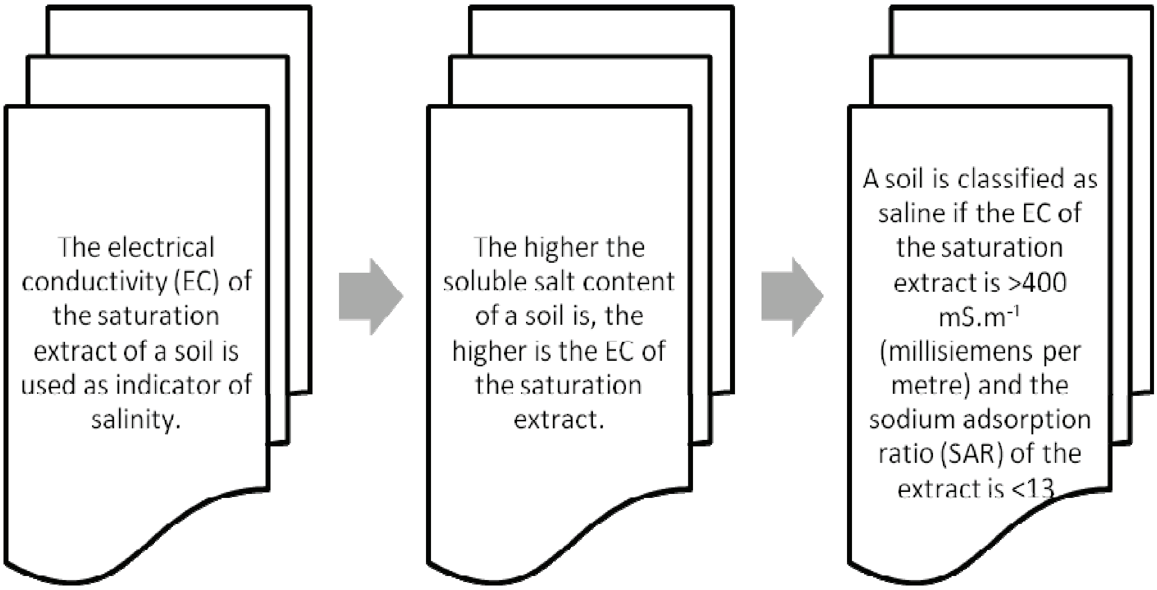
Three main types of salt affected soils distinguished			
	Saline soils – high levels of soluble salts the problem	**Sodic soils** – where high exchangeable sodium percentage is the problem	**Saline-sodic soils** – in which both salinity and sodicity are problems
ESP	<15	>15	>15
EC	>400	<400	>400

1. Saline soils

Definition

Saline soils are soils with high soluble salt contents. The salts in saline soils are mainly “neutral” salts. Consequently the pH of these soils is usually below 8.5 – but above 7.0. Chloride (Cl^-) is usually by far the most abundant anion. In some cases sulphate (SO_4^{-2}) is significant, with small amounts of bicarbonate (HCO_3^-) or carbonate (CO_3^{-2}) also present. The dominant cations are sodium, magnesium and calcium.

Figure 1. Saline conditions visible under a drip irrigation system (Source: R Stirzaker)



The SAR limit is included to indicate that salinity is the only problem in a saline soil, while sodicity is not. In practice the 400 $mS.m^{-1}$ criterion is absolutely meaningless, because

i. This is defined as the saturation extract EC at which moderately sensitive crops will suffer 50% yield loss due to salinity, which is really not affordable, and

ii. There are very big differences between crops commonly grown under irrigation in regard to their sensitivity or tolerance to salinity. Sensitive crops suffer great yield reductions at saturation extract EC values as low as 200 $mS.m^{-1}$, while some highly tolerant crops can give 100% yield at EC values as high as 800 $mS.m^{-1}$ or more. The sensitivities and tolerances of different crops are discussed later.

1.1 Factors causing development of saline soils

There are mainly two main causes for the development of saline soils namely:

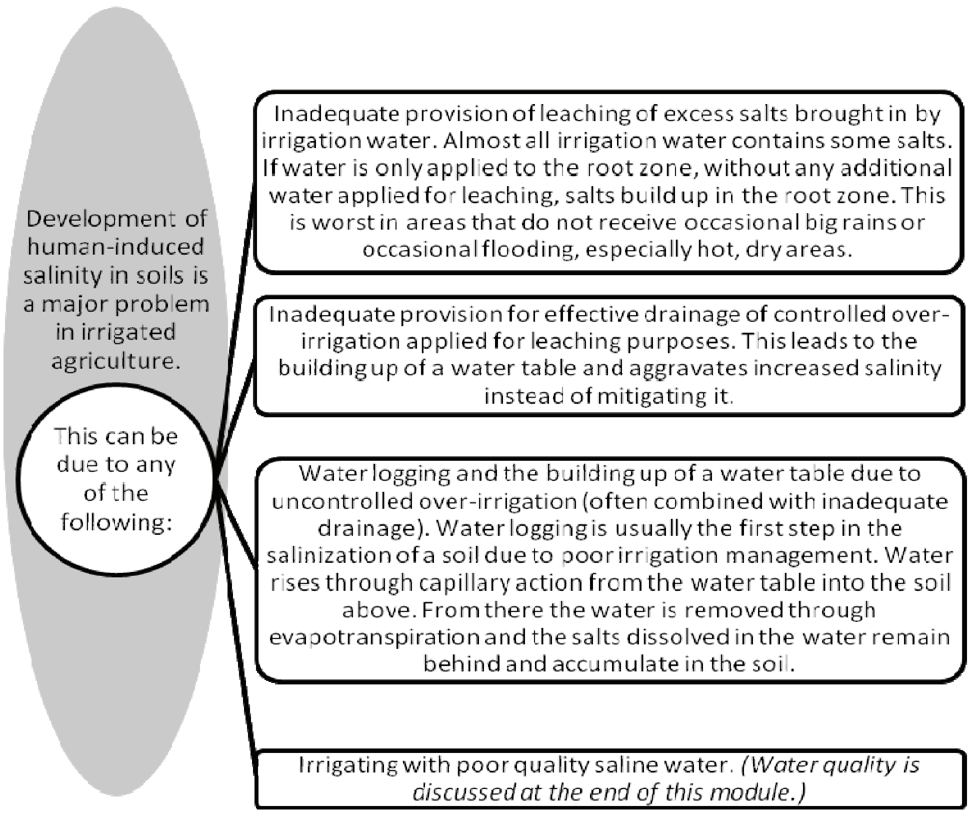
a. *Natural induced salinity in soils*

The primary sources of salts for naturally occurring saline soils are salt-rich geological materials. In various locations of South Africa there are different types of mudstones and shales that are rich in salts. The most extensive areas are the mudstones and shales of the Beaufort group, commonly found in parts of KwaZulu-Natal, the Free State and the Eastern Cape.

Saline soils are typically found in areas having very high evapotranspiration and low rainfall (i.e. hot, dry areas). In such areas leaching is poor and salts accumulate in the soil. Topography also plays a role in that salts are leached to the lowest points in the landscape, such as river terraces. Combinations of these three factors (high evapotranspiration, low rainfall and topography) have caused the occurrence of natural salinity in some deep river terrace soils in the Eastern Cape.

Another cause for the occurrence of natural salinity in the three major irrigated areas of the Western Cape originates from: (i) salt spray from the sea and salt dust from the coast and (ii) salt rich geological materials. Salt spray and dust is carried inland for several tens of kilometres by the strong winds to areas where they are deposited, as salty rain or dry aerosols. In the case of the Berg River most salt is blown in from the sea, with little originating from the Malmesbury shales. In the upper Breede River most salts is from Karoo sediment origin, mainly from Bokkeveld shales. The lower part of the Breede River also receives salt blown in from the sea. In the Olifants River area both mechanisms are important: Part of the catchment drains from sediments in the Karoo (via the Doring River), while the whole Olifants River itself receives salt sea spray and dust. In the Berg river catchment there is much more intense accumulation of salt (originating from the sea) in the finer textured soils originating from the Malmesbury shales than in the sandy soils of Table Mountain sandstone origin. Someone working in other coastal areas should look out for possible similar situations.

b. *Human induced salinity in soil*



The general objective with irrigation is to overcome the permeability of sodic soils. Irrigation methods that apply water frequently in small amounts allow water to penetrate sodic soils and allow the crop to obtain sufficient water from the less sodic top soil. Under furrow irrigation, water penetration can be greatly improved by forming small hills and making broad flat interspaces. Lower flow rates and slopes will improve soakage and restrict run-off.

1.2 General effects of salinity on crops

Saline soils have good physical conditions due to the high salt content, which promotes flocculation. Thus, high salinity does not have any major negative impact on the soil itself. The big problem in saline soils is the big increase in the osmotic potential of soil water by the high salt content. This makes it difficult for plants to absorb water and causes "physiological drought" stress in plants. Table 1 lists the relative sensitivities and tolerances of crops commonly grown under irrigation to soil salinity.

Table 1. Tolerance of different crops to soil salinity[1,2)]

High tolerance*	Medium tolerance*	Low tolerance*
	Fruit crops	
Date palm	Fig Olive Grape Papaya Sweet melon (Spanspek) Watermelon	Deciduous fruits Citrus fruits Avocado Mango Pineapple Strawberry
	Vegetable crops	
Garden beets Asparagus Spinach	Tomato Broccoli Cabbage Brussels sprouts Cauliflower Lettuce Potatoes Carrot Onion Peas Squash Cucumber Celery Pumpkin	Green beans Celery Radish Carrot Onion Peas
	Field crops	
Sugarbeet Barley Cotton (Rye) Durum wheat	Wheat Oats Rye Sorghum Maize Sunflower Groundnuts Soybean Sugarcane	Field beans
	Forage crops	
Kikuyu Lucerne	Clovers Lucerne (at germination)	

** These are general ratings. There are differences between rootstocks, clones, cultivars*

Table 1 gives a fair reflection of relative differences between crops. Particular attention should be given to the salt tolerance of crops during germination or the seedling stage. Some crops that are very tolerant to high salinity during later growth stages are very sensitive to it during germination. Amongst the most extreme examples are sugar beets (introduced in the Eastern Cape as a potential biofuel crop), lucerne and garden beets.

1.3 Effects of specific ions associated with salinity on crops

In addition to the general salt effects in saline soils, several individual ions that may accumulate in high concentrations in saline soils may have specific negative effects on crops. Only chlorine (Cl) and boron (B) are discussed here.

Figure 2. Salinity symptoms in a vineyard (Source: R Stirzaker)

a. *Chlorine:* Chlorine is present in soils as the anion chloride (Cl-). Chloride is by far the most abundant anion in the vast majority of saline soils. Specific toxicity of excessive chloride levels has internationally been reported for the following crops: Peaches and other stone fruits, grapevines, citrus, avocados, pecans. High chloride levels have strong negative effects on the quality of potatoes and tobacco. The whole tobacco industry in the Katriver Valley in the Eastern Cape was destroyed when the chloride levels in the soils rose too high.

b. *Boron:* Boron toxicity is always mentioned as a potential problem in irrigated soils. This is because (i) the difference between deficient and toxic boron levels is extremely small and (ii) the sensitivities and tolerances of different crops are very different. The minimum boron concentration required to avoid deficiencies in a tolerant crop may be toxic for a sensitive crop. Boron toxicities normally originate from irrigation with water having high boron concentrations. This is mainly borehole water from deep boreholes. In South Africa boron toxicities seem to be quite unknown. Boron toxicities have been found in sensitive ornamental crops due to irrigation with water from a deep borehole near Bloemfontein containing a high boron concentration. So, it would be wise to always check for it. Tables indicating the boron sensitivities and tolerances of various crops have been published and can be consulted if required.

1.4 Management of soil salinity

Practices aimed at minimizing soil salinity and its effects include:

a. Drainage to remove or avoid waterlogging

Waterlogging is one of the most serious causes of salinisation of irrigated land. Water moves upward from the water table by capillarity and at the capillary fringe water is removed by evapotranspiration, leaving dissolved salts behind in the soil. Areas with natural high water tables would require artificial drainage. Artificial drainage may be by means of tile drains. Instillation of such expensive systems is not always required.

In some cases, especially in fairly deep sandy soils on a clay layer, ditch drains are highly effective and have been used for this purpose on the sandy plains near Cape Town and at Vaalharts, for example. Overseas the planting of suitable trees that act as “biological pumps” to lower natural water tables have been used for very long times. In the Western Cape interest has developed in using, for example, eucalyptus or olive trees for this purpose. Wood and other products from the trees can also be harvested and provide income.

Development of waterlogged conditions under irrigation is a widespread problem, leading eventually to salinilisation of the soil. It can be avoided by implementing good irrigation management that would avoid injudicious over-irrigation. In addition adequate drainage must be provided if natural drainage is inadequate.

b. Controlled over-irrigation to avoid salinisation under irrigation

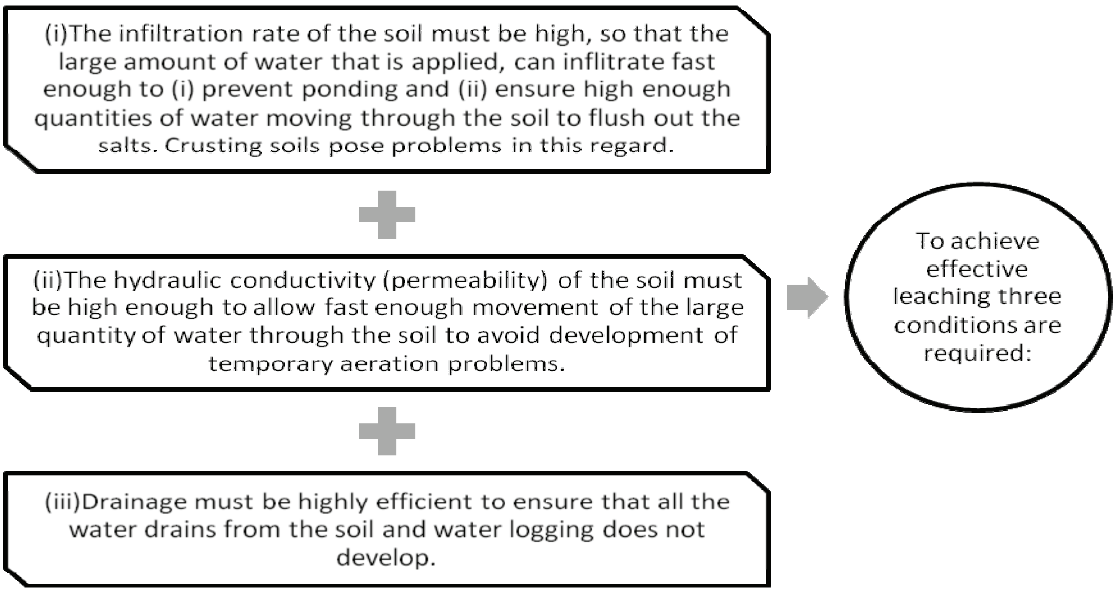
Salts that are brought into soils by irrigation water have to be leached from the soil to avoid building up of excessive salt levels in the soil. If one starts irrigation with water with low salinity on a non-saline soil, one could initially get away without applying more water than the crop requires and allow the salt content of the soil to rise to a maximum allowable limit that has been decided upon, indicated by a maximum allowable EC of the saturation extract of the soil. The maximum allowable limit will be determined by (i) the sensitivity or tolerance of the crop and (ii) the maximum percentage allowable yield loss that has been decided upon (usually ranging from none to 20%).

c. Leaching of excess salts

Once this salt concentration is attained, a “steady state” condition must be maintained. This simply means that the same amount of salts that enters the soil must be removed by leaching.

