Water Use Efficiency - interpretation and training in the use of soil moisture data

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AHR Training Pty Ltd

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VG06136

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AHR Training Pty Ltd

Final Report for Horticulture Australia Ltd

Project VG 06136

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Report compiled by Dr Jenny Jobling

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Water Use Efficiency – interpretation and training in the use of soil moisture data

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MEDIA SUMMARY

The vegetable sector is the largest segment of the horticultural industry and is virtually 100% irrigated and as a result sometimes attracts attention as a large user of scarce irrigation water.

In reality, the high water use efficiency and profit water index means that irrigated vegetables are already a more efficient and profitable way of using water than industries like dairy cattle, cotton and irrigated cereal crops.

For many growers, the key issue is how to use available water as efficiently and effectively as possible.

This project developed a training guide that was distributed to over 1100 growers that outlined the principles of managing water for maximum yield and profit. In addition to the booklet 5 training days were run around Australia to which 67 growers attended.

The main principles of the course included; calculating the crop water use to develop a water budget, knowing the readily Available Water (RAW) of your soil, matching the crop water use to the RAW of the soil type to schedule irrigation events and how to use and interpret the data from soil moisture monitoring equipment.

The feedback from the training days was very positive and AHR have subsequently received requests to run the course again in areas that were out of the scope of this project.

Copies of the publication Managing Water for Yield and Profit can be obtained from AHR Training by telephoning 02 9527 0826 or by emailing lynn@ahr.com.au or a copy can be downloaded from www.ahr.com.au.

INTRODUCTION

Of all the inputs that drive the vegetable industry, adequate quantities of good quality water for irrigating crops is one of the most critical issues the industry currently faces.

In addition, Government and regulatory pressures to improve irrigation water use efficiency are increasing. The hope is that increasing the efficiency or reducing wasteful water use will make more water available for productive use or to meet environmental needs.

For the vegetable industry there are currently two related issues in regards to irrigation water use;

1. Managing water to ensure maximum yields and quality

2. Meeting the Government and community expectations for efficient water use. For this priority it is not that the vegetable industry is inefficient it is that there is not enough data to demonstrate the relative efficient water use of the industry.

The vegetable sector is the largest segment of the horticultural industry and is virtually 100% irrigated. This means it sometimes draws attention as being a large user of scarce irrigation water. In reality, the high water use efficiency and profit water index means that irrigated vegetables are already a more efficient and profitable way of using water than industries like dairy cattle, cotton and irrigated cereal crops.

In 2003/04 the vegetable industry accounted for just 4.6% of the total water used by irrigation (ABS Water Use on Farm 2003-04). The industry average water use is 4.1 ML per hectare, which is below the national average for agriculture which is 4.3 ML per hectare.

However, recent drought and an increased demand for water across many of the growing regions in Australia have made vegetable growers well aware of the need for highly efficient irrigation systems in order to produce high yielding, quality crops in dry seasons.

Many growers are adopting more efficient systems including sub surface drip irrigation, and computer controlled overhead sprinklers or soil moisture monitoring equipment. These techniques ensure high yields are produced as water is supplied when and where it is needed.

The course and training booklet developed for this project aimed to provide more information for growers to help them manage crop water use for maximum returns, as well as helping them minimise the production risk and calculate the real value of the water applied.

TECHNOLOGY TRANSFER STRATEGY AND ACTIVITIES

The initial phase of this project was to analyse the data collected by AHR from previous field trials. This data would provide case studies and real data for the training course that would demonstrate the impact and importance of managing water well. It would also provide real examples of the type of data that is generated when soil moisture monitoring equipment is used. This data set the scene for developing the training course and booklet “Managing Water for Yield and Profit”.

The training material and training booklet were prepared in January 2008. Arris Pty Ltd published and printed 2,000 colour training booklets. The training booklet was an A4 full colour 24 page booklet and was set out in an easy to read format. The booklet was written in grower friendly language.

The topics covered in the booklet included;

1. Why plants need water – impact of under or over watering on crop quality and yield.

2. Water and soil – understanding the readily available water content of different soils.

3. Determining the timing and amount of irrigation – calculating a water use budget using crop coefficients and crop factors with evapotranspiration and transpiration data. Matching crop water use with the readily available water content of the soil.

4. Understanding how to use the output from soil moisture sensors – examples of real data from AHR field trials using soil moisture probes.

5. A reference and resource list of other materials that cover water use efficiency training and soil moisture monitoring.

The training book was given to each course participant. The course participants were also given a folder which contained additional information that reflected the material delivered at the training sessions (PowerPoint presentations, workshop sheets and answers, other additional resources from Departments of Agriculture). The additional resources were tailored according to the location of each training course and included printouts of relevant fact sheets, a website reference page and CD’s and booklets of relevant material such as the Department of NSW Agriculture Growing Manuals for Onions, Tomatoes and Melons.

At the end of each training session participants were asked to fill in a feedback form to allow AHR to evaluate the training and make any necessary changes to improve the training course.

Five training sessions were run across Australia in 2008. The dates for each session are shown in Table 1.

Table 1: Dates for the Lettuce Training Days in 2007

District	**Number of Participants**	**Date**	**Venue**
Adelaide	12	28th August	University of Adelaide, Waite Campus Adelaide
Mildura	11	11th September	Victoria DPI, Sunraysia Horticulture Centre
Darwin	25	24th September	DPI Humpty Doo
Sydney	10	13th October	Flemington Markets
Gatton	9	13th November	Gatton Research Station
Total	**67**		

A mail out was also done, with booklets sent to the Industry Development Officers in Tasmania to distribute 100 copies, in NSW to distribute 300 copies and in Victoria to distribute 200 copies. Arris Pty Ltd also arranged for 200 copies to go to the SA growers and AHR posted 133 copies to the EnviroVeg members. An additional 100 booklets were left in Darwin after the workshop for distribution and 100 were left in Gatton for AHR to distribute in Qld.

That made a total of 1133 booklets posted to vegetable growers that did not attend the training course.

The Managing Water for Yield and Profit booklet also appears on the HAL and AHR website (www.ahr.com.au) as a pdf file and copies of the booklet are also available on CD. As of February 2009, 13 copies of the booklet have been downloaded from the AHR website.

The training courses were advertised in local newspapers and articles were also printed in Vegetables Australia Volume 4.4 Jan/Feb 2009 and vegelink issue 16 Spring 2008. Since completing the workshops and following the publication of these articles, AHR has had requests for more booklets and also requests to run additional training days. The booklets have been mailed out and negotiations are continuing in regards to running additional courses.

EVALUATION AND MEASUREMENT OF OUTCOMES

The main outcome of this project was;

The reduction in the water used to grow vegetable crops through improved on-farm water use efficiency (WUE).

This ambitious aim was to be achieved by:

- ☐ Improving information to support irrigation choices and water management by developing real Water Use Efficiency (WUE) and water movement data in common vegetable crops from major growing regions

- ☐ Training growers and industry support people on how to use soil moisture data to efficiently schedule irrigations and maximize yield and quality based on crop water requirements and water movement in their local soil types.

