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Modern Soil Moisture Monitoring for Drought Resilience

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South-West WA Drought Resilience Adoption and Innovation Hub

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Abbreviations

ETO	Evapotranspiration
SMM	Soil Moisture Monitoring

Attributions

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Executive Summary

This report provides a comprehensive analysis of soil moisture monitoring systems' implementation and effectiveness across 15 farms in Western Australia. The study focuses on apple, avocado, and tomato growers, aiming to assess how soil moisture monitoring enhances drought resilience in horticultural farms and promotes efficient and effective irrigation scheduling. Key findings include the benefits of precision irrigation, early detection of water stress, tailored water management, and resource conservation. Challenges such as interpreting complex data and barriers to adopting modern soil moisture monitoring are identified and addressed, however, barriers such as an adequate support system in Western Australia for the uptake of data driven practices still require addressing. The report ultimately demonstrates the significant impact of soil moisture monitoring on optimising irrigation strategies, enhancing crop productivity, and contributing to sustainable agricultural practices.

Introduction

Droughts and their adverse impacts have been increasingly prevalent in the agricultural landscape of Australia, posing significant challenges for horticultural farms across different regions. As more hurdles emerge, farmers face mounting pressure to secure their crops yields and maintain economic stability. In response to these challenges, soil moisture monitoring has emerged as a promising approach to improve drought resilience in irrigated agriculture (Stirzaker, 2006).

This report presents a comprehensive study conducted across 15 farms in Western Australia over 12 months, focusing on the implementation and effectiveness of soil moisture monitoring systems. The participating farms in Western Australia included 10 apple and avocado growers from the South-west region along with 5 tomato growers from the Carnarvon Horticulture district. By encompassing a diverse range of crops and geographical regions, the study aims to provide a holistic understanding of soil moisture's impact on drought resilience in various agricultural contexts.

The objectives of this study revolve around assessing the efficacy of soil moisture monitoring in enhancing drought resilience on horticultural farms, identifying crop-specific water requirements, and exploring the practical benefits of real-time soil moisture data in decision-making processes related to irrigation and resource management.

Despite the promising benefits, the widespread adoption of soil moisture monitoring systems faces several barriers that hinder its implementation in horticultural farming practices. By examining the barriers to adoption of this technology, we aim to better understand the factors that hinder its uptake and seek potential strategies to overcome the challenges.

Through the integration of cutting-edge technology, on-field collection, and farmers' insights, this study seeks to offer valuable insights into the practical implications of soil moisture monitoring on crop productivity and water management. The findings of this research endeavour are expected to contribute to the knowledge base of fertilizer and water management, enabling farmers and researchers to optimize their irrigation strategies and cultivate greater resilience against future drought events.

How does Soil Moisture Monitoring improve irrigation management and drought tolerance?

Soil Moisture Monitoring plays a crucial role in improving irrigation practices and enhancing drought tolerance in horticultural farming. By providing real-time data on soil water content, farmers can make informed decisions regarding irrigation, leading to several benefits:

1. **Precision Irrigation**

Soil moisture monitoring enables precision irrigation, where water is applied precisely when and where it is needed. Instead of irrigating on a fixed schedule or relying on visual cues, farmers can use data-driven insights to determine the optimal timing and amount of water required for each crop. This targeted approach minimises water wastage and prevents overwatering, leading to more efficient water use and reduced irrigation costs.

2. **Avoiding under or over irrigation:**

Under-irrigation can lead to water stress in plants, hindering their growth and reducing crop yields. On the other hand, over-irrigation can result in waterlogging, causing root rot and other adverse effects. An experienced apple grower claims that water stress from either over or under irrigating can cause a loss of up to 20mm in fruit diameter come harvest. Soil moisture monitoring helps maintain soil water content within the ideal range, ensuring that crops receive sufficient water without drowning or drying out their roots.

3. **Early detecting of water stress**

Soil moisture sensors can detect early signs of water stress in plants by monitoring the soil water content. As the soil moisture decreases, farmers are alerted to potential water deficiencies in the root zone, allowing them to take proactive measures before visible signs of stress appear in the plants. This early detection helps prevent yield losses and promotes better crop health; this is critical when avoiding total crop abscission in avocadoes during the summer as an example.

4. **Drought mitigation strategies**

During drought conditions when rainfall has been scarce or increased demand of water has caused cuts in allocation, soil moisture monitoring becomes even more critical. By continuously monitoring soil levels, farmers can optimize irrigation schedules and prioritize water usage for the most vulnerable crops or growth stages. This strategic approach ensures that available water resources are utilized efficiently during drought periods, minimizing the overall impact on crop production.

5. **Tailored water management**

Different crops have varying water requirements at different growth stages. Soil moisture monitoring allows farmers to tailor their water management strategies based on the specific needs of each crop. They can adjust irrigation schedules and volumes based on real-time data, optimizing water distribution and maximizing crop productivity.

6. **Resource conservation**

Efficient water management through soil moisture monitoring not only benefits crops but also contributes to broader resource conservation efforts. By using water more judiciously, farmers can conserve this valuable resource, reducing their environmental impact and contributing to sustainable agricultural practices. With the use of pressure transducers, crop water demand can be combined with farm water availability to design water budgets that could be critical in ensuring business stability in a water deficit environment.

Factors affecting crop irrigation scheduling.

Effective irrigation scheduling is essential for maximizing crop yields, conserving water resources, and promoting sustainable agricultural practices. Several factors influence the timing and frequency of irrigation, and understanding these factors is crucial for optimizing water use and crop productivity.

Crop Type and Growth Stage

Crop water requirements vary significantly throughout their growth stages. During the seedling and early establishment phase, crops necessitate short and frequent irrigation scheduling to ensure successful establishment. As crops mature, their developed root systems enable them to access water from deeper soil layers, reducing the need for frequent irrigation events and allowing longer intervals between watering. The variety of the crop and rootstocks used also influence water demand. A thorough understanding of the specific water needs at each growth stage is essential for precise irrigation scheduling. In this case study report, we will explore the unique water requirements of tomatoes, avocados, and apples, shedding light on effective irrigation strategies for each crop.

Soil type and properties

Soil characteristics, including texture, structure, and water-holding capacity, influence water availability to plant roots. Sandy soils drain quickly and do not have a large water-holding capacity, requiring more frequent irrigation at short durations, while clay soils hold more water for longer, necessitating careful irrigation management to prevent waterlogging.

Climate and Weather Conditions

Weather factors, such as temperature, humidity, wind speed, and evapotranspiration (ETO) rates, directly impact the rate of water loss from the soil and plant surfaces. Hot, dry, windy weather accelerates evaporation, increasing the crop's water demand. Monitoring weather conditions and forecasts allow adjustments of irrigation scheduling to meet changing water needs present and in days to come.

Weather stations offer valuable data on ETO and evaporation, both of which play crucial roles in irrigation scheduling. ETO and evaporation data specific to Western Australia can be readily accessed through the following website: https://weather.agric.wa.gov.au/

Irrigation Method and System

The choice of irrigation method (e.g., surface, sprinkler, drip) and the efficiency of the irrigation system impact water distribution and utilization. Efficient irrigation systems reduce water wastage and allow precise application optimizing water use efficiency. Water wastage in an inefficient system has leaks in the irrigation infrastructure, water exposed to evaporation such as water on the surface or from sprinklers. An important characteristic to understand about irrigation infrastructure is the water distribution throughout a given irrigation block and the water distribution caused by the sprinkler, drip, or surface irrigation technique used for that given soil texture.

Irrigation water quality

Water quality, encompassing salinity levels and potential contaminants, exerts a significant impact on both crop health and water uptake. When marginally saline water is used for irrigation, the soil's salinity can escalate due to water removal by the crop and evaporation. To counteract this effect, additional water may be necessary to leach salts from the root zone, a practice commonly known as a leaching fraction. Alternatively, during the winter months, natural rainfall can often suffice to effectively leach harmful salts from the root zone. Soil moisture monitoring provides allows growers to achieve the necessary leeching effectively and efficiently by knowing exactly how much volume of water must pass through the soil to remove harmful salts to their crop.

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Barriers to Modern Soil Moisture Monitoring Equipment

Soil moisture monitoring holds the potential to empower growers with invaluable insights, enabling them to operate their agricultural business profitably and sustainably. Regrettably, this potential has remained largely untapped over the past few decades, despite the availability of soil moisture monitoring equipment capable of providing accurate data and information. The reluctance to embrace soil moisture monitoring practices has been caused by significant barriers. Addressing these barriers is pivotal not only for growers eager to embrace this practice but also for the overall enhancement and sustainability of the irrigated agriculture and horticultural industry in Australia as water becomes greater in demand and risks becoming scarcer.

Installation and site selection

Soil moisture monitoring sensors require good installation and site selection. It is common for soil moisture sensors to be installed incorrectly in the soil due to poor contact or debris potentially interfering with the data. Poor contact with the soil means the sensor has a pocket of air in its monitoring field if using a capacitance probe (commonly volumetric) and can lead to misleading results.

Site selection is critical for determining the irrigation management for an irrigation block. When using soil moisture sensors, only a small volume of soil is being measured for its soil water content and this information needs to be used to make decisions on the irrigation management for the entire irrigation block. It is important to have the sensor installed in a location the is comparable to the rest of the block. For instance, it does not make sense to install the sensor where the soil texture is unique or receives greater amounts of water due to the slope of the area causing runoff to that location. It is important to know if leaking irrigation is nearby that can cause misleading results. Without good site selection it is possible that the area with the sensor will be favoured by the irrigation management while the rest of the crop will be neglected.

Return on Investment

Growers can find it hard to justify the cost of investing into soil moisture monitoring equipment if they do not see the value they can offer. It is difficult for a grower and an agronomist to determine with confidence what return on investment they will expect by implementing soil moisture monitoring practices. It is possible to estimate what value can be gained by comparing the agriculture business performance to benchmark studies, but it does not conclude that the gap in value is caused by a lack of soil moisture monitoring practices. However, what can be certain is the variability of water and fertiliser input there is for the same crop between different growers highlights a critical gap that can be addressed with soil moisture monitoring that can improve not only accuracy and productivity in the horticulture and irrigated agriculture industry but also pave the way towards a sustainable industry that is building greater resilience to availability of water and fertiliser.