The fraction of the applied water that must drain through the soil to remove these salts is called the "leaching fraction" (LF). **Leaching Fraction (LF)** is determined by the maximum allowable salt concentration in the soil solution, which is the same as the maximum allowable concentration in the drainage water, and the salt concentration in the irrigation water. The higher the salt concentration in the irrigation water, the greater is LF. Some call it the **"leaching requirement" (LR).**

Where the salt content is in excess of what the crop can tolerate, i.e. the EC of the saturation extract of the soil is higher than the allowable level, the excess salts must be leached from the soil. An excess salt content in the soil may be natural or due to previous poor irrigation practices. Leaching by means of heavy water applications must continue until the EC of the saturation extract has been reduced to the level where normal controlled leaching can be applied to maintain a steady state situation, using the LF principle. In the Western Cape it may take three years to reduce the high salt levels in natural soils derived from Malmesbury shales to levels where steady state conditions can be applied. Leaching the access salts from saline soils to make them irrigable potentially has huge negative implications for downstream irrigators.



d. Selection of crops according to salt tolerance

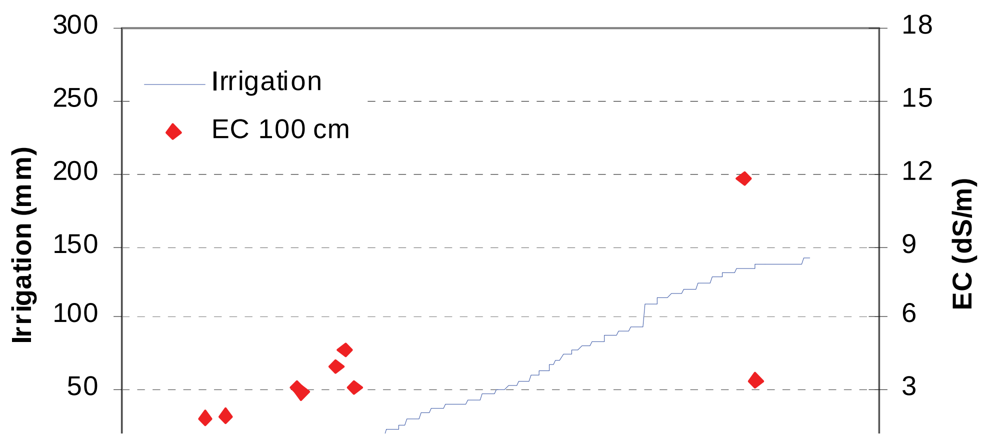
Where soil conditions and water quality are such that production of high yields of high quality of a sensitive crop can no longer be maintained, a choice has to be made between (i) continuing with production of a sensitive high value crop, but at much lower yields, or (ii) switching to a lower value tolerant crop. In the end the decision must be on economic grounds. A point may eventually be reached where the first alternative is not a viable option. If a switch is made to a more tolerant crop it must be kept in mind that it will still require maintaining a steady state situation at the maximum saturation extract EC valid for that crop.

2. Sodic and saline-sodic soils

Case study: *Use of poor quality irrigation water in irrigation of table grapes (Source: R Stirzaker)*

Grape growers are using poor quality water in a winter rainfall area. They use small amounts of water to grow premium quality grapes.

Year: 2003
Rain: 436 mm
Irrig: 141 mm
EC measured 3 dS/m at start of season
EC measured 11.8 dS/m at end of season



It is considered more logical to group sodic and saline-sodic soils together, with a view to discussions on their management and reclamation.

Definition

A **sodic soil** is described as a soil with a low soluble salt content, but sufficient adsorbed sodium to cause significant dispersion. It is defined as a soil with an exchangeable sodium percentage (ESP) >15 and a saturation extract EC <400 $mS.m^{-1}$. Its pH is usually >8.5, i.e. it is strongly alkaline. The general description above is fine, but the definition, based upon a 1954 American publication, advocating an ESP of 15 as the cut-off point, is absolutely meaningless in South Africa and various other countries – as indicated earlier. Serious problems of "sodic behaviour" (dispersing and swelling) in soils occur in many soils with much lower ESP levels. As indicated earlier, many soils in South Africa (and elsewhere) with sodic behaviour are actually soils with lopsided Mg:Ca ratios. These are sometimes called "magnesic" soils.

A typical sodic soil is characterized by a B horizon with a high clay content and very distinct prismatic or columnar structure. The B horizon is overlain by a thin structureless, much more sandy A or (A + E) horizon. The transition between the overlying horizon and the B horizon is abrupt (sharp), giving the soil a characteristic "duplex" (two-deck) character.

A **saline-sodic soil** is a soil that contains both sufficient soluble salts and exchangeable sodium to have a negative effect on crop growth and production. It is defined as a soil having an ESP >15 and a saturation extract EC > 400 $mS.m^{-1}$. Again, the general description is fine, except that there are also magnesic variants, but the definition is meaningless – for the reasons explained earlier for saline and sodic soils.

2.1 Factors causing development of sodic and saline-sodic soil

Geology (parent material) is the main factor responsible for the development of naturally occurring sodic soils. Sodic/magnesic and saline-sodic soils occur widespread in the areas underlain by mudstones and shales of the Beaufort group. These areas include the northwestern parts of KwaZulu-Natal, the southeastern and southern Free State and the western and northwestern parts of the Eastern Cape. The red variants of these soils, associated with purple mudstones and shales of the Elliot formation (Herschel in the Eastern Cape and the southeastern Free State) and Tarkastad subgroup (Queenstown and surrounding areas), are the worst ones. Such soils also occur in other parts of the country. They are relatively abundant in various parts of the Western Cape Province. In the Lowveld of Mpumalanga and Limpopo province they are found on the foot slopes of undulating granitic areas. The latter is also the case in the granite and sandstone areas of the Waterberg area in Limpopo.

Sodic soils develop under irrigation due to irrigation with poor quality sodic water and inadequate measures to remove the sodium from the soil. Unlike the case of salinity, adsorbed sodium cannot be removed simply by effective leaching of the soil.

2.2 Effects of high sodicity in soils

Sodic and sodic/magnesic soils are problem soils. The relatively high exchangeable sodium (although still low in absolute terms) and/or magnesium contents of the B-horizons cause severe physical problems in these horizons. They disperse and swell, thus drastically reducing their macro-porosity. Consequently water infiltration into the subsoil is seriously inhibited. Their hydraulic conductivity becomes very low, i.e. water movement through these horizons becomes very slow. In laboratory studies with sodic clayey soil from the Riet River irrigation scheme the hydraulic conductivity of the soil was zero. The whole soil column in the permeameter did not even become wet. The top part of the soil in the permeameter just "closed" when it became wet, preventing any further infiltration. The same was found with sodic soils from the Petrusville area in the northern Karoo during surveys for possible irrigation development on them under the Orange River scheme. Root development into such horizons is seriously inhibited. These soils are also highly erodible.

Saline-sodic soils have the same problem with restricted water uptake by plants due to the high osmotic potential of the soil water as discussed for saline soils. Because of their high salt contents their physical condition is much better than that of sodic or sodic/magnesic soils. Their physical condition deteriorates quickly when such soils are leached to reclaim them, unless special measures are taken to retain their physical condition.

2.3 Management of soil sodicity

The management requirements to prevent development of sodic or sodic-magnesic soils and to reclaim such soils are very different from those for saline soils. It is much more difficult to prevent development of sodic or sodic-magnesic soils and to reclaim them than it is for saline soils. In the case of salinity it is simply a matter of leaching out excess salts. In the case of sodicity a two-step process is required:

Step 1: For **prevention of development of sodic or sodic-magnesic conditions**, adsorption of excessive levels of sodium and/or magnesium must be blocked by means of an acceptable cation and the excess sodium and/or magnesium must be leached from the soil.

Step 2: In the case of **reclamation of a sodic soil** the excess adsorbed sodium and/or magnesium must be replaced from the exchange sites in the soil by means of an acceptable cation and the replaced sodium and magnesium must be leached from the soil. Calcium is by far the most abundant adsorbed cation in any normal fertile soil. Increasing the adsorbed calcium content of the soil is thus not a big issue. Calcium is also adsorbed far stronger than sodium or magnesium and can thus replace them effectively on the exchange complex of the soil. From both these points it is the ideal cation to use for preventing development of sodic conditions or reclamation of existing sodic conditions. Thus it is the only economically viable cation that is used for this purpose.

To be adsorbed the calcium must first be in the soil solution. Agricultural gypsum or phosphogypsum is used as source of soluble calcium, because it is easy to obtain and relatively inexpensive. An application of 5 t gypsum (or phosphogypsum) per hectare at a time is usually recommended. At Riet River it was found that a total of 40 t gypsum per hectare, applied in batches over time, was needed to reclaim sodic soils on the scheme. Gypsum is calcium sulphate. Gypsum (or phosphogypsum) is in many guidelines incorrectly described as a "readily soluble" source of calcium. This is not true. The solubility of gypsum is relatively low, which causes problems in the reclamation of sodic or sodic-magnesic soils. To create conditions for leaching out the sodium and/or magnesium replaced by the calcium the soil must be flocculated. For this a minimum salt concentration in the soil solution is required. This is called the "threshold concentration", which differs between different cases. The solubility of gypsum is usually not high enough to give a dissolved salt concentration above the required threshold. This is especially the case if the gypsum is applied on top of the soil, as some guidelines recommend. The situation is improved if gypsum is incorporated into the soil. Organic matter or soil conditioners can be used to improve the physical condition of a sodic soil. These can create conditions for leaching, but cannot replace the adsorbed sodium and/or magnesium and thus cannot "push" them into the soil solution from which they can be leached. South African research (e.g. at Oudtshoorn) has shown that a combination of gypsum and a soil conditioner can be highly effective, with the gypsum providing the calcium for replacing the sodium and/or magnesium and the soil conditioner creating the conditions required for effective removal of the sodium and/or magnesium by leaching.

In the case of saline-sodic soils the soil has a high enough salt concentration to ensure flocculation. Adding gypsum on such soil to provide the required calcium can then be effective. Problems arise when the salt concentration in the soil is reduced too fast by leaching, relative to the removal of sodium and/or magnesium and the salt concentration drops below the required threshold concentration. The soil will then disperse and further leaching of the replaced sodium/magnesium will be inhibited. This is also the danger when a switch is made from relatively saline irrigation water to better quality water with low salinity on a saline-sodic soil.

Rule of thumb

A practice that must **NEVER** be used in an attempt to alleviate the negative impacts of sodic subsoils is deep ploughing to mix this horizon with the rest of the soil profile. It has erroneously been done in some cases in South Africa, *inter alia* in the Free State and Western Cape, with predictable disastrous consequences.

3. Irrigation water quality in relation to soil salinity and sodicity

A variety of water quality factors have to be determined before a decision can be made about the suitability of water for irrigation and how to manage it. These include factors that affect blockages of irrigation equipment, corrosion, availability of plant nutrients, heavy metal pollution, etc. A more detail discussion of water quality on other aspects of irrigation management is discussed in Part 4: Module 3 (Irrigation water quality) aspects related to salinity and sodicity will be discussed.

3.1 Water quality related to salinity

Salinity is a matter of salt concentration. Thus the total dissolved salt content of irrigation water is the water quality factor determining the suitability of the water for irrigation. Similar to soils is measured in terms of the electrical conductivity (EC) of the water. The generally used classification of irrigation water according to salinity is given in Table 2.

Table 2. International classification of irrigation water quality in terms of salinity[1]

EC range (mS/m)	Suitability
<25	Low-salinity water, which can be used for irrigation of most crops on most soils with little possibility that salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils with extremely low permeability.
25-75	Medium-salinity water, which can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
75-225	High-salinity water, which cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and only crops with high salt tolerance should be selected.
>225	Very high salinity water, which is not suitable for irrigation under normal conditions. It may be used under the following very special circumstances: The soils must be highly permeable; drainage must be very good, excess irrigation water must be applied to provide considerable leaching and only very highly salt tolerant crops should be selected.

The classification of the suitability of irrigation water in terms of salinity used in the South African water quality guidelines for irrigated agriculture is given in Table 3. These classifications are in respect to salinisation of soils under irrigation. No guidelines have yet been developed in regard to salt concentrations that will cause scorching of leaves during overhead irrigation.

Table 3. South African classification of irrigation water quality in terms of salinity[1]

EC range (mS/m)	Effects
<40	Should ensure that salt-sensitive crops can be grown without suffering a yield decrease when using low frequency irrigation systems. A leaching fraction of 0.1 may be required and wetting of the foliage of sensitive crops should be avoided.
40-90	A 95% relative yield of moderately salt-sensitive* crops can be maintained under a low-frequency irrigation system. A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be prevented.
90-270	A 90% relative yield of moderately salt-tolerant* crops can be maintained under a low-frequency irrigation system. A leaching fraction of up to 0.15 may be required and wetting of the foliage of sensitive crops should be prevented.
270-540	A 80% relative yield of moderately salt-tolerant crops can be maintained under a low-frequency irrigation system. A leaching fraction of up to 0.20 may be required and wetting of the foliage of sensitive crops should be prevented.

**See Table 3 of Appendix 2 of the "South African water quality guidelines for agriculture" for classification of crops as "moderately sensitive" and "moderately tolerant".*

The concentrations of several potentially harmful ions should be checked in irrigation water. It has already been mentioned that chloride and boron are key ones. Tables giving the classification of irrigation water according to boron content can be consulted. For chloride the following approximate guidelines can be given:

i. Water containing >25 mg Cl^{-1} per litre can affect tobacco quality negatively.
ii. Water containing <100 mg Cl^{-1} per litre should be safe for use in overhead sprinkler irrigation for most crops under conditions that are not extremely hot or dry.
iii. Water containing >100 mg Cl^{-1} per litre is generally considered to pose slight to moderate danger of foliar injury (leaf scorch), although it appears to be somewhat more severe in Western Cape vineyards. Systems giving a fine mist cause bigger problems than systems where large drops wash much of the deposited salts from the leaves.
iv. Water containing up to about 150 mg Cl^{-1} per litre can be used safely in surface irrigation systems (flood or furrow).
v. Water containing 150-350 mg Cl^{-1} per litre will give slight to moderate problems when used in surface irrigation systems.
vi. Water containing >350 mg Cl^{-1} per litre can give severe problems when used in surface irrigation systems.

3.2 Water quality related to sodicity

In soils sodicity is expressed in terms of the "exchangeable sodium percentage" (ESP). In water it is expressed in terms of the "sodium adsorption ratio" (SAR). SAR is defined as:

$$SAR = \frac{[Na]}{([Ca] + [Mg])^{½}}$$

Where [ ] = concentration of ions in mmol/l

Generally literature still uses the SAR norms that were originally developed more than 50 years ago. According to these norms the SAR values distinguishing between different degrees of sodium hazard are not fixed, but vary as the salt concentration of the water varies. According to these the critical SAR values are higher, the lower the dissolved salt content (EC) of the water is. The reasoning is that less precipitation of Ca and Mg occurs if the salt content of the soil solution is lower. Knowledge of the threshold concentration concept shows that the reverse is actually true: The negative effect of sodium is higher (critical concentrations lower), the lower the salt concentration of the water is. The South African Water Quality Guidelines for irrigated agriculture give guidelines for SAR (Table 4), but state clearly that it is known that there are irrigated soils in South Africa that are more sensitive than these guidelines indicate. The big problem is that in the calculation of SAR Mg is grouped with Ca as a "good" ion, while it is in reality a problem ion in soils in regard to soil physics, as has been indicated. The South African guidelines for water quality for irrigated agriculture thus state very clearly that local data and site-specific guidelines should be used as far as possible.

