WATER CONSERVATION TECHNICAL BRIEFS

TB5 - The Importance of Soil to Water Use

SAI Platform

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Water Conservation Technical Briefs

TB5 - The Importance of Soil to Water Use

Soil properties strongly influence water storage and availability. A comprehensive understanding of the movement of water in soil can help understanding how much water the soil holds, the movement of water in soils assessing irrigation practices and designing an adequate irrigation system. This technical brief aims at describing how soils hold water and identifying soil moisture monitoring tools and methods. This brief is intended to be an introduction to irrigation scheduling.

The structure of the technical brief is as follows: Section 1 explains the size and arrangement of soil particles and pores influences water movement in soil. Sections 2 and 3 provide an explanation of soil properties: texture and structure respectively. Section 4 outlines the water movement in soil such as infiltration, runoff and capillarity. Section 5 presents how soil can be sampled to determine soil moisture levels. Section 6 describes soil moisture. Section 7 introduces briefly how to schedule irrigation by measuring soil moisture. Section 8 presents technical soil moisture monitoring equipment available for farmers to monitor water use. Section 9 suggests how to interpret data from the monitoring equipment. Section 10 illustrates a case study of use of tensiometres to assess soil moisture to grow tomatoes. Finally, Section 11 recommends some further reading.

Contents

SECTION 1: HOW SOIL INFLUENCES WATER USE?

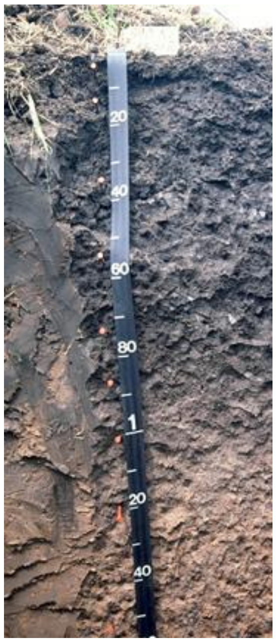

Figure 1: Soil profile

Soil management is linked to water use as soil properties influence the movement and storage of water. Soil texture and soil structure, strongly influence the way water behaves in a soil. Moreover, these properties affect the movement of water into the soil, drainage and water storage in the soil profile.

The reason that texture and structure have such a strong influence on water storage and availability is the size of soil particles and pores, and their arrangement. The soil texture determines the capacity of the soil of holding water. A soil with large particles and large pore spaces (e.g. sand) hold the least amount of water. On the other hand, a soil rich in clay has small particles and can store a large amount of water. However, not all of it is available to plants as small pores hold onto water very tightly. Compacted soil has small, disconnected pore space which reduces the amount of water that is available to plants. Figure 1 depicts a soil profile where different types of soil can be distinguished.

By understanding how soil properties affect water storage before designing an adequate irrigation system can help optimising water use by plants.

SECTION 2: WHAT IS SOIL TEXTURE?[1]

Soil texture is the amount of sand, silt and clay in the soil. It has a strong influence on water storage and availability because of the variation in the particle size distribution and the surface area. Figure 2 shows the different textures of soil depending on its percentage of sand, silt and clay.[a] Clay particles are small (diameter < 0.002mm) compared to larger sand particles (diameter

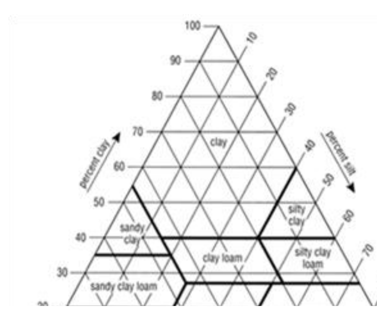

Figure 2: Percentage of clay, silt and sand in the basic soil textural classes.

[a] To see an enlarger version of the figure visit soils.usda.gov/

between 0.02 – 2 mm). Smaller particles fit together more tightly than larger particles and therefore the pores for air and water are also smaller. Small pores retain water against gravitational forces, drainage and also against plant use, while the larger pores found in sand allow water to drain.