Interpreting Soil Moisture Monitoring Data

The information provided by soil moisture monitoring equipment can be difficult to understand and can overload the user with too much information. When it comes to volumetric data points, which is what is commonly used in modern soil moisture monitoring equipment, the information has not been standardised for their soil unlike tensiometers where it is easier to understand the stress of crops by measuring water tension in the soil. This requires standardised practices that can be applied to all or most soil types to make it easier for growers to understand the data coming from the sensors.

With modern soil moisture monitoring equipment, they often measure temperature as well as EC in the soil. It is also possible, since the data is online, to have other data inputs into graphs such as evapotranspiration, rainfall, air temperature, which can easily overload the user with too much information. For users starting soil moisture monitoring equipment it may be best to begin with only a few soil moisture data sensor inputs to become accustomed to the information before advancing with further inputs such as evapotranspiration and rainfall.

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Limitations of Soil Moisture Monitoring Technology

Soil Moisture Monitoring Installation

The installation process of digital and analogue soil moisture monitoring equipment is critical for successfully obtaining information about your soil moisture and irrigation water behaviour through the soil profile. Poor installation and poor location of the sensors can provide misleading or unreadable information that can cause damage if irrigation decisions are made based of the soil moisture monitoring information alone. Soil moisture sensors cannot compensate for poor installation and poor location selection within a crop.

Sensor field of observation vs size of irrigation block

The volume of soil that the soil moisture sensors observe for moisture levels is incredibly small relative to the area that is being cropped. In an ideal world, a grower knows the moisture levels throughout their farm to accurately place water and fertiliser as needed to maximise efficiency and productivity. It is not economically reasonable to install multiple soil moisture sensors throughout an irrigation block unless there are drastic changes in soil texture, crop maturity, or any other factor affecting water supply/demand. This gap in soil moisture monitoring is currently being attempted by using simulated models that predict the water content in the soil throughout the farm by correlating weather data with the soil moisture sensor data from a single point on the farm. This is done by monitoring irrigation, analysing the soils water holding capacity, adjusting moisture according to evapotranspiration and testing the simulation by going out into the field to collect samples.

Tension vs volumetric

The most common soil moisture monitoring equipment used in Australia is the tensiometer which measures the water tension in the soil by using a porous tip that allows water in the tensiometer tube to interact with the capillary forces in the soil. This capillary force is measured in pressure as Kpa or bar and is called the water tension. Water tension provides information to the grower as to what the crop is experiencing in the soil. This information can be easily interpreted by growers, agronomists and researchers and applied to their irrigation management strategy. Modern soil moisture monitoring, on the other hand, uses volumetric water content and alone does not provide the user clear insight as to how they should manage their irrigation scheduling. Therefore, it takes the user time understanding the results the sensors provide and about the physical characteristics of their soil.

Support services

Given the complicated nature soil moisture monitoring can find itself in, it can be increasingly appealing to seek a consultant such as an agronomist to assist in the interpretation of the data and provide recommendations on irrigation scheduling management. Unfortunately, there is not a wide availability of consultants and agronomists in the horticulture and irrigated agriculture industry. An industry in WA too small and segmented may be to blame for a lack of these specialised services that would provide a lot of value not only to soil moisture monitoring practices but to other practices in cropping as well.

Soil Moisture Monitoring Equipment Overview

Modern soil moisture monitoring for improved drought resilience primary objective was to support growers in adopting the soil moisture monitoring practice and having the opportunity to get hands on experience alongside with comprehensive guidance from an irrigation development officer. The type of equipment provided to each of the participants in the project were:

- Teros 12
- EnviroPro
- Teros 21 (for select growers)
- Pressure transducer
- Logger + solar panel

Teros 12

The Teros 12 is a prong style soil moisture probe that provides information such as volumetric water content % (VWC), temperature, and bulk electrical conductivity (EC). Each grower in the project received three Teros 12 sensors to be strategically placed at various depths to capture the distribution of irrigation. The sensors were installed by using a 150mm post hole auger which allowed the sensors to be installed horizontally. See the table below for the depths of the sensors for the different crop types:

Teros 12	1st sensor	2nd sensor	3rd sensor
Tomato	10cm	20cm	40cm
Avocado	10cm	20cm	50cm
Apple	20cm	40cm	60cm

The reasoning behind the different depths selected for each crop is to understand the moisture content in the effective root zone, which is where more than 70% of the fine root hairs can be found which are responsible for majority of water and nutrient uptake in most crops, and to monitor for leeching which is how water and fertiliser can be lost. Tomatoes and avocadoes have shallow root systems, majority of the fine root hairs occurring in the top 20cm of the soil, therefore one sensor is placed in the middle and one at the bottom of the effective root zone, apples have a slightly deeper effective root zone and not as concentrated in the top 20cm, so the first two sensors are more spaced apart. The deepest sensor is where little or no roots are normally found for tomato, avocado, and apple crops, these were placed at 40, 50, and 60cm respectively. Now with the knowledge of the project, placing the 3rd sensor for the avocado and tomato crops at 50cm or even 60cm would not go unwarranted as it was observed that both crops have the capacity to remove significant amounts of water from that depth.

EnviroPro

The EnviroPro is shaped like a cylinder with sensors every 10cm down its length measuring VWC%, temperature, and EC. There were two versions used in the project, a 40cm that was used in the tomatoes and a longer version of 80cm for the apple and avocado orchards to monitor leeching at greater depths. The EnviroPro offers a sleek design to make installation of the equipment and getting multiple sensors into the ground easier. The installation of the EnviroPro has various methods, the best two used in the project were:

1. **150mm post hole auger**
   In the southwest for the apple and avocado growers, a 150mm post hole auger was used to drill a hole 850mm deep. The reason for drilling such a wide hole was to ensure good soil contact by replacing the soil around the sensor by hand. The soil was placed in the hole back in order from subsoil to topsoil at the original compaction. This provided quality data on soil moisture.

2. **Timber auger**
   The second method was using a timber auger with a diameter slightly smaller than the probe (25-35mm) connected to a battery drill. This created a smooth hole into the ground in a single drill. Once the hole was made the EnviroPro was squeezed in, this ensured good soil contact for quality data. This was the best method in Carnarvon since the tomato growers would rotary hoe the soil and irrigate the beds making the soil extremely soft, after drilling a hole there was very little resistance with installing the EnviroPro into the ground, often taking less than a minute to install.

Teros 21

The Teros 21 features a porous ceramic tip and provides water tension and temperature. This was used on selected growers to assist them in referencing the volumetric water content with water tension to get a better idea of what the crop was experiencing. Only one Teros 21 sensor was installed and was positioned in the topsoil, to install the sensor either the 150mm post hole auger or a spade was used since the depth of the sensor was to only be 10-20cm deep.

Pressure Transducer

Each grower in the project had a pressure transducer installed into the irrigation line near to where the soil moisture sensors were installed. This allowed data to be collected on the pressure in the irrigation lines which corresponded to when the irrigation system was turned on, with this information we can:

- Determine the pressure the irrigation is being applied where the sensors are and understand the drop in pressure from the pump.
- Know when the irrigation system was turned on and for how long. This allows growers to adjust their irrigation duration and frequency accurately if they notice they have over or underwatered.
- Determine the amount of water being applied to an area or per tree/plant.
- Determine the amount of water applied each day, month, season, and year. With this information, growers can budget for future years.
- Identify problems such as burst pipes, solenoid failures, misuse of irrigation controllers, and pump failures.

The pressure transducer proved itself as an invaluable piece of equipment when it came to improving water use efficiency in irrigated crop production.

Soil Moisture Monitoring Sensor Site Selection and Installation

The installation process of digital and analogue soil moisture monitoring equipment is critical for successfully obtaining information about your soil moisture and irrigation. Poor installation and poor location of the sensors can provide misleading or unreadable information that can cause damage to the crop if irrigation decisions are made based off the soil moisture monitoring information alone.

Sensor Location

To determine the location to install soil moisture sensors depends on a range of factors. The main purpose of soil moisture sensors is to assist in managing the irrigation for a particular area of crop that receives the water at the same time from the same irrigation infrastructure. In this situation we want to choose a location that can represent most of the irrigation block so that appropriate water is delivered to the crop to maximise efficiency and productivity. A desirable location for this is:

- An area that contains the soil texture dominant through the irrigation block.
- The crop is healthy, doesn't have diseases, and is at a similar maturity as the rest of the crop.
- The crop was planted at the same time.
- If there is a slope, the ideal location might be in the middle of the slope where water placement is at an average.

Another objective might be to understand a particular area that is not performing well. This is called troubleshooting and what growers might want to know could be:

- Is the area receiving more or less water than intended?
- Does the soil have a different texture, is it heavier or sandier and how is this affecting water availability?
- Is the water demand for the crop not has high because the crop isn't as mature?
- Is the area drying slower or faster because the environment is different?

Sensor Installation

Good installation of a soil moisture monitoring sensor is critical for clear and concise information. Poor installation can become misleading and cause damage to the crop if it results in over or underwatering.

Depending on what type of sensor is being used a different technique will need to be adopted.

- Teros 12, 21 and other single unit sensors (see image 1 below), a hole is dug, and the sensor is buried at the ideal depth. A post hole auger has been used in the case studies of this project to great success. However, as the soil becomes heavier with a greater clay content it can become difficult to fill the hole and ensure there are no gaps that will allow water to infiltrate faster. In this case, the soil removed from the hole is broken up into small pieces and watered to reduce the chances of air gaps in the soil.
- EnviroPro sensors and others sensors with a cylindrical type body can be installed into the ground by using a timber auger that has a diameter just less than the sensors body to ensure a tight fit or by installing the EnviroPro by using the 150mm post hole auger and then filling the hole by hand around the sensor to ensure good soil contact which was the main installation method for all of the case studies.

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Crop Specific Irrigation Management

Avocado Irrigation

A notable percentage of avocado roots primarily inhabit the topsoil, easily revealed by gently removing a thin layer of surface soil. In orchards employing mulch, these roots extend into the decomposing mulch layer. Interestingly, avocado roots have the capacity to not only source significant amounts of moisture from the topsoil but from as deep as 80cm in the soil, indicating a root system the takes advantage of deeper subsoil moisture. This phenomenon becomes particularly pronounced during periods of heightened heat and evapotranspiration stress observed during the project.