Table 4. South African classification of irrigation water quality in terms of sodicity[1]

SAR range $(mmol/l)^{0.5}$	Effect
0-1.5	Should ensure an adequate infiltration rate in soils that are sensitive to the formation of surface seals that would reduce infiltration rate under rainfall during the irrigation season.
1.5-3.0	Should ensure an adequate infiltration rate in soils that are moderately sensitive to the formation of surface seals that would reduce infiltration rate under rainfall during the irrigation season.
3.0-5.0	Chemical soil amelioration (e.g. with gypsum) could decrease the formation of surface seals that would reduce infiltration rate and ensure adequate infiltration rates in sensitive soils under rainfall during the irrigation season.
5.0-10.0	Increasing difficulty is experienced in maintaining infiltration rate through soil amelioration. At soil ESPs exceeding 10 in sensitive soils, infiltration rate cannot be maintained with chemical amelioration methods alone.

Notes:

1. *Several irrigation soils in various parts of South Africa, especially the Eastern Cape, are more sensitive than the criteria used to derive the above SAR ranges.*
2. *Depending upon the specific soils involved and availability of local information, the guidelines should be adjusted and made more site-specific for local conditions.*

3.3 Irrigation water quality in South Africa

In general the quality of South Africa's irrigation water is generally considered to be good. The situation is deteriorating due to the effects of:

- Irrigation
- Mining
- Industrial
- Urban development.

In many areas irrigation expansion plays a major role in lowering the quality of irrigation water downstream. At a measuring point in the Great Fish River the salinity of the water for a period decreased after transfer of high quality water from the Orange river. Thereafter it started increasing again. This increase was directly correlated with the increase in the irrigated area upstream from the measuring point – leading to increased return flow.

Significant areas have surface waters, which are classified as "Mostly unsuitable" are mainly in the Karoo and Eastern Cape rivers draining from the Karoo. The latter receive water from the areas with mudstones and shales of the Beaufort group. These mudstones and shales have high salt contents and also high sodium and magnesium contents. Rivers like the Great Fish River receive many salts from these materials as ground water flow after heavy rains. Base flow water in the rivers during dry periods is also highly saline and sodic. The worst scenario is where farmers have to pump highly saline water from pools in these rivers during prolonged droughts. Water quality furthermore decreases downstream, as indicated above.

Activity

Activity

Group activity

1. What is the difference between saline and sodic soils

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2. Elaborate on the factors causing the development of these "cancer" conditions in soil.

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3. Farmer Moses wants to plant vegetables like carrots and green beans under flood irrigation. However with the inspection of the field the extensionist and the farmer saw clear evidence of serious salt accumulation conditions which exist. What will be the recommendation of the extensionist to the farmer in this specific situation?

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References

1. Department of Water Affairs & Forestry, 1993. South African Water Quality Guidelines. Volume 4 – Agricultural Use
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

My notes............

Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

Technical Learner Guide

Assessing of soil resources

Level 5

Module 10

Soil water dynamics

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Soil water dynamics, soil water infiltration, infiltration rate, cumulative infiltration rate and wetting front
- Water infiltration under drip irrigation
- Water infiltration under furrow irrigation (ridged and non ridged)
- Water infiltration into stronger stratified soils
- How to measure infiltration rate
- The implications of infiltration capacity of soils on irrigation management
- Hydraulic conductivity of soils

Table of contents

1. Soil water dynamics

Definition

Soil water dynamics deals with the movement of soil water, including water movement into the soil, in the soil and from the soil.[1]

The movement of water into, through and out of the soil is critically important with regard to irrigation system selection and design and drainage system selection and design. Important aspects include:

- Water infiltration
- Redistribution of water after infiltration
- Movement of water to roots
- Upward movement of water from a water table
- Drainage
- Leaching
- Evaporation

The rate of water movement through a porous medium is mainly determined by

- The pore size characteristics and stability of the medium.
- The energy difference of water between two points, i.e. the difference in water potential.

2. Water Infiltration and infiltration parameters

Definition

Infiltration is the movement of water into a soil through the soil surface. Infiltration of water into a soil and its subsequent redistribution in the soil are the key factors in irrigation system selection and design. Infiltration is a qualitative term[2)]

Cumulative infiltration (I): This is the total quantity of water that has entered the soil over time[1)].

Infiltrability: This is the maximum flux of water that a soil can take in through its surface. Thus, it is the maximum infiltration rate (i_m), which can be achieved in a soil[2)].

The following quantitative terms describe different infiltration parameters:

2.1 Infiltration rate (i)

This is the volume of water entering a specific area of soil in a specific time, i.e. the flux of water entering the soil.

a. With pressurised irrigation systems the rate at which you apply water must not exceed the soils' infiltration rate.

b. With surface irrigation systems the application at any point in time must be long enough to allow enough water to enter the soil profile.

c. Exceeding the infiltration rate can depending on a specific situation result in soil damage and run-off. It can also cause erosion, loss of fertilisers and excessive water logging of the root zone in low-lying areas.

Table 1. Average infiltration rates for various soil types[1]

Texture group	**Suggested application rate (mm/h)**		**Infiltration rate range (mm/h)**
	Average soil structure	**Well structured soil**	
Sand	50		20-250
Sandy loam	20	45	10-80
Loam	20	45	1-20
Clay loam	20	40	2-15
Light clay	2	5	0.3-5
Medium-heavy clay	0.5	5	0.1-8

2.2 Cumulative infiltration (I)

This is the total quantity of water that has entered the soil over time.

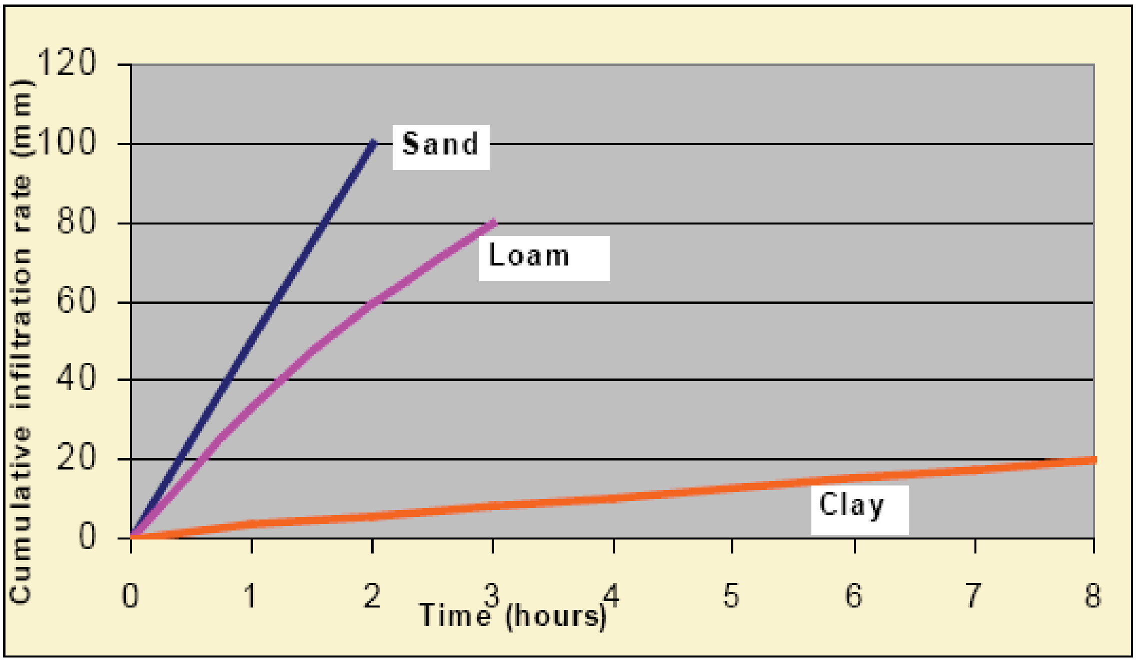


Figure 1. Cumulative infiltration of water[2]

Practical implications for the irrigator

1. *Irrigation Applications can be increased if* :

- Soils are well structured (especially red in colour)
- Soil aggregates are stable when wet
- Soil relatively resistant to erosion
- Moderate soil salinity present

2. *Irrigation Applications should be reduced if:*

- Soils have an unstable structure (single grain size or /and massive structure)
- Soil is bare
- Slope more than 5%
- Sodic content of soil above 6% ESP

3. *Management techniques that increase the infiltration rate of soil:*

- Opening of surface (breaking of hardpans, well defined layers, crusts)
- Relieve soil compaction (cultivating, spiking)
- Breaking of impermeable layers by subsoil cultivation
- Retaining of surface cover (mulch, stubbles, pasture)
- Overcoming of water repellence by methods like organic matter in the top soil

2.3 Infiltrability

This is the maximum flux of water that a soil can take in through its surface. Thus, it is the maximum infiltration rate (i_m), which can be achieved in a soil. This is a key factor in irrigation system selection and design. When the water supply rate is higher than i_m (maximum infiltrability of the soil), then water cannot infiltrate and causes ponding and/or runoff.

The infiltrability of a soil decreases with time during an infiltration process until a constant rate, called the steady state **infiltrability or final infiltration rate (FIR),** is reached. Irrigation water application rate should not exceed FIR. FIR is dependent on the following soil factors:

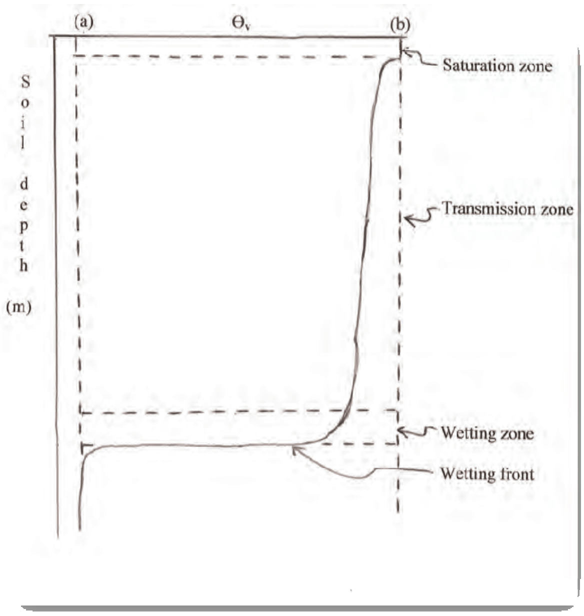
- Texture, especially the amount and type of clay. In general **FIR** decreases with increasing clay content.
- Structure, especially stability of the structure of the topsoil.
- Crusting. This is related to ii above and is determined by soil properties and irrigation water quality, as discussed earlier. In most irrigated soils in South Africa this is probably the most dominating factor affecting FIR.
- The uniformity (or conversely, degree of layering) of the soil profile.

2.4 Water redistribution in a homogeneous soil during infiltration

The following situation is found when a layer of water is maintained on any initially dry soil with a homogeneous profile (Figure 2):

- For a few mm below the surface there is a zone that is completely saturated with water **(saturated zone)**. Below the saturated zone is a lengthening zone of fairly uniform, almost complete wetness, called the **transmission zone**.

- Below this zone is the **wetting zone**, in which the water content decreases with an increasing gradient to the wetting front. At the **wetting front** the water content gradient (difference) is so sharp that it appears as if there is a sharp boundary between wet soil behind it and dry soil in front of it.



(a) = Initial water content
(b)= Saturation water content
$ø_v$= Volumetric water content

Figure 2. Water infiltration into an initially dry homogenous soil profile[2]

A soil with a coarse (sandy) texture typically has a much sharper and clearer wetting front than a soil with a fine texture (clayey). The wetting front is sharper defined during infiltration into an initially dry soil than into an initially relatively wet profile. The wetting front also tends to become less clear as infiltration proceeds deeper into the soil profile.

Regarding the type of pattern illustrated in Figure 2 it should be kept in mind that it is valid only:

a. For a relatively homogeneous soil profile.
b. For situations where at least a thin layer of water is maintained all over the soil surface i.e.as rainfall that exceeds the infiltrability of the soil; flood bed irrigation or badly planned and/or managed overhead irrigation systems (including micro-sprinklers), in which the application rate exceeds the infiltrability of the soil.
c. If irrigation is cut off (stopped) the moment that the wetting front reaches a certain depth in the soil, and then there is a lot of water in the macro pores above the wetting front that will still move further down into the soil after irrigation has been cut off. This period of redistribution of water deeper into the soil profile can last several days in fine textured soils.
d. Where overhead sprinkler or micro-sprinkler irrigation is applied at rates lower than the infiltrability of the soil the scenario is as follows;

- There is no saturated zone below the surface. The transmission zone starts at the soil surface.
- The transmission zone is not nearly completely wet.
- The wetting front is very diffuse (vague).

e. Drip and furrow irrigation are special cases in which the infiltration patterns and mechanisms differ completely from that depicted in Figure 10.1. A good understanding of these patterns and mechanisms is very important for sensible decisions regarding the use of these systems and their planning. For both these systems lateral redistribution of water in soil is critically important to ensure that a large enough volume of soil is wetted.

   i. *Infiltration under drip irrigation:* Drip irrigation is a point application of water. If water movement was only vertically downward under the drippers, the soil in almost the whole irrigated field or orchard would virtually remain dry. Thus good lateral (sideways) movement of water applied by a dripper is essential. Lateral movement is by means of capillary movement (the “sucking” of water into small pores) in the micro pores under a soil matrix potential difference. The ideal is to get a big “onion” shaped wetted area under the dripper (Figure 3). The diameter of the “onion” should preferably not be less than two-thirds of its length (wetted depth). To achieve this effectively a soil must have adequate micro pore volume. This is the situation in medium-textured to clayey soils. Sandy soils, especially medium to coarse sands such as those on the Cape Flats and Joostenberg Flats in the Western Cape, have very limited micro pore volume. Consequently lateral water movement is extremely limited. In addition they have large macro pore space, causing very fast vertical downwards movement of water under the influence of gravity under the dripper. Therefore a wet “onion” cannot develop under a dripper, but only a narrow “carrot” (Figure 3). The largest part of the soil remains dry. Drippers are not suitable on sandy soils.

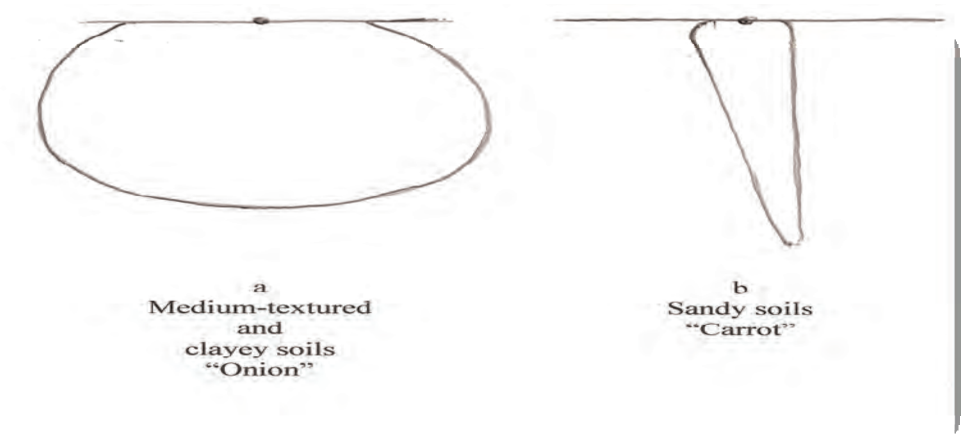


Figure 3. Water infiltration under drip irrigation

ii. Infiltration under furrow irrigation: In the case of furrows without ridges, on a flat area very much the same situation as for drippers is required to create a wide enough wet strip on both sides of the furrow. Typical wetting patterns for sandy, medium textured and clay soils respectively are shown in Figure 4. Again the problem with sandy soils can be seen clearly. Furthermore, in sandy soils vertical water infiltration from furrows is very fast, leading to over-irrigation and water logging problems at the top ends of furrows.