The training course and booklet addressed the aims outlined. The booklet has been sent to 1133 people, there have been 13 downloads from the AHR website and 67 people attended the training courses.

The value and enjoyment of the day is reflected in the feedback received from the participants. Each course participant was asked to complete an evaluation sheet at the end of the day. The feedback has been compiled and is summarised in the following Figures and Tables.

Figure 1 shows a summary of the rating of the overall benefit of the training day. The Figure shows that most people found the day to be either very beneficial or beneficial.

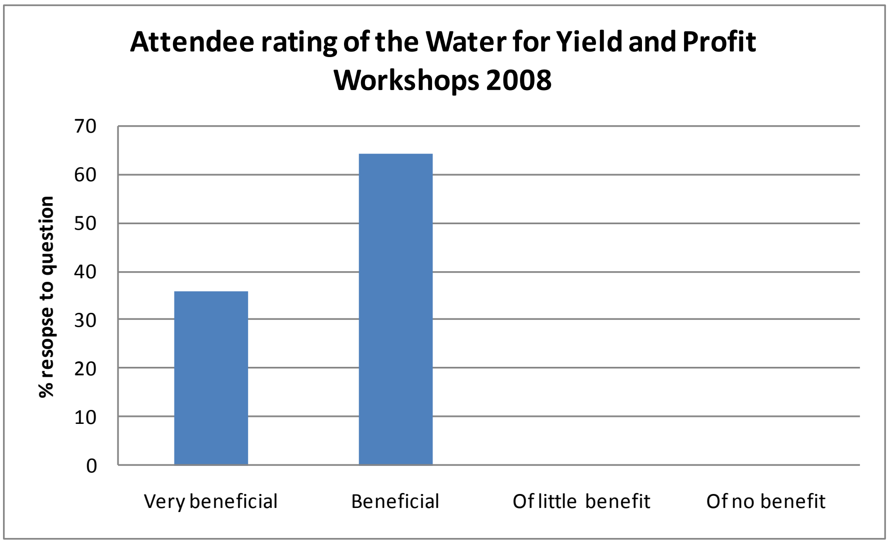


Figure 1. Feedback from participants on the overall benefit of the training day.

All of the sessions were highly nominated when the participants were asked to indicate which sessions were the most helpful (Figure 2).

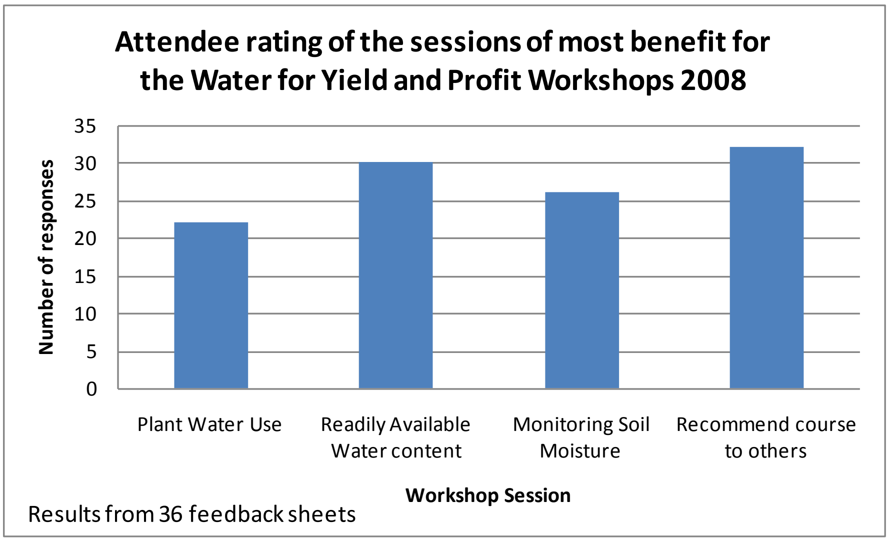


Figure 2. Breakdown of what sessions the participants thought were valuable in the lettuce training day 2007.

The following table (Table 2) lists some general comments from the course participants about the course. The main theme was that the course provided good background and introductory theory for understanding plant water use and the need to manage water well.

Table 2. Summary of some of the comments from the Training Day evaluation indicating how growers will use the information discussed on the day.

General comments on value of course
Important to know how crop usage and refill work together so we don't waste water
Need more topics related to soil salinity management - relevant to irrigation, area specific suggestions.
Good presenters, easy to understand and very welcoming.
Great idea in having activities, bucket of water activity was worth while.
Important to know how crop usage and refill work together so we don't waste water
Very good baseline to apply and build on. Difficult to put to vege's but probably as well pitched as a fruit run could be.
Good presenters, easy to understand and very welcoming
Need more topics related to soil salinity management - relevant to irrigation area specific suggestions.
Workshops of this kind are very beneficial to growers, but we are all so time poor - it is difficult to attend unfortunately
This is a good workshop to learn to save water.
Stimulating and re-inforces. Action only usually follows hearing things many times.
Very Good
There is a way of working out what a plant uses.
Very valuable, I would be interested in the waterwise courses.
Further enhanced knowledge of water and plant health
The course has made me more water wise and will help with efficiency
A good introduction to the practical side of water use efficiency
The course will be an asset to our business
Very good value - learnt a lot about water efficiency
Very good value.
Quick , to the point while making sure every one understood

Additional observations and learning's from the training courses

- All the training courses were well received. Participants responded well to the interactive training style and enjoyed participating in the hands on activities.

- Participants commented that the training was delivered in a clear and very easy to understand way and kept them engaged.

- The participants at training courses were varied and included Growers, Extension Officers, Irrigation Consultants, Agronomists, and Department of Agriculture and Primary Industry Staff.

- The presenters were mindful of current conditions of each location and adapted the way in which key messages were delivered. It was important to be sensitive to these conditions, e.g. being aware that most participants attending the Mildura course would have 0% water allocation whereas participants at the Humpty Doo training session have unrestricted access to water. Whilst the limitations on growers varied enormously between locations, the key message of managing water efficiently for yield and profit remained relevant and it was the important that all participants received that message.

- Growers provided feedback on the training manual and said that it was easy to read and presented in a clear and simple manner.

- The training course at Humpty Doo was combined with a training session in the morning on Soil Health. This lead to the training course being attended by non vegetable growers including a grower of mangoes and several growers in the nursery industry. Although the course was aimed at vegetable growers, these participants still found the training valuable with and reported an improved understanding of the key areas of plant water use, readily available soil water content and how to use soil moisture monitoring equipment.

- The course at Mildura included a section delivered by the Drought Information Officers, Alison McGregor and Graeme Thornton. This section was extremely relevant to participants given the current conditions, and allowed to run over the allotted time slot of 40 minutes to 1 ½ hours. This was the first group of vegetable growers whom had been presented the drought information program. Alison and Graeme commented on the simplicity and ease of the exercises that AHR had developed for calculating a water budget and this exercise was able to be used in conjunction with the production and profit spreadsheets from the drought information program. Copies of the AHR exercise workbook were provided to Alison and Graeme for future use with horticulture growers.

