SMART FARMING TECHNOLOGY GUIDE FOR HORTICULTURE

About this document

This document has been prepared for Australian horticultural operations that are seeking an overview of emerging smart farming sensors and software.

Information is presented briefly to provide an overview of common sensors and technology used by adopters of smart farming techniques. Some of the most useful and readily available sensors are discussed in this guide, with clear instructions on how to select, install, and maintain sensors, and how to interpret measured data. Links to further reading and instructional videos are available throughout the document

This document is based on experiences with the Hitachi Vantara Control Tower, which has been developed in consultation with two industry leading pilot farms and a production nursery. Some technologies are unique to the Control Tower, however many of the concepts are applicable to other smart farming dashboards.

Authors
Liam Southam-Rogers
Henry Hyde

Contributors
David Hunt
Paulette Baumgartl
Kelvin Montagu
Dallas Gibb

Design
Jihee Park | Jihee Park Creative

Produced by Applied Horticultural Research
First published January 2022

Disclaimer
Horticulture Innovation Australia Limited (Hort Innovation) and Applied Horticultural Research Ltd (AHR) make no representations and expressly disclaims all warranties (to the extent permitted by law) about the accuracy, completeness, or currency of information in this book produced under ST19023 Digital remote monitoring to improve horticultures environmental performance. Reliance on any information provided by Hort Innovation or AHR is entirely at your own risk. Hort Innovation or AHR are not responsible for, and will not be liable for, any loss, damage, claim, expense, cost (including legal costs) or other liability arising in any way, including from any Hort Innovation or AHR or other person's negligence or otherwise from your use or non-use of information from this book or from reliance on information contained in the material or that Hort Innovation or AHR provides to you by any other means.

Hort Innovation NURSERY FUND

This project has been funded by Hort Innovation using the nursery research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

This project has been funded by Hort Innovation from the Australian Government's National Landcare Program, the nursery research and development levy, and matched funds from the Australian Government. Special thanks to the pilot farms owned and operated by Gavin Devaney, David De Paoli and Wayne Parr.

Is smart farming right for you?

Australian horticultural industries are facing increased challenges with climate variability, supply chain reliability and labour shortages. While no single measure can address all these challenges, farmers can adopt new technologies to optimise management and remotely monitor farm conditions.

Improving the productivity and environmental performance of farming systems using sensors and technology is referred to as smart farming. In smart farming, sensors located at various locations around the farm remotely monitor key parameters and feed the data into a centralised management tool, known as a dashboard. The Hitachi Vantara Control Tower is an example of such a dashboard. In addition to the data feed from on-farm sensors, dashboards can also use models and other tools to increase the value of measured data. This guide discusses some of the models available for productivity and environmental forecasting.

Selecting appropriate sensors to monitor a property is the first and most important step in setting up a smart farm.

The number of available sensors can be overwhelming, which is why this guide has broken sensors down into those focussed on productivity and those focussed on environmental monitoring.

Sensors need to be properly installed and maintained to ensure that measured data is accurate and useful. This guide outlines recommended installation and maintenance techniques for a range of sensors. The sensor manufacturer's manual is the best source for more detailed information regarding the installation and maintenance of sensors.

Once sensors have been selected and installed, it is essential that the data being collected can be correctly interpreted and used for management decisions. This guide provides information on the interpretation of data from a range of sources and contains links to further reading.

IS SMART FARMING RIGHT FOR YOU?

KEY CONSIDERATIONS

AIM & BUDGET

WHAT DO YOU WANT TO ACHIEVE?
Determine which areas will benefit most from being remotely monitored and how much monitoring will cost.

WATER MANAGEMENT

HOW DO YOU MANAGE WATER?
The availability of water will determine the importance of moisture monitoring.

EXISTING FARM TECHNOLOGY & MANAGEMENT SYSTEMS

WHAT IS ALREADY PRESENT?
Existing sensors can be integrated and be enhanced. Consider compatibility, storage requirements and connectivity.

INTERNET CONNECTION

ARE YOU CONNECTED?
Assess the connectivitiy on your farm. Most sensors require strong and constant reception.

KNOWLEDGE & TRAINING

ANY KNOWLEDGE GAPS?
Before installing sensors, ensure staff have sufficient training.

DATA STORAGE

HOW WILL IT BE STORED?
Sensors often include data management software.

POWER SUPPLY

HOW WILL THE EQUIPMENT BE POWERED?
Solar panels can power most sensors, but batteries and mains power can also be used where appropriate.

CROP TYPE

HOW ARE EXISTING CROPS MANAGED?
The crop grown will determine the type of sensors required.

ENVIRONMENTALLY SENSITIVE

ARE YOU IN A SENSITIVE AREA?
Smart farming can assist with environmental performance by monitoring and predicting environmental impacts.

ENVIRONMENTAL MARKETING

GREEN CREDENTIALS?
Monitoring environmental performance can improve the green credentials of your property and help obtain certifications.

Hitachi Vantara Control Tower

The Hitachi Vantara Control Tower is currently being developed to holistically measure farm productivity and environmental stewardship. The key basis in developing this system is to provide a single integrated platform that captures data from all key sensors used across a farm or nursery.

The integration of sensor data, weather forecasts and biophysical models can be collated and analysed. The data are then presented as simple user interfaces or actionable insights to enable users to make decisions regarding business operations. The Control Tower can automate much of the Freshcare Environmental audit reports and provide decision support tools for managing nutrient runoff and leaching.

Figure 1. Hitachi Vantara Control Tower

Key Functions developed within the Hitachi Vantara Control Tower

Some of the key features of the control tower include:

FARM AND FIELD DESIGN

Users can draw and create management blocks, allowing distinct production areas to be managed independently

SENSOR CONFIGURATION AND INTEGRATION

Sensors can be individually managed and provide configurable alerts regarding operating status

WEATHER DATA MONITORING

A Bureau of Meteorology forecast is built into the dashboard

IRRIGATION MANAGEMENT

Prediction models are used to highlight water use for selected rooting zones

PRODUCTIVITY MONITORING

Crop stress and growth information is collected by sensors and displayed to the user

ENVIRONMENTAL MONITORING OF WATER

The integration of environmental models and sensors provides insight into nutrient runoff and leachings to be managed independently

FARM ACTIVITY TRACKING

Activities such as spray events can be GPS located and visualised

SUPPLY CHAIN TRACKING

The control tower can facilitate the integration of supply chain monitoring equipment, allowing the location and temperature of consignments to be monitored from the farm gate to the shop floor

COMPLIANCE REPORTING

The information collected by the Control Tower streamlines compliance with environmental management systems

GENERAL SENSOR INSTALLATION TIPS

Any sensor installation should account for and not interfere with the movements of farm workers and machinery.

The location of installed sensors should be well marked and the sensors themselves labelled with their serial numbers.

Solar panels need to be installed above the maximum expected tree canopy, to avoid issues with shading.

Sensors should be installed with access for maintenance in mind. Large, galvanised steel poles for mounting sensors can be purchased with a hinge approximately 1m above the ground level, which provides easier access to the sensor node installed at the top of the pole.

Before field installation of any sensor, it is important that tests are carried out in controlled conditions to ensure that sensors are working and calibrated correctly.

It is recommended to record the GPS location of installed sensors.

Figure 2. Best practice for solar powered sensor installation in banana or perennial crop.

PRODUCTIVITY MONITORING

Sensors installed to monitor productivity can inform management decisions and optimise crop growth. Productivity sensors include those which measure soil moisture and irrigation line pressure. A comprehensive selection of productivity sensors has been included in this guide.

Although detailed installation procedures are provided with the sensors, we have included the key considerations and basic installation steps for each sensor type to help make the process as easy as possible. Maintenance advice is included in this guide, but it is recommended to consult the specific maintenance guidelines provided by sensor manufacturers.

Look out for QR codes and other links to videos, online tools, and further reading.

MOISTURE SENSORS (SOIL BASED)

Soil moisture sensors can help optimise irrigation management, which can increase profitability by improving yield and quality, and reduce inputs. Using soil moisture monitoring tools can also reduce off-farm environmental impacts by decreasing the volume of leached nutrients (See Environmental Monitoring section).

For soil moisture sensors to be effective, they must be correctly installed, data checked and used in combination with other management information.

Selecting the sensor

There are a wide range of commercial soil moisture sensors available. For smart farming platforms, soil moisture sensors that give a soil moisture percentage (Volumetric Water Content %) are required. This allows water budgets to be developed.

Key points in selecting a soil moisture sensor:

- Choose a sensor that is compatible with the smart farm platform and can provide automatic readings in near real time and communicate data to the cloud
- Ensure local support is available for timely servicing; sensors are not set and forget
- Consider costs, both upfront and ongoing, for example, any subscriptions for communications
- Ensure the sensor can be buried at suitable depths for your crop
- Confirm the ease of installation and extraction when sensors are used in annual crops
- Confirm that the installation does not interfere with farm operations
- Consider the soil volume measured by the sensor; the bigger the better

Installing the sensor

Key points when installing a soil moisture sensor (specific instructions should be provided in the sensor manufacturer's installation guide):

- Ensure sensors are installed in an area which is typical for the crop to optimise irrigation for this area
- Avoid field edges and wet or dry areas, unless you are specifically trying to manage these areas
- Use your knowledge of the paddock, aerial photos, satellite imagery and soil maps to help locate the right area
- Note that a sensor located within a row will be influenced by the irrigation system and crop
- Determine the number of sensors required and placement depth of probes by examining the crop and soil conditions
- Place a sensor below the root zone to monitor water movement at depth and potential nutrient leaching
- Figure 3 shows an example of correct soil moisture probe installation

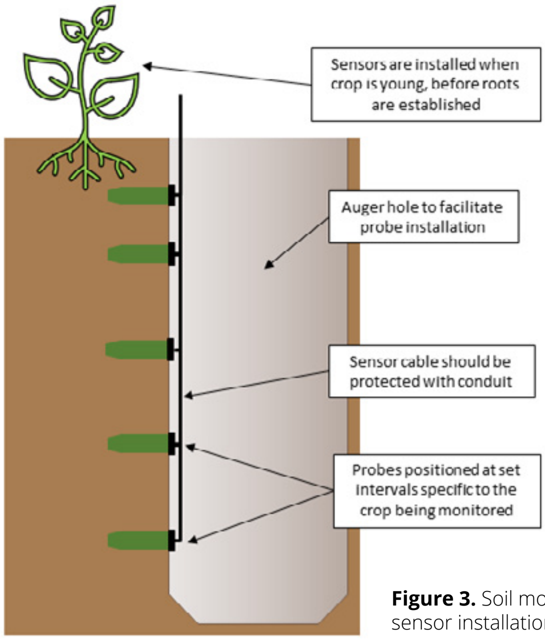


Figure 3. Soil moisture sensor installation.

A TYPICAL INSTALLATION PROCESS IN AN ANNUAL CROP

Once the field location and row position relative to the irrigation system has been decided, installation can occur.