Avocado growers in the South-West of Western Australia commonly employed a uniform irrigation practice during summer, allocating approximately an hour of irrigation (equivalent to roughly 50 litres per tree) every day to every second or third day. This standardised approach was consistently applied across all orchards, regardless of variations in soil textures. Notably, growers may not have been considering their soil's distinct water holding capacity and the specific evapotranspiration rates experienced by their orchards, highlighting a potential oversight in optimizing water management strategies. During the winter months avocado growers would stop their irrigations until the weather warmed up again and rain became too infrequent. Unfortunately, this exposed the orchard to drought stress since avocadoes have a water demand throughout the year and is not consistently satisfied by rainfall. The sensors have allowed growers to monitor the soil moisture and provide irrigation when the soil was reaching a critical point of water stress.

The standardised approach through summer and winter resulted in several issues:

- Prolonged irrigation events, leading to orchards being overwatered, causing leeching of water and fertiliser, and exposing the orchard to ideal conditions for phytophthora.
- Irrigation too frequent; orchards receiving too much water too frequently, leading to overwatering stress and leeching.
- Irrigation too infrequent; the orchard experiences drought stress.
- Not compensating for increased evapotranspiration; when the orchard's water demand increases or experiences a heat wave, the irrigation is not adjusted accordingly. This leads not only to drought stress for the days of the heatwave but for the week following as the subsoil has dried and no longer has enough moisture to provide to the orchard until the topsoil becomes saturated again and allows moisture to penetrate deeper into the soil.

Apple Irrigation

Unlike avocado trees, apple trees effective root zone appears to be deeper and more spread though the topsoil and subsoil. Apple trees have a significant portion of their water demand from spring, when bud burst occurs, to autumn or the beginning of winter where the orchard falls into dormancy. Drip irrigation is the most common practice in the apple orchard industry and proves to be much more efficient at penetrating deeper into the soil than sprinklers at the cost of horizontal application of water.

Apple growers who have not focused on optimising their irrigation scheduling were found facing the same issues as the avocado growers who also have not focused on this practice. This means their orchard often faced over and under irrigation during the growing season from not understanding their soil's water holding capacity and the variability in their orchard water demand.

Tomato Irrigation

Tomato irrigation practices in Carnarvon exclusively rely on drip irrigation, a method enhanced by the use of a thin plastic mulch layer to minimise water evaporation. This innovative combination of drip irrigation and plastic mulching has become the predominant technique in the Carnarvon horticulture vegetable production district, effectively replacing the outdated flood irrigation system.

Notably, tomato crops have substantial proportion of their roots concentrated within the upper 20cm of the soil, where they access vital moisture and nutrients. To accurately gauge soil moisture levels, sensors were strategically placed at depths of 10cm, 20cm and 40cm. Surprisingly, during the monitoring process, it became evident that in the fertile earth loam, tomatoes were actively extracting a significant amount of water from the 40cm depth. This revelation suggests the potential existence of tomato roots extending to the 40cm mark. Consequently, for more effective monitoring of leaching, it would be prudent to relocate the 40cm sensor to a depth of 50cm.

Similarly, to apple and avocado growers, tomato growers had not prioritized the improvement of their irrigation scheduling practices. Consequently, they encountered various issues, including:

1. Over-or under-irrigation, leading to problems such as excessive leeching of water and fertiliser or insufficiently moistening the effective root zone.
2. Inconsistent irrigation frequency, causing either constantly saturated soil conditions or frequently dry soil.
3. Failure to account for increased evapotranspiration rates, resulting in soil drying out and inadequate water availability.
4. Neglecting to adjust for decreased evapotranspiration, leading to leaching and saturated soils.

Addressing these challenges through more precise irrigation scheduling is crucial for optimizing tomato cultivation and ensuring efficient resource utilization.

Evapotranspiration and Rainfall

Weather conditions, particularly evapotranspiration, and irrigation scheduling are intricately linked and hold significant importance for the horticulture industry, understanding how evapotranspiration influences crop water demand is crucial. Even a single scorching day in January, coupled with suboptimal irrigation scheduling, can wreak havoc on avocado yields, apple quality, and tomato fruit set. As the potential for evaporation rises, so does the crop's thirst for water. This is visibly reflected in soil moisture monitoring equipment, which reveals the gradual drying of the soil profile in the vicinity of the plant roots.

Growers must grasp this intricate connection and utilise soil moisture monitoring equipment to irrigate with purpose and precision. Furthermore, rainfall is another pivotal weather factor that warrants precise monitoring. Many growers in the project have tended to overestimate the impact of rainfall. In reality, it takes a minimum of 15mm of rain to make a substantial difference in soil moisture content, and this moisture in the soil is often removed by the crop with the following 24 hours.

Fortunately, there are an array of weather stations and tools readily accessible for gathering location-specific data, allowing growers to make informed decisions regarding crop water demand. This data can be seamlessly integrated into online soil moisture monitoring platforms, enhancing the accuracy and efficiency of irrigation strategies tailored to each grower's unique conditions.

Soil Moisture Monitoring Interpretation.

Using the graphs created by the soil moisture sensors is not about identifying critical volumetric water contents of the soil but understanding the behaviour of water in soil. A key understanding is that soil can only hold onto so much water, sand holding the least and loams and clays holding the most. With this in mind, the soil will only pass water deeper if it cannot hold onto it or because there is a layer of compaction, therefore, we must essentially saturate the soil's holding capacity before the water can travel deeper, this is important to do because we want to ensure that water is being delivered to as much of the crop's root mass as possible to create an environment where the crop can efficiently and effectively assimilate water and fertilizer.

Soil moisture monitoring graph characteristics

To gain a deeper understanding of the irrigation scheduling currently being implemented and what it is achieving, several key characteristics in the graphs need to be understood. This can offer valuable insights into what is transpiring and indicate how effective current irrigation scheduling is and how it can be improved.

Irrigation events

By Utilising soil moisture monitoring equipment coupled with a pressure transducer, we gain a comprehensive view of irrigation events. In the figure below, the pink lines represent the pressure transducer's data, clearly indicating when and for how long irrigation events take place. Simultaneously, the impact of these events on soil moisture levels is evident through the data from the three Teros 12 soil moisture sensors positioned at depths of 15cm, 30cm, and 60cm, color-coded as blue, green, and red, respectively.

A distinctive trait of irrigation events is the rapid and discernible increase in soil moisture content recorded by the shallowest sensor (blue line). This immediate response at the shallower depth is a reliable indicator of successful irrigation application. However, deviations from this pattern, where a deeper sensor registers increased soil moisture levels before a shallower one, may suggest an alternative water movement path, such as horizontal dispersion in a dripper irrigation system.

In the figure below, the blue line serves as a visual representation of these characteristic irrigation events, clearly showcasing the sharp and distinctive spikes in moisture content. This insightful data empowers growers to precisely monitor and assess the effectiveness of their irrigation practices, ensuring the crops receive adequate water.

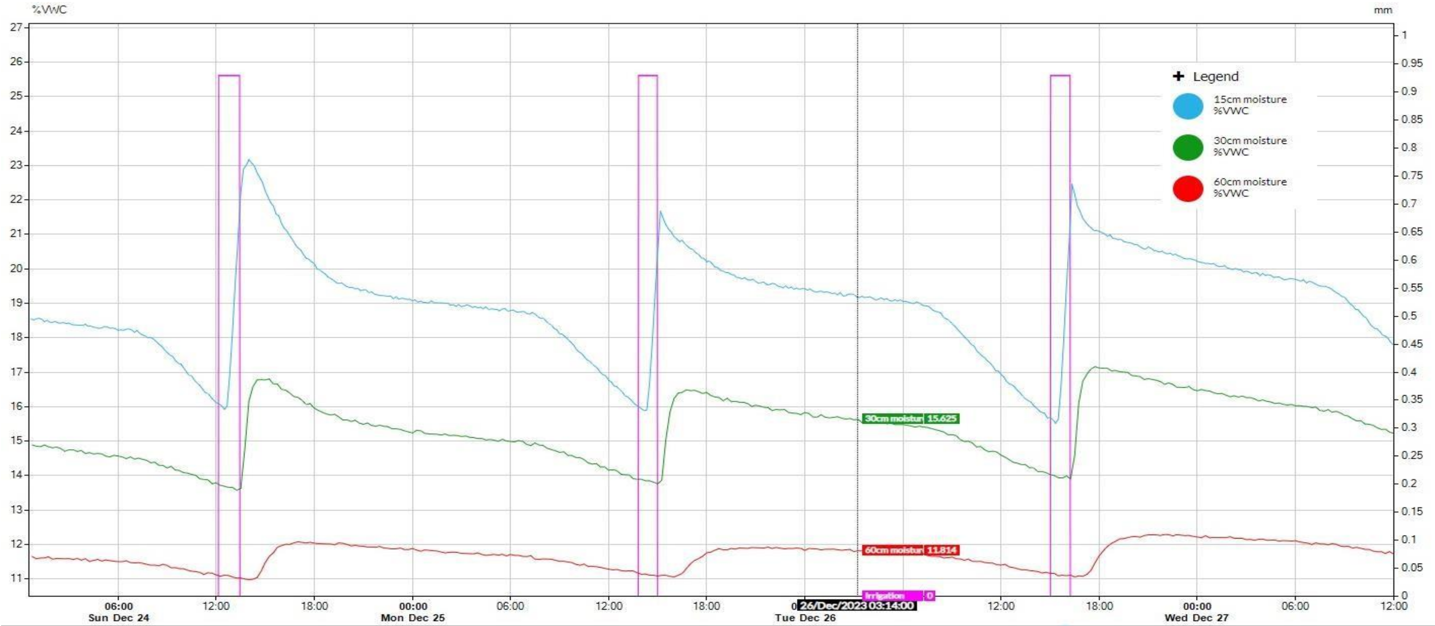

Figure 1 Wildeye online platform graph of the Teros 12 soil moisture monitoring equipment and pressure transducer in an avocado orchard in the southwest on sandy soils.