DISCUSSION

There is a huge volume of information available to growers on water use and soil moisture monitoring – in some cases this is seen as "information overload". With this in mind, AHR designed the workshops to provide a summary of the key principles, a summary of the list of additional information available and also a series of practical examples where growers could work through the calculations that are required during the workshop to determine their irrigation needs.

The training courses were a success and in terms of improving the level of knowledge of the industry as well as encouraging industry members to evaluate their business and to make positive changes. Some important improvements that growers mentioned during the day were to;

1. Actually calculate a water budget for the crop to know how much water is required.

2. Dig soil pits in order to know their soil and to be able to calculate and understand the Readily Available Water (RAW) content of their soil. Also dig pits to see the variability of soil types and RAW across a paddock.

3. To check the wetting pattern of the soil after an irrigation to check the entire root zone is wet.

4. Investigate the options for using soil moisture monitoring to manage irrigation scheduling.

RECOMMENDATIONS

- The format of this project in terms of promoting, organising and presenting training material is a good model for future workshops.
- This training course can be presented again in the future, at a cost to participants if there is sufficient industry demand.
- The training booklet is available to interested growers on the HAL and AHR websites

Maximising Yield and Quality by using Water Well


Boom reel irrigator


Furrow irrigated tomatoes

A bit of background

Two priorities for the industry



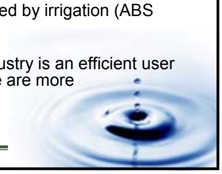
1. Managing water to ensure maximum yields and quality.

2. Meeting the Government and community expectations for efficient water use.

   For this priority it is not that the vegetable industry is inefficient it is that there is not enough data to demonstrate the relative efficient water use of the industry.

Good news

- The vegetable industry is roughly twice as efficient in its use of water as it was a decade ago.
- the value return from vegetable production increased from \$1,762/ML used in 1996/97 to \$3,207/ML in 2000/01 (ABS 2001).
- The industry average water use is 4.1 ML per hectare, which is below the national average for agriculture which is 4.3 ML per hectare.
- The industry uses 4.6% of the total water used by irrigation (ABS Water Use on Farm 2003-04).
- These statistics show that the vegetable industry is an efficient user of water compared to other sectors but there are more improvements to be made.



Bad news

- In the thirteen years between 1983/84 and 1996/97 irrigation water use in Australia increased by 75%.
- In Australia, irrigated agriculture uses 65% of consumed water.
- A recent report estimated that 26% of Australia's river basins and 34% of Australia's groundwater were exceeding sustainable extraction limits (Australian water resource assessment, 2000).
- Future growth depends on efficiency gains rather than further allocations of scarce water resources.

Improving Yield and Quality by using Water Better

Furrow irrigated tomatoes

Plants need water

- Managing water use is about maximising plant growth.
- Too much or too little water will cause plant stress which impacts directly on the physiology of the plant.
- The disrupted metabolism causes an increased risk of disease and also reduces the growth rate, yield and quality of the crop.

***Managing water is essential for maximising profits*.**

Positive industry examples

- **Processing tomato production**
  - Louis and Geraldine Chirnside

  The water savings are in the order of 0.82 to 1.3 ML/Ha or 16 – 26% of the total crop water requirement by use permanent drip tape.

  “Monitoring makes us as efficient as possible and gives a guide to what is happening under the soil surface”.

- **Potato production**
  – Kain Richardson

  Change resulted in 20 tonnes produced per ML under drip compared to 7 – 8 tonnes per ML under gun irrigation.

Aim to apply only what water you need to for maximum yield and profit.

Meeting Government and Community Expectations

What does the industry need?

A recent Horticulture Australia project VG04010 “Australian vegetable crops – Maximising returns from water” Hickey, M (2006) stated

1. A need to conduct a detailed study of the threshold cost of water, beyond which vegetable growing becomes uneconomic.

2. Install water flow meters to enable growers to collect water use data for their farm and develop baselines for water use efficiency initiatives.

3. More real farm data to strengthen Horticultures position in future water allocation negotiations eg. 31% of Australia's surface water management and 30% of ground water management units have **no** recorded use data.

Water Use Efficiency

Water use efficiency is a generic term that covers a range of performance indicators irrigators can use to monitor the performance of their irrigation practices.

Irrigation water use index (IWUI) = $\dfrac{\text{Total production for farm (Tonnes)}}{\text{Irrigation water applied to farm (ML)}}$

Operating profit water use index (OPWUI) =

$\dfrac{\text{Gross return (\$) - Variable costs (\$) – Overhead Costs (\$)}}{\text{Total water used on farm (ML)}}$

Water Use Efficiency

- Water monitoring means the cost benefit can be accurately measured.
- The biggest improvement in the net return for the grower is not in a lower cost of water but an improvement in crop yield and quality.
- Water use efficiency of the industry can be demonstrated to Government and the wider community.

What to expect today

- Technical information
- Trial data and real examples
- Hands on sessions to discuss and consider the information presented based on your situation

Why Plants Need Water

Without water, life as we know it would not exist

Water is a unique compound

- *Thermal properties* – it is a liquid over the range of temperatures biological reactions occur. This is important because most reactions can only occur in the liquid medium. Water is also important for temperature regulation as it doesn't heat or cool too quickly.
- *Solvent properties* – it is a universal solvent and can carry nutrients and solutes required for growth.
- *Transparency* – allows sunlight to penetrate to power photosynthesis.

Water is a unique compound

- *Biochemical reactions* – many of the biochemical reactions that are part of growth occur in water or water itself participates in the reactions.

Photosynthesis

Carbon dioxide + Water $\xrightarrow[\textit{Chlorophyll}]{\textit{Light energy}}$ Glucose + Oxygen

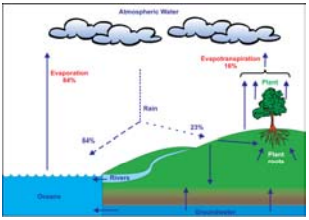
$$6CO_2 + 12\ H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Respiration

Glucose + Oxygen $\longrightarrow$ Carbon dioxide + Water

$$C_6H_6O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_20$$

Interconnectedness of water



Water is the most abundant constituent of most organisms.

The hydrological cycle emphasises the connectedness of soil, plant and atmospheric water.

Result is that there are many complexities for determining irrigation water use and scheduling.

Using water well

Why plants need water to grow

- Water is essential for crop production.
- Plant cells grow by increasing in volume and for the cells to increase in volume they must take up water. If a cell can't take up water it won't grow.
- On top of that all processes of metabolism, conditioned as they are by protein synthesis and enzyme function, require an aqueous environment in which to function.

  As a result water forms 80% or more of annual plant's substance and more than 50% of a woody species.