To install soil moisture sensor probes, the auger side-wall installation method is recommended. Scan the QR code for a video showing this method for an annual crop. This quick method facilitates installation at multiple depths leaving the soil undisturbed. It is best carried out soon after the annual crop is established but before roots have grown into the soil.

- Use an auger to core the soil to the required depth. The diameter of the corer is dependent on the length of the probes and their housing. The hole needs to be wide enough to allow the installer to reach in and manually push the probes into the wall of the hole.

- Insert probes at the desired depths making sure the probes are pushed in smoothly with minimal sideways movement to ensure good probe-soil contact.
- Repack soil from the hole in the reverse order it was removed (i.e. subsoil first; topsoil last) and compact to the same density as before to minimise effects of the hole on water movement.
- Let the installation settle, typically after rainfall or irrigation, to allow the disturbed soil to return to pre-installation conditions and roots to grow through the disturbed soil before using the data for management decisions.

Figure 4. Soil moistures sensors installed horizontally into key depths within the rootzone. Sensor depths are 10cm, 20cm, 30cm, 50cm, 80cm.

Figure 5. An example of portable, self-contained TDR soil moisture sensor.

Managing the data

Soil moisture sensors typically take a reading of the Volumetric Water Content (VWC%) around the probe every 30 minutes. For example, after irrigation, soil may have a VWC of 35%, which means that in the volume of soil measured around the probe, 35% is water and the other 65% is soil (60%) and air (5%).

For water budgets, VWC is converted into mm of water held in the soil. This is based on the VWC for each sensor and the depth of soil covered by that sensor.

This is calculated using the following formula:

VWC x soil depth = mm of water per depth of soil.

For example, a soil with a VWC of 35% will hold 3.5mm of water in 100mm depth of soil. Soil moisture software will do these calculations automatically and add up the various soil depths to calculate the mm of soil water at the specified depth. The volume of water in the soil when combined with irrigation, rainfall and plant water use allows water budgets to be calculated by smart farm platforms.

Soil types

Soil type has a major effect on how much water is held by the soil and available to the plant. In horticulture, to produce high yields only a small part of water held in the soil can be used by the plant. If the soil dries beyond this readily available water level, then plant growth and yield is usually reduced.

Setting full and refill points

Setting full and refill points is both a science and an art. Use Table 1 as a guide to initially set full and refill points. For example, for a sandy loam soil expect a VWC of 30% at full point and set a refill point at 25%, in 50cm of soil the soil will have 150mm of water at the full point and 125mm at the refill point. As a result, there is 25mm of readily plant available water. You now have a full and refill point that can guide your irrigation decisions, including when to irrigate and how much.

Full and refill points can be refined over the season to take account of your specific soil conditions, as good soil structure improves the amount of water held by the soil.

To refine the full point, refer to the soil water graphs after rainfall has occurred. A rapid increase in soil moisture should be evident during the rainfall event. Watch for rapid drainage occurring for the 24 hours following the rainfall event. The soil moisture levels should drop quickly initially and then slow down. Set the full point around the point when the soil moisture level changes from the rapid to the slow decrease, i.e. the inflection point.

Refill points are more difficult to set and will be influenced by the management objectives for the crop. For example, if a crop has a critical period, then the refill point can be set higher to trigger more frequent irrigations. Conversely, if the management objective is to slow vegetative growth, set a lower refill point to lightly stress the plant. In the first instance, use the values provided in Table 1; refine these based on your management aim and the data represented on the soil moisture graphs. After the full point is reached, decreases in soil moisture levels are driven mainly by crop water use. If potential crop water use is reasonably consistent (use evapotranspiration values), then the soil moisture content should decrease consistently each day. When crop water use slows it may mean that the readily available water stored in the soil has dropped and the crop is struggling to get enough water to meet its requirements. Initially this will be indicated by a drop in water use in the early afternoon and can be visually observed by wilting or changes in leaf angle, or by the leaves being warmer to touch.

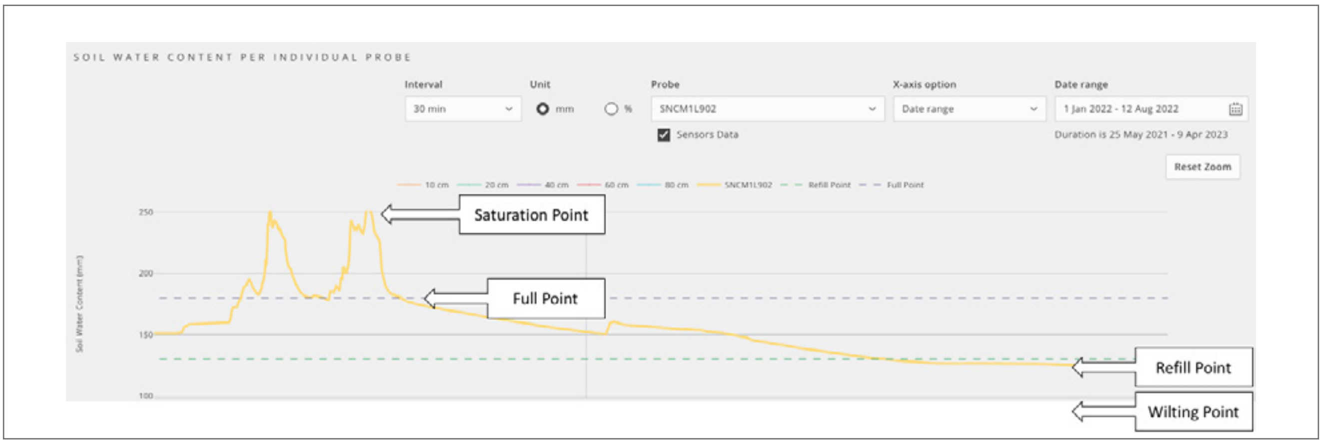


Figure 6. Example of soil moisture data

Soil texture	Full point % VWC	Refill Point %VWC	Readily Available water % VWC	Full point mm/50cm	Refill Point mm/50cm	Readily Available water mm/50cm
Coarse sand	10	8	2	50	40	10
Sand	20	16	4	100	80	20
Sandy Loam	30	25	5	150	125	25
Sandy Clay Loam	29	24	5	145	120	25
Clay Loam	40	37	3	200	185	15
Silty Clay Loam	48	44	4	240	220	20
Light Medium Clay	38	35	3	190	175	15
Medium Clay	41	38	3	205	190	15
Heavy Clay	47	44	3	235	220	15

Table 1: Soil moisture ranges by soil type.

Moisture levels

Saturation (very wet): refers to a soil's water content when all pore spaces in the soil are filled with water. Typically, this happens after heavy rain. When the soil is fully saturated, no more water can be stored in the soil. Saturated soils do not stay full of water for long; typically 24 hours after the rain stops, water held loosely in the soil will drain out leaving the soil at full point. This can take longer if drainage is poor due to a high water table or compaction layers.

Readily Available Water (RAW): the water that a plant can easily extract from the soil. RAW is the soil moisture held between field capacity and a nominated refill point for unrestricted growth.

Full Point (wet; field capacity): As much water as the soil can hold, 2 or 3 days after heavy rainfall, when the soil is fully saturated. At this point, there is very little downward movement of soil water due to gravity and very little suction due to capillary action.

Refill Point (moist): The refill point is the irrigation trigger point. Typically, this is set when all the RAW has been used by the plant. Beyond this point, the plant must work harder to extract water, reducing potential yield.

Wilting Point (very dry): The amount of water remaining in the soil when the plant wilts in a humid atmosphere. The water remaining in the soil is held tightly by soil particles, and plant roots cannot easily extract water.

Plant Available Soil Water: The amount of water in the soil between field capacity and the permanent wilting point.

Maintenance

Soil moisture sensors require minimal maintenance; however, battery voltage should be monitored. If battery voltage is too low, check whether the solar panel needs to be cleared of leaves or other debris.

Indicators of inaccurate soil moisture data are:

1. **Lack of response to rainfall events.** The soil should become saturated after a heavy rain event, and if the data does not reflect this, there is likely an issue with the soil moisture sensor. Try reinstalling the soil moisture sensor in a new location, ensuring there is no air gap between the sensor and the soil.
2. **Irregular data.** Data should gradually change over time. Rapid fluctuations or regular zero values in soil moisture data could indicate a faulty sensor.

MOISTURE SENSORS (POTTING MEDIA – NURSERY)

Much of the information in the moisture sensors (soil based) section above is also relevant for potting media installations. Coir potting media is compatible with TDR soil moisture sensors, however, this is not the case with all potting media types.

Installing the sensor

- Select a plant/container or group of containers in the irrigation zone that represents the irrigation requirements of the crop
- Ensure the representative container is in the middle of the crop and away from external influences, such as overspray from other irrigation zones
- Ensure that the container is not in an unusually shaded area, or on the edge of the irrigation zone that is affected by high temperatures
- Install the probes either vertically into the top of the container, or horizontally through the side of the container
- Select method according to the size and depth of the container, and whether multiple sensors are used to monitor the moisture content at different depths within the container
- For vertical installation, gently push the sensor down into the growing media until the probes are fully covered; do not wiggle or move the sensor when inserting as this will affect the probe/growing media interface
- For horizontal installation, either cut out the side of the container to fit the head of the sensor, or drill holes in the side of the container and insert the sensor probes directly into the growing media; the sensor may need to be secured in place using cable ties to reduce probe movement.

NOTE: for some soil moisture sensors a specific calibration for organic growing media may be needed to account for the high air-filled porosity. Check the sensor manufacturer's instruction booklet for calibration requirements.

Managing the data

Containerised nursery production and protected cropping (close greenhouse) production use a variety of organic growing media blends that have been engineered to perform in a container to optimise the root zone environment for plants. These organic growing media can be a single material or a combination of materials, such as coir, pine bark, perlite, vermiculite, zeolite, sphagnum peat, or rockwool. The water holding capacity (WHC), air-filled porosity (AFP), and wettability will vary with the type of medium used or percentage of each ingredient used in a blend.

Coir (coco peat, coir fibre pith or coconut fibre derived from the husk of the coconut) is often the main ingredient in growing media blends as it is a sustainable and renewable resource. It is available as a fine dust, fibre or coarse chips with most growing media containing a blend of all three sizes. Generally, a 100% coir growing media blend is 60% coir chip and 40% coir fibre. It can hold eight to nine times its dry weight in water and maintains an air-filled porosity of approximately 20%. The average water holding capacity of a coir growing media is 40%, but this can increase with different blend combinations. Physical properties will vary according to the blend. A water holding content test is required for each growing media blend to determine the wilting point and container capacity by volume.

A video on conducting an Air-Filled Porosity test and a Water Holding Content test can be found on the growing media page of the Australian Plant Production Standards website - https://nurseryproductionfms.com.au/growing-media/

Figure 7. TDR moisture probes inserted into a plastic container.