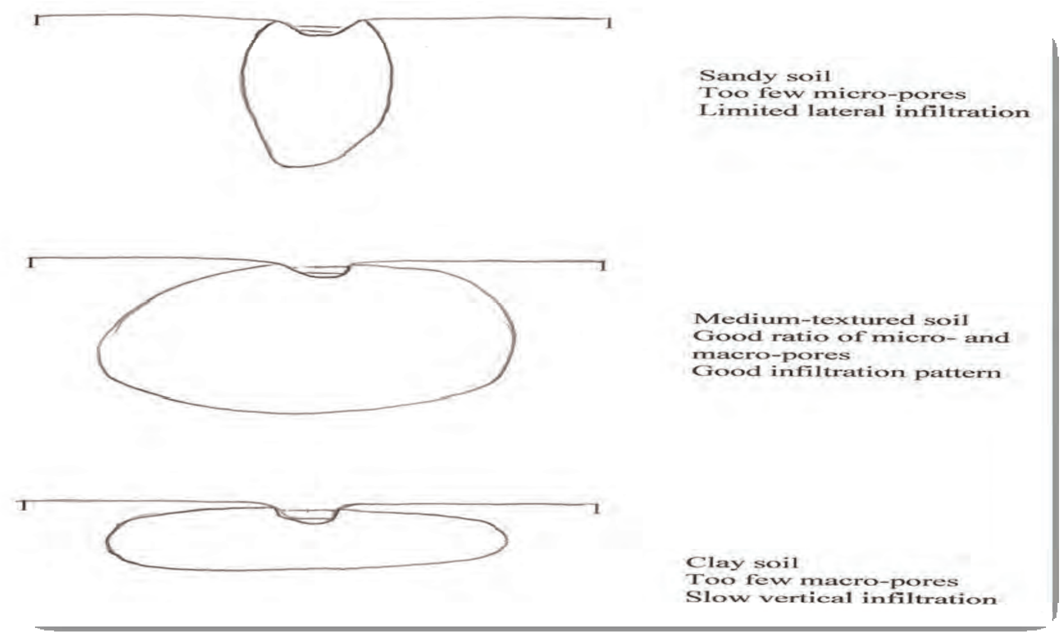


Figure 4: Water infiltration from shallow (non-ridged) furrow in different soils

iii. In the case of furrows with ridges the situation is quite different. Plants are usually planted on top of the ridges or in the sides of the ridges. (Not in the bottoms of the furrows.) This means that the root zone in the ridge must be wetted from the furrow. Wetting of the ridge is achieved most effectively by deep application of water in the furrow (Figure 5). The central top part of the furrow is wetted by means of capillary rise of water. To achieve uniform water distribution along the furrow the furrow must have uniform slope and a large stream must be used so that the water flows fast along the furrow.

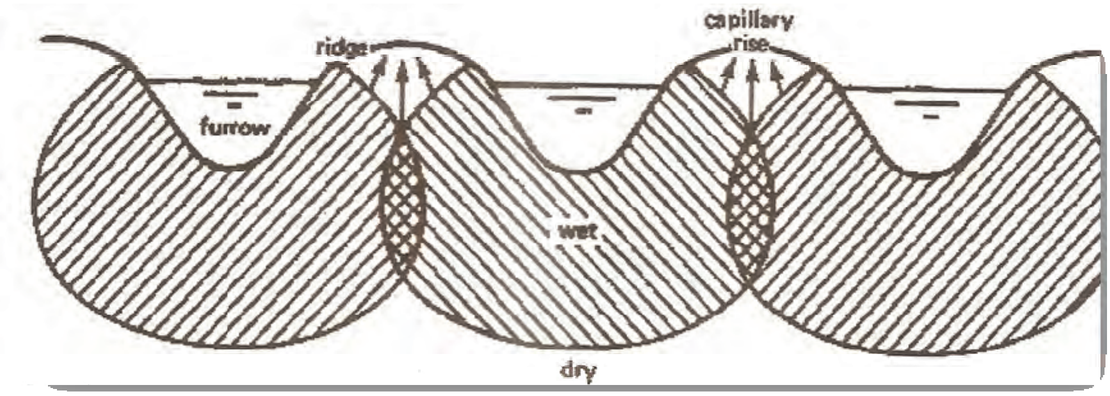


Figure 5. Ideal wetting pattern in deep furrow irrigation with ridge[2]

All these principles are applied highly successfully by small-scale farmers using short furrow irrigation, e.g. at Dzindi irrigation scheme in Limpopo province (Figure 6). Spacing of furrows is important so as to ensure that adjacent wetted areas just overlap (Figure 5).

Figure 6. Short furrow irrigation at Dzindi irrigation scheme in Limpopo Province

2.5 Infiltration into strongly stratified soils

Strongly stratified soils occur widely in nature, especially on the lowest terraces along rivers where much irrigation is practised. Infiltration is much more complex in such soils than the situation in homogeneous discussed above. Two basic patterns are found, viz. (i) where a coarse textured layer or horizon abruptly overlies a fine textured layer and (ii) where a fine textured layer abruptly overlies a coarse textured layer. In stratified alluvium several sequences of these are usually found within one profile.

i. Coarse textured layer with high infiltrability over fine textured layer with low infiltrability: Initially the coarse textured layer determines the infiltration rate. When the wetting front reaches the fine textured layer, infiltration slows down and is eventually determined by the infiltrability of the fine textured layer. A perched (sitting) water table develops on top of the fine textured layer.
ii. Fine textured layer with low infiltrability over coarse textured layer with high infiltrability: Infiltration rate is determined by the infiltrability of the fine textured layer at the top. When the transition to the coarse textured layer is reached, infiltration stops temporarily while a hanging water table develops in the bottom part of the fine textured layer. Only when enough water has accumulated to provide a high enough pressure to push water from this layer into the underlying coarse textured layer will infiltration resume. The infiltration rate will then still be determined by the infiltrability of the fine textured layer. When a high enough pressure has been built up, the break through of water into the coarse layer is often the form of “fingers” or “pipes” with the soil in-between remaining dry. Thus a coarse layer (sand or gravel) underlying a clayey layer does not improve drainage of the clayey layer, but inhibits it.
iii. The above scenarios are for cases where the transition between layers is abrupt (sharp) or clear transitions involving large differences in clay content. When the transitions are gradual the situation is much better.

2.6 Methods for determining the infiltrability of soils

Various methods can be used to determine the infiltrability of soils. When infiltration measurements are made for irrigation planning, the method used, **MUST** simulate infiltration under the irrigation system that will be used.

It is essential that the infiltration measurement must be done on a soil that is similar to that for which the planning must be done and its expected physical and chemical condition after some years under irrigation. Infiltration measurements should NOT be done on virgin soils, because they have for example higher organic matter levels that stabilise the structure of the surface soil.

The water, which is used during the infiltration determinations, must be similar to that which will be used for irrigation - especially in regard to EC and SAR.

Activity

Activity1: Measuring infiltration rate

Group activity

1. Remove one end of the can with a standard can opener, retaining the rolled edge.
2. Remove the other end including the rolled edge, to leave a sharp edge. This can be achieved with some types of can openers, but if these are not available, use tin snips.
3. Mark a line around the outside of the can, 50 mm from the sharp edge.
4. Find a clear flat site and place the can on the ground with the sharp edge down.
5. Place the board on top of the can and hit it with the hammer until the can is pushed down to the 50 mm line.
6. Place the rule in the can so you can measure the distance between the top of the can and the initial height of the water as soon as the water is put in (see step 7).
7. Pour water into the can until it is near the top and note the level on the rule. Start the stopwatch at the same time.
8. Record how long it takes for the water to infiltrate the soil and move down to ground level. (If there are any obvious leaks around the can, fix them and start again!)
9. Calculate the infiltration rate using the following steps:
   - Record the change in water level in the can as **D** (in mm, the distance between first height and ground).
   - Note the total time in minutes it took to fall that distance. Call this time **T.**
   - Calculate the infiltration (called **I**, in mm/h), using
     I = D/ T x 60
     (60 is the conversion from minutes to hours)
10. Record your answer in the table below.
11. Remove the can and store it safely until required again.

Infiltration record sheet

Site Number	Soil Type	Infiltration Depth (D)	Infiltration Time (T)	Infiltration Rate (I) I=D/T x 60
1.				
2.				
3.				
4.				

Note: This field test is an estimate only. Many factors will influence the results from this test and give varying results. Such factors may include soil moisture, structure and organic matter. It is however important to understand the infiltration rate of your soils as they will play an important role in the water use efficiency of your irrigation.

3. Hydraulic conductivity

Definition

Hydraulic conductivity, or its qualitative related term permeability, indicates the flow rate (or flow density) of water in a soil. Hydraulic conductivity (more correctly "saturated hydraulic conductivity") is determined by the macro porosity of the soil. Thus it is strongly dependent on the texture and structure of the soil. If hydraulic conductivity of a soil is too low, then:[1]:

1. Poor aeration results while the water is moving through the soil
2. Drainage of excess water and leaching of salts from the soil becomes very difficult

It is normally accepted that drainage and leaching is extremely difficult if the hydraulic conductivity of a soil is less than 1 $mm.h^{-1}$. It was found that 3 $mm.h^{-1}$ is the lowest hydraulic conductivity that is adequate for effective water movement in soils from the Vaalharts, Lower Orange River and Riet River Irrigation Schemes. Soils with hydraulic conductivities less than 3 $mm.h^{-1}$ are consequently classified as totally unsuitable for any irrigation. Soils with zero hydraulic conductivity have been found at Riet River and in the vicinity of Petrusville in the northern Karoo.

Several laboratory methods are used for the determination of hydraulic conductivity. Use is made of soil columns in so-called *"permeameters".* Since structure is very important with regard to pore geometry, this is for many soils, not a good method. It is better to use systems in which undisturbed soil cores can be used.

Activity

Activity 2

Individual activity

1. What do you understand underneath "soil water dynamics"?

   ....
   ....
   ....
   ....

2. Define "Final Infiltration Rate (FIR)".
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....
....
....

3. Discuss the main soil factors that determine the infiltration rate of soil.

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4. a. After an irrigation application, water infiltrates the soil profile slowly. What do you understand underneath the following :

   i. Saturated zone

   ii. Transmission zone

   iii. Wetting zone

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....

   b. Explain the difference with regard to the infiltration pattern of irrigation water between furrow and drip irrigation on the same type of soil.

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References

1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Stirzaker R, Stevens JB, Annandale J, Maeko T, Steyn M, Mpandeli S, Maurobane W, Nkgapele & Jovanovic N,2004. Building capacity in irrigation management with Wetting Front Detectors. WRC Report TT 230/04. WRC, Pretoria.

My notes............

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Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

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Technical Learner Guide

Assessing of soil resources

Level 5

Module 11

Soil water statics

Study objective

After completion of this module, the learner should be able to:

- Define soil water potential
- Define soil water retentivity curve and the use for irrigation management
- Define saturation point, field capacity and permanent wilting point
- Define Readily Available Water (RAW) and Plant Available Water (PAW)
- Calculate the RAW for the effective rootzone

Table of contents

Soil water statics entail mainly the following, which are all important in irrigated agriculture:

- The forces with which water is held in the soil.
- The water-holding capacities of a soil, with reference to different types of soil water.
- The availability of the water for plants.
- Factors which determine the water-holding capacity of a soil.

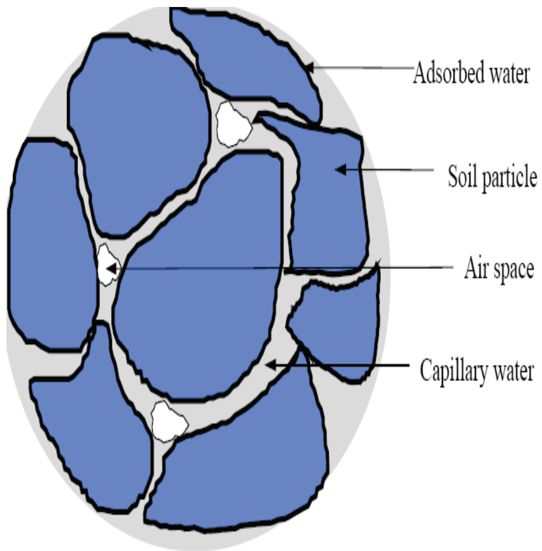


Figure 1. Forms of soil water

1. Soil water potential

Soil water is described in terms of its energy status, or soil water potential. **Soil water potential** has different components (different types of potential) that together determine the overall potential. In any normal (non-saline) soil the matric potential is the over-riding water potential. It is a negative potential for which the term “soil water tension” is sometimes used. The matric potential is caused by a combination of capillary and adsorption forces, which the soil matrix (solid phase of the soil) exerts on water. In clayey soils both adsorption and capillarity are important. In sandy soils capillarity dominates and adsorption is relatively insignificant. Because capillarity dominates in many soils, matric potential is sometimes called capillary potential. In saline soils both the matric potential and osmotic potential are important. Osmotic potential does not affect the strength with which water is retained in the soil, but affects the uptake of water by plants.

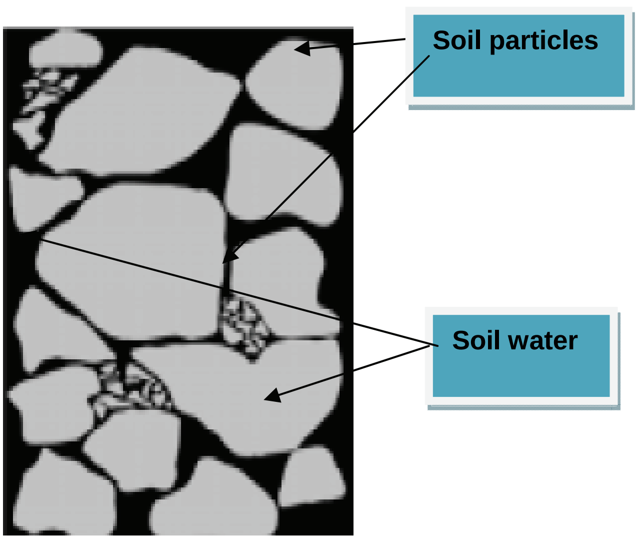
2. Soil water constants and water retentivity curves

A **soil water retentivity curve** describes the relationship between the water content of a soil and the matric potential at each water content. Certain points on the soil water retentivity curve are considered to be very important for plant growth. These are the so-called soil water constants, of which "field capacity" (FC) and the "permanent wilting point" (PWP) are the most important.

How "tightly" soil holds on its water, and how much effort the plant has to exert to extract this water, can be described as "soil water tension". A negative pressure in kPa describes this tension, and by measuring soil water describes the condition of the soil at each stage of irrigation and crop use - from saturation point to permanent wilting point.