Ideally, a soil will contain a range of pore sizes, larger pores which drain readily so as to prevent water logging following soil saturation and smaller pores which store water for plant use. Not all water held in very small pores is available to plants because water can be retained strongly.[b]

The amount of water that can be absorbed by the soil increases as the surface area of the particles in the soil increases. Fine clay has about 10,000 times as much surface area as the same weight of medium-sized sand. Soil with high organic matter can also retain water very well.

Soil texture can be determined in farm by the way the soil behaves when a small amount of soil is moistened and pressed out between the thumb and forefinger to form a ribbon. Figure 3 shows a methodology used when determining the texture of a soil in farm.[c]

[b] Of most importance for plant growth is the amount of water stored in the soil that is readily available for uptake by plants rather than the total amount of water stored in the soil profile. The water that plants can easily remove from the soil is called Readily Available Water (RAW).

[c] An enlarged version of the figure can be found at http://attra.ncat.org/attra-pub/soil_moisture.html

Section 3: What is soil structure?

Soil structure is the arrangement of the solid components of soil and the spaces in between. Ideally, soil should have pores for the flow of water and gases, and pores that contain water and dissolved nutrients for plant growth.[d]

Plants grow best when they have a suitable balance of water and air in their root zones. The soil within the root zone needs to be able to store as much water as possible in the plant available range but also needs to be able to drain enough water so that aeration is quickly re-established after irrigation and/or rainfall.

To maintain a good structural form some measures can be taken. Some of them are to improve organic matter content, to encourage soil fauna such as earthworms and to avoid cultivation when it is too dry. When a soil is badly compacted structural form needs to be firstly regenerated using biological solutions (e.g. rotation crops) and appropriate tillage methods.[e]

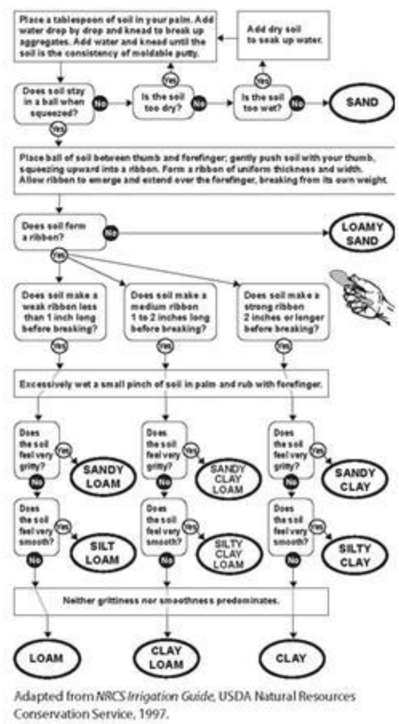

Figure 3: Methodology to assess soil texture in farm.

[d] A soil is badly compacted if the pore space is reduced so the water transmission through the soil is slowed and water storage and aeration is minimised. A surface crust increases runoff, which reduces the efficiency of rainfall and irrigations. A compacted soil will have reduced readily available water (RAW), compared to a soil with the same texture but with better structural form. A reduction of RAW can cause a moisture stress on a compacted soil even if there is sufficient rainfall and irrigation, because of a reduction in RAW. Root growth is also impeded in a compacted soil and they are not able to harvest water from as large an area as would be possible if their growth was not restricted.

[e] See technical Brief on Conservation Tillage for further information.

SECTION 4: MOVEMENT OF WATER IN SOIL

a. Water infiltration

A function of soil is to absorb water at the land surface, and store it for use by plants or slowly release it to groundwater through gravitational flow. When rainfall hits the ground, most water will infiltrate the soil; but some may run off the surface, and some may stand in ruts or depressions before infiltrating or evaporating.

The infiltration capacity is the maximum amount of rainwater that can enter a soil in a specific time. It is influenced by the soil type, structure, and moisture content at the start of the rain.