Figure 8. Weight based potting media moisture monitoring system.

WEIGHT BASED MONITORING (NURSERY)

Weight based irrigation management is useful when traditional soil moisture probes cannot be used, for example, if the container is too small or the growing medium is not compatible with soil moisture sensors. Trends observable in weight graphs are similar to those in soil moisture graphs, with the same diurnal fluctuations. However, units of measurement will be different.

A weight-based monitoring system (Figure 8) uses load cells to measure container weight and can be calibrated to estimate water content from container capacity. A set of load cells can be positioned within a nursery to provide accurate water content measurements. If properly configured, irrigation controllers can be triggered to irrigate when containers reach a set minimum weight and stop when a target weight is reached.

Installing the sensor

Select a plant/container or group of containers in the irrigation zone that represents the irrigation requirements of the crop.

Ensure the total weight of the saturated containers does not exceed the capacity of the load cell or weight scale. The load cell and representative plant should be in the middle of the crop and away from external influences, such as overspray from other irrigation zones, in an unusually shaded area, or on the edge of the irrigation zone where there may be high temperatures.

Provide sufficient space around the weight scale to ensure adjacent plants are not touching the scale and influencing the readings.

Watch this video from the Australian Plant Production Standards website on how to calculate water holding content Water Holding Content (WHC).

Setting full points, refill points and irrigation triggers

There are two methods that can be used to set the irrigation points: the scientific method and the field method. Setting the irrigation points within an irrigation controller will depend on the type of controller and the programming method used. If the controller requires actual weights to be entered, use the scientific method. However, if the weight can be set by sitting a container on the weight scale and pressing a 'set point' button for each irrigation trigger, then the field method is easier.

The scientific method

Calculate the physical characteristics e.g., air-filled porosity and water holding content of the growing media in the representative containers. This is a multi-step process that when completed will provide the volume of water in either millimetres or as a percentage that can be held in the growing media. From these measurements the irrigation trigger points can be determined.

Once the WHC has been identified, calculate the respective weights for the desired moisture content and set the irrigation trigger weights in the irrigation controller. Set the initial irrigation trigger weights to the equivalent moisture percentages of 20% wilt point, 40% irrigation start, 60% irrigation stop point, and 100% container capacity. Monitor the irrigation events and adjust the irrigation set points as required.

The field method

Set up containers. Take at least three containers/plants - one that has been fully saturated with water (container capacity/saturation point), one that has been irrigated to an acceptable moisture content or target moisture content (irrigation stop point), and one with the minimum amount of water acceptable before an irrigation event (the irrigation trigger).

Note: if you are using multiple containers e.g., 6 containers on one weight scale, then all six containers must have the same moisture content when setting irrigation trigger points.

Set irrigation trigger points:

- Activate the weight-based system, remove any containers from the weight scale, and tare the scale. Ensure the weight reading is zero before proceeding.
- Insert the driest containers and record this weight as the irrigation start weight.
- Replace the dry containers with the containers that have been wet to a moisture content representing the target moisture at the end of an irrigation event. After approximately 30 seconds record the weight as the irrigation stop weight. If using the same containers and wetting them on the weight scale, be careful not to allow excess water to pool on the weight scale as this will give a false reading.
- Replace the previous containers with the saturated containers and record the weight as the container capacity.

Table 2: Water loss in grams per container size

Container Size (mm)	Weight loss (g) for 1mm of water
80	5
100	10
150	20
170	25
200	30
250	50
300	70

- Set the irrigation start and stop weights into the irrigation controller.
- Monitor and adjust the irrigation trigger points as required to achieve the preferred moisture content.

Whether using the scientific or field method, it is important to monitor the irrigation events and adjust the trigger weights as required for the first several irrigation events to maintain an appropriate moisture content. Irrigation weights can be increased in 5- or 10-gram increments for small (140mm) to medium (400mm) containers, and 50-to-100-gram increments for large (500mm+) containers.

Trigger weights may also need adjustment to account for the increase in plant weight, especially for fast growing plants or plants that are kept in the container for long periods where the root ball approaches the capacity of the container.

Managing the data

The graphs and trends provided by weight-based monitoring data are largely the same as those from soil moisture data. The same diurnal steps are identifiable as the plant transpires during the day, before transpiration slows down overnight. Irrigation events can be identified through a rapid increase in plant weight, as displayed in Figure 9. An increase in container weight is related to the length of the irrigation or rain event. A large increase in weight indicates a long irrigation or heavy rainfall, whereas a small increase in weight indicates a short irrigation or rain shower.

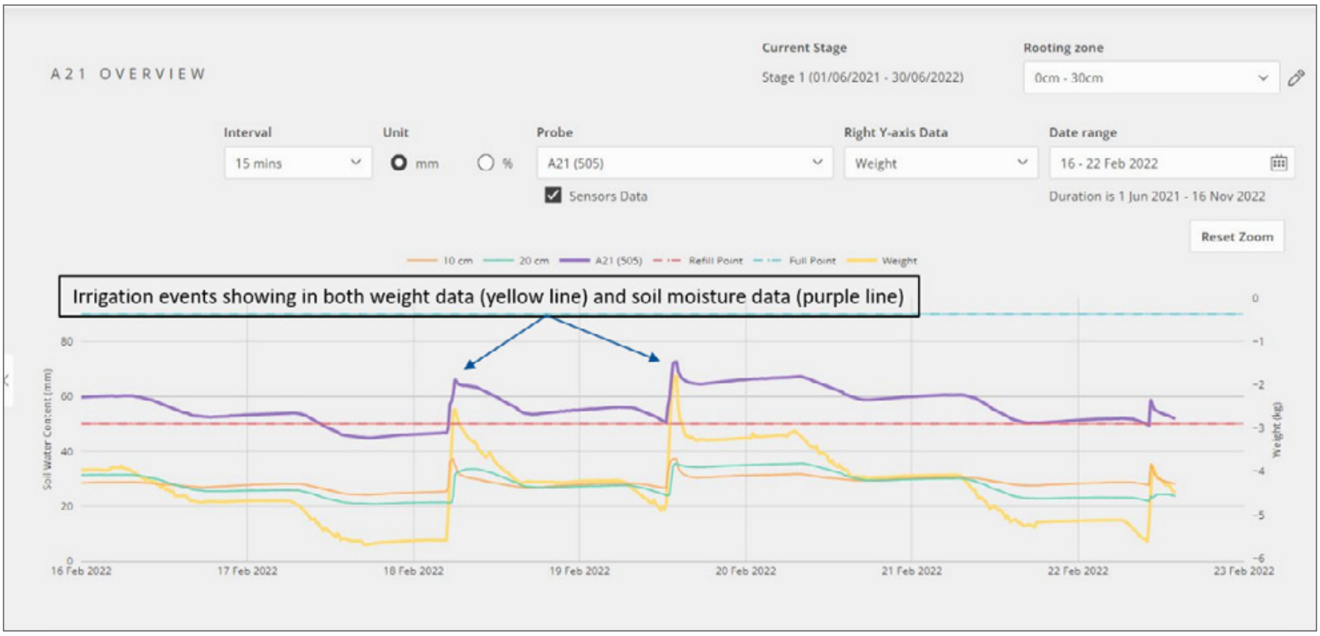


Figure 9. Weight based irrigation compared to soil moisture data.

Maintenance

Once the weight-based system is setup, little maintenance is required. However, the weight scales or load cells should be checked regularly to ensure other plants have not fallen onto the weight scale to influence the readings.

Indicators of inaccurate weight data are:

1. No change in container weight readings after an irrigation or rain event: This could indicate debris caught under the weight scale stopping full movement, or a blown irrigation pipe.
2. Container weights fluctuating excessively: this can be caused by high winds blowing the plant canopy, or adjacent plant branches intertwined in the monitored plants. Check that the weight scale/load cell and plant have free movement and are not being influenced by neighbouring plants.

Further reading

Automating Irrigation Scheduling in Nursery Production

Using container weights to determine irrigation needs: a simple method

Figure 10. Container scales which are used to estimate moisture in potting media.

DENDROMETERS

Dendrometers precisely measure plant growth, fruit maturity and stress. As plant growth is very sensitive to growing conditions such as water supply, weather conditions and nutrition, they can be useful indicators of how the crop is being managed. Care is required in interpreting dendrometry growth data as many factors affect growth. They are best used as learning tools – for example, to watch finer-scale growth patterns in the crop – rather than a simple decision support tool.

Dendrometers can be used to:

- Measure stem, trunk, or fruit expansion as an indicator of growth
- Look at contraction of the stem or fruit as an earlier indication of water stress
- Remotely monitor the maturity of the fruit
- Determine plant stress levels and fruit maturity

Types of dendrometers

For smart farming, dendrometers that can monitor and send data back in near-real time are required. There are two types of dendrometers commonly used in horticulture:

1. **Pivot dendrometers** are used for annual crops with stems up to 40mm in diameter. They are simple to install and are lightweight. They can be installed 4-6 weeks after seedling stage.
2. **Band dendrometers** are used for tree crops and are designed for long-term semi-permanent installations. They have a large range of motion and can be installed on all sizes of trees with trunk diameters greater than 80mm.

Installing the sensor

Pivot dendrometer

- Ensure the sensors are installed in an area which is typical for the crop
- Attach and secure the dendrometer to the stem of the plant being monitored by opening the three pressured levers and closing them around the stem
- For smaller stems, the weight of the dendrometer may need an external support

Band dendrometer

- Ensure the sensors are installed in an area which is typical for the crop
- Measure the circumference of the selected tree
- The provided steel tape should be 25cm longer than the circumference of the trunk
- Secure the tape to the dendrometer and wrap the tape around the tree, before inserting back into the dendrometer
- Ensure the tape remains under tension during the installation process
- The scale on the dendrometer should be greater than 5mm from the 0 mark, this reading will be the offset value during circumference calculation

Managing the data

Measurement frequency will be determined by the type of dendrometer used. Typically, hourly measurements are taken so that daily stem growth (mm/day) and maximum daily shrinkage can be calculated.

Stem growth rate

Trunk or stem growth rate is a good overall indicator of plant health. A healthy plant will show a consistent, continual growth rate, whereas a stressed plant will grow slowly. There are many factors which can change trunk or fruit growth rates including soil moisture (waterlogged or dry soils), weather conditions outside the plants favoured conditions (e.g., to cool or warm), poor nutrition, crop load, tree phenology, shading, and pest and diseases. It is best to compare stem growth rates to historical data from the same or a similar crop or compare data from other dendrometers installed on the farm.