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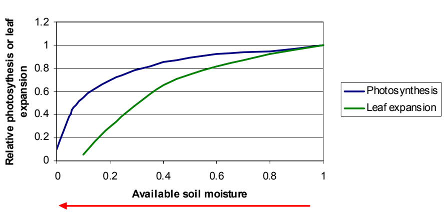
Using water well

Water determines yield

- Water stress causes photosynthesis and growth to stop. This impacts directly on yield.



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Too much water is also a problem

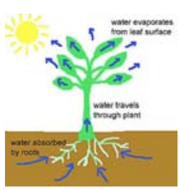
- Excess water or flooding limits the amount of oxygen available to the roots of the plant.
- This in turn limits respiration, nutrient uptake and critical root function resulting in poor plant growth, yield and quality.
- Stress makes the plant more prone to disease.

Practical implication

- Water is a unique resource.
- Water stress reduces crop yield and quality by upsetting plant metabolism.
- Both under and over watering cause yield and quality problems.

Water use by plants - Transpiration

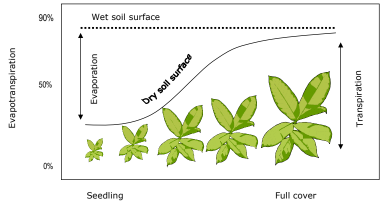
- Transpiration is the name of the process of water movement through the plant from the roots to the atmosphere.



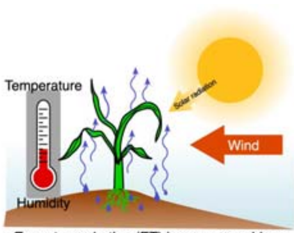
- Transpiration produces the energy gradient that largely controls the ascent of sap through the plant - it cools leaves and increases the absorption of minerals.

Water use by plants

- Evaporation from the soil and transpiration occur simultaneously so it is difficult to distinguishing between the two processes.
- Evapotranspiration is the combined loss due to transpiration and evaporation.



What effects Evapotranspiration rate?



- Evapotranspiration (ET) is an energy driven process.
- ET increases with temperature, solar radiation and wind.
- ET decreases with increasing humidity.

Practical implication

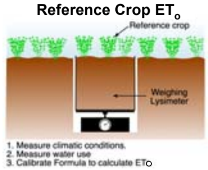
- Mulching crops reduces evaporative water loss from the soil.
- Knowing a plants water needs ensures stress as either over watering or under watering can be avoided.

Calculating crop water use

***Crop water use (mm)* =**
***Crop Coefficient* x Evapotranspiration (ET_o)**

The crop coefficient relates the crop water use at a particular development stage to the evapotranspiration rate of a reference crop.

Reference Crop ET_o

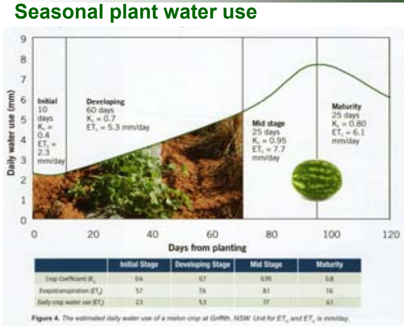


***Crop water use (mm)* =**
***Crop Factor* x Pan Evaporation (Epan)**

The crop factor relates the evapotranspiration from a plant to the rate of evaporation from an open pan.

Seasonal plant water use

- Typically four growth stages
- Water use changes as plants develop
- Different stages are more affected by water stress
- Seedlings are often over watered to reduce transplanting shock



Flowering and fruit set are the most critical stages but stress during growth will impact yield and quality for leafy crops

Practical Implications

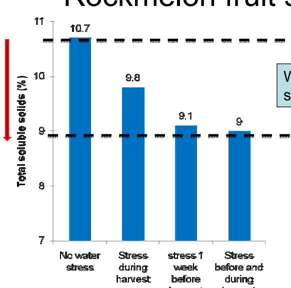
- Managing water use is about maximising plant growth.
- Too much or too little water will cause plant stress which impacts directly on the growth of the plant.
- Managing water is essential for maximising profits.

Irrigation Case Studies

Key Messages

- Water stress caused by too much, not enough or irregular irrigation ***reduces yield***
- Irrigation management affects ***crop quality***
- Different types of irrigation can achieve same result if ***managed well***
- ***Most of the data is from AHR trials***

Water Stress Reduces Rockmelon fruit sweetness (Brix)



Water stress near harvest reduced fruit sugars (Brix) from ***10.7 to 9*** (25%)

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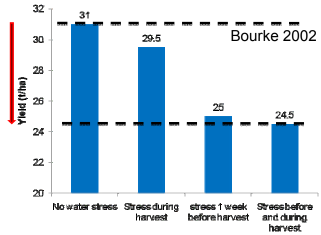
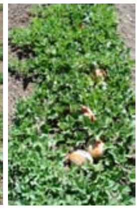
Effect of water stress on rockmelon yield

Water resulted in a ***20% yield reduction*** due to effects on ***fruit size***



Water stress



No water stress

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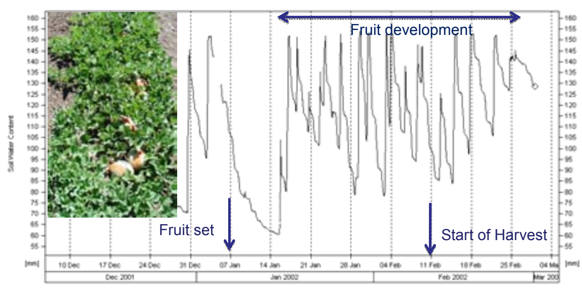
Irrigation thru to the end of harvest

No stress thru fruit development – vine healthy



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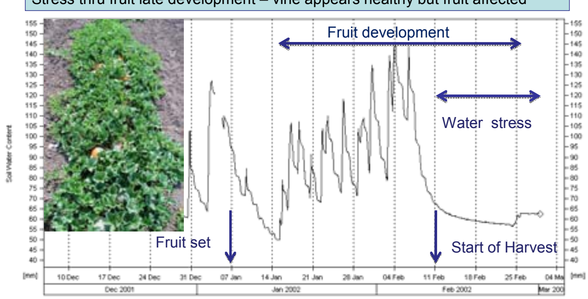
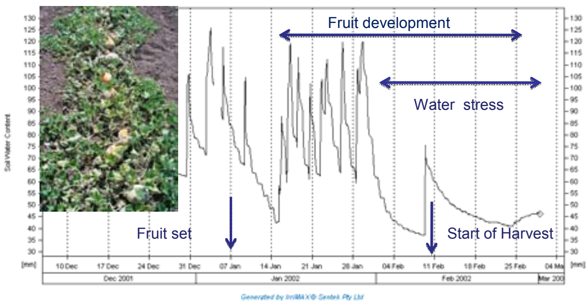
Water stress imposed at start of harvest

Stress thru fruit late development – vine appears healthy but fruit affected

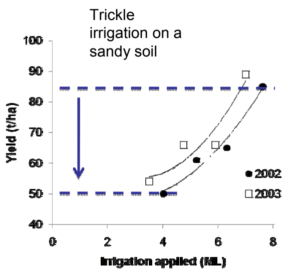


Water stress starts 1 week before harvest

Stress thru fruit development – vine also affected



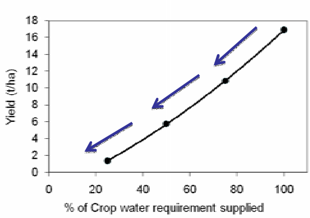
Influence of irrigation water on watermelon yield (Summer crop – sandy soil, Turkey)



Simsek, M., Kacira, M., Tonkaz, T. (2004) Aust J Ag. Research 55:11 1149-1157

Reducing irrigation from 7 ML/ha to 4 ML/ha reduced yield by 40% from about 85 t/ha to about 50 t/ha (Experimental yields – usually higher than commercial).