Sandy and gravelly soils have more large pores than fine loams and clays, and therefore they maintain better infiltration during a storm. But soil texture influences the number of pores and their sizes: When finer-textured soils have strong aggregates due to good management, they can also maintain high infiltration rates.

Soil compaction can reduce the infiltration rate. Soil compaction occurs when soil particles are pressed together, reducing pore space. Heavily compacted soils contain few large pores and have a reduced rate of both water infiltration and drainage from the compacted layer. This occurs because large pores are the most effective in moving water through the soil when it is saturated.[2]
There are several forces, natural and man-induced, that compact a soil. This force can be great, such as from a tractor, combine or tillage implement, or it can come from something as small as a raindrop.[f]
A compacted soil can be repaired using a workable combination of break and rotation crops that provide natural crop-induced wetting and drying cycles to crack the soil; root penetration to break up massive and platy soil structure; increased organic matter to enrich and strengthen the soil.[3]

b. Runoff

When rainfall exceeds the soil's infiltration capacity, runoff is produced. Rainfall or snowmelt on frozen ground generally poses even greater runoff concerns, as pores are blocked with ice. Runoff happens more readily with poorly managed soils, because they

[f] For more information on how to reduce ploughing see Technical Brief on Conservation Tillage.

lack strong aggregates that hold together against the force of raindrops and moving water and, therefore, have few large pores open to the surface to quickly conduct water downward. Such runoff can initiate erosion, with losses of nutrients and agrochemicals as well as sediment. Runoff directly depends on the rainfall and raindrop impact on soil, the soil erodibility which is based on soil properties, slope gradient and extent, soil cover and conservation practices.[4]

c. Capilarity

Capilarity rise is the process where groundwater is sucked upward by the soil through very small pores that are called capillars. The movement of the water depends on soil texture; in clay soils the upward movement of water is slow but covers a long distance. In sandy soils, the upward movement of the water is quick but covers only a short distance.[5]

SECTION 5: SOIL SAMPLING[6]

Soil sampling is commonly used to determine the amount of soil moisture. The wetness of the soil can be described as the gravimetric soil water content, the volumetric soil water content and the soil water potential (also known as soil water suction).

- **Gravimetric soil water content**: is the quantity of water in the soil on a weight basis. It is expressed on gr of water per gr of dry soil)
- **Volumetric soil water content**: is the quantity of water on a volumetric fraction of soil. It is measured by calculating the quantity of water per unit of soil and multiply it by the soil bulk density. It is expressed in cc[g] of water per cc of soil.
- **Soil water potential or soil water suction**: is the pressure needed to extract water from the soil. This measure is used because some soils hold water more tightly than others, and all soils hold water more tightly as they dry. It represents the energy plants must exert to draw water from the soil. Soil water suction can be measured by porous media (e.g. gypsum blocks) or wetting front detectors (e.g. FullStop), which are devices that detect when water moves down through the soil to them. The soil water potential is expressed in kilopascals (kPa).

[g] cubic centimetres

SECTION 6: SOIL MOISTURE LEVELS

Soil texture and structure information can be used to estimate soil water holding capacity, which in turn is used in planning irrigation design and operation. Ideally, the soil condition should be assessed before a new field is developed for vegetable production so that the irrigation design can be matched to the soil types in the farm. If this is not done then some areas can be over-watered, while others will not be watered enough. The amount of water to be applied per irrigation event, and the time between irrigation events will vary between soil types.

Figure 4 below shows the percentage of soil moisture levels over time for a specific crop. As shown in the picture, the soil moisture varies from saturation to permanent wilting point. This diagram helps to understand when the crops require water. Some useful concepts depicted on the figure 4 are described below.