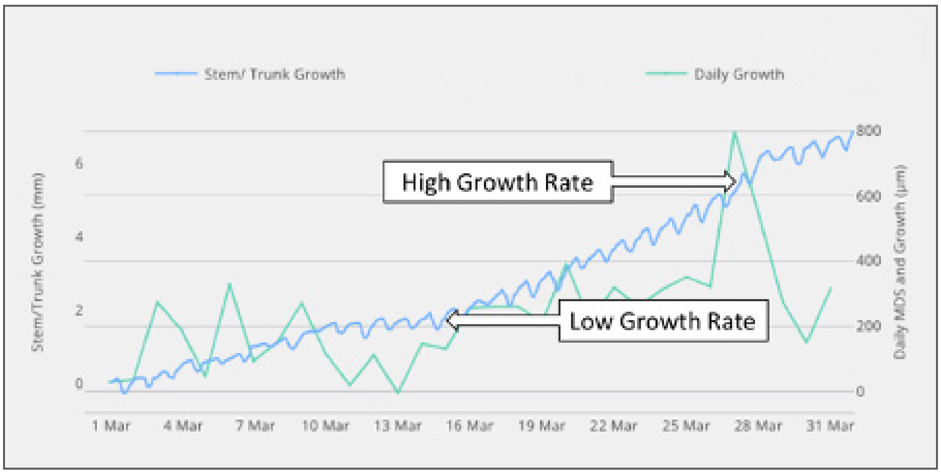


Figure 11. Pivot dendrometer data.

Further reading

[Washington State University guide to dendrometers]

[This band dendrometer manual provides a more in-depth installation guide]

Maximum daily shrinkage

High resolution dendrometers are used to monitor the diurnal swelling and shrinkage of stems or fruits, in other words the daily 'peak to trough' difference in stem or fruit diameter. The peak diameter is reached in the early morning, with most growth happening overnight. During the day, stems and fruit will shrink and reach a trough by night-time. This occurs because large amounts of water are lost from the foliage as the plant captures CO_2 from the atmosphere as part of photosynthesis. With so much water being transpired, the trunk or fruit can shrink or not grow during the day.

Maximum Daily Shrinkage (MDS) measures the daily peak to trough, and with careful interpretation it can be used as an early indicator of plant stress when combined with daily growth measures. MDS is the most sensitive physiological measurement for detecting early plant stress. There are strong positive relationships between MDS and evapotranspiration, solar radiation, and vapour pressure deficit.

Under well-watered conditions, daily growth will be positive and the MDS values will vary depending on environmental conditions. When plants are under early water stress, growth stops (daily growth low or zero) and MDS values increase, indicating a water deficit (Figure 11).

If the water deficit increases, daily growth can become negative and the MDS values will increase further until a threshold value where the trunk of the tree has no water reserves. At that point, MDS values will rapidly decrease under severe water stress. This level of water stress might have a negative effect on long-term tree health and productivity.

Figure 12. Band dendrometer installed on an avocado tree.

Maintenance

Pivot dendrometers

Pivot dendrometers use spring tensioned fingers to hold onto small diameter stems and require very little maintenance over their service life. The dendrometer should be inspected periodically to ensure it has not shifted on the stem, however this would likely be obvious from a rapid change in stem diameter data.

Band dendrometers

Band dendrometers use a strip of metal tape to measure changes in a trunk diameter, which needs to be replaced as the tree grows past the maximum range of the dendrometer. For example, if the circumference increases by about 60mm, the dendrometer will need to reset near zero with a new longer piece of dendrometer tape installed.

A dendrometer should be installed on the south side of a tree (in the southern hemisphere) to reduce the equipment's exposure to direct sunlight.

Figure 13. Pivoting stem dendrometer installed on a young citrus tree.

SAP FLOW

Sap flow sensors measure the flow of water and nutrients through the target plant. The measurement of sap flow can be used as an indicator of transpiration rate which can subsequently inform irrigation management. Sap flow is measured by applying a pulse of heat into the sapwood, with up and downstream needles measuring heat difference over time.

Installation

Sap flow sensor installation is complicated and should be undertaken only by an experienced professional. The following steps are a high-level summary of the installation process.

- Select a tree or plant for sap flow measurement. This specimen should be in good health and representative of the management area.
- Measure stem diameter, bark depth and sapwood thickness. These measurements are essential for the correct placement of the needles within the water conducting xylem of the plant.
- Select a flat, straight section of stem with no damage or imperfections. Attach the installation guide at first branch. The guide is attached using 4 anchor pins and it should not move during installation.
- Carefully drill three vertically spaced holes. If a drill bit breaks or the guide moves, the installation should be abandoned.
- Grease and insert the needles using only finger pressure. Attach the sap flow meter to the tree, ensuring that there is no strain on the cables once the communications node is installed.

Figure 14. Sap flow sensor installed on an avocado tree, note the three prongs inserted into the trunk.

Data

Raw sap flow data is difficult to interpret without training.

Sap flow is the movement of water through a plant and can be used as an indicator of transpiration. Increased sap flow is an indicator of a healthy plant which is actively transpiring, and reduced sap flow can be an indicator of plant stress, or sometimes poor climatic conditions. It is important to consider the potential evapotranspiration weather conditions when interpreting sap flow data.

Sap flow changes in response to the climatic conditions as it is directly related to transpiration. On a cloudy day, transpiration rates will be lower and sap flow declines. Similarly, wet canopies can have reduced (up to half the normal) transpiration rates, causing lower sap flow. Peak sap flow will decline is a plant enters water stress. This can help indicate when an irrigation event is needed.

> **Further reading**
> [Agriculture Victoria - Plant-based sensors for irrigation management]
>
> [Sap flow installation manual]

Sap flow readings can also be compared to daily evapotranspiration data or maximum air temperature to help identify when an irrigation event is needed. High evapotranspiration readings should correspond to high sap flow, if water is not limiting.

Maintenance

Sap flow sensors use a small heater and two thermometers to measure heat changes in sap, and thus the velocity of sap moving through the sap wood. Great care must be observed when installing sap flow sensors, however once they are successfully installed, there is very little ongoing maintenance required.

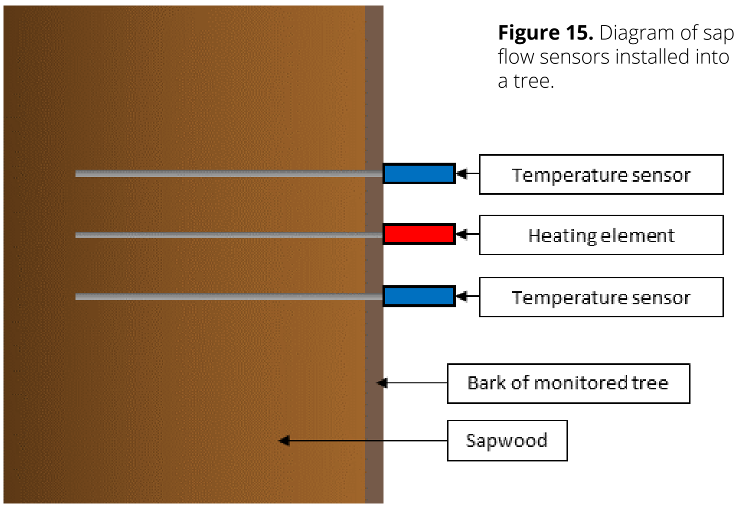


Figure 15. Diagram of sap flow sensors installed into a tree.

WEATHER STATION

A weather station provides accurate and live weather data. Although weather forecasts and readings are available online, weather can vary significantly, even over a few kilometres. Therefore, an on-farm weather station is an integral component of the smart farm.

Important weather parameters include temperature, relative humidity, rainfall, atmospheric pressure, and wind speed and direction.

Installing the sensor

The types of parameters to be measured will influence the correct location of a weather station. The weather station should always be easy to access for readings and maintenance.

Wind parameters: Position the station on level terrain as far away from obstructions as possible.

Rain gauge and wind gauge: Position rain gauges on a horizonal plane, open to the sky and above a height at which splashing rain could influence the measurement. Ensure rain and wind gauges are positioned away from each other.

Temperature and humidity sensors: Position these sensors in an open, level area, as far as possible from obstructions and paved areas.

Other sensors: Shield [all/other/additional] sensors from thermal radiation and ensure that they are well ventilated.

Maintenance

Regularly clean tipping bucket rain gauges to avoid blockages and check and remove any items from the rain funnel and debris filter. Open the rain gauge and remove any foreign objects. If your rain gauge is self-emptying, check for any obstructions in the exit path. Use a soft, damp cloth to wipe away dust.

> Weather station data should be regularly cross referenced against the nearest Bureau of Meteorology station or using historical SILO data.

Figure 16. Weather station installed on a portable tripod at a production nursery. Temperature, wind and humidity sensor (left), tipping bucket rain gauge (center) and solar radiation sensor (right) are shown. This weather station monitors the micro-climate within the net house.

Figure 17. Closeup of temperature, wind and humidity sensor.

Figure 18. Weather forecast data

PRESSURE TRANSDUCERS

There are two types of (fluid) pressure transducers commonly used in horticulture:

1. **Submersible pressure transducers** measure water levels in dams, tanks, troughs, and flumes (Figure 19).
2. **Irrigation line pressure transducers** detect irrigation events and monitor irrigation pressure (Figure 20)

Submersible pressure transducers

Submersible pressure transducers are used to manage water storage levels. Water pressure values are converted to a measurement of water head height, so it is important to purchase a pressure transducer with the correct range of measurement. For example, a 10-metre water tank will provide about 14 psi of head pressure.

Irrigation Line Pressure Transducers

Pressure transducers are used to monitor an irrigation system and to identify when the system is not operating to specifications. If the correct pressure is not attained during irrigation this can indicate a broken pipe or failing irrigation pump. Identifying a fault early can help to save plants and reduce energy costs.

Installing the sensor

Submersible pressure transducers

- Submersible pressure transducers must be installed 10 – 30cm above the bottom of a water body such as tank or dam.
- Pressure transducers can be installed vertically or diagonally in the water body, with sensor opening facing downwards.
- Pressure transducers are commonly installed inside a PVC or plastic pipe with small openings drilled near the base. The pipe protects the sensor from damage and keeps it in the desired location at the side of a tank. For a dam installation, a weighted PVC pipe can be lowered from the shore diagonally to lowest area of the dam, which allows for dry access to the sensor for cleaning. The pressure transducer can be installed at an appropriate distance from the end of the PVC pipe so that the sensor is not resting in sediment at the base of a dam or tank.