Drainage event

Differentiating between drainage and crop water uptake can be difficult, as their patterns can often appear quite similar. Drainage events typically manifest immediately after irrigation or rainfall and exhibit a steeper decline in moisture content. One key trait indicative of drainage is the rise in moisture readings at deeper sensor depths.

In figure 1 above, we can closely observe the behaviour of these characteristics through the color-coded lines representing soil moisture sensors at various depths. The blue line, associated with the 15cm sensor, shows a pronounced and rapid increase during and shortly after each irrigation event. Towards the conclusion of the irrigation event, the green line (30cm sensor) exhibits a sharp uptick in moisture content. This observation strongly suggests the movement of water from the 15cm soil profile into the 30cm soil profile – a clear indication of drainage.

As the green line plateaus, it has become evident that water has now drained from the 30cm profile into the 60cm profile, indicated by the rising moisture levels on the red line (60cm sensor). This subsequential pattern of moisture content changes from shallow to deep sensors confirms the downward movement of water through the soil profile.

By recognising these distinct patterns and trends growers can effectively differentiate between drainage events and crop water uptake patterns. By knowing when drainage occurs gives understanding about the soil's water holding capacity to avoid leeching. If an irrigation event causes moisture to excessively drain to the 60cm sensor, then the event is at high risk of causing leeching that results in a loss in fertiliser, and water that would have been used for crop productivity.

Leeching event

While leaching and drainage both involve water moving to deeper soil depths, they serve different purposes and have distinct characteristics. Leaching occurs when water drains beyond the reach of the crop's roots. Its primary objective is to remove salts, particularly sodium from irrigation water, from the effective root zone. The frequency extent of leaching events depends on the salinity of the irrigation water. However, excessive leaching can lead to unnecessary water and fertiliser loss.

During leaching, water carries soluble salts, including fertilisers such as nitrates and other essential nutrients like magnesium, potassium, phosphorous, and calcium, deeper into the soil. This can result in a loss of crop productivity, as fertilisers are removed from the effective root zone, potentially causing nutrient deficiencies that growers may not be aware of.

To identify leaching events, one can monitor the moisture content at the deepest sensor, typically located outside the effective root zone. In figure 2 below, represented by the red line at 60cm depth, we can observe how moisture levels change after rainfall or irrigation events to determine if leaching has occurred and to what extent.

For instance, on May 15, 2023, during the first irrigation event, a slight increase in moisture at 60cm is noted. This indicates that the irrigation effectively utilized the soil's water -holding capacity without excessive leaching. Its acceptable to have a minor moisture increase at 60cm, as long as it doesn't exhibit a steep increase followed by a steep decrease, a characteristic associated with drainage.

However, on May the 16th, an accidental double irrigation occurred, resulting in more water than intended reaching the 60cm depth. This event indicates a leaching occurrence, and growers may need to consider replenishing fertilisers in the subsequent irrigation to compensate for the loss of nutrients from the root zone.

By recognising these specific characteristics of leaching, growers can make informed decisions about their irrigation practices, ensuring optimal salt management and nutrient availability for healthy crop growth.

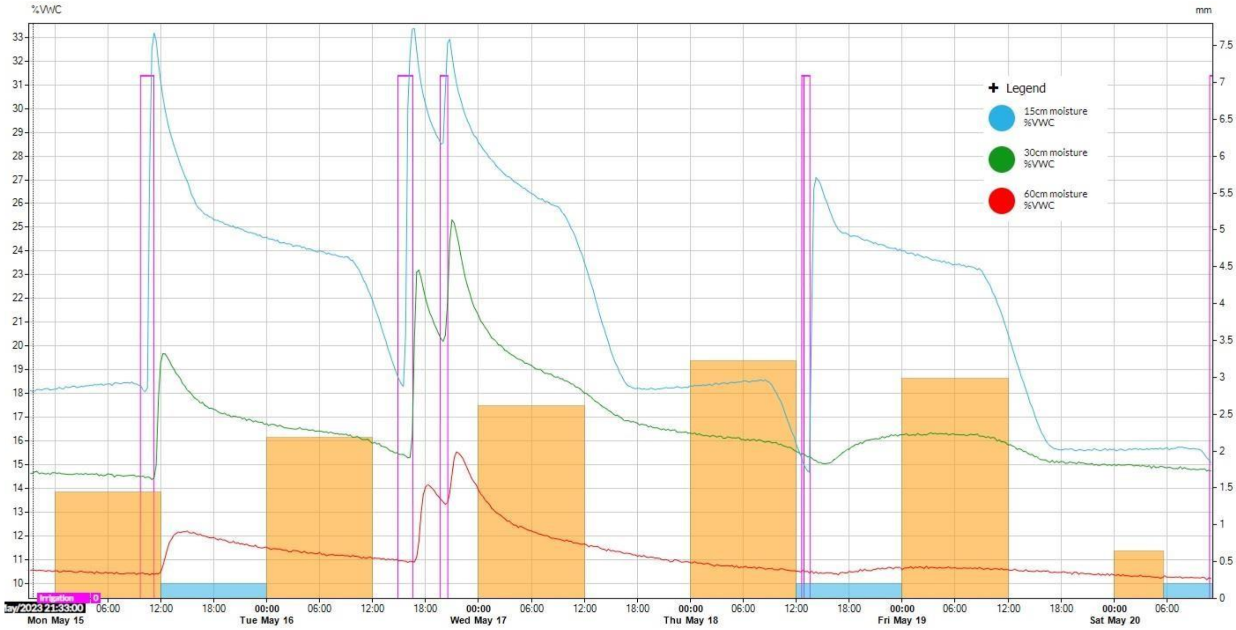

Figure 2 Wildeye online platform graph of the Teros 12 soil moisture monitoring equipment and pressure transducer in an avocado orchard in the southwest on sandy soils.

Crop Water Uptake

Monitoring crop water uptake can indeed pose challenges, particularly when dealing with concurrent irrigation, drainage, and leaching events. Fortunately, there are identifiable patterns associated with crop water uptake, especially during low light or evapotranspiration conditions, such as nighttime or cool overcast days.

In figure 2 above, a noteworthy example of crop water uptake is observed on May 17. The moisture content data reveals interesting behaviour during different time intervals.

1. From 00:00 to 06:00, we witness drainage occurring, characterized by the blue line's steep decline going into a plateau. This behaviour arises when soil moisture content exceeds the soil's water-holding capacity, resulting in gradual drainage. As it nears its water holding capacity, the drainage sows down, leading to the
2. Between 06:00 and 12:00. A marked decrease in moisture content is noted on the blue line, extending until 18:00 (6pm). This decline is not attributable to drainage but rather indicates the effects of plant uptake. It can be confidently ruled out as evaporation from sunlight, given that the sensor is positioned at a 15cm depth, where the influence of sun and atmospheric evaporation is minimal.
3. Additionally, we observe plant uptake effects at the 30cm depth during the same time period.
4. However, minimal moisture change is observed at the 60cm depth. This could be attributed to the absence of roots at this depth, as it lies outside the effective root zone, or it may signify that there is insufficient moisture at this depth for the crop to access.

With the above information in mind, we can now observe crop water demand on a daily basis and find it is closely correlated with evapotranspiration. This relationship will then help us identify when irrigation needs to occur because as the soil moisture content decreases, the crops' ability to remove soil moisture decreases as well resulting in a lower removal rate of water from the soil. By identifying when this occurs, growers can ensure timely irrigation to avoid moisture stress to their crop.

Determining Optimal Irrigation Timing

Understanding crop water uptake is a critical step in determining the timing of irrigation events, with the overarching objective being to allow the crop to assimilate the maximum amount of water daily. The irrigation objective may change depending on your crop and irrigation strategy. Based on the data from figure 3, here's a summary of the irrigation strategy:

WARNING!

This example is for an Avocado orchard in a sandy soil in the South-West of Western Australia. The example will not provide you when irrigation should occur on your farm with your crop, this example explains how you can find when you need to irrigate your crop on your soil. **Do not take the figures from this example** and use as your own indicators for when to irrigate because there are variations in the performance of different sensor models and calibration curves. Your will not have the exact same soil texture and it cannot be guaranteed that each sensor installation will provide the same readings despite being in the exact same soil. There is also great variability in different crop demands and the crop's ability to remove water from the soil. If you are finding it difficult to manage your irrigation scheduling from soil moisture sensors seek assistance from a profession such as an agronomist who is familiar with your crop and local area, DPIRD officers who have experience with your crop and area, or the suppliers, manufacturers of the equipment you are utilizing.

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1. **Observing Moisture Trends:** In figure 3, an irrigation event occurs on August 27, followed by drainage before crop water uptake becoming the dominant feature in the soil moisture content characteristics at 15cm (blue line) on August 28. However, as the soil becomes drier, the rate of decrease diminishes.
2. **Identifying target range:** Between 13% and 18% soil moisture content, it's evident that the crop faces increasing difficulty in extracting moisture from the soil. This range becomes the target for the next irrigation event.
3. **Frequency Consideration:** Based on this information, it is reasonable to plan for irrigation every 3rd day to ensure the crop consistently has access to adequate water.

However, there are important factors to consider when determining a crops water uptake demand and the crop's ability to remove water:

1. **Evapotranspiration Factor:** It's crucial to monitor evapotranspiration rates. If evapotranspiration remains relatively stable during the period when soil moisture content decrease, then the irrigation conclusion holds. But if evapotranspiration significantly decreases on subsequent days, it must be taken into account.
2. **Seasonal and daily variability:** Crop water demand can vary substantially from day to day and even more season to season. Therefore, it's imperative to continuously monitor both crop water demand and evapotranspiration patterns throughout the year. This monitoring will enable adjustments to the irrigation frequency based on changing environmental conditions.

In summary, the determination of optimal irrigation timing involves a dynamic process that considers both soil moisture content trends and evapotranspiration rates, The target soil moisture range and irrigation frequency should be adjusted as needed to accommodate the changing demands of the crop, ensuring it receives the necessary water for healthy growth and productivity.