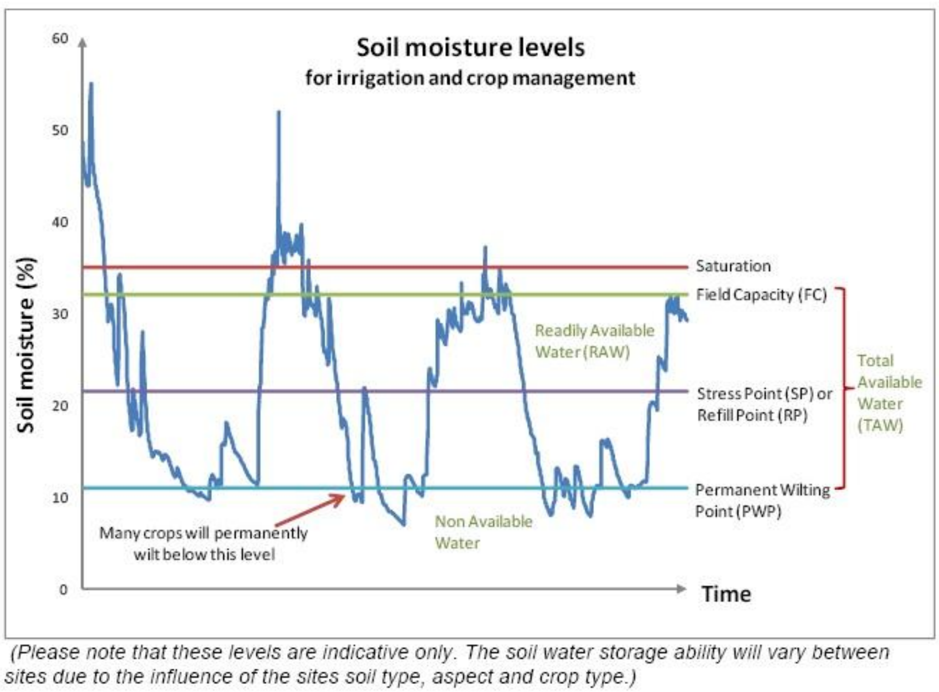

Figure 4. Soil Moisture over time[7]

a. Readily Available Water (RAW)[8]

In simple terms, the Readily Available Water (RAW) is the water that a plant can easily extract from the soil. RAW is the soil moisture held between field capacity and a nominated refill point for unrestricted growth. In this range of soil moisture, the plants have good condition to grow and are neither waterlogged nor water-stressed.

The RAW can be calculated by multiply the thickness of each soil layer (in centimetres) by the RAW of that layer[h]. Then add the values for each soil layer in the root zone to get the total root zone[i] RAW.

b. Refill point

As water is removed by plants and by evaporation from the soil surface it becomes more and more difficult for plants to extract water as it clings more tightly to soil particles and in small pore spaces. When water extraction becomes difficult for plants and more water is required to maintain growth rates, the soil is said to be at the 'refill point'. If the soil dries to the permanent wilting point, the plant can no longer remove any water from it. The drier the soil, as shown by high tensiometer values, the more water needs to be added to bring the soil back to field capacity. Refill point for horticultural crops lies between a tension of -20 and -60 kPa.

c. Permanent wilting point

Eventually, if the soil continues to dry, it will hold some water which cannot be extracted by plant roots and plants wilt and cannot recover. This is called the Permanent Wilting Point (PWP). Plant production will slow/stop before PWP is reached (a tension of -1500 kPa).

d. Gravitational water

As water infiltrates the soil, it fills the pore spaces between the soil particles. Gravitational water is the status when pores are completely saturated and therefore water percolates down through the soil profile and below the root zone. Gravitational water may take a few hours to drain away in sandy soils, or days or even weeks in clay soils (See figure 5 below).

e. Field capacity

Field capacity is the condition of equilibrium when the gravity forces are equal to the evaporation forces. Evaporation at the soil surface pulls water upward through capillary

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[h] The RAW properties are fixed values that depend on the texture of the soil and vary according to the area.