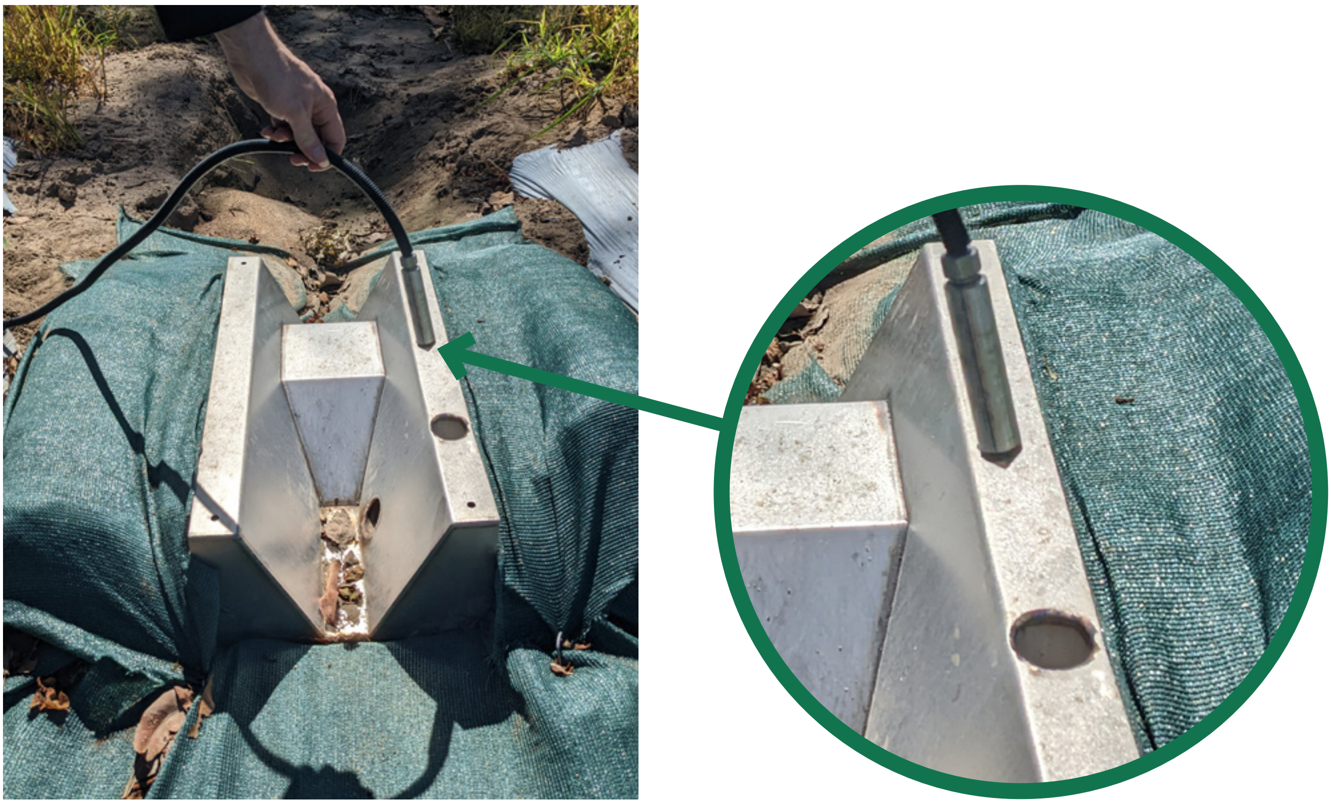


Figure 19. Submersible pressure transducer for accurately measuring water levels. Source: Keller Instruments.

Irrigation line pressure transducers

Irrigation line pressure transducers are easy to install with the right fittings.

- Fit the clamp to the irrigation zone sub-main and drill an appropriately sized hole to allow the pressure transducer to sit securely in the pipe.
- The size of the hole required will be stated in the pressure transducer instruction sheet that comes with the sensor.

Maintenance

Pressure transducers require regular cleaning, especially if they are installed in stagnant water. They can be cleaned with a microfibre cloth and clean water.

Some pressure transducers have a drying tube filled with desiccant. The desiccant needs to be replaced periodically, indicated by a change in colour from blue to pink. Replacement intervals will depend on the local relative humidity.

Figure 20. Irrigation pressure transducer installed on 40mm Polyethylene tube irrigation line at a production nursery.

LEACHATE BY VOLUME (NURSERY)

Leachate by volume is an irrigation management technique used to help identify the frequency and duration of irrigation events. Water which drains from containers following a rain or irrigation event is called leachate. The leachate contains nutrients from applied fertiliser and growing media particles, both of which can impact water quality in dams or local waterways if not treated. Excessive irrigation can cause the complete loss of primary nutrients from the growing media, effecting plant quality and requiring further applications of fertiliser, as well as leading to large volumes of wasted water.

Limiting the volume of leachate draining from containers minimises runoff, reduces nutrient loss and increases irrigation efficiency.

The volume of leachate draining form a container is called the 'leaching fraction'. This is directly related to the volume of water applied during an irrigation event and is calculated by dividing the leaching fraction captured from a container by the volume of water applied to the container during an irrigation event.

LF% = Amount of leachate X 100
Amount of water applied to container

Installing the sensor

- Select a location in the irrigation zone that represents the irrigation requirements of the crop.
- Two tipping bucket rain gauges must be securely fastened to a support.
- The tipping buckets should be at a similar height to other containers in the management area.
- One of the tipping buckets is left uncovered to measure irrigation volume and the other is adapted to allow a container to be inserted.
- Refer to Figure 21 for an annotated example of a leachate monitoring system

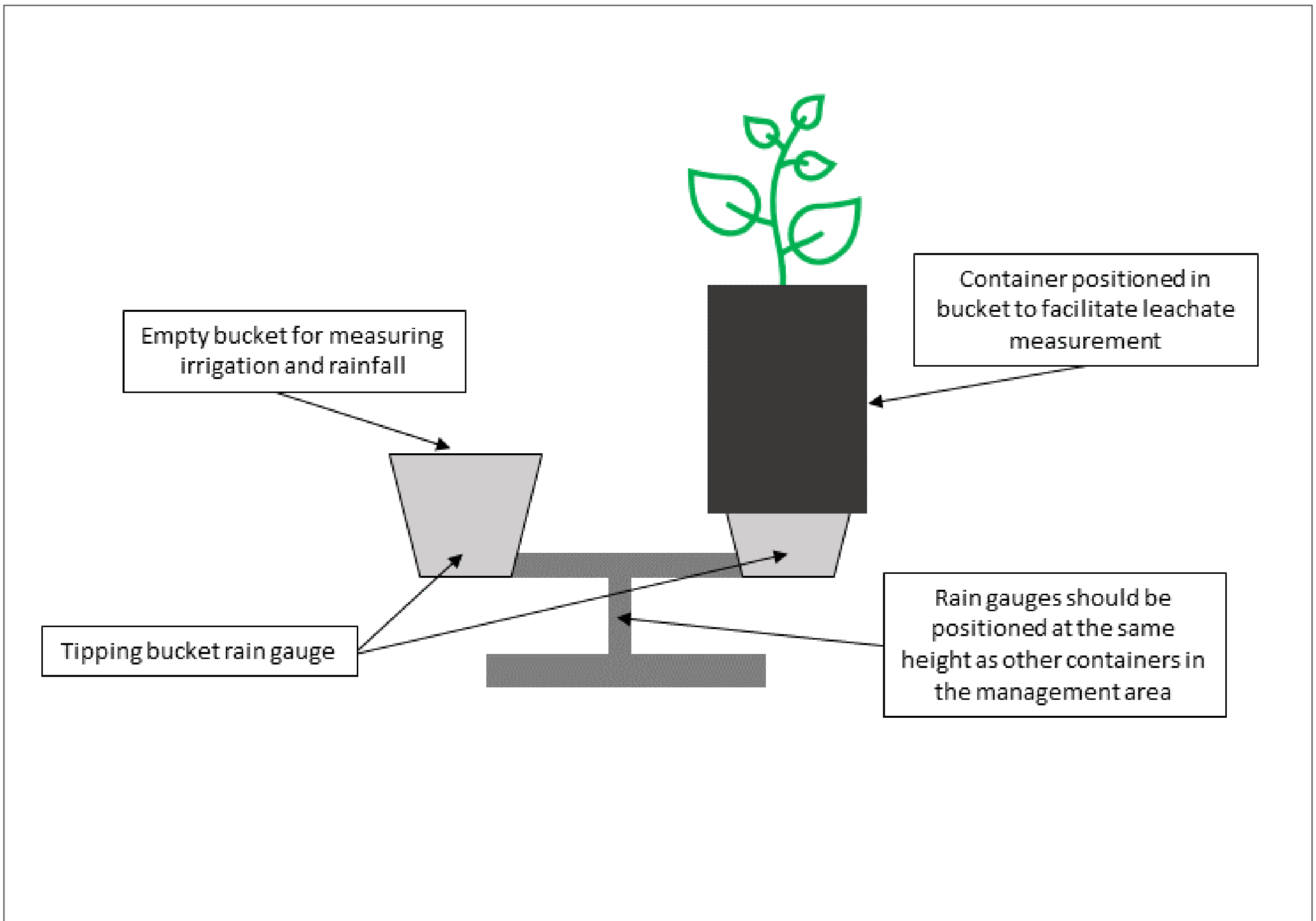


Figure 21. Diagram of a pot leachate sensor.

Managing the data

The target leaching fraction for containerised nursery production is 12%. A 12% leaching fraction has been shown to provide sufficient leaching to stop a toxic build-up of nutrient salts within the root zone, while increasing water use efficiency. Monitoring the volume of leachate can be used to refine the irrigation schedule. If the leaching fraction is constantly being reported as 20% then the irrigation duration should be adjusted down by small increments until the leaching fraction is approximately 12%.

As the application rate of some irrigation systems is too high for precise adjustments, a leaching fraction of between 12% and 20% is acceptable.

Maintenance

Tipping bucket rain gauges require regular cleaning to avoid blockages. Check and remove any items from the rain funnel and the debris filter. Open the rain gauge and remove any foreign objects. If your rain gauge is self-emptying, check for any obstructions in the exit path. Use a soft, damp cloth to wipe away dust.

Figure 22. Two tipping bucket rain gauges used to measure irrigation volume applied to a container (left) and leachate volume from a container (right). Both tipping buckets are normally covered by a container and plastic shroud. Production nurseries often target a leachate fraction of 12%.

VEHICLE TRACKING

Vehicle tracking is an innovative way to record on-farm activities such as fertiliser spreading, harvesting, and spreading dates and times. Location and time data can be used to supplement or even replace many of a farm's manual records.

Installing the sensor

GPS trackers are installed on the roof of vehicles, or on raised areas of equipment to avoid damage and provide the greatest GPS and 4G signal. Trackers can be wired into the vehicles 12- or 24-volt electrical system for maintenance-free use.

Maintenance

GPS trackers need to be recharged regularly if they are not hardwired into a vehicle's electrical system.

Figure 23. Tractor with a GPS tracker installed on the roof. Data is transmitted every five minutes. The GPS tracker is connected to the vehicle power supply.