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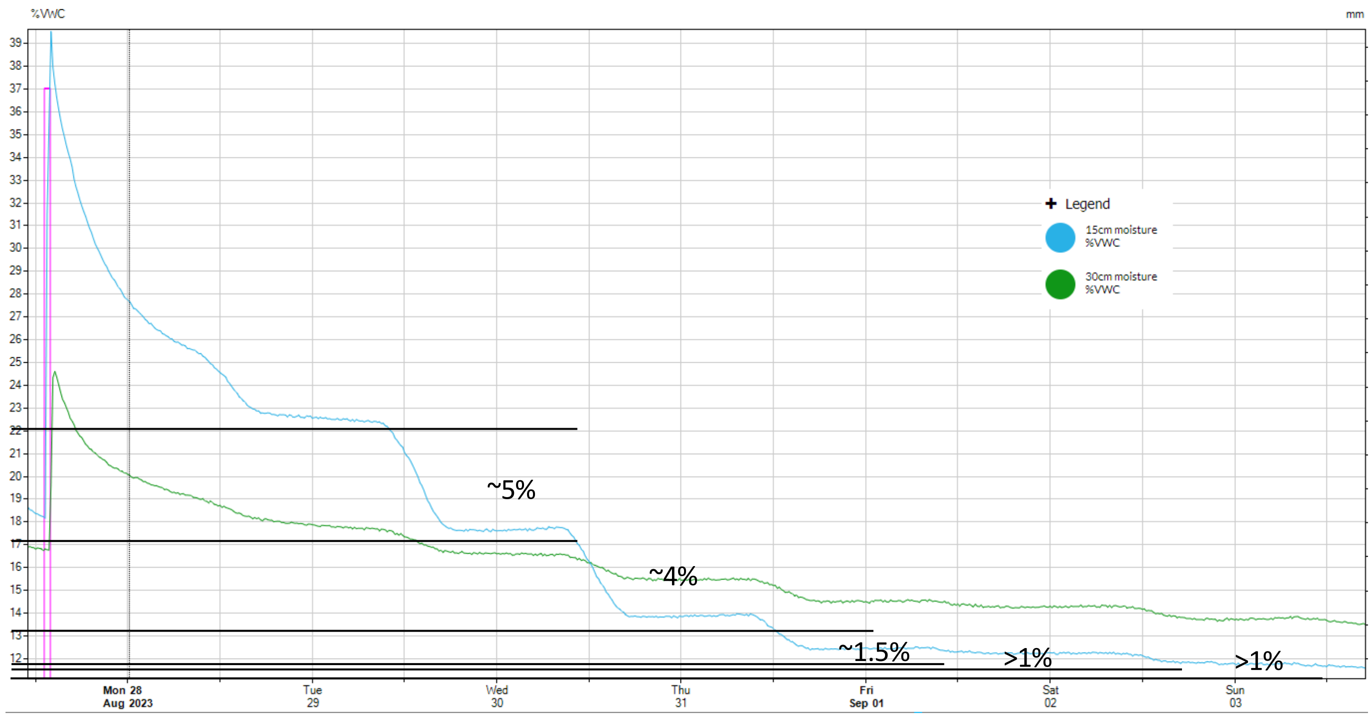

Figure 3 Wildeye online platform graph of the Teros 12 soil moisture monitoring equipment and pressure transducer in an avocado orchard in the southwest on sandy soils displaying the change in soil moisture content from crop water uptake.

Determining Optimal Irrigation Duration

Comprehending how drainage and leaching occur is crucial in determining the optimal duration for irrigation events. The primary objective is to saturate the soil's water holding capacity in the effective root zone without causing excessive drainage or leaching. To achieve this, three sensors are strategically placed: one within the effective root zone, another at the bottom of the effective root zone, and one deeper away from the effective root zone to measure leaching.

Figure 4 illustrates irrigation dynamics effectively. Light orange bars indicate the length of each irrigation event, and a pink line marks the start and end of irrigation. This setup enables us to analyse the impact of various irrigation durations on soil moisture levels from 15cm to 60cm depth. Key observations include:

- **Enhance understanding of irrigation impact**
  Identifying the ideal irrigation duration is essential to maximise water efficiency. Our aim is to ensure adequate drainage through the soil surface and the effective root zone, while preventing water from draining beyond this zone and causing leaching. We use two sensors to monitor moisture levels: one within the effective root zone and another at its base, assessing if adequate moisture is applied. A third sensor, placed deeper, measure potential leaching. Allowing minimal water to reach the deepest sensor outside the effective root zone (as depicted by the red line in figure 4) as acceptable, provided it doesn't indicate drainage or leaching, as observed on May 16th and 17th. Drainage and leaching characteristics on the red line indicate irrigation duration is too long for the given the soil moisture content at the start of the irrigation.

- **Figure 4s analysis: Duration and Moisture Content**
  Figure 4 features light orange bars, indicating the duration of each irrigation event, and a pink line specifying when irrigation commenced. This allows us to observe the effects of different durations on soil moisture from 15cm to 60cm. Notable instances include May 16, where two irrigation events led to significant

drainage, indicated by steep increases and decreases in the blue and green lines, and leaching, as shown by the sharp rise and fall in the red line. Conversely, on May 10th, a shorter irrigation period only slightly increases the soil moisture at 30cm, indicating that further irrigation may have benefitted the orchard.

- **Determining Optimal Irrigation Duration**
  By analysing figure 4, we can deduce the most suitable irrigation duration. On May 22nd, a 65-minute irrigation allowed minimal water to reach the 60cm depth. Similarly, on May 12th, 18th, 20th, and 24th, approximately 55 minute-irrigations moistened the topsoil with negligible impact at 60cm depth. Therefore, the ideal irrigation duration for this orchard lies between 55 and 65 minutes, though this may vary with changes in weather conditions like overcast skies or heatwave, as well as the soil water content at the beginning of the irrigation event.

- **Variability in Soil Moisture Response**
  From May 10th to 25th, it's evident that each irrigation event uniquely affects soil moisture, contingent on the existing water content in the soil. A consistent 60-minute daily irrigation can result in varying outcomes, from leaching to insufficient watering, due to fluctuating soil moisture influenced by the crop's evapotranspiration rates.

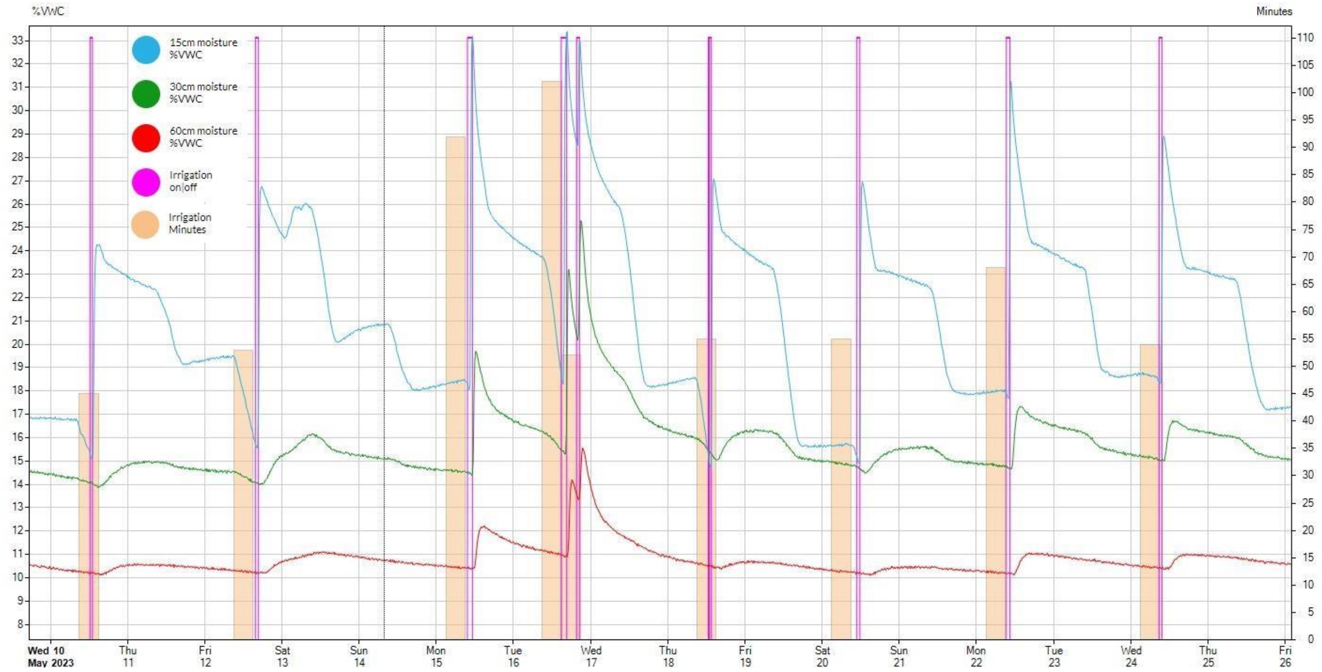

Figure 4 Wildeye online platform graph of the Teros 12 soil moisture monitoring equipment and pressure transducer in an avocado orchard in the southwest on sandy soils

Project Case Studies

Avocado Orchard Yallingup Siding

Crop	Avocado (Hass) 3 years since transplant	
Soil	Topsoil: Sand, Subsoil: sand @ 70cm	
Pan Evaporation	1607mm average from 2013 - 2023	
Rainfall	974 mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	1 sprinkler/tree @ 50L/h	No change
Irrigation months	Spring to Autumn	All year
Irrigation frequency	Daily to every 3 days	Depending on VWC%
Irrigation duration	15-30 minutes	45-60 minutes

This Avocado orchard, characterised by its notably light sandy soil, demonstrated impressive growth within a relatively short time frame. The young trees, initially 6ft tall in November, exhibited a robust increase in height, reaching 10ft by the following June. This growth spurt, accompanied by vigorous development and healthy buds, signals a promising outlook for the 2024 season. While attributing this success solely to soil moisture monitoring would be misleading, its significant contribution to optimising water and fertiliser usage cannot be overlooked, contributing to a flourishing orchard.

The orchard's pre-project irrigation approach was seasonally driven, starting in spring with rising temperatures and ceasing in autumn as rains became more frequent. The sandy soil, however, posed a challenge with its limited plant available water-holding capacity of around 6% volumetric content. This characteristic led to rapid depletion of soil moisture within just a few days without rainfall, creating a water-stressed environment for the orchard.