[i] Plants get most of their water from the upper (shallow) portion of the root zone. The term effective root zone refers to about the upper half of the root zone depth, where roughly 70 percent of the plant's water is taken up.

forces, while capillary forces also hold water around the soil particles. In this condition, water stops moving downward and is held by surface tension in the soil. (See figure 5)

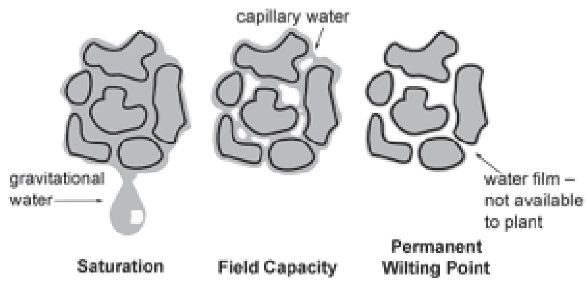

Figure 5: Saturation, Field Capacity, and Permanent Wilting Point.

Section 7: When to irrigate?[j]

Irrigation should occur before soil moisture depletion reduces crop yields. Two approaches for determining when to irrigate are based on the recommended soil moisture tension and the allowable depletion.

- **Recommended soil moisture tension**: Water stress in plants is related to soil moisture tension. The higher the tension the greater the potential for water stress. Research has determined the soil moisture tension at which irrigation should occur. For example, some typical recommended values for citrus are 50-70 kPa[9], where it is recommended to use the larger values in cool, humid conditions and the smaller values on warmer and dry conditions.

- **Allowable depletion**: Allowing a plant to deplete most of the available soil moisture can reduce yields because of the excessive water stress. Thus, soil moisture depletions are limited to those depletions that cost no yield lost defined as the allowable depletion (frequently expressed as a percentage of the available moisture). For example, for citrus the recommended allowable depletion is 50% of the available soil moisture.[10]

[j] See Technical Brief on Irrigation Scheduling for further information.

SECTION 8: HOW TO MEASURE SOIL MOISTURE?[11]

Measuring the soil moisture content allows monitoring the water available to the plant for growth. When the water at any depth falls below the refill point or where there is no remaining readily available water (RAW) then an irrigation event must be scheduled. See Figure 4 in Section 4 to analyse when irrigation was conducted in that case.

Types of measuring equipment

There is a wide range of technical soil moisture monitoring equipment currently available for farmers to use to help manage and monitor water use in the field. The types of soil moisture monitoring equipment available can be divided into two categories: soil suction measurement systems and soil moisture content measurement systems.

a. Soil Suction Measurement Systems

Soil suction devices measure the (negative) pressure required by the plant to be able to extract water from the soil. This force from the plant on the soil to draw the amount of water it needs to grow can be measured as tension. The drier the soil, the more tightly the water is held, and the more energy the plant has to use to extract the water from the soil. Therefore devices that measure soil water potential are very good indicators of the stress plants are under.

These devices enable farmers to keep crop stress to a minimum by managing irrigation to ensure the correct soil water potential is maintained. In the case of water sensitive crops, such as vegetables, a tension of –20 kPa is considered the refill point. The RAW is the amount of water that is held between field capacity –8 kPa and –20 kPa. The devices however, do not inform the farmer as to the volume of water that is required to be applied.

- **Tensiometers:** A tensiometer is essentially a tube filled with water that has a porous ceramic tip which is buried in the soil at the depth which soil moisture need to be measured. Tensiometers can be buried at 2 to 3 different depths in the root zone in order to obtain a soil moisture profile. The water will move out to the drier soil until the

potential within the tensiometer is the same as that of the soil water. A vacuum gauge records the level of suction required by the plant to draw water from the soil. The vacuum gauge can be read manually by the farmer, but can also be measured electronically and logged. See case study for an application.