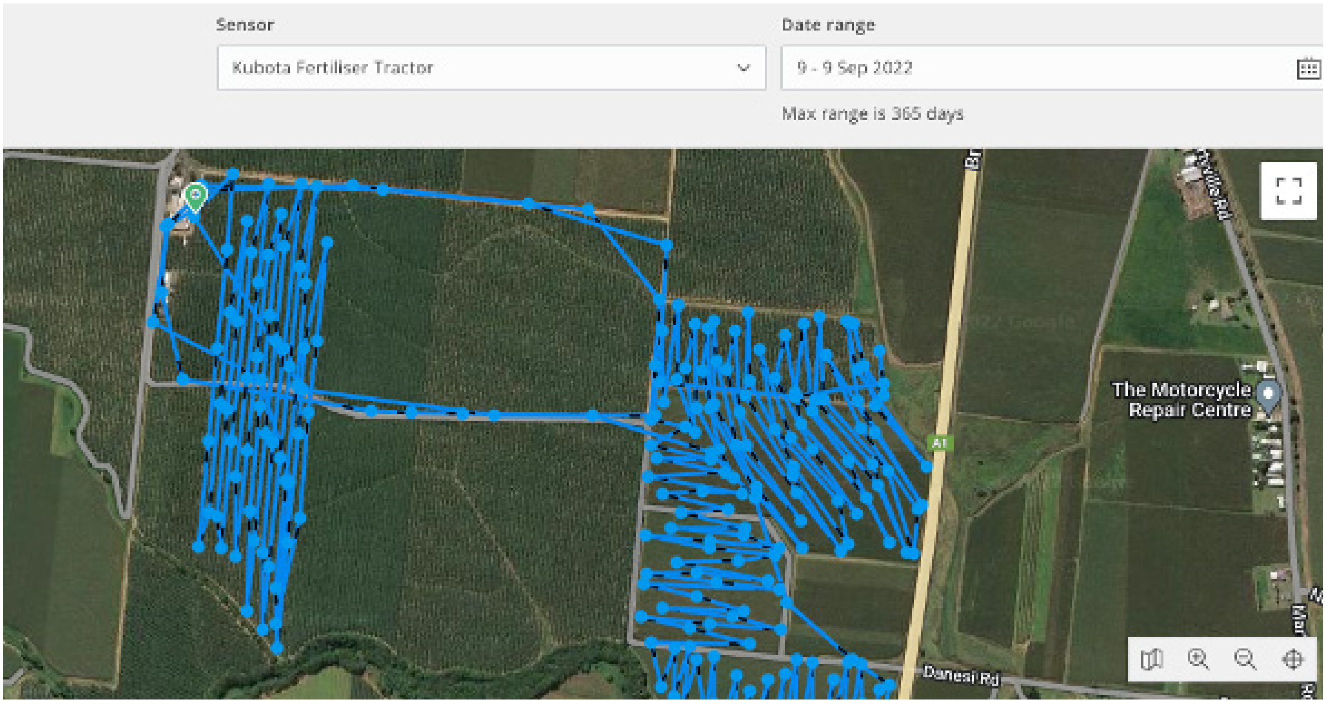


Figure 24. Vehicle tracking data of a fertiliser spreading

IRRIGATION WATER QUALITY

Irrigation water quality monitoring is important when using variable water sources or when growing sensitive crops. Water quality sensors include those that measure pH, electrical conductivity and nutrient concentrations in irrigation water.

Although detailed installation procedures are provided with the sensors, we have included the key considerations and basic installation steps for each sensor type to help make the process as easy as possible. Maintenance advice is included in this guide, but it is recommended to consult the specific maintenance guidelines provided by sensor manufacturers.

Look out for links to videos, online tools, and further reading.

PH

pH measures the alkalinity or acidity of a solution and is measured on a scale of 0 to 14, where readings above 7 are alkaline and readings below 7 are acidic. The acidity or alkalinity of water can adversely affect plant growth and irrigation equipment.

Installing the sensor

For submerged sensors, it is important that the body of the sensor is secured and not left suspended by the cable, as this may lead to damage. Refer to Figure 25 for an annotated example of how to install pH sensors in a water storage dam.

In water storage applications, poles can suspend the sensor at the desired point of measurement.

- The installation should allow the sensor to be removed easily, so that cleaning and maintenance can occur at regular intervals.
- The housing used to secure the sensor should allow good water flow, so that the sensor is measuring a representative sample of the water body
- It is recommended that the sensor is positioned close to the location from where the irrigation water is collected

Managing the data

Most natural waters are between pH 5 and 8. If you need to adjust your water pH, try to keep it between pH 5.5 and pH 7. Water in this pH range:

1. Maintains nutrient balance
2. Prevents scale formation in irrigation equipment
3. Provides effective chemical disinfection.

A pH **greater than 7.5** is likely to reduce the effectiveness of chlorine disinfection.

A pH **less than 5.5** can interfere with plant root growth by making growing media acidic.

Water pH can be adjusted by adding an acid or an alkaline substance to the water supply. The appropriate substance may be injected into the pipeline for automated systems or mixed in a tank for manual systems or larger volumes of water. The use of an acid (such as sulfuric acid) will lower the pH, while an alkaline substance (for example, lime) will increase the pH.

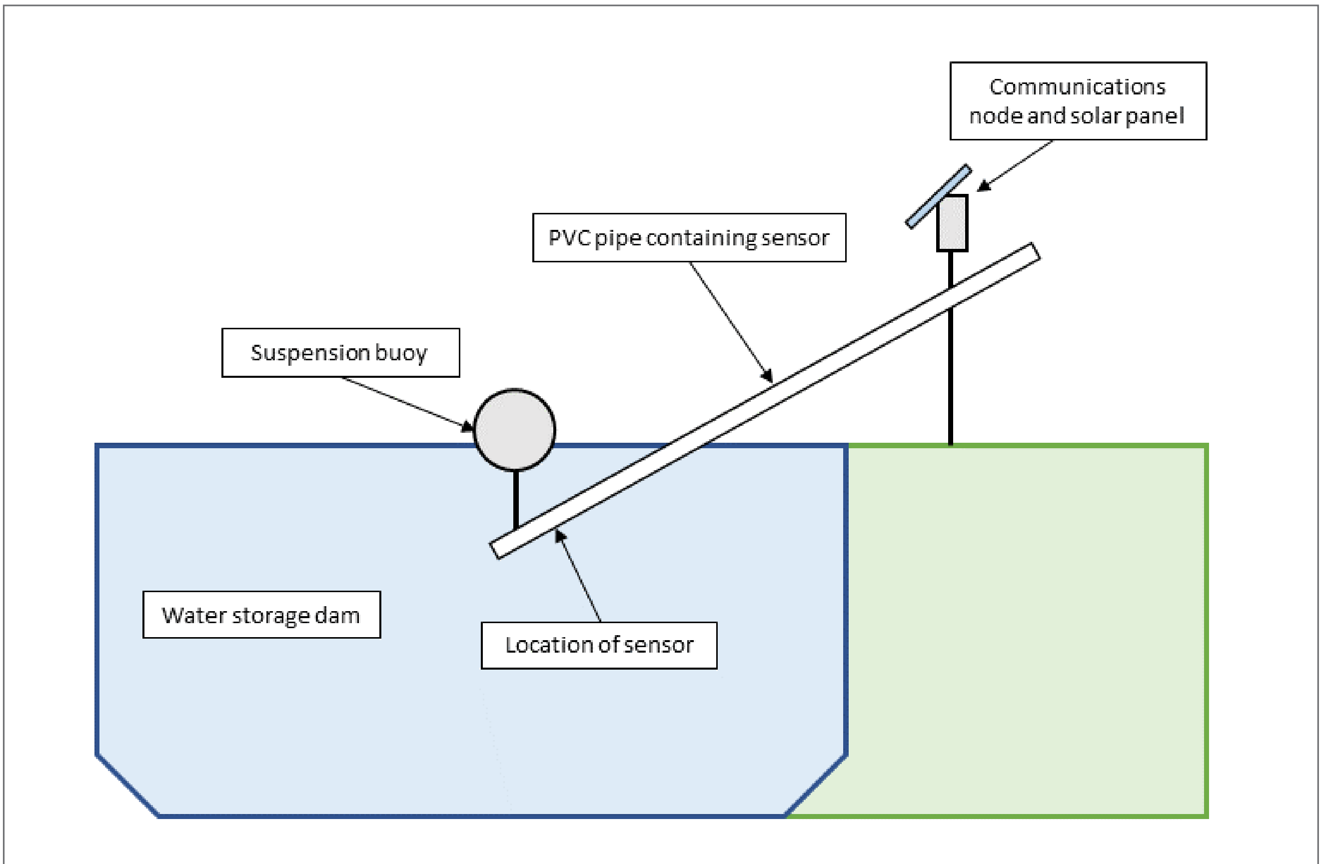


Figure 25. Diagram of pH and EC sensors suspended below the surface of a dam.

Maintenance

The pH sensor needs to be regularly cleaned, especially if installed in an area of stagnant or dirty water, such as a runoff drain. The body of the sensor can be cleaned using a microfibre cloth. To clean the pH bulb, place the sensor in a cleaning solution for a few hours and rinse again before use. Check the calibration of pH sensors annually using a pH standard.

Further reading
NSW DPI Farm water quality and treatment

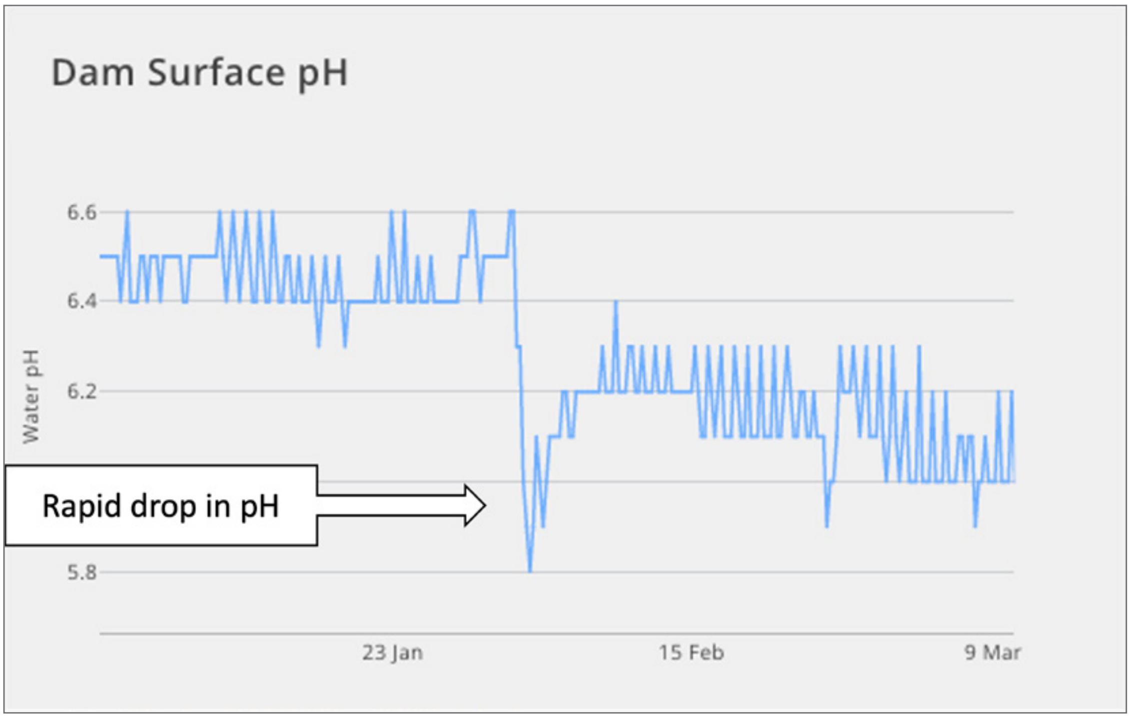


Figure 26. pH data from a dam at a production nursery. Rapid changes in pH can be quickly resolved after a notification is received through a smart farming dashboard.