Water stress and yield broccoli



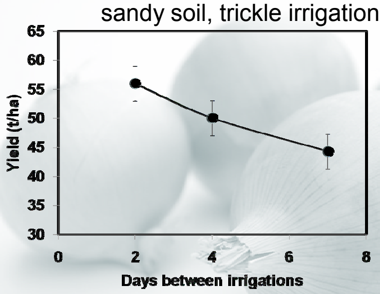
From Periola et al. (1993) Acta Hort. 33:265-270

Sandy loam soil outdoor crop - Italy

Failing to supply the irrigation required amount of irrigation significantly reduces broccoli yield (head weight)

Why ?

Mild onion yield in response to water stress – sandy soil, trickle irrigation in Griffith



Increasing the time between irrigations even though total water applied the same reduces yield by 20%

Onions were going into water stress during development

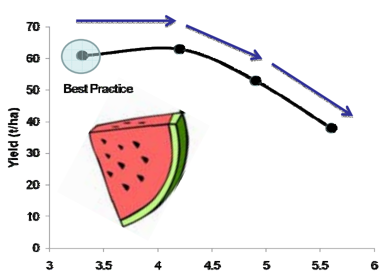
Why a reduction in yield ?

(Griffith NSW) Hickey et al (2005) Mild onion irrigation HAL Project VN04015

Too much water can reduce yield

Condobolin - watermelons

Effect of Irrigation water on yield on transplanted seedless watermelons (Autumn crop)



It is also possible to supply too much water to watermelons: reduces yield (actual amount depends on soil type and climate.

Also problems with root disease and fruit splitting

Effect of correctly regulating soil moisture

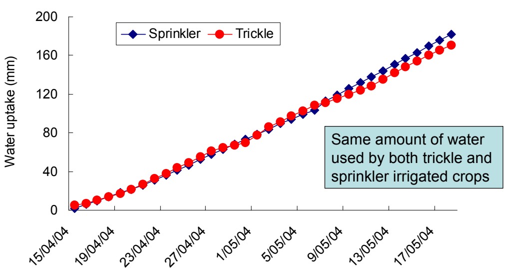
Water management by measurement

Water Management by “feel”

Different types of irrigation can delivers water effectively if properly managed

- Trickle irrigation or and sprinkler result in same crop water uptake if well managed.

Water Uptake by Lettuce Crop (transpiration, leaching and evaporation)



Case Studies

Trickle v's sprinkler on yield and water use of iceberg and cos lettuce

Irrigation Type	Water applied to the plant row (mm)	Estimated water applied to whole area (ML/ha)*	Water taken up in the plant row (mm)	YIELD (g/head)
Sprinkler				
Cos	160	3.2	136	690 ±50
Iceberg	164	3.3	167	580 ± 40
Trickle				
Cos	102	1.0	142	540 ± 50
Iceberg	116	1.2	168	640 ± 40

* assuming 40% of soil area irrigated using trickle and 100% with sprinkler

Sprinkler uses about 3 ML/ha while trickle uses about 1 ML/ha to produce a comparable crop.

Case Studies

How to achieve the yield and quality results

Two examples: ***Melons and leafy crops***

- ***Principle 1***: fully wet soil profile at planting
- ***Principle 2***: keep plants stress-free during growth and maturation of harvestable part
- ***Principle 3***: water requirement can diminsh as plants mature – may need less water to avoid waterlogging

Case Studies

Melons – planting to first flower

Fully wet the soil profile at planting

- Roots can't grow into dry soil, but you can encourage the roots to explore deeper soil as the profile dries down
- If you do have to water, then fully re-wet the soil profile, avoid short frequent irrigations unless the soil has a very low RAW.

Melons - Flowering to Harvest

Keep the plants free of water stress to harvest

- The best yields and quality come from irrigating just before the soil dries to the ***Onset of Stress***
- Irrigate fully to ***Full Point*** each time by adding the ***RAW***

Leafy Vegetables - Establishment

Establishment is critical – sprinkler irrigation

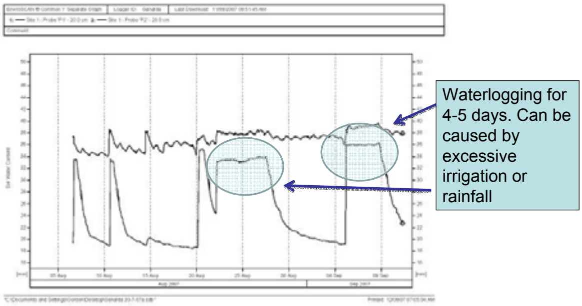
- Keep the topsoil moist for the first 7-10 days after planting to maximise plant stand
- Water stress early can induce premature heading (bolting)

Leafy Vegetables - Growth

Keep the plants free of water stress

- Irrigate before the soil dries down to the onset of stress point
- Irrigate up to full point (apply RAW)
- Avoid leaching Nitrogen with excess water

Avoid waterlogging



Key Messages

- Water stress caused by too much, not enough or irregular irrigation ***reduces yield***
- Irrigation management affects ***crop quality***
- Need to measure moisture to correctly manage water.

Measurement and Interpretation of soil moisture

Measuring Soil Moisture

Key Messages

- What to measure: plant or soil water status?
- Types of measuring equipment.
- Answering the critical questions of ***when to water*** and ***how much to apply***?

Measuring Soil Moisture

What gives us the best information about the crop water status ?

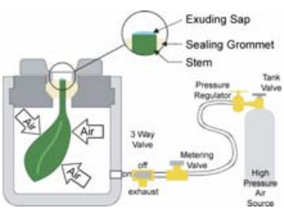
- Plant based measures, or
- Measuring much water there is in the soil ?

Plant Based Measures

There are three common measures that are used to measure plant water status:

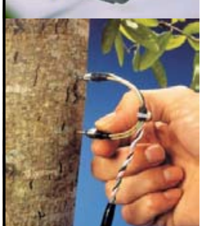
- ***Leaf or Stem water potential***
- ***Sap Flow***
- ***Growth micro measurements***

Measuring Leaf / Stem water potential

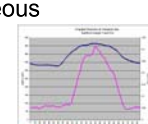


- Use a Scholandler bomb (pressure bomb) to force the sap out of the end of a cut leaf.
- Drier the plant, the more pressure required to express sap
- More of a research tool

Sap Flow meters



- Measures the speed at which water moves xylem tissue.
- Can actually measure while plant transpiration in this way
- Mainly used for research and more on woody species rather than herbaceous plants.