The introduction of soil moisture sensors revolutionised the orchard's irrigation strategy. These sensors enabled the grower to recognise and rectify the limitation of their previous irrigation scheduling, particularly vital given the soil's propensity for rapid moisture loss. Additionally, water stress was not only a winter phenomenon when irrigation was halted but also a concern during milder weather in the summer months, catching the grower off guard.

The sandy soil's minimal water retention capacity was further highlighted by the sensors, revealing how easily fertilizer, particularly nitrogen in nitrate form, could leach from the topsoil. The integration of soil moisture sensors with a pressure transducer in the irrigation line allowed for more precise and timely adjustments in irrigation practices. This approach, reliant on near-real-time sensor data, surpassed the accuracy and effectiveness of traditional subjective methods commonly used by growers.

An intriguing observation during winter was the deep soil saturation, potentially indicative of the water table's presence or rainfall-induced saturation slowly draining towards the property's dam.

In conclusion, the orchard's challenges primarily revolved around under-irrigation during winter and high crop-water demand periods, and occasionally over-irrigation leading to fertiliser loss. The combined efforts of the soil moisture monitoring system and guidance from a nutritional consultant have been instrumental in the orchard's remarkable growth and hold promise for its future productivity.

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Figure 5 Yallingup Avocado orchard in November 2022 (left) and June 2023 (right).

Avocado Orchard, Northcliffe

Crop	Avocado (Hass)	
Soil	Topsoil: Loam, Subsoil: clay	
Pan Evaporation	1285mm average from 2013 - 2023	
Rainfall	1266mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	2 sprinklers/tree @ 50L/hour	No change
Irrigation months	Spring to Autumn	All year
Irrigation frequency	Every day	Spring to Autumn: every day
Irrigation duration	60 minutes	90 mintues

This established avocado orchard in a loamy topsoil and a loamy/clay subsoil located in Northcliffe has been performing well and the grower was interested in improving their irrigation scheduling. Since the orchard appeared to be healthy there was an expectation that not a lot of management to the irrigation scheduling was needed to be changed. However, it was found that through summer the orchard was potentially being severely underwater, posing as a high risk to fruit drop during heat events.

It was found that leeching was not a common occurrence thanks to the good water holding ability of the rich loamy soil and clayey subsoil. With increased irrigation through summer and opportunistic irrigation through winter, the orchard is very hopeful for the coming 2024 season and beyond.

There was much appreciation for the modern soil moisture monitoring equipment as it allowed the grower to remotely monitor the orchard without being in Western Australia due to travel plans. With a 2IC on the property, the grower was able to make well informed decisions surrounding the irrigation and fertiliser with a greater degree of confidence in their decision-making and their employees.

Avocado, Manjimup

Crop	Avocado (Hass)	
Soil	Topsoil: clay, Subsoil: clay	
Pan Evaporation	1385mm average from 2013 - 2023	
Rainfall	946mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	2 sprinklers/tree @ 50L/hour	No change
Irrigation months	Spring to Autumn	All Year
Irrigation frequency	Everyday	Everyday
Irrigation duration	60 minutes	90 mintues

An established avocado orchard in Manjimup with loamy clay topsoil and a clay subsoil experiencing biannual bearing and what appears to be phytophthora spotted through 2%-5 of the orchard. Heavier soils that contain higher quantities of clay are much more difficult to monitor because they have high water holding abilities and very slow water mobility. It takes approximately 2 hours for irrigation water to penetrate 15cm, 3 hours to reach 30cm, and 5 and a half hours to reach 60cm. With such slow water mobility, the information from the sensors come out looking very smooth such as in the figure below.

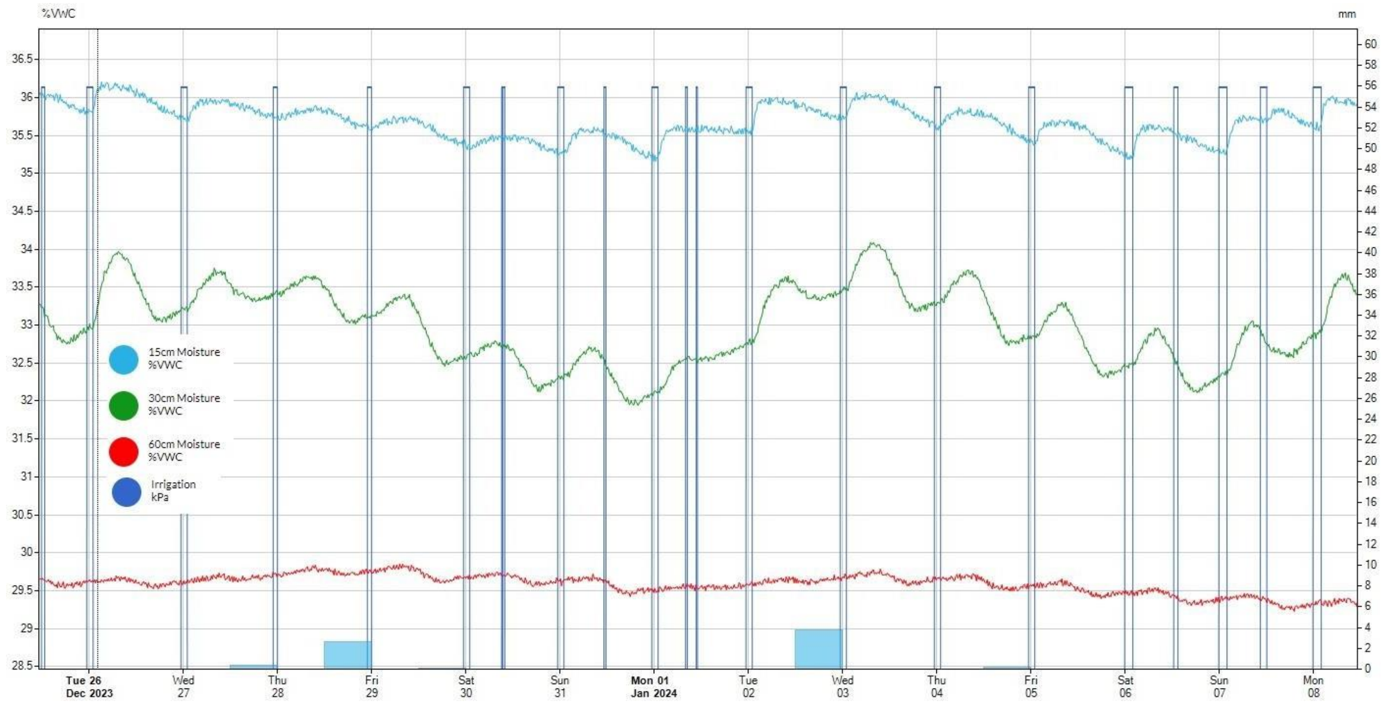

Figure 5 Wildeye online platform graph of the Teros 12 soil moisture monitoring equipment in an avocado orchard in the southwest on clay soils.

From the above figure, we can observe how much longer it takes compared to lighter soil types for irrigation to reach the soil moisture sensors at the same depths. There is no longer the characteristic irrigation event trait of a sharp increase in soil moisture content and no steep decrease in drainage. Due to such slow mobility of soil moisture, it can become difficult to monitor for crop demand and water availability. What we can observe is where evapotranspiration is high and low and if the orchard can remove moisture from the soil. From the 26th of December to the 31st we can observe declining moisture in the top 30cm of soil due to greater demand for water from the crop. From the 31st to the 3rd we observe soil moisture begin to increase in the top 30cm. Irrigation duration has not changed, therefore we can conclude that the demand for water has increased and the orchard was able to source this water from the soil, something the grower can do is compensate for the increased demand and

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evapotranspiration by increasing the irrigation duration and delivering more water to the orchard and when demand and evapotranspiration reduces do the same for the irrigation to avoid overwatering and waterlogging the orchard.

A year from installing the soil moisture monitoring equipment, the grower is very pleased with the informative information to help them assist in their irrigation scheduling. It has improved the health of trees affected by phytophthora and the 2024 season looks ever more promising than before. A big bonus was the ability to remotely monitor the orchards irrigation scheduling and soil moisture content that provided him with confidence while they were away from the farm.

Avocado, Brunswick

Crop	Avocado (Hass)	
Soil	Topsoil: loamy clay + 10% gravel	
Pan Evaporation	1727mm average from 2013 - 2023	
Rainfall	862mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	1 sprinkler per tree	No change
Irrigation months	Spring to Summer	All year
Irrigation frequency	Everyday to every third day	Everyday
Irrigation duration	Unknown	Average 40 mintues

The avocado orchard in Brunswick is less than 2 years since it had been transplanted. The soil is a loamy clay with a high gravel content and a clay subsoil. Since installing the soil moisture monitoring equipment, the grower who is new to the irrigated agriculture and horticulture industry, became confident in their irrigation scheduling by understanding how long it took to irrigate to the point of leaching and where compensation was required for increased evapotranspiration. So far, the orchard is growing well, is looking healthy and hopefully not too long before it starts producing quality avocados for harvest.

Avocado, Northcliffe

Crop	Avocado (Hass)	
Soil	Topsoil:	
Pan Evaporation	1285mm average from 2013 - 2023	
Rainfall	1266mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	2 sprinklers/tree @ 50L/hr	2 sprinklers/tree @ various rates/hr
Irrigation months	Spring to Autumn	Spring to Autumn
Irrigation frequency	Every 2nd or 3rd day	Everyday to every 2nd day
Irrigation duration	Unknown	Average: 60 minutes

In this case of avocado orchard, five years since transplantation, highlights some significant challenges faced by growers when it comes to irrigation scheduling. The orchard, situated on a clay topsoil and subsoil, has encountered issues related to potential phytophthora, variable soil texture, and uneven water distribution. In addressing these challenges, soil moisture monitoring equipment played a crucial role in improving irrigation practices.

Initially, the orchard's soil moisture monitoring equipment provided valuable data. However, due to variations in tree growth stages, health conditions, and soil texture within the orchard, it became evident that a ore tailored approach to irrigation was necessary. Some trees were receiving excessive water for their specific soil texture and growth stage, while others, despite being healthier and larger required different water management strategies.