Figure 27. Dam monitoring system with buoy to keep sensors at a constant depth.

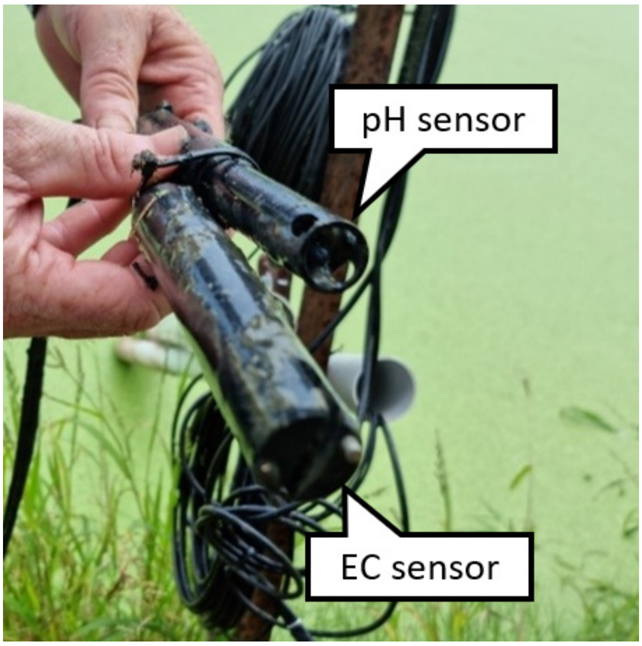


Figure 28. EC sensor (left) and pH sensor (right) removed from a dam for cleaning

ELECTRICAL CONDUCTIVITY

Salinity is the total quantity of dissolved salts in the water and is measured by electrical conductivity (EC). The greater the concentration of salts, the higher the electrical conductivity of the water.

Electrical conductivity (EC) can be measured at multiple locations on a farm or nursery, such as water storge, irrigation lines, leachate zones and runoff zones.

There are several units of measurement used for salinity or EC and it can get confusing. EC can be quoted in micro-Siemens per centimetre (μS/cm), deci-Siemens per metre (dS/m), Siemens per centimetre (S/cm), milli-Siemens per millimetre (mS/mm), or millihos per centimetre (mmho/cm).

The most common unit of measurement is dS/m as this is easier to convert to parts per million (ppm)

1 dS/m = 0.1 S/m = 1 mS/cm = 1000 μS/cm = 1 mmho/cm

Installing the sensor

For sensors that are to be submerged in water, it is important that the body of the sensor is secured and not left suspended by the cable as this may lead to damage.

In surface-water applications, poles can suspend the sensor at the desired point of measurement.

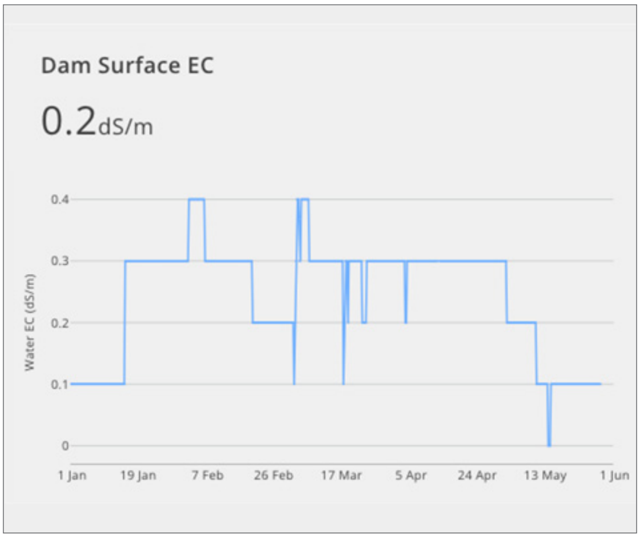


Figure 29. EC measured at the dam surface provides data on water quality used for irrigation. If EC increases above 0.8-1 dS/m, irrigation water should be diluted with another water source.

- The installation should allow the sensor to be removed easily, so that cleaning and maintenance can occur at regular intervals.
- The housing used to secure the sensor should allow good water flow, so that the sensor is measuring a representative sample of the water body
- It is recommended that the sensor is positioned close to the location from where the irrigation water is collected

Managing the data

As plants are generally most susceptible to salinity damage during the germination and seedling stages, greater care in managing water quality should be taken at the nursery stage.

Fluctuations in water EC are expected at different times of the day. As moisture evaporates from a dam, or drains from a plant container, nutrient salts are concentrated thus raising the EC reading.

Conversely, following irrigation or rain, EC levels in leachate and runoff into the dam may increase as concentrated nutrients are leached from the containers and nutrients are diluted.

EC fluctuations will vary depending on weather conditions, and whether a fertigation or plain water irrigation system is used.

Negative effects of salinity become apparent when electrical conductivity values of the circulating solution range from 2.5 - 3.0 dS m^{-1} for fruits, from 4.5 - 5.0 dS m^{-1} for stems and leaves, and from 6.0 dS m^{-1} for roots.

EC (dS/m)	Total dissolved solids (ppm)	Salinity level
0–0.80	0–456	Low salinity
0.80–2.50	456–1425	Moderately salty
2.50–5.00	1425–2850	Salty
>5.00	>2850	Very salty

Maintenance

The EC sensor needs to be regularly cleaned, especially if installed in an area of stagnant or dirty water, such as a runoff drain. The sensor can be cleaned with a microfibre cloth and clean water. Check the calibration of EC sensors annually using an EC standard.

MODELLING

Software models can be used to predict a variety of environmental and productivity parameters. Examples of these are the HowLeaky model, which can predict the runoff and leaching of nitrate, and Growing Degree Days (GDD) models that model the maturity of a crop. All models require an initial setup and ongoing validation of output data.

Look out for links to videos, online tools, and further reading.

GROWING DEGREE DAYS MODEL

Growing degree days (GDD) are a measure of heat accumulation used to predict the rate of crop development.

The data that is fed into dashboards can be further leveraged through the integration of various models. Growing Degree Day (GDD) models can be used to forecast plant maturity by predicting key dates such as flower emergence. The data required for GDD models can be collected using a remote monitoring camera and access to temperature records.

Setting up the model

GDD models assume that plant growth only occurs if the temperature is above a minimum threshold. Minimum thresholds must be determined for each crop type. A growing degree's day model needs to be initiated with a good data set of critical dates (e.g., maturity or harvest dates). The accumulated growing degree days between planting and maturity of similar previous crops need to be calculated. Online tools are available (for example here).

Figure 30. Remote field camera is used to collect precise fruit maturity dates.

Managing the data

Cameras can be used to collect accurate maturity dates (Figure 30) such as flower emergence and fruit maturity. Key dates are recorded and converted into growing degree days since transplanting, which are used as target points in a crop forecasting tool. Crop maturity dates can then be forecasted using future expected GDD's, which are calculated with short-term and seasonal weather forecasts.

Further reading

Using Growing Degree Days to Predict Plant Stages

Agronomy Fact Sheet: Growing Degree Days (GDDs)

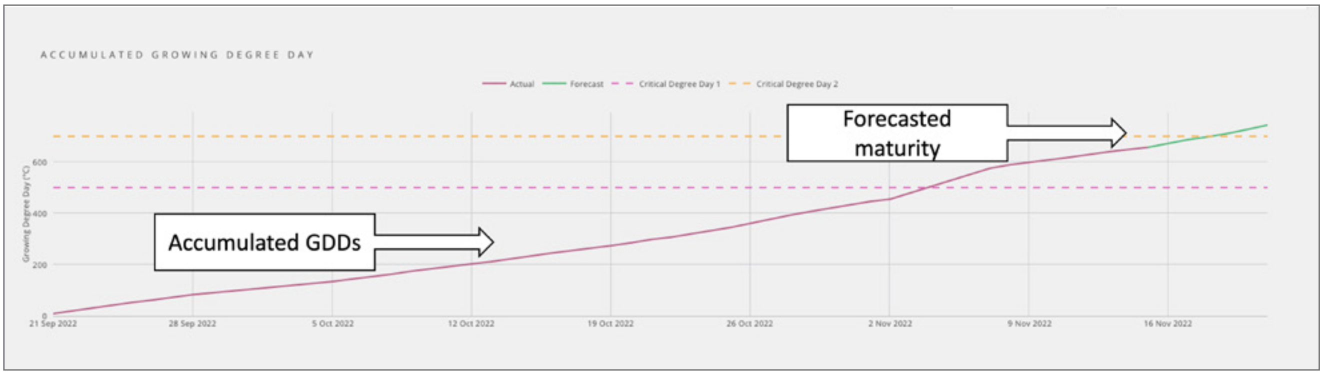


Figure 31. Example of a Growing Degrees Day model used to predict critical dates, such as fruit maturity.

NUTRIENT LOSS MODEL

Various models are available to predict nutrient and water surface runoff and leaching to groundwater from a paddock. These models require the initial input of soil and vegetation data, but can then be automatically fed with weather, fertiliser, and irrigation information from a smart farming dashboard, such as the Hitachi Vantara Control Tower. A nutrient model can provide insight into the volume of fertiliser leaving a property. This information can be used to maximise the efficiency of fertilisation, while also mitigating environmental impact.

HowLeaky is an open-source water balance and water quality model. HowLeaky was developed to assess the impacts of different land uses and management practices on water balance and quality. HowLeaky requires a few key parameters for initial set up but has different optional modules, which allow the investigation of a variety of management practises. HowLeaky is a daily time step model, which means that outputs are summarised as daily totals. HowLeaky can be run using forecasted weather data and planned irrigation and fertiliser applications to give a prediction of leaching and runoff. HowLeaky is typically run manually on a desktop computer but has been configured to run online via the HowLeaky website. As with all models, the data output provided from HowLeaky should be validated using real world data.

Input	Description	Required or Optional
Climate data	Can be automatically populated by pulling data from SILO	Required
Soil parameters	Soil information is required for each layer in the soil profile, these data must be inputted manually.	Required
Crop parameters (Cover)	Each crop being modelled must have a separate module created. A variety of crop modules are available online.	Required
Irrigation parameters	Can be automated if the data are accessible from a farm management system.	Optional
Nitrate parameters	Can be automated if the data are accessible from a farm management system.	Optional

Table 3. Data inputs into HowLeaky for estimating nitrate runoff and leaching.