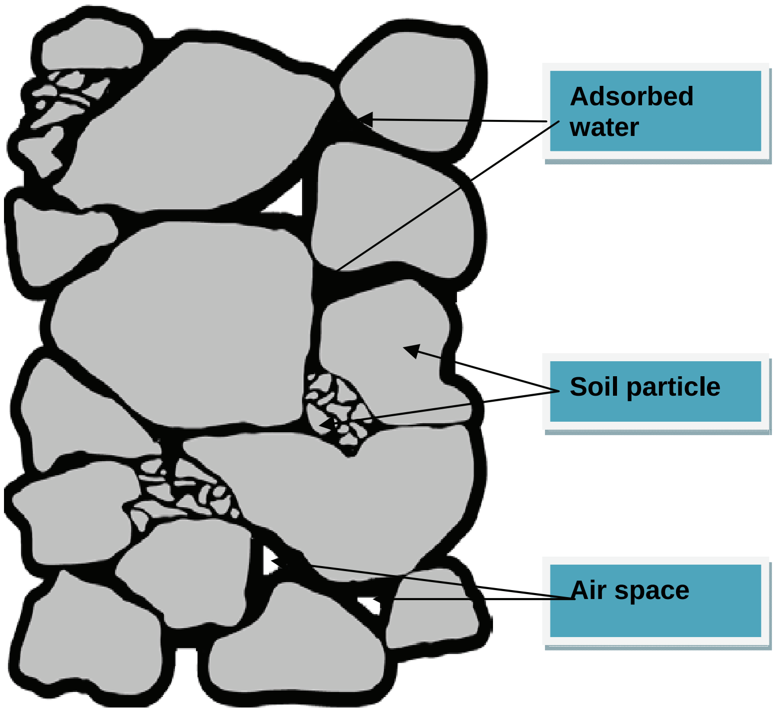
- ### Saturation point

  Saturation point is where all soil pores are filled with water, and applying of more water causes ponding, run-off and deep drainage. In a condition of saturation, there is no air for the plant roots, which will stress most actively growing plants.



- ### Field capacity

Field capacity is the maximum quantity of water that soil can retain which cannot drain from the soil under the force of gravity. Thus it is the quantity of water retained in the soil after all free water has drained from the macro pores under the force of gravity. Field capacity is the upper limit of plant-available water in a soil.



The soil water potential at field capacity can for any specific soil be determined by taking potential readings during the determination of field capacity in the field. The readings can, for example, be taken with tensiometers. It can also be read off from a water retentivity curve determined in the laboratory. It is important to read off the potential at the water content equal to the **field**-determined field capacity.

For many decades it was assumed that the matric potential at field capacity is the same for all soils. It was believed to be about -33 kPa (kilopascals). Field studies have shown that this value may be acceptable for clayey soils, but greatly underestimates the field capacity of sandy soils. For sandy soils the matric potential at field capacity is considerably higher than -33 kPa. A value of -10 kPa is presently fairly widely used for sandy soils, although there are indications that it may be even closer to -5 kPa. Incorrect assumptions regarding soil water potential at field capacity, and thus also of the soil water content at field capacity, can have serious implications in irrigated agriculture, such as:

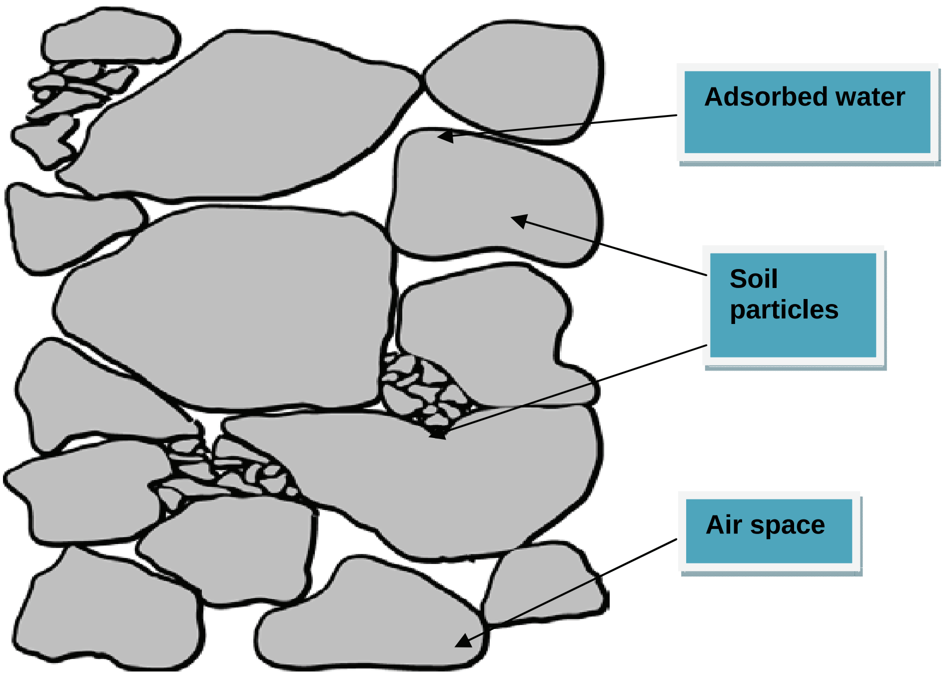
i. If it is for a sandy soil assumed that FC is at a soil water potential of -33 kPa, then the field capacity of the soil will be far underestimated. The irrigation system designed for such a small FC will be unnecessarily big and expensive. Furthermore, the real available water capacity will not be utilized during peak demand periods.
ii. If it is for a clayey soil assumed that FC is at a soil water potential of -10 kPa (or even worse, at -5 kPa) and irrigation scheduling is, for example, done to maintain the soil water potential between -30 and -10 kPa, the soil water content will permanently be above field capacity. Thus the soil will permanently be excessively wet and inadequately aerated. This will lead to poor root functioning, aggravated root rot

disease incidence and consequently poor yield. Such error was made some years ago when soil water potential norms that were derived for the irrigation of citrus trees on the sandy soils of Citrusdal were used for the irrigation of citrus trees on much finer textured soils in the Sundays River Valley, leading to serious problems in the latter case.

Due to these uncertainties there is, especially for irrigation scheduling, no substitute for field determined field capacity. If it is absolutely impossible to determine FC in the field and it is unavoidable to use field data, then it is safest to use -33 kPa as measure of the matric potential at FC for clayey and unstable medium textured soils and -10 kPa for sandy and stable medium textured soils. If a meaningful decision can be made regarding an appropriate matric potential for a specific case, then the soil water content at that matric potential can be calculated by means of empirically derived multiple regression equations. These equations differ between different geographic areas and each is applicable only in the area for which it was derived. Various such equations have been derived for various areas in South Africa and any person involved in irrigation planning and advice should obtain the equation applicable to his/her area. In most cases the (silt + clay) content of the soil is the soil factor determining the water content at field capacity, but the relationships differ between regions.

- **Permanent wilting point**

Permanent wilting point (PWP), or just wilting point, is supposed to indicate the lower level of plant-available water in the soil. It is the water content at which plants cannot extract water fast enough to satisfy their requirement during periods of low demand, such as at night.
PWP is defined as the soil water content at which a plant wilts and does not recover if it is placed overnight in a humid atmosphere. It will recover if water is added to the soil.



The standard method for determining PWP is to grow sunflower seedlings in small-standardized containers from which evaporation is prevented until the situation described above is reached. The PWP determined in this way correlates well with a soil matric potential of -1 500 kPa. PWP is reached at about the same matric potential by almost all non-xerophytic plants. The soil water content at a matric potential of -1 500 kPa can for any soil also be calculated by means of multiple regression equations with other soil parameters. As in the case of FC these equations differ between different regions. Various equations have been derived for different regions in South Africa. Best correlations are, as for FC, usually obtained with (silt + clay) content of the soil.

It has for many decades been accepted that the soil water content at -1 500 kPa or laboratory determined PWP by the sunflower method also indicates the lower limit of plant-available water under field conditions. It is still often used for this purpose in irrigation planning and scheduling. Research has shown that this assumption is incorrect. Laboratory determined PWP or the water content at -1 500 kPa matric potential is not an indication of the lower limit of plant-available soil water under field conditions. A different approach is required. This is discussed later.

3. Soil water retentivity curves

Definition

A **soil water retentivity curve** is a curve showing the relationship between soil water potential (matric potential) and soil water content. Soil water retentivity curves are strongly related to soil particle size distribution (texture).

Typical curves for sandy and clayey soils show how big and important these differences can be:

i. In a sandy soil most of the micro pores are of fairly uniform size and are relatively large (within the micro pore range). Because of the uniform pore size most of the water has the same matric potential. Because most of the pores are large, water is held relatively loosely in them, i.e. most of the water has a high matric potential. This means that most of the water can be extracted easily, before there is a significant decrease in matric potential. Further extraction of water is accompanied by a drastic reduction in matric potential.

ii. In a clayey soil the pore size distribution of the micro pores is non-uniform, i.e. graded from large to small. Consequently the matric potential decreases gradually as the water content decreases. Water having matric potential higher than -100 kPa (in this case between -33 and -100 kPa) is usually considered to be freely available to plants (can be extracted easily). In the case of the clayey soil only a small proportion of the water held between -33 and -1 500 kPa would thus be considered to be freely available. In the case of the sandy soil almost all of the water would be considered freely available. Adsorption of water also plays a significant role in the clayey soil. The consequence is that a lot of water in the clayey soil is not available to plants, as seen by the high soil water content at a matric potential of -1 500 kPa. Although the latter potential is no longer regarded as really applicable, the principle remains the same.

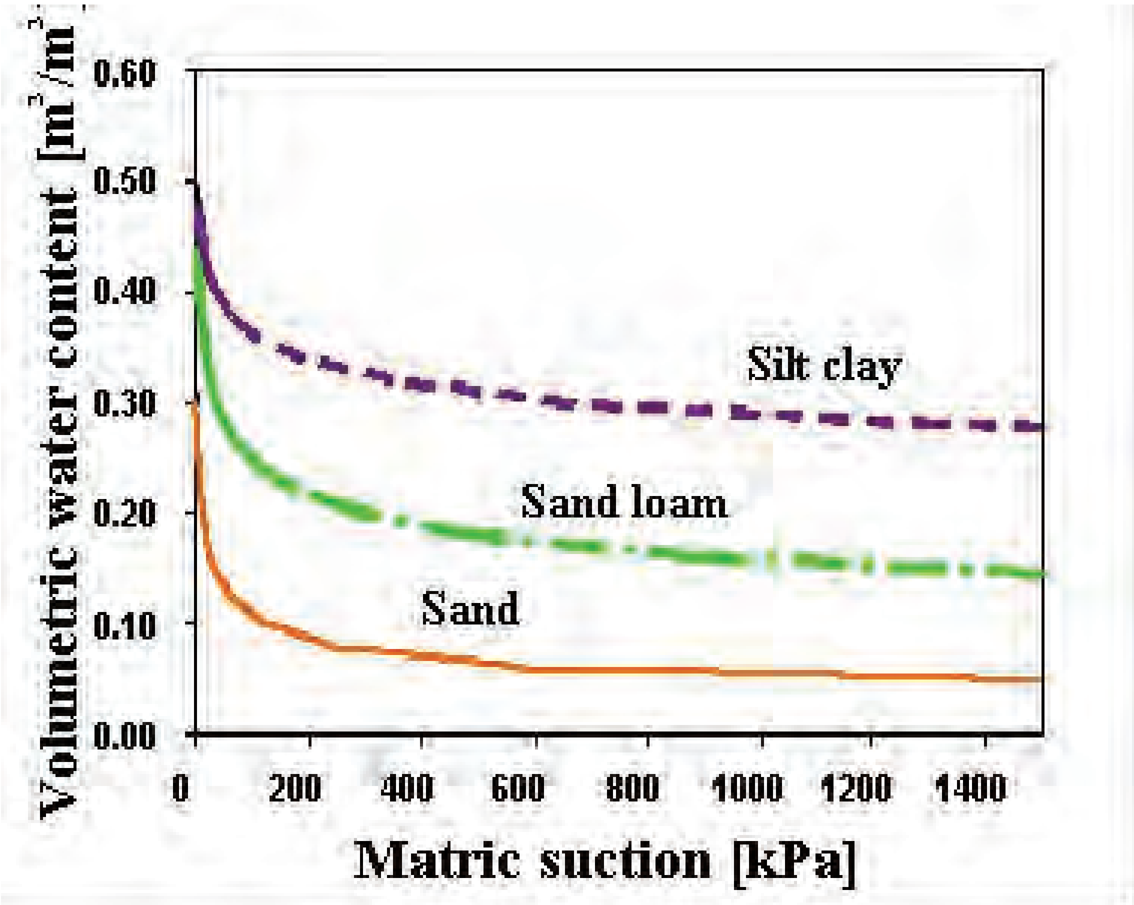


Figure 2. Soil water retention curve for different soil types

4. Plant Available Water (PAW) and Readily Available Water (RAW)

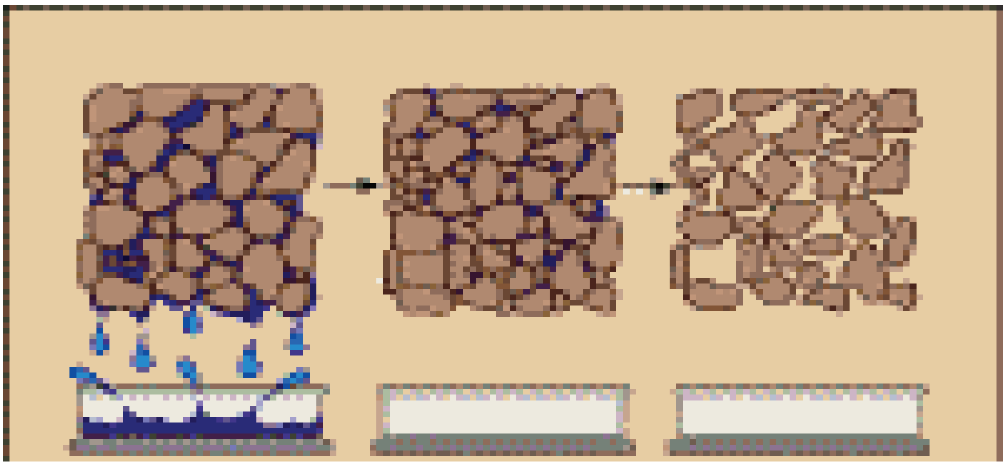
Appropriate irrigation planning and scheduling is not possible with a thorough understanding of the availability of soil water to plants and the amount of plant-available water that any specific soil can store.

- In the first place the upper limit of plant-available water must be known. Otherwise it may lead to either (i) over-irrigation that may cause water logging, salinisation, leaching losses of nutrients, etc. or (ii) under-irrigation, leading to unnecessarily high irrigation frequencies that may cause unnecessary evaporation losses of irrigation water.

- Secondly, an appropriate lower limit for plant-available water must be known. Otherwise it may lead to either (i) extraction of too much water between irrigations, leading to soil-induced water stress in plants and reduced yields or (ii) unnecessarily frequent irrigations due to fear that the latter may happen. The amount of soil water between these upper and lower limits is the "allowable depletion".

Definition

A plant cannot use all the water held in the soil. Only the water between Field Capacity and Permanent Wilting Point is available to the plant. However, as the soil water content decreases and approaches the permanent wilting point, the plant has to work harder to obtain the water. This usually causes unnecessary stress for the plant. For the irrigator to improve water use efficiency, they must work with the water that can be readily removed from the soil by the plant. This is called **Readily Available Water (RAW).**



Saturated soil	Field capacity	Permanent Wilting Point
Pores are full of water	Available water for plant growth	No soil water available for plants

Figure 3. Available water for plant growth

Table 1 illustrates the maximum amount of water that different soil types can retain under normal conditions.