- **Resistance/Gypsum Blocks**

Resistance blocks such as gypsum blocks are made from a porous material with two electrodes embedded in the material. They are buried in the soil and they take on the soil water characteristics of the surrounding soil, creating equilibrium. The electrical resistance within the blocks is measured. The electrical resistance of a block is directly proportional to its water content, which is related to the soil water potential of the soil surrounding the block.

- **Wetting Front Detectors**

Wetting front detectors are simple devices that are buried at points of interest and provide information to farmers as to when water has reached that point in the soil profile. When soil moisture increases above a set point the detector switches on, or is activated, indicating that water has reached a given depth. When the soil moisture dries to below a set point the detector switches off. Wetting front detectors are often placed near the bottom of the root zone so that they can be used to warn against over irrigation.

b. Soil Moisture Content Measurement Systems

Instruments that indirectly measure soil moisture content use sensors that are placed in the soil at various depths in the root zone. The sensors measure properties that are closely related to soil water content. Calibration equations can be used to convert the property being measured by the sensor to soil water content.

- **Capacitance - Frequency Domain Reflectometry devices (FDR)**

FDR devices use the dielectric constant of the soil water media to calculate soil water content. These types of instruments work on the basis that the dielectric of dry soil is much lower than that of water. The soil dielectric is calculated by applying a voltage to the plates and measuring the frequency.

- **Time Domain Reflectometry devices (TDR)**

TDR devices operate similarly to capacitance devices as they use the dielectric constant of the soil water media to calculate soil water content. An electromagnetic signal is sent down a steel probe which is buried in the soil at the desired depth. The signal reaches the end of the probe and is reflected back to the control unit. The return time of the signal varies with the soil dielectric constant and therefore relates to the water content of the soil surrounding the probe.

- **Neutron Probe**

Neutron probes emit fast moving neutrons. When the neutrons collide with hydrogen in the soil they are slowed and deflected. A detector on the probe counts returning slow neutrons. The number of slow neutrons detected can be used to calculate soil water content because changes in the amount of hydrogen in the soil between readings will only come about from changes in water content. A wet soil will contain more hydrogen than a dry soil and therefore more slow neutrons will be detected.

How to choose the right instrument?

Devices vary in their complexity, cost, accuracy and labour requirement for the installation, monitoring and during the servicing. Individual requirements should be indentified before purchasing a soil moisture monitoring device. As a minimum, a soil moisture monitoring instrument needs to provide water content readings for the plant root zone before and after irrigation and rainfall.

Before deciding on a soil moisture monitoring device farmers should consider the type of information that the soil water monitoring device provides and the way how information would be used, the labour intensity of the device and assess its labour capacity, the suitability of the device for the farmers soil type/s and crop/s, the investment and maintenance cost and the accuracy and repeatability of measurements.

Section 9: How to interpret soil moisture data?

Interpretation of soil moisture data is a key step on determining when to irrigate and how much water to apply.

Interpretation of tensiometer data

The correct interpretation of tensiometer data is straightforward because it measures the relative difficulty plants will be experiencing when their roots extract water from the soil at a particular point in time. The table below provides some guidelines for interpreting tensiometer readings. Soil type does not strictly affect interpretation, but loam and clay soil types can hold a lot more available water than sandy soil, so the time between irrigations and the critical reading of approximately 20 kPa indicating it is time to irrigate will be greater in a clay soil than for sandy soils.[k]

Table 1: Critical soil tensiometer for vegetable crops[12]

Soil moisture status	Tensiometer reading kPa	Interpretation
Nearly saturated	0	Nearly saturated soil often occurs for a day or two following irrigation. Danger of water-logged soils, a high water table, poor soil aeration, or the tensiometer may have broken tension if readings persist.
Field capacity	-10	Field capacity. Irrigations discontinued at field capacity to prevent waste by deep percolation and leaching of nutrients below the root zone.
Irrigation range	-20	Usual range for starting irrigations. Most of the available soil moisture is used up in sandy loam soils. For clay loams, only one or two days of soil moisture remain.
Dry	-30	This is the stress range for most vegetable crops.
Extremely dry	-80	Top range of accuracy of tensiometer. Readings above this are possible but many tensiometers will break tension between 80 to 85 kPa.