Growth micro measurements

- Works on the idea that the growth rate of fruits and plant parts closely linked to plant water status.
- Ie. If the turgor pressure drops due to water stress → then (fruit) expansion rates slows.

Measuring Soil Moisture

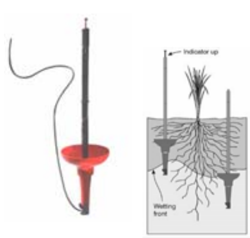
Type of measurement	Examples
Soil Suction	Tensiometers
(how tightly the water is held)	Gypsum blocks
	Wetting front detectors
Soil Moisture Content	Capacitance sensors
(how much water)	TDR
	Neutron Probe

Minor instruments for measuring soil suction

Gypsum Blocks

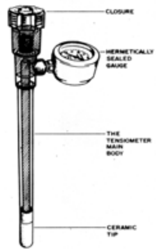
Cheap and work best in sandy soils

Wetting Front Detectors



Tensiometer

There is a porous tip which allows water to move into soil, and creates tension which is read of the gauge



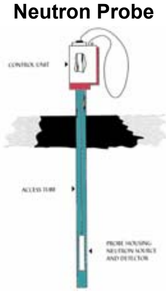
Interpretation of Tensiometers

Soil moisture status	Reading (kPa)	Interpretation
Nearly saturated	0	Nearly saturated soil often occurs for a day or two following irrigation.
Field capacity	10	Field capacity.
Irrigation range	20	Usual range for starting irrigations.
Onset of stress	30	This is the stress range for most vegetable crops.
Extremely dry	80	Top range of accuracy of tensiometer.

Minor Instruments for measuring soil moisture

TDR

Neutron Probe

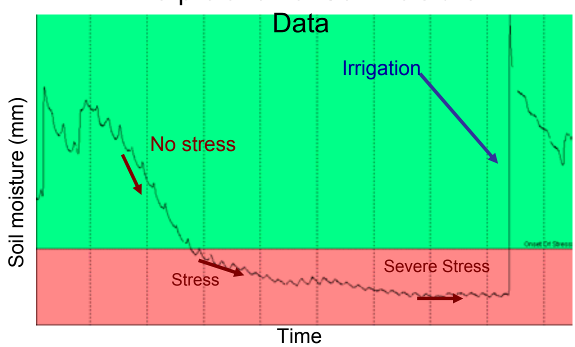


Soil Capacitance Measures

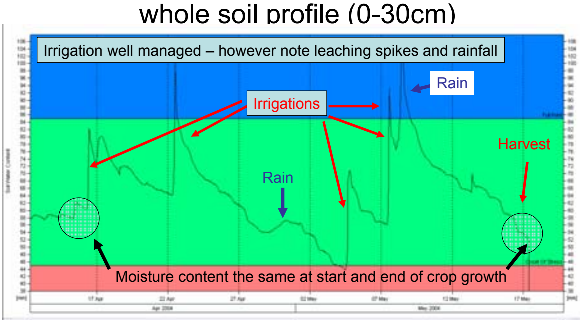
Soil capacitance sensors measure soil moisture in a small volume of soil around each sensor

They are suited to continuous monitoring of moisture at different soil depths

Interpretation of Soil Moisture Data

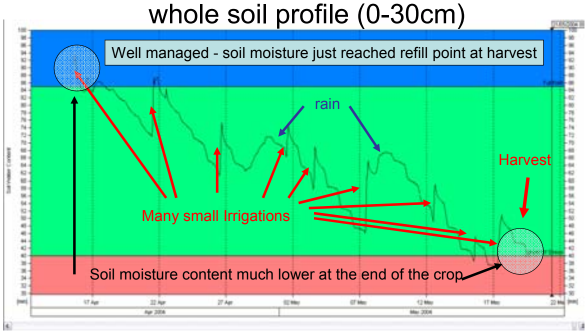


Soil Moisture - Sprinkler Irrigation whole soil profile (0-30cm)



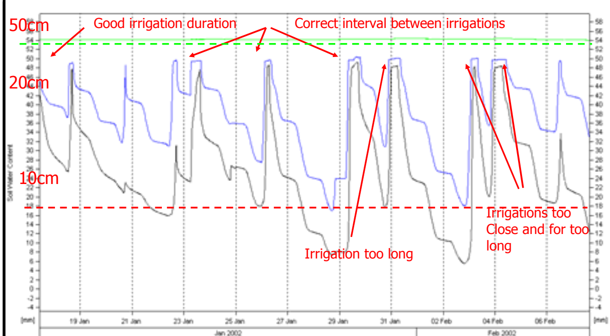
Measuring Soil Moisture

Soil Moisture – Trickle Irrigation whole soil profile (0-30cm)



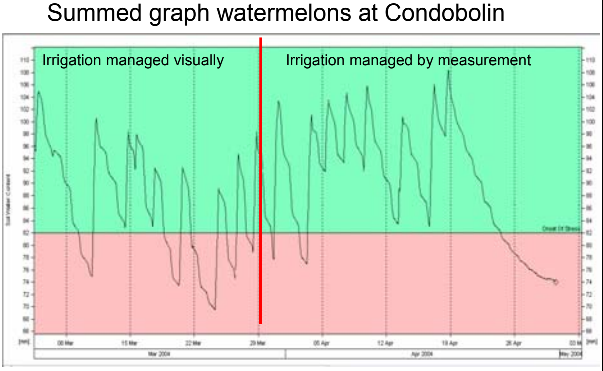
Measuring Soil Moisture

Rockmelons Bourke – Fruit development



Measuring Soil Moisture

Summed graph watermelons at Condobolin



Selection of monitoring equipment

Manual monitoring
Continuous monitoring
Soil moisture and EC
Data access

Manual monitoring

Diviner 2000 (Sentek)

- Manual measurements
- Can measure many sites
- Install access tubes for each monitoring site
- Inexpensive for additional sites

Continuous Monitoring

- Main players are:
  - C-Probe (Aquaspy)
  - EnviroScan (Sentek)
- Log soil moisture data a various depths

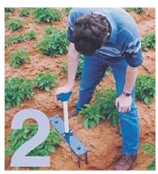
Large Scale Systems

C-Probe (Aquaspy)
EnviroScan (Sentek)

- Log soil moisture data at various depths
- 50mm diameter access tubes
- Flexible positioning of sensors (depths)
- Not well suited to being moved
- More suited to tree and vine crops

Small Scale Systems

EasyAg (Sentek)
Aquaspy moisture probe (Aquaspy)