Table 1. Total amount of water (Total available moisture (TAM) or Plant Available water (PAW) retained for the different soil types

Clay content (%)	Waterholding capacity (mm)
0-5	20-100
5-15	80-130
15-35	100-140
35-55	130- 180

The classical concepts of plant-available water are very interesting, but they have been superseded by newer approaches that are of more practical relevance. Thus, the classical concepts will not be discussed here. Present concepts regarding plant-available soil water are based on the principle that that the soil-plant-atmosphere continuum (SPAC) forms an integrated unit that must be handled as such in soil-plant-water relationships. Factors such as rooting density and depth, soil structure, evaporative demand, etc. all play roles that cannot be simulated in laboratory or greenhouse pot studies.

There is no basic difference between the classical and newer concepts regarding the upper limit of plant-available soil water. Field capacity is still considered to be the only practical norm for the upper limit of plant-available water. The main difference is that there is presently much more emphasis on the importance of using field determined field capacity and regression equations to derive it and less on the water content at certain soil water potential (like -33 or -10 kPa).

The biggest differences between the classical and newer concepts of plant-available water are in regard to the lower limit of plant-available water. The emphasis is on field determined lower limits and regression equations to derive them. Different lower limits are defined for dryland (rainfed) and irrigated situations. The basic principle is to identify the onset of soil-induced water stress in plants, i.e. the soil water content at which plants suffer stress because the soil is too dry. It is distinguished from atmospherically induced water stress, i.e. where there is adequate plant-available water in the soil, but the plants go into stress because the atmospheric demand is too high.

5. Factors that influence RAW

The factors that influence Field Capacity and Permanent Wilting Point will also influence the quantity of plant available water. Two prominent factors that will be discussed are:

a. Texture
b. Organic matter

5.1 Texture

The influence of texture can be best illustrated with the following figure[1].

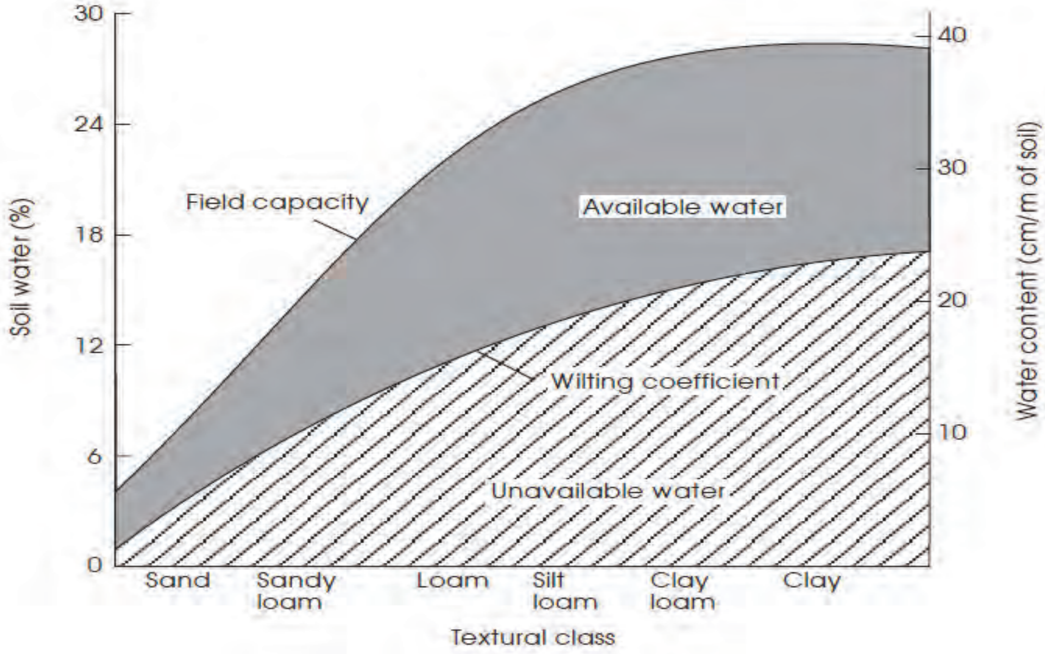


Figure 3. Link between texture and soil water [1]

This figure clearly illustrates that silt loam has the optimum plant available water quality. The finer the texture, the higher the total water storage capacity of a specific soil, but the more tightly the soil water will be held, and therefore the unavailable water volume will be large.

5.2 Organic matter

A well-drained mineral soil with an organic matter content of 5% will be able to store more water than a similar soil with a 2% organic matter content. The reason for this is not only attributed to the higher organic matter content and its effect on soil retention capacity, but also the favourable influence of the organic matter on the structure and in turn on the porosity. Humus in general has a high filed capacity, but also a relatively high wilting point, as in clays.

RAW is expressed in millimetres per meter (mm/m) and indicates the depth of water (mm) held in every meter of soil depth (m) 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. It is important to calculate RAW for the full soil profile and then determine the effective rootzone. The RAW values differ for the different crop types (Table 2):

- Water sensitive crops like vegetables, and some tropical fruits
- Most fruit trees and vines with well developed root systems which can exert a moderate to strong tension on the soil
- Most pasture crops, lucerne, maize, soybeans

- Annual pastures and hardy crops like cotton, sorghum and winter crops

Table 2 indicates approximately values for RAW for different crops and texture classes.

Table 2. RAW and AW values for different soil texture classes and crop types

Water tension	**0-20 kPa**	**0-40 kPa**	**0-60 kPa**	**0-100 kPa**	**To 1500 kPa**
	A	**B**	**C**	**D**	**E**
	Water sensitive crops: vegetables and some tropical fruits	Most fruit crops and table grapes, most tropical fruits	Lucerne, pasture crops, crops like maize and soybeans, and grapes*	Annual pastures and hardy crops like cotton, sorghum and winter crops	Available water (AW) = Total water available in the soil (Plant 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

**Except when partial rootzone drying is practised on wine grapes*

5.3 How to calculate rootzone RAW

Stepwise calculation of rootzone RAW?

The best way to determine RAW for a particular situation is to dig a soil pit and get your hands dirty!!!!! The RAW stored within effective root zone can be calculated by:

Step 1: Identify and measure the thickness of each soil layer

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 to determine the RAW for the soil layer.

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

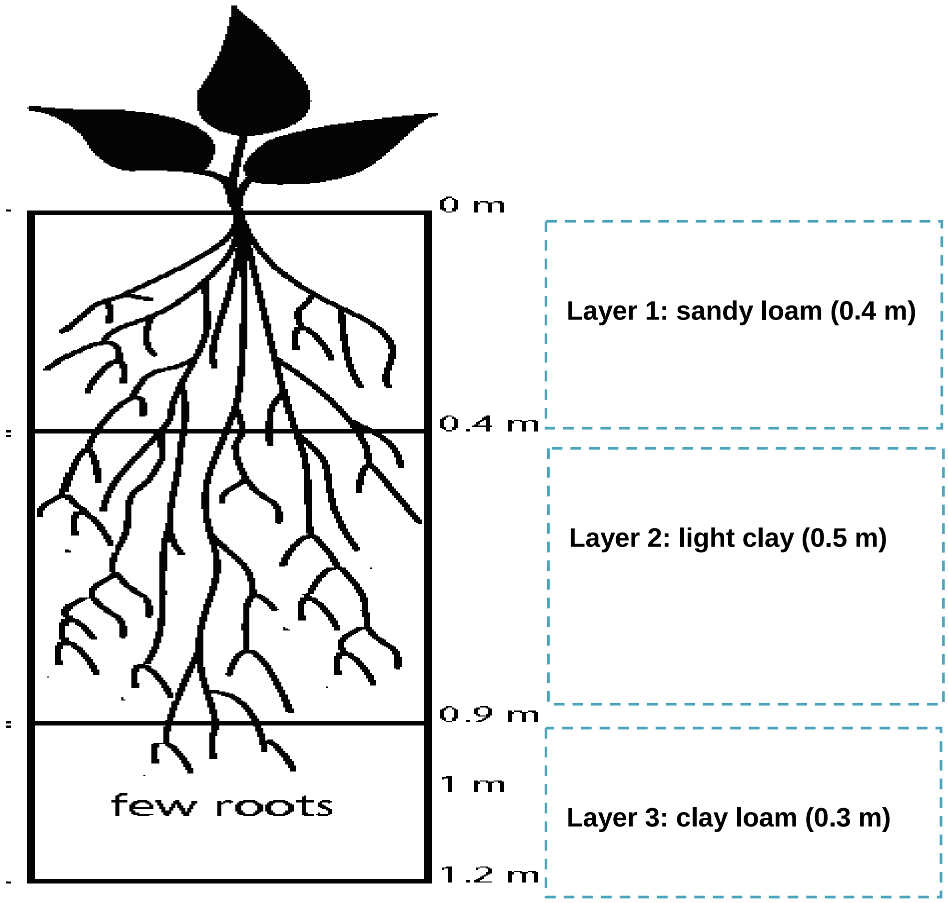
Step 5: Add up the RAW for each soil layer to obtain the total soil profile RAW

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

Example

Calculate the effective rootzone RAW for a lucerne crop that is growing on a sandy loam soil (0.4 m) over 0.5 m of light clay, which is followed by clay loam (0.9-1.2m).



Step 1: Identify and measure the soil layers

Layer 1: 0-0.4 m = 0.4 m

Layer 2: 0.4-0.9 m = 0.5 m

Layer 3: 0.9-1.2 m = 0.3 m

Step 2: Determine the soil texture of each layer

Layer 1: Sandy loam

Layer 2: Light clay

Layer 3: Clay loam

Step 3: Select the crop water tension using Table 2 and identify the RAW for each soil layer (RAW values for each layer for lucerne (Column C))

Layer 1: Sandy loam = 65 mm/m

Layer 2: Light clay = 55 mm/m

Layer 3: Clay loam = 65 mm/m

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

Layer 1: 0.4 m x 65 mm/m = 26.0 mm

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

Layer 3: 0.3 m x 65 mm/m = 19.5 mm

Step 5: Add up the RAW for each layer to obtain the Total RAW stored within the soil profile

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

= 26.0 mm + 27.5 mm + 19.5 mm

= 73 mm

Step 6: Identify the effective rootzone

Effective root zone = 0.9 m

Step 7: Add up the Effective Rootzone RAW

Layer 1 RAW + Layer 2 RAW

= 26.0 mm + 27.5 mm

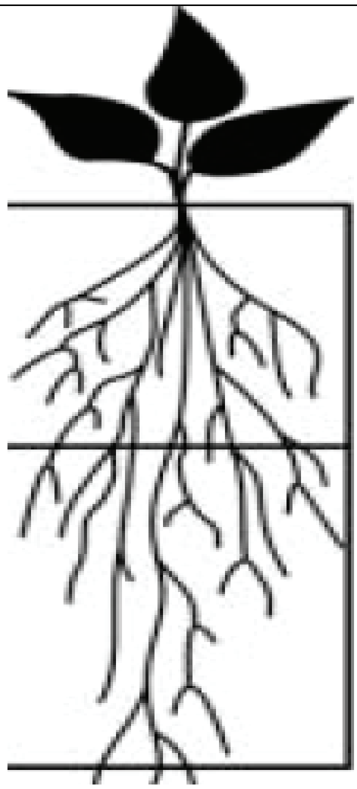
= 53.5 mm

Activity

Activity 1

Small group activity

A cotton crop is growing on a top soil layer of loam (0.25m) over layers of clay loam (0.45m) and light clay (0.25m). Calculate the RAW for this site. The effective rootzone is 0.7 m.

		
Layer 1: Loam		0-0.25m
Layer 2: Clay loam		0.25-0.7m
Layer 3: Light clay		0.7-0.95m

1. Soil layers

Layer 1: RAW 1 =…………m x …………….mm/m

=………………mm

Layer 2: RAW 2 = …………m x …………….mm/m

= ………………mm

Layer 3: RAW 3 = …………m x …………….mm/m

= …………………..mm

2. Soil profile RAW for this site = RAW 1 +RAW 2 + RAW3

= ………..mm + ………………..mm + ……………..mm

=…………..mm

3. Effective rootzone RAW for this site is:

= RAW 1 + RAW 2 + RAW 3 (part)

= …………mm + ………..mm +…………mm

=……………mm.

References

1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

My notes............

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Authenticators: Prof Chris du Preez & Mr D Haarhoff

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Module 12

Soil fertility in irrigated agriculture

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- The difference between macro and microelements
- Soil pH and understand the effect of soil pH on availability of plant nutrients
- The role of macro and micro nutrients in the soil
- Taking of representative soil samples for analysis

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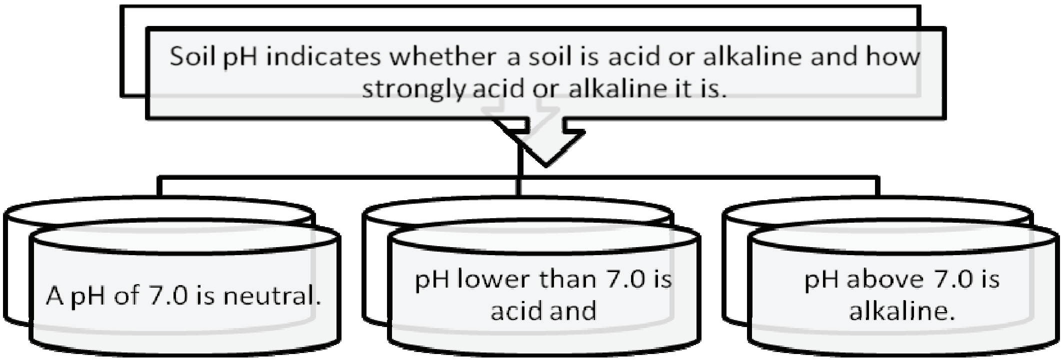
Appropriate and efficient soil fertility management is critically important in irrigated agriculture. Irrigated agriculture is an intensive crop production system with high capital inputs and high production costs. Reductions in yield and/ or crop quality due to inappropriate and inefficient soil fertility management cannot be afforded. Neither can wastage of money on fertilizers to which there is no or inadequate response be afforded. Furthermore, inappropriate and inefficient soil fertility management can lead to unacceptable on-site and/or off-site pollution of soil and/or water that may have serious legal consequences for a farmer that commits such offence.

It is important to understand the effects of different soil chemical, physical and biological factors on the plant-availability of different essential plant nutrients in the soil. It is also important to understand the roles of different nutrients in plants and the big differences between different crops in terms of nutrient requirements.

1. Soil pH

Soil pH has a major influence on the plant-availability of nutrient elements in the soil.



The pH of soils is usually between 4 and 9, normally between about 5 and 8. The pH values of irrigated soils in sub-humid to semi-arid (and arid) areas are almost always between 7.0 and 8.5. The pH of sodic soils is usually higher than 8.5. The soils, on which irrigated orchards and vineyards are established in areas with high winter rainfall, especially sandy soils, often have low pH values. Table 1 gives a classification of soil pH levels.

Table 1 is valid only for soil pH measurements done in a soil: water suspension, also called pH (Water). A 2:5 soil: water ratio is usually used, using distilled water. Several laboratories determine the so-called pH (KCl). This is where KCl solutions are used instead of distilled water to prepare the suspension for the pH measurement. The KCl has a “salt effect” as a result of which the pH (KCl) value for any normal soil (a soil without a high salt content) is usually in the order of one pH unit lower than the pH (Water) for that soil. Thus, the pH (KCl) values for each class must be tuned one unit lower than the values given for that class in Table 1 It is clear that it is very important to know how the pH of a soil was determined and interpretation of the obtained value must be done accordingly. For example: A pH (Water) of 5.0 is too low and liming will be needed, but a pH (KCl) of 5.0 is an ideal soil pH.