To address this issue, a solution was devised to retrofit the sprinklers in the irrigation system for tree with lower water demand. This retrofit allowed for reduced water delivery to these trees, aligning more closely with their specific needs. Essentially, the strategy involved managing two distinct groups of trees with different water requirements within the same irrigation block.

This approach underscores the power of soil moisture monitoring in troubleshooting and optimising performance across an avocado orchard. What initially revealed under-irrigation in the vicinity of healthy trees led to the awareness of over-watering for less developed and struggling trees. The goal is soil moisture monitoring is not solely to reduce irrigation output, although it is invaluable during drought conditions. Instead, it aims to ensure that water resources are utilised efficiently and effectively, ultimately enhancing farm productivity.

In conclusion, the avocado grower's experience highlights the importance of data-driven decision-making and adaptability in irrigation management. Soil moisture monitoring serves as a valuable tool in achieving these objectives, enabling growers to fine-tune their practices and address specific challenges within their orchards for improved overall performance.

Apple, Perth Hills

Crop	**Apple (Bravo)**	
Soil	Topsoil:	
Pan Evaporation	1296mm average from 2013 - 2023	
Rainfall	1055mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	Drippers	Drippers
Irrigation months	Spring to Autumn	Spring to Autumn
Irrigation frequency	Everyday	Everyday
Irrigation duration	90 minutes	30 minutes and 60 minutes in summer

The case of the apple orchard in the hills east of Perth serves as an instructive example of the importance of effective soil moisture monitoring in orchard management. Despite the grower's extension experience with apple, pear, and stone fruit cultivation, they did not fully leverage the installed soil moisture monitoring equipment, relying instead on tensiometers that provided limited information.

Several key observations were made:

1. **Early Moisture Depletion:** One noteworthy discovery was that the apple orchard started depleting soil moisture as early as August, even before the official start of the irrigation season. This early moisture depletion went unnoticed, and it highlights the critical need for continuous monitoring to align irrigation scheduling with orchard's actual water demand.
2. **Year-Round Moisture Removal:** The data indicated that moisture was being consistently removed from the soil throughout the year, down to a depth of at least 30cm. This ongoing water uptake suggests that the orchard's water demand may not be confined to the traditional irrigation season and may require year-round attention.
3. **Over-Irrigation and leaching:** When irrigation did commence, the grower frequently over-irrigated, resulting in leaching during almost every irrigation event. This practice likely led to the unnecessary removal of fertilisers from the soil, potentially impacting orchard productivity.
4. **Lack of Compensation for Evapotranspiration changes:** The orchard's irrigation scheduling did not account for fluctuations in evapotranspiration and varying water demand, which could have resulted in crop water stress, fruit abscission, and potential effects on fruit size and quality.

In summary, this case underscores the crucial role of comprehensive and continuous soil moisture monitoring in orchard management. Dependence solely on tensiometers with limited information can lead to missed opportunities for efficient water resource utilisation, nutrient management, and crop performance optimisation. Soil moisture monitoring provides valuable insights into the orchard's water dynamics, enabling growers to adjust irrigation practices in real-time and ensure the best possible outcomes for fruit quality and yield.

Apple, Manjimup

Crop	**Apple (Bravo)**	
Soil	Topsoil:	
Pan Evaporation	1385mm average from 2013 - 2023	
Rainfall	946mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	drippers	Drippers
Irrigation months	Spring to Autumn	Spring to Autumn
Irrigation frequency	Everyday to every 3rd day	Everyday to every 3rd day
Irrigation duration	90 minutes	90-110 minutes

In the context of a 40-hectare horticulture enterprise producing a variety of crops, including apples, avocadoes, and truffle, the installation of soil moisture monitoring equipment has proven to be a game changer. It has provided the grower with valuable insights into several critical aspects of their operation:

- **Leaching Events:**
  Soil moisture monitoring equipment allows the grower to identify leaching events, ensuring that excess water is not being lost from the root zone. This knowledge helps in optimizing irrigation practices, reducing water waste, and preserving valuable resources.
- **Apple Orchard Dormancy**
  Monitoring soil moisture enables the grower to pinpoint when the apple orchard transitions out of dormancy. This information is essential for initiating appropriate irrigation and management practices as the orchard awakens from its dormant state.
- **Evapotranspiration vs Rainfall**
  By tracking soil moisture levels, the grower can determine when evapotranspiration (water loss through plant transpiration and soil evaporation) surpasses rainfall in the months leading up to bud break. This knowledge helps in anticipating increased water demand by crops and adjusting irrigation accordingly
- **Crop Water Deman Variability**
  Soil moisture monitoring provides real-time data on crop water demand variability. Different crops and growth stages have varying water requirements. Understanding this variability allows for precise irrigation scheduling tailored to the specific needs of each crop, optimising water use efficiency.
- **Water Resource Budgeting**
  With multiple dams on the property, water resource management is crucial. Soil moisture monitoring equipment assists in water resource budgeting by providing data on soil moisture levels, evapotranspiration rates, and crop water demand. This information aids in ensuring that water resources are allocated effectively and sustainably across the 40-hectare enterprise.

Overall, the implementation of soil moisture monitoring technology has enhanced water management, crop productivity, and resource conservation within the horticulture enterprise. It has empowered the grower with actionable insights to make informed decisions and maintain water security, a vita aspect of successful and sustainable agricultural operations.

Tomato, Carnarvon

Crop	Tomato (Duncan)	
Soil	Topsoil: red loamy soil	
Pan Evaporation	2504mm average from 2013 - 2023	
Rainfall	215mm average from 2013 - 2023	
	Before	**After**
Irrigation infrastructure	High flow T-tape	High flow T-tape
Irrigation months	Transplant to the end of harvest	Transplant to the end of harvest
Irrigation frequency	Every day – every 3rd day	Every day – every 3rd day
Irrigation duration	4 hours +/- 1 hour	3 hours +/- 1 hour

A tomato plantation in Carnarvon with clayey loam soil with tomato seedlings planted every 30cm. This tomato grower has years of experience growing tomatoes and has been using tensiometers to assist scheduling their next irrigation. From installing the soil moisture monitoring equipment there were numerous observations made such as:

1. **Deep water utilisation:** Initially, tomato crops were thought to have majority of the effective root zone in the top 30cm of soil but once the soil moisture sensors were installed, they were found removing significant quantities of moisture from soil 40cm deep. This means the 3rd sensor needs to be at least 50cm deep to accurately monitor for suspected leaching of water and fertiliser.
2. **Topsoil Cracking in Hot Environments:** The topsoil sensor at 15cm deep was exposed to the air due to a week of weather causing high evapotranspiration rates resulting in the topsoil to dry, shrink, and crack, exposing the soil moisture sensor in the topsoil. This caused the sensor to become useless at providing soil moisture data. To avoid this, ensure plastic mulch covers the soil surface where the sensors are installed or install the topsoil sensor to 20cm deep.
3. **Compensating for High Evapotranspiration:** In the case of the tomato plantation, the grower recognised the importance of compensating for periods of high evapotranspiration, a crucial aspect of efficient irrigation management. The soil moisture monitoring equipment played a pivotal role in this adjustment.
   Here is how the grower successfully compensated for high evapotranspiration:
   a. **Identification of High Evapotranspiration Events:** The grower was able to identify when the tomato crop experienced higher water demand due to elevated evapotranspiration rates. These events were likely associated with environmental factors such as warm and dry weather conditions or increased crop growth stages. There are also numerous services available online that provide free evapotranspiration data and forecasts.
   b. **Data Validation:** The soil moisture monitoring equipment provided concrete data that corroborated the observation of increased water usage during these high evapotranspiration events. This data served as a reliable reference point for understanding the crop's specific water needs during such periods.
   c. **Irrigation Scheduling Adjustments:** Armed with the knowledge of these high-water demand periods, the grower was able to adjust to make precise adjustments to their irrigation scheduling. By accurately timing irrigation to coincide with the increased water demand, they could ensure that the crop received adequate moisture without excess water leading to leaching.
   d. **Efficient Water Management:** This proactive approach allowed the grower to optimise water management practices. They could avoid over-irrigation, minimise the risk of leaching, and maintain maximum water availability for the crop, ultimately enhancing both water use efficiency and crop health.

Trouble Shooting

There are occasions that the data being observed doesn't match with what our expectation of what the reality of the situation is. This is when the sensor tells us it is wetter or drier than we think it is or if water is traveling deeper or shallower than what we expect it to be. We often conclude that there is something wrong with the sensor otherwise the only alternative is that our expectations as to what is happening is wrong. It is important when using soil moisture sensors to keep an open mind and if our view conflicts with what the sensor is telling us then we need to "prove" who is right or wrong.

Below are different scenarios where troubleshooting was required and the outcomes of each problem.

Sprinkler and dripper issues

On multiple occasions sprinklers have been the root cause to the reason that a sensor is telling us it is drier than it is because:

- The sprinkler/dripper is blocked.
- The sprinkler is stuck and not spinning.
- Grass or foliage is blocking the sprinkler from wetting the area near the sensor.

All the scenarios above occurred during the project. It is important to regularly check the drippers and sprinklers near the sensor to ensure the irrigation system is working as normal. Checking irrigation throughout an irrigation block is important to achieve uniform water distribution. Below is a graph of what we would expect if a dripper or sprinkler is not placing water near the soil moisture sensors.