Interpretation of capacitance data

Capacitance data is usually logged and then can be viewed using software supplied by the manufacturers.

Soil moisture at individual sensors

[k] It is recommended to interpret tensiometer readings with a table supplied by the manufacturer or assess it in relation to the soil profile in farm.

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The data is collected from each sensor and graphed over time. The soil moisture data can be collected at different depths in the soil profile. This type of data can be useful because it shows where in the soil profile the water is being taken from. If water is being extracted from deeper depths it means that the plant is working harder to get water and it can mean that the plant is under water stress.

Total soil moisture for the depth being monitored

The moisture readings from each of the sensors can be added together to give the total soil moisture for the depth of soil monitored. There are two key things to note from figure 6 below, which is an example of a total soil profile graph.

First, the irrigations can be noticed by the vertical lines where water is added to the soil by irrigation, or possibly a rainfall event. Second, the stairs pattern is explained as the soil moisture is used by the plant.

SECTION 10: CASE STUDY

Managing soil for grown tomatoes in the Gascoyne River area[13]

Water is a limiting resource in Carnarvon, so efficient use of the water allocation for vegetable crops is essential. Knowing the type of soil and measuring the moisture in the soils help farmers optimize water use in tomatoes.

Tomatoes can use 70% of the available soil moisture, without suffering significant yield loss. At this point, the soil moisture tension in Gascoyne fine sandy loam is at 40kPa[l].

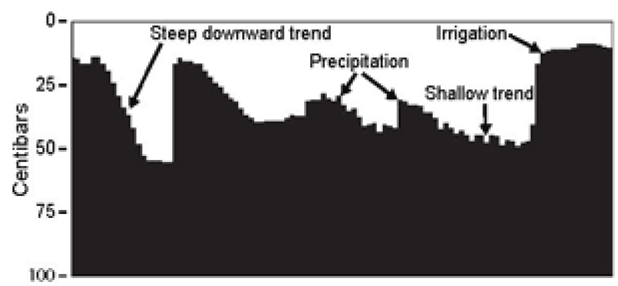

Figure 6: Soil profile[a]

In Gascoyne sandy loam, this watering regime resulted in a total seasonal water application between 350 and 450 mm (3500 to 4500 kL/ha), depending on the season and the amount of water, stored in the soil before planting.

Tensiometers were installed at 30, 50 and 90cm depth and continuous recording indicate the depth of the root system and the changing water demand, according to the stage of the crop.

Initially, irrigation was scheduled using the tensiometer placed at 30 cm depth. When it reads 40 to 45 kPa, farmers knew that the crop needed watering.

As the crop develops and roots grow deeper, water was withdrawn from around the tensiometer at 50 cm depth. When this starts to happen, and the tensiometer read 40 to 45 kPa.

Having tensiometers placed at several depths allow farmers to adjust water run times easier.

The key learning from this trial were that it was a good practice to allow one or two days after irrigation for water infiltration, before checking tensiometer readings.

• If the tensiometer at 30 cm depth indicates falling soil moisture and the one at 50 cm depth remains unchanged, increase the amount of water applied.

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[l] 1Centibar = 1 kPa

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• If the tensiometer at 90 cm depth indicates rising soil moisture after irrigation, water is draining below the root zone and being wasted. Decrease the amount of water applied.

• If the tensiometer at 50 cm depth does not react, even after long water runs, a hard pan is preventing the water from infiltrating and the site may be unsuitable for soil moisture monitoring.

SECTION 11: REFERENCES AND FURTHER READINGS

Technical Papers

Building soils for better crops, sustainable soil management
http://www.sare.org/publications/bsbc/bsbc.pdf
A comprehensive guide on soil including soil properties and nutrient cycles.