Table 1. Classification of soil pH

Soil pH(Water) range	Class name
<4.5	Extremely acid
4.5-5.0	Very strongly acid
5.1-5.5	Strongly acid
5.6-6.0	Medium acid
6.1-6.5	Slightly acid
6.6-7.3	Neutral
7.3-7.8	Mildly alkaline
7.9-8.4	Moderately alkaline
8.5-9.0	Strongly alkaline
>9.0	Very strongly alkaline

Figure 1 shows general relationships between soil pH [pH (Water)] and the availability of plant nutrients in soils. A number of things must be understood about the patterns illustrated in Figure 1, including:

i. Figure 1 shows general relationships between soil pH and availability of nutrients, not just effects of soil pH on nutrient availability.

ii. Low availability of micronutrients like zinc, copper, manganese and boron in strongly acid soils (low pH) is not due to pH-related chemical reactions that render them unavailable. It is because these elements have often been leached very intensively from such soils and the actual (absolute) levels of these nutrients are very low in them.

iii. Similarly, low availability of the macro-nutrient cations calcium, magnesium and potassium in acid soils is not due to pH-related chemical reactions that render them unavailable, but because they have been leached very intensively from such soils.

iv. On the other hand low availability of phosphorus and molybdenum in acid soils is caused by chemical reactions that bind them into unavailable forms.

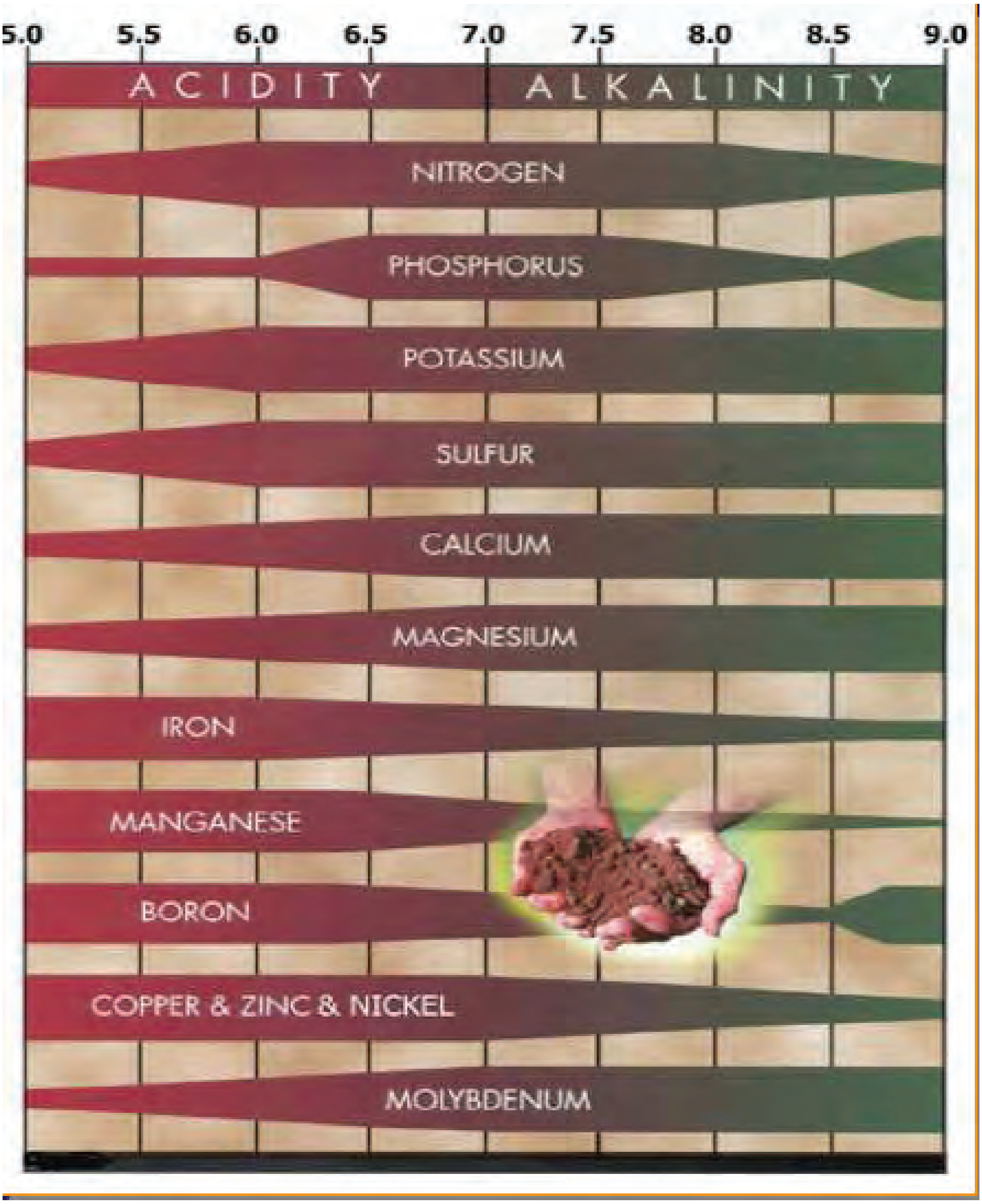


Figure 1. Effect of soil pH* on plant-availability of nutrients (*pH (Water))

v. Low availability of micronutrients like iron, copper, zinc, manganese and boron at neutral to alkaline pH levels is caused by chemical reactions that bind them into unavailable forms.

vi. Actual patterns can be quite different from these. Elements like manganese, zinc, copper, etc. are highly soluble and mobile in strongly acid soils. Thus, if a soil has a high content of any of these it will become highly available in strongly acid soil and its availability can even reach toxic levels. Conversely, deficiencies of a nutrient can be found in soil with a favourable pH if the absolute content of that element in the soil is very low.

2. Macro nutrients

Macro nutrients are nutrient elements that plants absorb in large quantities from the soil. They are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S).

Carbon (C), oxygen (O) and hydrogen (H) are found in very large quantities in plants, but they are obtained from the air and water and not from soil.

- ### Nitrogen

Nitrogen is the plant nutrient that is taken up in the second largest quantity by most plants from the soil (after potassium). The amount of nitrogen removed by the crop differs widely between different crops.

Example

Maize removes nearly 20 kg N per ton of grain, for example, while only about 2 kg N is removed by a ton of grapes. Nitrogen is very mobile in soils and is leached out very easily by injudicious over-irrigation or abnormally heavy rain. This not only means financial losses to the farmer, but also causes pollution of water downstream. Much nitrogen is also lost due to conversion to gaseous forms during waterlogging.

- ### Phosphorus

Almost all virgin soils, i.e. soils that had never been cultivated or fertilized, are extremely deficient in P and liberal P applications are needed for successful crop production. It has been found, however, that the soils of some of the dry parts of South Africa, including some of the dry river valleys, have substantial P levels in their virgin state.

Example

The Lower Fish river area is an example. Phosphorus is immobile in almost all soils, including red and yellow sandy soils. Consequently it stays where it is applied. Directly below the plough layer the P contents of even soils with excessive topsoil P levels are lower than in the virgin soils. One consequence is that the P contents of top soils build up over years. At Vaalharts Irrigation Scheme examples were found where the P content of top soils were so high that wheat yields were suppressed, up to 50%. Thus, P applications must be planned carefully according to soil analyses. Crops remove much less P than N and K from the soil. Again, there are big differences between crops. Maize removes about 3 kg P per ton of grain. Most vegetables remove only about 0.7 kg P per ton, but beans, for example, remove 5 kg per ton.

- **Potassium**

Potassium is needed in large quantities by almost all except grain crops. It is the most important nutrient for promoting high quality in most crops where quality is an important marketing factor and such crops must receive high K applications. It also increases the disease resistance of crops. In regard to both quality and disease resistance it is very important to maintain the correct balance between N and K nutrition. Too high N relative to K, leads to poor quality and low disease resistance. Injudiciously high K applications, especially to poorly buffered sandy soils, can induce (cause) magnesium deficiencies in crops.

- **Calcium and magnesium**

It is important to have correct Ca:Mg, Ca:K and Mg:K ratios in soils. Very high sodium levels in sodic soils can induce calcium deficiencies in crops.

- **Sulphur**

Very little attention is normally given to the sulphur nutrition of plants, despite the fact that plants absorb more S than P. Almost all irrigated soils contain enough sulphur. It is important to look out for sulphur deficiencies, however. Oil producing crops and legumes, especially lucerne, require high levels of S.

3. Micro nutrients

Micro nutrients are nutrients that plants absorb in small quantities from soil. Micro nutrients include iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), molybdenum (Mo), boron (B) and chlorine (Cl). Cobalt (Co) and nickel (Ni) are nowadays also added because of special functions that they have in regard to the nitrogen metabolism of plants.

B and Cl were discussed in the module on salt-affected soils and will not be discussed again here. Molybdenum (Mo) deficiencies are found mainly in strongly acid soils. At the pH levels normally found in irrigated agriculture, Mo deficiencies are highly unlikely. Copper deficiencies are found in the drier areas of South Africa – due to the high soil pH levels. The highly leached soils of the George area in the Southern Cape are also highly deficient in copper. Copper deficiencies are rare in crops in intensive irrigated agriculture, however, because copper compounds are applied regularly as fungicides. Mn deficiencies are unknown in irrigated areas in South Africa.

- ### Zinc

Zinc deficiencies are found widespread in South Africa, including in several irrigated areas, e.g. Vaalharts and the Lower Orange river (Upington). This is firstly due to inherent low Zn levels in the soil. Secondly, the high pH levels of irrigated soils, where Zn is bound in forms that are not available to plants, aggravate it. In sandy soils Zn deficiencies are induced when the pH(Water) of the soil goes over about 5.7 (which is not even a high pH). It is aggravated when high soil P levels are combined with high soil pH levels.

Crops differ widely in regard to their sensitivities to Zn deficiencies. For example: Maize is very sensitive to Zn deficiencies, especially the high yielding hybrids. In contrast wheat is very tolerant to Zn deficiencies. Fruit crops, like deciduous fruits (especially peaches) and citrus are very sensitive to Zn deficiencies.

- ### Iron

Iron is one of the most abundant elements in soils and is needed in only micro quantities by plants, and yet iron deficiency in crops is a well-known phenomenon. This is because Fe is made very unavailable to plants in high pH soils, such as commonly found under irrigation. It is especially severe in soils that contain free lime. Thus, iron deficiencies are problems in sensitive crops like peaches (and other deciduous fruits), citrus and subtropical crops. Areas with soils containing free lime, such as the Little Karoo (Oudtshoorn), are especially prone to iron deficiencies.

4. Soil sampling

A soil analysis is not the only factor taken into account when determining the fertiliser requirement of a land. Information regarding the physical properties and history of the soil is required as well.

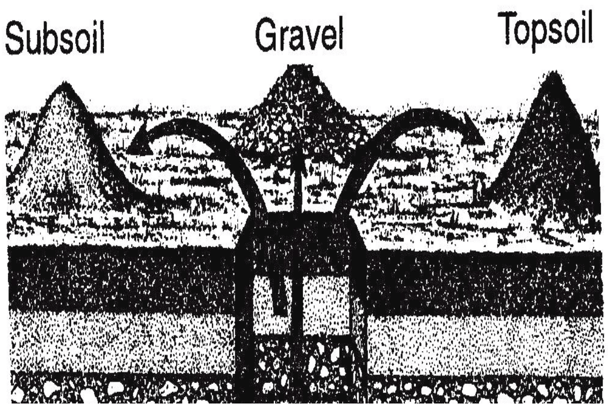
4.1 Determining of soil type and physical properties

Before sampling, determine whether a part or parts of the land differ from the remainder with respect to colour, texture, crop growth, etc. If differences occur the various soil types should be sampled separately, provided the areas are large enough to manage as separate units.

4.2 Why should you sample the soil?

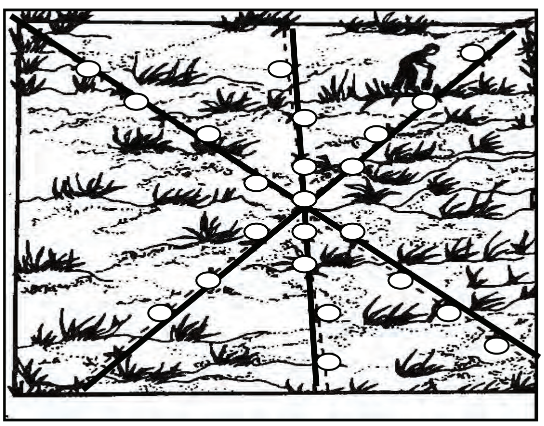
- If you know the properties of the soil (how good or how bad) you will be able to manage it better
- You will know what nutrients are in the soil for the crop you plan to plant. It will save you money because you will only add the nutrients that are necessary.
- You will also know how much water the soil can hold and how often it should be watered.

4.3 How deep must I take a soil sample?



If no soil auger is available for sampling, two spades can be used. Dig a hole at least 90 cm deep in each soil type to be sampled. Compacted layers, rock and "ouklip" may limit the depth of the holes to les than 90 cm. Place the blade of one spade against the side of the hole at the depth to which the sample is to be taken. Use the second spade, slice layers of the soil of the side of the hole, collecting soil on the first spade.

- Topsoil samples must be taken at a depth of 300 mm below the soil surface.
- Subsoil samples must be taken at a depth of 300-500 mm below the soil surface.



4.4 How many samples and where to take them?

- The land should be sampled in several places as indicated in the illustration. Diagonally across the land to get a very good representative sample of the whole land. Avoid near gates, old straw piles or lime dumping sites.
- The samples should be well mixed and a representative sample taken from the mixture. Do not use an old fertiliser bag for this purpose.

- A ½ kg-sample of this mixture is then packed in a clean plastic bag or a clean suitable container
- Each sample must be clearly marked with :
  - Your name
  - The number of the land
  - The depth at which the sample was taken.

Activity

Activity 1

Small group activity

1. List the macro elements occurring in soils
   ....
   ....
   ....
   ....

2. What is the difference between micro- and macro elements?
   ....
   ....

3. Which TWO micro-elements are encountered in relatively large quantities?
   ....
   ....

4. Under what conditions will element deficiencies occur?
   ....
   ....
   ....

5. What happens to phosphate at a low pH?
   ....
   ....
   ....
   ....

6. Explain briefly how to take a soil sample that will be representative of a specific land.
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References

1. Forth HD, 1990. Fundamentals of Soil Science. 8th Edition, New York. John Wiley.
2. Brady NC, 1990. The nature and properties of soils. Collier MacMillan.