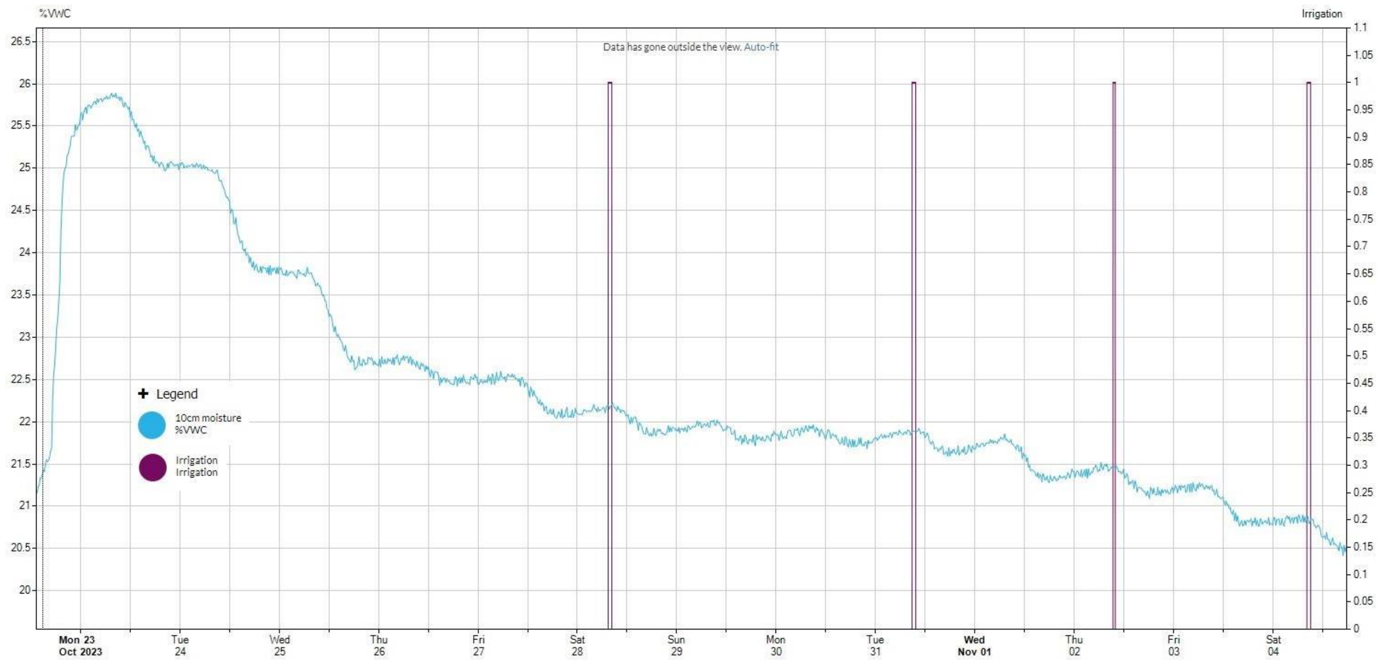

Figure 6 Wildeye online platform graph of the Teros 12 sensor and pressure transducer in a clayey loam soil of an avocado orchard in the South-West of Western Australia.

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Inadequate irrigation

Growers have been caught out not irrigating as much as they were led to believe. Teros 12 and EnviroPro sensors have observed drying trends in the soil due to growers not irrigating more during higher-than-normal evapotranspiration periods and when the water content has decreased, and the water no longer penetrates as deep into the soil as before. As the soil dries out, the soil has more room to hold water, this drying can be caused by increased water demand because:

- Evapotranspiration has increased.
- The crop has grown vegetation, roots, and fruit.

The crop has essentially removed more water from the soil than is being irrigated. If irrigation duration does not increase, then we will observe that the water will not penetrate into the soil as deep as before because the topsoil is no longer being saturated from irrigation and leeching deeper. Below is an example of what topsoil drying and inadequate irrigation may look like on soil moisture monitoring graphs:

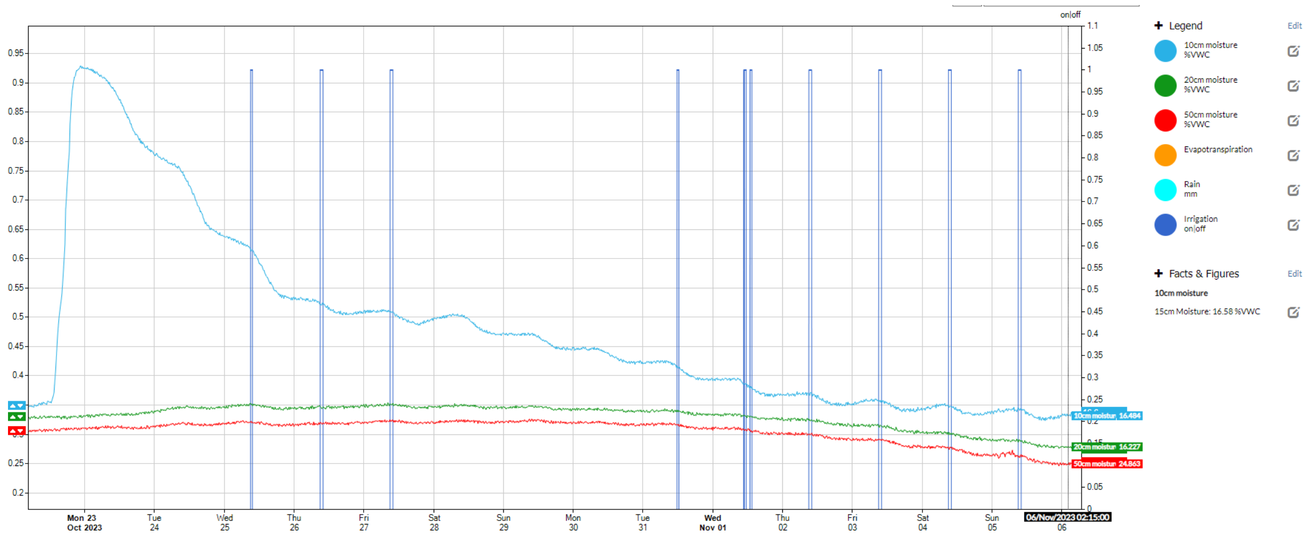

Figure 7 Teros 12 sensors in an avocado orchard in loamy soil in the southwest of Western Australia

In the figure above a rain event occurs on the 22nd of October increasing the soil moisture content to 27.5%. Afterwards there are irrigation events shown by the blue lines that have little to no impact on the soil's moisture content. Even though the sensor is only 10cm from the surface, the sprinkler irrigation system is not applying enough water to the wetting area to penetrate 10cm deep into the soil. Each irrigation event went for 1 hour and was delivering 50L/h per sprinkler. When an observation is made like this, it is important to go out into the field and prove that it is indeed dry by digging around the sensor. After irrigation, there should be a distinct zone underground where soil goes from "recently wetted" by the irrigation to a drier soil where the moisture is not reaching. Once it is confirmed that water is indeed not reaching deep into the soil, various questions need to be answered:

- Is the sprinkler blocked?
- Is the sprinkler distributing water evenly?
- Is the water soaking into the soil or running away?
- Is enough water being applied?
- Is there grass/weeds/crop foliage obstructing the sprinkler/dripper?
- Is the sensor positioned appropriately, does it need relocating?

Broken solenoid

Malfunctioning solenoids present a significant challenge for irrigators, particularly in cases like avocado crops, which are prone to excessive fruit drop when subjected to stress from drought conditions. As illustrated in the figure below, a key indicator of a broken solenoid is the absence of irrigation events, as evidenced by the data from the pressure transducer. This absence is due to the failure in generating adequate water pressure within the irrigation lines.

In the specific instance of the grower referenced in figure 8, irrigation was scheduled daily. Unfortunately, the defective solenoid resulted in a nine-day hiatus of water supply to the crops. Fortuitously, this incident occurred in May when the evapotranspiration rates in the avocado orchard were relatively low. However, a lapse in the grower's routine checks of their soil moisture monitoring devices delayed the detection of the malfunction. Timely monitoring could have led to an earlier discovery of the issues, allowing for quicker remediation and the resumption of proper irrigation, thus mitigating the risk to the crops.

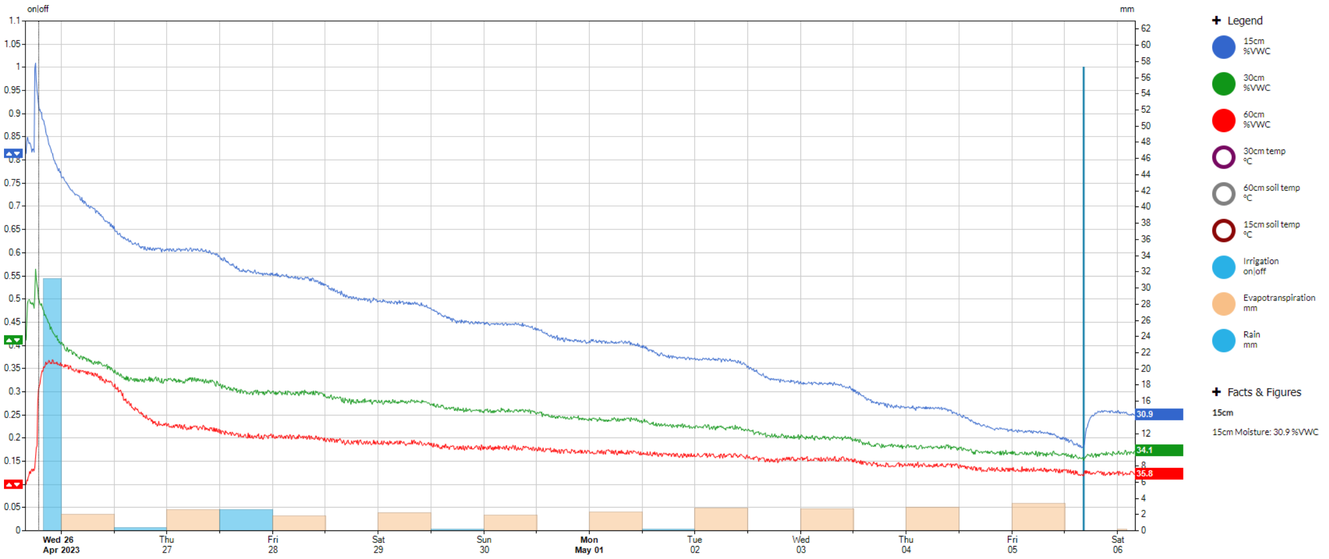

Figure 8 Wildeye online platform graph of the Teros 12 sensors in a clayey loam soil of an avocado orchard in the South-West of Western Australia.

References

STIRZAKER, R. 2006. *Soil moisture monitoring: state of play and barriers to adoption*, Citeseer.

Australian Government Department of Agriculture, Fisheries and Forestry
Future Drought Fund
GROWER GROUP ALLIANCE Together we grow
South-West WA Drought Resilience Adoption and Innovation Hub