Department of Agriculture WA: Irrigation
http://www.agric.wa.gov.au/search/search.cgi?collection=external&form=custom&meta_y_and=0LWE0WATER0IRR0&sort=date
Contains fact sheets including information on soil moisture monitoring tools, irrigation best management practices and irrigation systems.

Department of Primary Industries Queensland: Managing Water Resources
http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/4789_4346_ENA_HTML.htm
Information such as water balance scheduling and use of soil moisture monitoring tools.

Other Publications

International Soil Moisture Equipment Comparison
http://www.cprl.ars.usda.gov/wmru/pdfs/WF-vol5-No2.pdf

Soil Water Monitoring with Inexpensive Equipment. 2000. By Richard Allen, University of Idaho.
www.kimberly.uidaho.edu/water/swm

Tensiometer Use in Irrigation Scheduling. 1997. By Mahbub Alam and Danny H. Rogers. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS. 6 p.
www.oznet.ksu.edu/library/ageng2/l796.pdf.

Measuring Soil Moisture**.** 1998. By Blaine Hanson and Steve Orloff. University of California, Davis, CA. 34 p.
http://gwpa.uckac.edu/pdf/direct_soil_mositure_measurement.pdf.

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Soil Texturing

http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/irr/asoiltexturingsmall.pdf

This fact sheet provides useful on how farmers can distinguish soil texture.

Web Sites

Calculating Readily Available Water

http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/irr/rawrh.pdf

This fact sheet provides useful information on how to calculate Readily Available water

The Soil Water Content Sensor discussion group

http://www.horticulture.com.au/

An Internet search under "soil moisture monitoring" (or similar key words) will yield hundreds of additional Web sites offering products, reviews, and guidelines.

Vegetables WA: Efficient Irrigation of vegetables on sands

http://www.vegetableswa.com.au/ Information on good irrigation management; soil moisture monitoring in sand; and calculating water requirements.

Soil

http://www.cprl.ars.usda.gov/wmru/pdfs/C2_Irrigation%20Monograph%2030.pdf

Soil Moisture Monitoring: Low-Cost Tools and Methods

http://attra.ncat.org/attra-pub/PDF/soil_moisture.pdf

Soil Water and Monitoring Technology

http://www.cprl.ars.usda.gov/wmru/pdfs/C2_Irrigation%20Monograph%2030.pdf

Soil Health Knowledge Bank

http://soilhealthknowledge.com.au/

This site provide an overview of current soil health knowledge and tools to assess soil condition providing information on soil properties, processes and management for profit across a range of industries and regions of Australia.

Soil types

http://websoilsurvey.nrcs.usda.gov/app/

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This website provide information on soil types throughout USA

Tools and systems for assessing soil health

http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_health_tools_1

Soil Health Knowledge Bank in Australia

soilhealthknowledge.com.au

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[1] For more information on soil texture. See http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/irr/rawrh.pdf

[2] http://www.extension.umn.edu/distribution/cropsystems/components/3115s01.html

[3] http://www.fao.org/ag/ca/doc/Soil_compaction.pdf

[4] http://epa.gov/nps/agmm/chap4c.pdf

[5] http://www.fao.org/docrep/r4082e/r4082e03.htm#2.5.3 capillary rise

[6] http://www.horticulture.com.au/librarymanager/libs/165/Managing_Water_Yield_Profit.pdf

[7] http://www.hbrc.govt.nz/WhatWeDo/Climate/SoilMoisture/tabid/1046/Default.aspx

[8] For more information see http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/irr/rawrh.pdf

[9] http://www.specmeters.com/pdf/6450WD.pdf.

[10] Blaine Hanson and Larry Schwankl On-Farm Irrigation. Scheduling Irrigations: When and How Much Water to Apply. University of California. 2007

[11] http://www.horticulture.com.au/librarymanager/libs/165/Managing_Water_Yield_Profit.pdf

[12] (Source: www.horticulture.au)

[13] http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/irr/fn027_1990.pdf