- Easy installation and removal
- Present sensor depths
- Log ata

Data Access

- ***Manual download*** – labour intensive and not usually done often enough
- ***Download using modem*** – need to actively dial up modem and download
- ***EnviroScan Plus*** (Sentek) – uploads data to a client website, need software
- ***AquaSpy T20*** (Aquaspy) – uploads data to Agwise website and always available, Don't need software

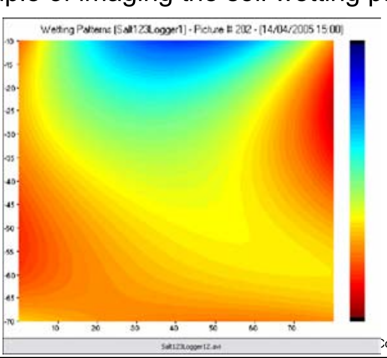
Soil water plus EC

- ***TriScan sensors*** (Sentek) – measures both simultaneously
- ***Hydra Probe*** Soil Moisture Sensor (Stevens) – also measures moisture and EC

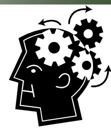
Key Messages

- What to measure: plant or soil water status?
- Types of measuring equipment.
- Answering the critical questions of ***when to water*** and ***how much to apply***?

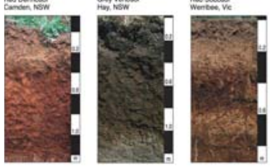
Example of imaging the soil wetting pattern



RAW Activity



Calculating Readily Available Water



Calculating RAW

1. Estimate effective root depth (this can be done by examining roots of past crops in a soil pit or using published estimates of effective root depths of the crop to be grown)
2. Measure the depth (in metres) of each soil layer in the root zone
3. Determine soil texture for each layer
4. Identify the RAW (in mm/m) for each texture type identified in the root zone (use a table that identifies the RAW for a range of tension levels for different soil textures)
5. Multiply the thickness of each soil layer by its RAW value to determine the RAW for each soil layer
6. Add the RAW values for each soil layer together to the depth of the root zone to obtain the total RAW for the root zone

Key Calculations

RAW of a layer (mm) = Depth of that layer (m) X RAW value for texture class of that layer (mm/m)

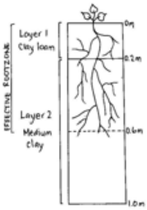
(need to obtain RAW value for chosen refill point, e.g. -20 kPa)

Root zone RAW (mm) = the addition of the RAW of each layer in the root zone (e.g. Layer 1 RAW + Layer 2 RAW)

Profile RAW (mm) = the addition of the RAW of each layer in the soil profile

Question

Determine the root zone RAW for a melon crop growing at Griffith. Use a refill point of -20 kPa.



Effective root depth = m

Depth of Layer 1 = m

Depth of Layer 2 = m

RAW for clay loam = mm/m

RAW for medium clay = mm/m

Water for Yield and Profit

Layer 1 RAW = m X mm/m

= mm

Layer 2 RAW = m X mm/m

= mm

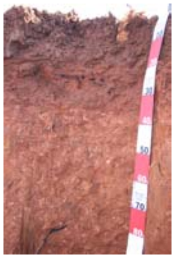
Root zone RAW = Layer 1 RAW + Layer 2 RAW

= mm + mm

= mm

Therefore when the soil dries to refill point, mm of water would need to be applied to bring the soil to field capacity.

Water and Soil



Soil properties and water

- Soil properties, in particular texture and structure, strongly influence the way water behaves in a soil
  - Infiltration
  - Drainage
  - Water storage (how much stored water is readily available for uptake by plants?)
- Need to have knowledge of soil properties, and how they vary, across a farm or a paddock before designing an irrigation system (create a soil map, with the help of soil pits)

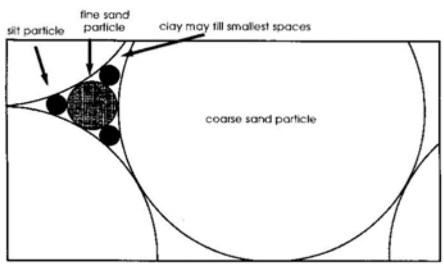
Readily available water

- Known as RAW
- Is water that plants can easily remove from the soil
- Plants remove water from soil using suction
- A smaller amount of suction (energy) is required to remove water from large pores than small pores

Soil texture

- Amount of sand, silt and clay in a soil
- Influences water storage and availability because of particle size distribution and surface area
- Clay particles are smaller and have greater surface area than sand particles
- Smaller particles fit together more tightly than large ones – pores are also smaller

Theoretical packing of soil particles



Pore size and water storage

- Large pores – drain easily (sands)
- Small pores – retain water against gravitational forces, drainage
- Very small pores – retain water but not available to plants (clays)
- Ideally a soil will contain a range of pore sizes
  - Large ones that drain readily so as to prevent waterlogging
  - Smaller ones to store water for plant use
- Most important is amount of water stored in soil that is readily available to plants, rather than total amount

Determining soil texture

- Determine for each soil layer (horizon) within the root zone
- Knowledge of texture is required to estimate available water

Field texture classes

Field texture group	Description	Approximate clay content
Sand	Nil to slight coherence. Ribbon of 0–15 mm.	Less than 10%
Sandy loam	Coherent but very sandy to touch. Ribbon of 15–25 mm.	10–20%
Loam	Coherent, spongy and greasy feel with no obvious sandiness or silkiness. Ribbon of about 25 mm.	About 25%
Silt loam	Coherent, very smooth to often silky when manipulated. Ribbon of about 25 mm.	About 25% and with silt 25% or more
Sandy clay loam	Strongly coherent, sandy to touch with medium size sand grains visible in finer matrix. Ribbon of 25–40 mm.	20–30 %
Clay loam	Coherent plastic bolus. Smooth to touch with no obvious sand grains. Ribbon of 40–50 mm.	30–35%
Light clay	Plastic bolus. Smooth to touch with slight resistance to shear. Ribbon of 50–75 mm.	35–40%
Medium to heavy clay	Plastic bolus. Smooth to touch. Feels like normal to stiff plasticine. Moderate to firm resistance to shear. Ribbon of 75 mm or more.	40% or more

Soil structure

- Soil structural form is the arrangement of the solid components of soil and the spaces in between (pores)
- Ideally soil will have > 2/3 small (mostly less than 5 mm diameter) rounded aggregates
- Need range of pore sizes
  - Flow of water and gases
  - Storage of water and dissolved nutrients

Good soil structure

Poor soil structure

Compacted soil

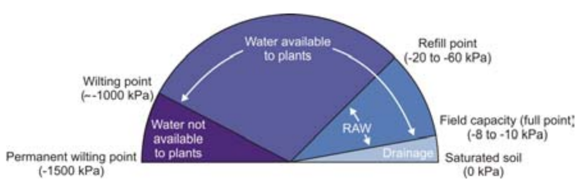
- Pore space reduced
  - Water transmission slowed
  - Water storage reduced
  - Aeration reduced
- Surface crusts a sign of poor structure
  - Increases runoff, reducing efficiencies of rainfall or irrigation
- Reduced RAW
- Plants may experience moisture stress, even if there is sufficient rainfall and irrigation
- Root growth impeded – limiting area of soil that plants can harvest water from