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Authenticators:

- Prof Chris du Preez
- Mr D Haarhoff

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Module 13

Soil surveys for irrigated agriculture

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- The process of soil survey
- The important criteria used in soil surveys
- Scale of grid and representativeness of soil pits
- The compiling and use of base maps
- Definitions of a mapping unit, map unit and soil delineation

Table of contents

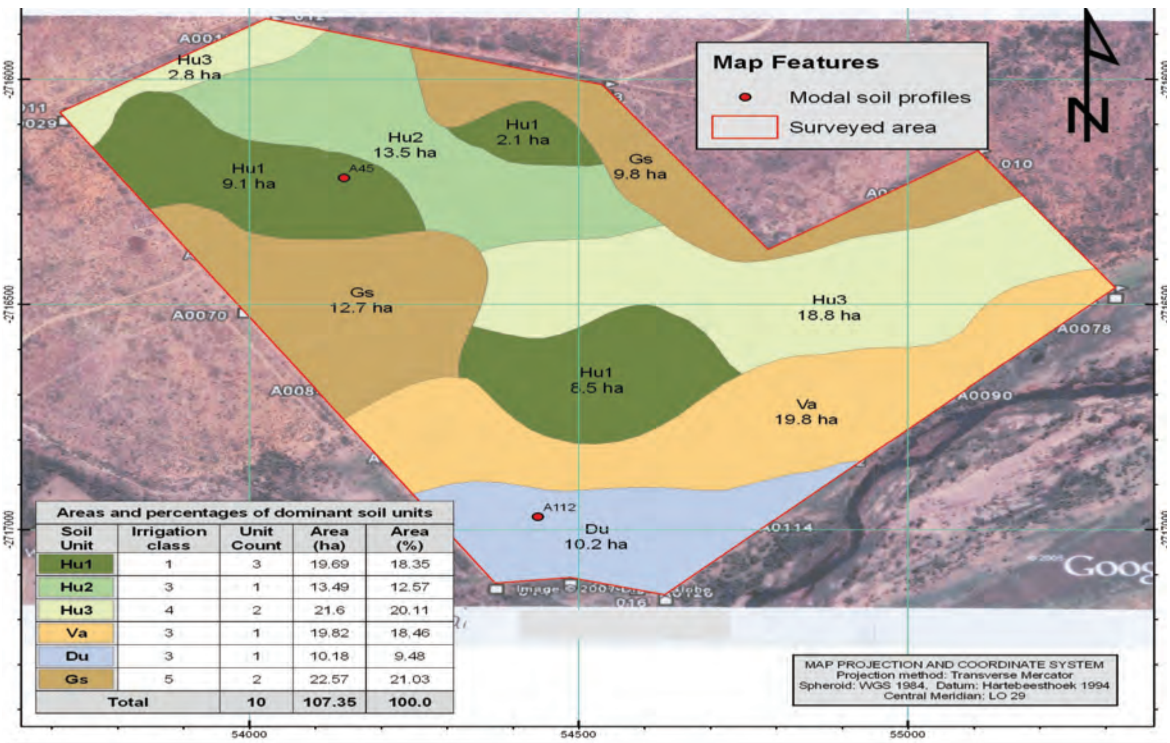
High quality detailed soil surveys are absolutely essential for successful sustainable irrigation planning and management. It is not possible to include training in soil surveying in this course. The objective here is to give students essential background information to enable them to understand what is required from soil surveys for irrigated agriculture and what the basic characteristics of useful soil surveys, soil maps and soil survey reports for irrigated agriculture are. It should also enable students to become soil surveyors for irrigated agriculture after attending short courses in detailed soil surveying.

1. Preliminary semi-detailed soil surveys

Detailed soil surveys are expensive and cannot be conducted over large areas where preliminary information is required regarding identification of areas with potential for irrigation development and for feasibility studies. For this purpose **semi-detailed soil surveys**, usually at a scale of 1:50 000, are required if adequate information is not yet available. In South Africa there is a tendency to conduct semi-detailed surveys throughout the whole of such area at the same intensity. This is a waste of money, time and manpower. In most cases there are large areas that are obviously not suitable for irrigation, which can be mapped out by superficial fieldwork or even by quick desktop studies. These would, *inter alia*, include

- All areas above the highest line to which water can be commanded.
- All obviously shallow soils on the crests of hills.
- All areas with too steep slopes.

In one case it was found that about 80% of an area could have been eliminated by a simple very quick desktop study. This was not done and in the end too little information was collected in important areas like alluvial river terraces and far too much detail on different shallow soils on hilltops. In many cases judicious use of the available land type maps in combination with the land type inventories could provide most of the information required to map out areas that obviously have no or little irrigation potential. In the case where only a small area needs to be investigated one would go directly to a detailed soil survey.



Areas and percentages of dominant soil units				
Soil Unit	Irrigation class	Unit Count	Area (ha)	Area (%)
Hu1	1	3	19.69	18.35
Hu2	3	1	13.49	12.57
Hu3	4	2	21.6	20.11
Va	3	1	19.82	18.46
Du	3	1	10.18	9.48
Gs	5	2	22.57	21.03
Total		10	107.35	100.0

Figure 1. Example of a soil survey of an irrigation scheme in Limpopo Province

2. Detailed soil surveys for irrigation planning

In the areas identified as possibly having irrigation potential during the semi-detailed survey, detailed soil surveys must be done for irrigation planning. These must be highly intensive surveys at large scale, usually 1:5 000 or 1:6 000.

2.1 Base map

Recent orthophoto maps of large enough scale are the ideal base maps to use during fieldwork for detailed soil surveys. Advantages are:

- Their scales are corrected over the whole map.
- They have contour lines, which enable interpretation of slopes (steepness forms, etc.).
- They have lots of ground detail, which enables exact pinpointing of observation points, often even more accurately than with GPS.

Unfortunately for many areas orthophoto maps are at a scale of only 1:10 000, which is too small for maps for irrigation planning. For the central parts of the Eastern Cape Province, i.e. the whole of the former Ciskei, orthophoto maps at a scale of 1:5 000 are available. Although these are quite old, they are still better than any other base map, especially if observation points are sited by means of GPS.

Where orthophoto maps of acceptable scale are not available, enlarged aerial photographs at a scale of 1:5 000 or 1:6 000 should be used as base maps. These have lot of ground detail, but do not have contours indicated on them and the scales are not uniform all over a photograph. The latter can be overcome by using aerial photograph mosaics made from the central parts of different photographs where the scales are correct.

It should be noted that it is **absolutely not** acceptable to use small scale (e.g. 1:50 000) base maps and “blow up” their scales. This does not make them acceptable and only gives a false impression of accuracy.

2.2 Survey techniques

For detailed soil surveys for irrigation planning there is only one acceptable soil survey technique and that is intensive fieldwork. Remote sensing technologies are not suitable for this type of survey. *“FAO Soils Bulletin 42: Soil survey investigations for irrigation”* gives clear (and correct) guidelines regarding the requirements for a good, useful soil survey for irrigation development. For a survey at a scale of 1:5 000 (or 1:6 000) these guidelines include:

a. The density of observations should be 2/ha, averaged over the whole surveyed area. Acceptable densities of observations for different parts of the survey vary between 4/ha (where soil patterns are complex or important soil boundaries have to be demarcated very accurately) to a minimum of 1/ha (where soils are uniform).

b. The average rate of progress per surveyor per 20-day month is 500 ha. It will be lower where soils patterns are complex and higher where they are simple.
c. The positions of all delineation boundaries should be checked throughout their whole length on the ground.
d. Sites must be representative of the larger areas, so avoid drainage depressions, eroded areas, etc. Ensure sites are located in both poor and good production areas to allow comparison.

Fixed grid surveys should be used in all surveys done by inexperienced soil surveyors. It should also be used during surveys by experienced soil surveyors in areas where soil patterns are complex and where there are no topographical and/or vegetation features that can help to located delineation boundaries, especially on alluvial plains and terraces. Fixed grid survey means that observations are made along equally spaced straight lines and observations along lines are equally spaced.

- Generally, where land use is crops or pastures and the soil and landform variations not great, a 200x200 m grid is adequate
- Permanent horticulture crops , a grid of 7x75 m should be used

Where surveys are done by experienced soil surveyors and there are topographic and/or vegetation features that assist in locating delineation boundaries, it is better to use free grid surveys. Free grid surveys in such cases give more accurate location of boundaries and/or save manpower and time. Free grid surveys are where observations are made along grid lines that are not equally spaced and/or observations along grid lines are not equally spaced.

2.3 Definition of mapping units and map units

Correct definition of mapping units and map units is essential for the compilation of soil maps and accompanying reports that are useful for effective suitability evaluations and planning in irrigated agriculture. In order to avoid confusion, it is important to know what the following terms mean:

a. Mapping unit: On the basis of the kinds of soils identified in the area during semi-detailed surveys on the one hand and the requirements of the potential irrigated agriculture land uses identified on the other hand, soil parameters and class limits are defined according to which it is decided which soils may be mapped together and which must be separated during the field survey. A group of soils, which is mapped together, is called a **mapping unit**.

b. Map unit: During the detailed field survey changes are often made to mapping units. Each group of soils, which is finally differentiated on the soil map, is called a map unit. Each **map unit** is identified by a unique symbol, colour or other indicator, or combination of these (e.g. a colour and a symbol) on the map and in the map legend.

c. Delineation: Each area, which is completely circumscribed by a soil boundary on a map, is called **soil delineation**. Each delineation demarcates an area occupied by a specific soil map unit. A map usually contains several delineations representing a specific soil map unit.

To be useful, soil mapping units, and eventually map units, must be defined on the basis of the soil requirements and tolerances of the envisaged possible land utilization types for the irrigation farm or project for which the soil survey is done. Possible land utilization types are identified on the basis of land utilization types that are possible on the basis of

- Crops that are adapted to the climate of the area are potentially economically feasible and are acceptable to the farmer or farmers.
- Envisaged management techniques and technologies (e.g. type of irrigation system).

Agronomists, horticultural scientists, agricultural economists and irrigation engineers must, together with soil scientists, identify the potential crops and management systems and the requirements and tolerances of each **before** the soil survey is conducted.

2.4 Taxonomic soil units *versus* soil map units

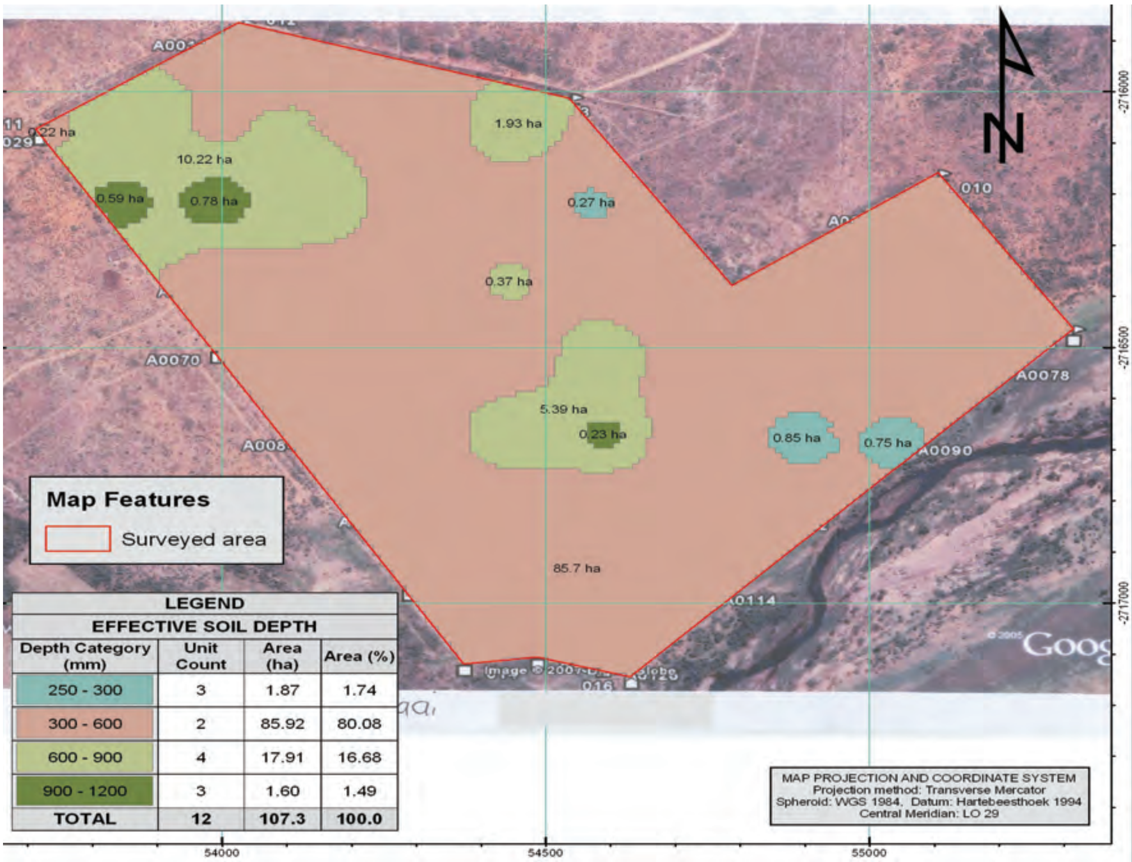
In order to avoid confusion and improve communication it is important to have taxonomic classification of the individuals in a community, e.g. in plants or in animals, etc. For soils different taxonomic classifications exist in different parts of the world. South Africa has its own taxonomic soil classification system. In detailed soil surveys for irrigated agriculture in South Africa it is very important to use the South African taxonomic soil classification system in the classification and naming of soil map units. This not only improves communication and especially technology transfer, but also gives important information regarding the qualities of different soils. However, taxonomic classification is not enough. Important other soil characteristics and properties must also be recorded that is required in land suitability evaluation and land use planning. These are used in the classification and mapping of so-called "phases" of taxonomic units. Various parameters can be used for defining soil phases, as required by the circumstances of a specific soil survey. Different class limits are also used in different cases for a specific parameter/criterion.

2.5 Soil maps and soil survey reports

The primary final product of a soil survey is a soil map and its accompanying report. It is very important to note that a good soil map must be made and not just interpretative maps like soil potential or land suitability maps. Differences of opinion may arise about the interpretations and these can only be resolved by going back to the basic soil map and its report. Furthermore interpretations may become obsolete as new information becomes available and new land utilization types (new crops or cultivars, new technologies, etc.) become relevant. If a good soil map was made, these new interpretations can be done without having to do a new soil survey all over again at great cost (even after several decades).

A good map cannot be made if the fieldwork was poor. On the other hand good fieldwork is not a guarantee for a good and useful soil map. Some errors that can lead to a poor quality map include:

- Incorrect transfer of information from field sheets to the map. Unfortunately there are several examples of serious errors that have been made in South Africa in this regard. Two types of errors are made, viz. (i) allocating incorrect map units to some delineations and/or (ii) incorrect location of delineation boundaries.
- Compiling a poor map legend that makes it difficult to use the map. Since (i) colours are mostly not uniform over an entire map, especially if it has several map sheets and (ii) it is difficult to find delineations belonging to a specific map unit if only symbols and no colours are used, it is best to use a combination of colours and symbols. A poorly arranged legend also makes it difficult to use a map. To be useful, letter symbols must be arranged alphabetically and number symbols must be arranged in numerical order in the legend.
- Making a map that has too much small delineation, thus seriously reducing the "legibility" of the map.



LEGEND			
EFFECTIVE SOIL DEPTH			
Depth Category (mm)	Unit Count	Area (ha)	Area (%)
250 - 300	3	1.87	1.74
300 - 600	2	85.92	80.08
600 - 900	4	17.91	16.68
900 - 1200	3	1.60	1.49
TOTAL	12	107.3	100.0

Figure 2. Effective soil depth map

A soil map, even a good one, is useless if it is not accompanied by a good quality report. Unfortunately it is general experience that far too little time, manpower and funding is budgeted for the compilation, drawing and printing of a good, useful map and the compilation of a good soil survey report. Budgeting for fieldwork usually receives careful attention (although budgeting for the preparation phase for field work is normally neglected), but very little serious attention is given to budgeting for the compilation of the final products.

Activity

Activity 1

Small group activity

The facilitator will provide you with a detail soil map of a specific area. Use this map to identify the following:

1. Different soil types or soil boundaries
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2. Discuss the production potential of each these soil types identified
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3. Also discuss the different water holding capacities of the different soil types and what precautionary measures the irrigation farmer should include in the planning for irrigation.
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My notes............

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Authenticators: Prof Chris du Preez & Mr D Haarhoff

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