Maintaining good structural form

- Improve organic matter content
- Encourage soil fauna
- Avoid cultivating when too dry or too wet
- Implement controlled traffic farming
- If badly compacted regenerate using biological solutions such as rotation crops and appropriate tillage strategies
- Gypsum is useful for sodic clays

Water storage for plant growth

- After prolonged heavy rainfall, when all pores full of water (no air) – 'saturated'
- Following free drainage the soil is at maximum water storage capacity – 'full point' or 'field capacity' (FC); -8 kPa
- Water is removed by plants and by evaporation, becoming harder to extract with time, eventually clinging tightly to soil particles and in small pores
- Water extraction difficult for plants – 'refill point'; -20 to -60 kPa for horticultural crops
- Water cannot be extracted by plant roots – 'permanent wilting point' (PWP); -1500 kPa

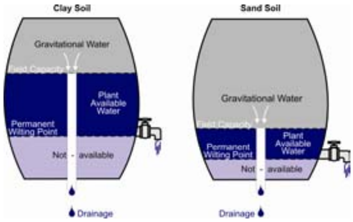


Estimating soil water holding capacity

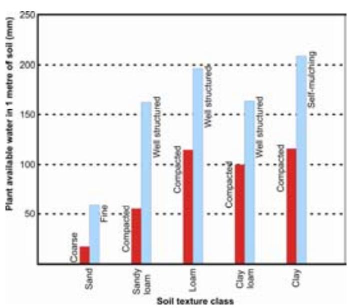
- Texture and structure information can be used to estimate soil water holding capacity
- If irrigation design does not match soil condition some areas will be over-watered, others under-watered
- Amount of water to be applied per irrigation event, and the time between irrigation events will vary between soil types

Soil moisture characteristics

- Vary due to variations in particle size and pore size



Plant available water



Calculating RAW

- Need to know:
  - effective root depth
  - depth of each soil layer
  - texture type of each soil layer
  - RAW (mm/m) for each texture type
- RAW reduced if coarse fragments such as gravel present
- RAW values can be greater or less than predicted values, depending on structural form

Rooting depths

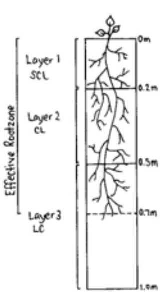
Crop	Rooting depth (m)
Tomato	0.5 – 1.5
Onion (green or dry)	0.3 – 0.6
Watermelon	0.8 – 1.5
Carrot	0.5 – 1.0
Lettuce	0.3 – 0.5
Broccoli	0.4 – 0.6
Cabbage	0.5 – 0.8

RAW values for some texture classes

Soil Texture	RAW (mm/m)				AW (mm/m)
	A[1] -8 to -20 kPa	B[2] -8 to -40 kPa	C[3] -8 to -60 kPa	D[4] -8 to -100 kPa	E -8 to -1500 kPa
Sand	35	35	35	40	60
Sandy loam	45	60	65	70	115
Loam	50	70	85	90	150
Sandy clay loam	40	62	71	101	143
Clay loam	30	55	65	80	150
Light clay	25	45	55	70	150
Medium – heavy clay	25	45	55	65	140

[1] Column A for water-sensitive crops such as vegetables and some tropical fruits
[2] Column B for most fruit crops and table grapes (most tropical fruits are irrigated between -25 and -40 kPa)
[3] Column C for wine grapes (except during partial root zone drying), most pastures and field crops such as maize and soybeans
[4] Column D for lucerne, annual pastures and hardy crops such as cotton, sorghum and winter cereals

Example RAW calculation



Effective root depth = 0.7 m; Refill point is -20 kPa

Layer 1 RAW = 0.2 m X 40 mm/m = 8 mm
Layer 2 RAW = 0.3 m X 30 mm/m = 9 mm
Layer 3 RAW = 0.2 X 25 mm/m = 5 mm

Root zone RAW = Layer 1 RAW + Layer 2 RAW + Layer 3 RAW
= 8 mm + 9 mm + 5 mm
= 22 mm

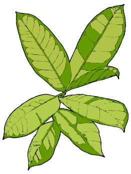
Profile RAW (to 1.0 m) = 8 mm + 9 mm + 12.5 mm
= 29.5 mm

Practical Implications

- Soil properties strongly influence water storage and availability.
- RAW is water that plants can easily remove from the soil.
- Irrigation design should be matched to soil type.

Plant Water Use Activity

Calculating Daily water use



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Key Calculations

Daily Water Use

ETc = Crop coefficient (Kc) x Evapotranspiration (ETo)

Daily irrigation requirement (mm/d)

= (ETc – effective rainfall*)/ application efficiency

**Effective rainfall* = during spring, summer and autumn periods, subtract 5mm from the total daily rainfall. In winter, all the rainfall is assumed to be effective.

Question 2

Assume 7 mm of effective rain fell in the morning and also assume you are using a well maintained drip irrigation system with very few leaks. You have an irrigation efficiency of 0.9.

The ETo today is 9.6 mm and the crop is in the mid-season development with a crop coefficient of 1.05.

What is your daily irrigation requirement?

Answer:

For the 30 Hectares of melons planted what is the amount of irrigation water required?

= (area of crop x daily irrigation requirements) / 100

=

=

Dividing by 100 is the conversion factor for changing mm to Megalitres

Question 3

For the soil used in the previous example the RAW was calculated to be 16 mm.

	A	B	C	D	E	F	G
Date	ET_o Evapo-transpiration	K_c Crop Coefficient	ET_c (A x B) Daily crop water use	ETc/ Efficiency Example = 0.8	Effective rain* or irrigation (mm)	Daily change in water balance (E – D)	Remaining available water (G + F)
7th Jan	8.2	0.95			30 mm irrigation	20.2	+1.4 drainage means 0.0
8th Jan	8.0	0.95			0		
9th Jan	8.2	0.95			10 rain		
10th Jan	8.1	0.95			0		
11th Jan	8.2	0.95					

Soil is full to start

Deficit is more than RAW

*Effective rainfall = during spring, summer and autumn periods, subtract 5mm from the total daily rainfall. In winter, all the rainfall is assumed to be effective.

** Table adapted from WaterWise – Scheduling and Benchmarking. NSW Agriculture 2001.

How often to irrigate

Irrigation Interval (days) =

$$\frac{\text{RAW}}{\text{Crop requirement (mm/day)}}$$

Irrigation Interval (days) =

Interval is longer in the table because in this calculation the rain event is not included.

In Summary

1. Evapotranspiration data and Crop coefficient data can be used to calculate daily water use and irrigation scheduling
2. On farm data specific to you conditions is most accurate
3. Knowing the amount of water applied ensures you don't over or under water your crop and this ensures maximum yield and profit