Output	Description
Water balance	Includes volume of water runoff and deep drainage.
Erosion	Includes hillslope erosion
Nitrate	Includes volume and concentration of dissolved nitrate in runoff and deep drainage.

Table 4. Data outputs from HowLeaky.

Further reading
HowLeaky Technical Documentation

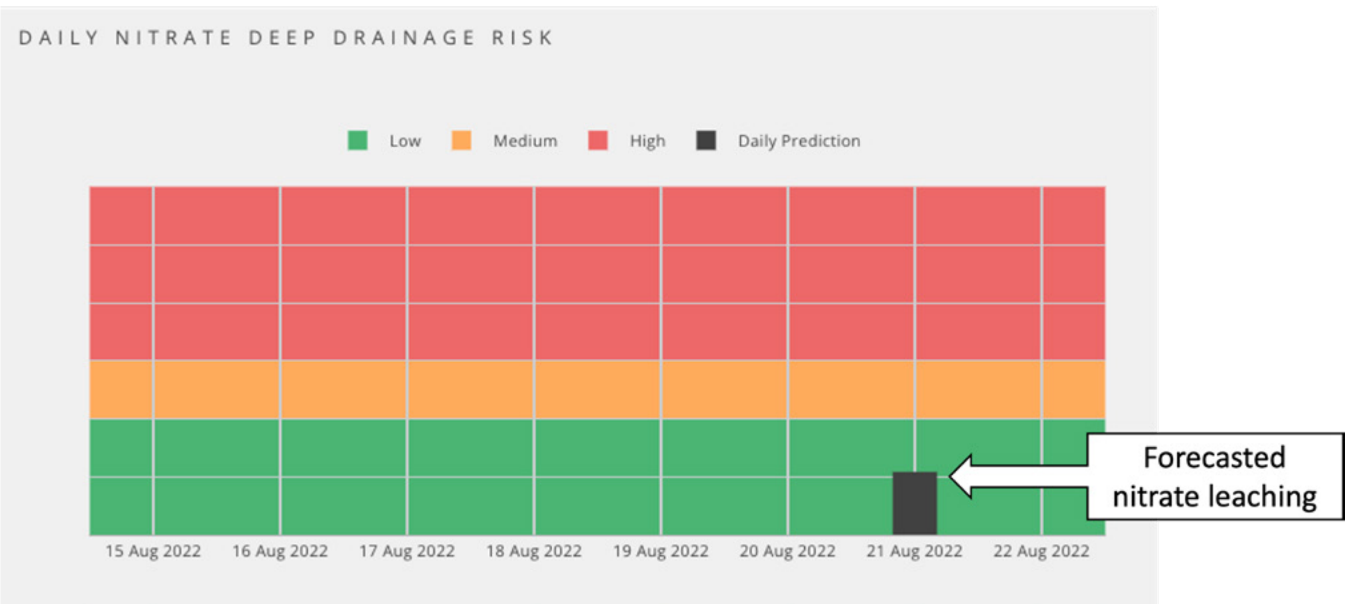


Figure 32. Example of forecasted nitrate deep drainage

CAMERAS

Cameras can be used to remotely monitor the maturity of plants, pest traps and sensors, and visually confirm events such as irrigation. Images and video can be fed live into a centralised dashboard.

Look out for QR codes and other links to videos, online tools and further reading.

REMOTE FIELD CAMERAS

Remote field cameras can be installed to monitor crop development and important sensor installations. Images from field cameras can be used to remotely verify the operating status of sensors.

Installing the camera

- A 3G or 4G enabled trail camera is sufficient
- Ensure the camera is equipped with a solar panel or has adequate battery life
- Consider the signal available to the camera
- Establish and set up the frequency of image capture has been setup on the camera (this could be multiple times a day or as low as once a week depending on requirements)
- Securely install with an uninterrupted view of the subject
- Configure to send images via email or uploaded directly to a server

Managing the data

Remote field cameras are excellent for capturing dates of events, such as flood, runoff events, fruit maturity and soil amendments. Cameras are also useful to review changes in a crop over time, such as pest damage or wilting. Cameras do not automatically produce data; however, they provide a very versatile record which can be analysed quickly.

Maintenance

Remote cameras should require little to no maintenance if installed properly. It may be necessary to periodically inspect and clean the lens.

PEST TRAP CAMERAS

Pest trap cameras remotely monitor insect sticky traps and share images with pest consultants. The use of remote pest trap cameras and regular monitoring can save labour time normally used for pest scouting and facilitate timely detection of pest outbreaks. As high-resolution cameras with access to ethernet cabling are required, pest trap cameras are more suited to nurseries or protected cropping operations.

Installing the camera

- Connect camera to power via ethernet cabling.
- Install cameras and sticky traps within the plant canopy as this is the predominant zone of pest activity
- Install cameras in a fixed position if the crop has a uniform canopy height
- Install cameras on an adjustable bracket for long term monitoring or for fast-growing crops to allow the camera to be raised up as the plants grow
- Ensure camera is sheltered from rain and irrigation splash.

Figure 33. Photos from remote field cameras, which are used to monitor crops or important equipment. Photos are sent via email, text message or to a smart farming dashboard.

- Ensure cameras and cable connections are waterproof and have an operating temperature rating for the local conditions
- Ensure cameras installed within the crop canopy are aligned or covered so overhead irrigation does not fall directly on the camera lens as this will cause salt build up on the lens and reduce image quality

Data

Camera images can be viewed live through the on-site camera system, which will usually include a high-resolution monitor, or through images which are emailed to registered users each morning.
Camera images will alert nursery or farm managers to the presence of pests stuck in the trap (Figure 34), however, a manual inspection of the pest traps will usually be required to confirm the identity of very small pests, such as thrips.

Future work will apply automated image recognition to pest trap camera images, which will be able to provide alerts of relevant pests to nursery and farm managers.

Maintenance

- Sticky pest traps will need to be replaced periodically, as per existing practice.
- Cameras will need to be raised as plant height grows.
- Cameras lenses will need to be periodically wiped clean with a microfibre cloth.

Figure 34. Camera with pest trap mounted.

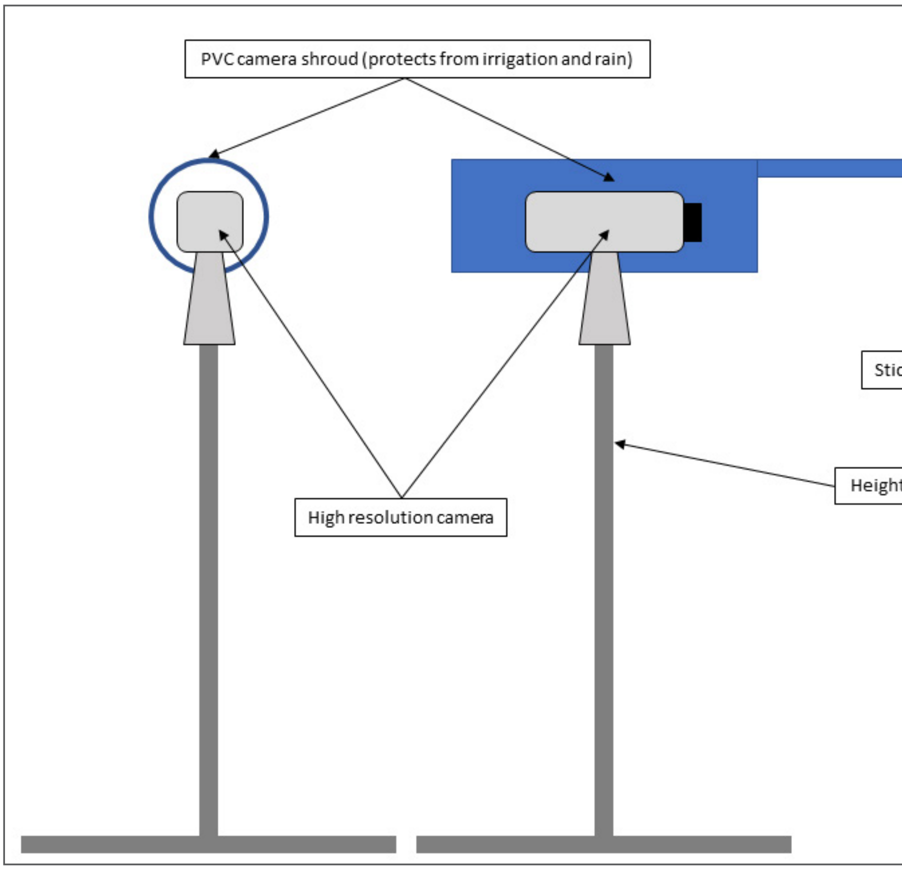


Figure 35. Diagram of a pest trap camera and shroud

ENVIRONMENTAL MONITORING

Monitoring the environmental performance of a farming operation can be challenging and time consuming. Sensors that monitor the environmental performance of a farm can streamline this process and reduce the time required for recordkeeping. A selection of environmental sensors has been included in this guide, focussing primarily on water quality monitoring.

Although detailed installation procedures are provided with the sensors, we have included the key considerations and basic installation steps for each sensor type to help make the process as easy as possible. Maintenance advice is included in this guide, but it is recommended to consult the specific maintenance guidelines provided by sensor manufacturers.

Look out for links to videos, online tools and further reading.

TRIOS NICO PHOTOMETER

Photometers, such as the TriOS NICO, can be used to continuously measure a wastewater parameter at a single point. These sensors usually require dedicated infrastructure and a continuous flow or full submersion in water to be effective. In-situ photometers are significantly more expensive than desktop photometers but remove the need for manual sample collection and can return continuous data to a dashboard.

Figure 36. TriOS NICO installed in an RBC-200 flume, measuring nitrate concentrations and flow rates of water from an ag-pipe installed 1m below the surface.

The TriOS range of real-time photometers are currently the most reliable models on the Australian market. The photometer measures changes in nitrate concentration in water by analysing the level of light absorption at three wavelengths. It is imperative the lenses are kept clean and unscratched. A TriOS NICO must be regularly checked for fouling from algae growth or sediment build up. The recommended 2-3 times weekly check is greatly simplified with the installation of a remote camera, such as a battery-operated wildlife camera.

Installing the sensor

For the monitoring of paddock runoff or leachate, it is recommended that the TriOS NICO is installed with an RBC flume and pressure transducer (Figure 36). This combination allows nitrate load to be estimated, increasing the value of the collected data. The RBC flume is most effective when installed in drains or irrigation channels. Refer to Figure 37 for an annotated example of an RBC flume with photometer installed

- The installation should allow the sensor to be removed easily, so that cleaning and maintenance can occur at regular intervals

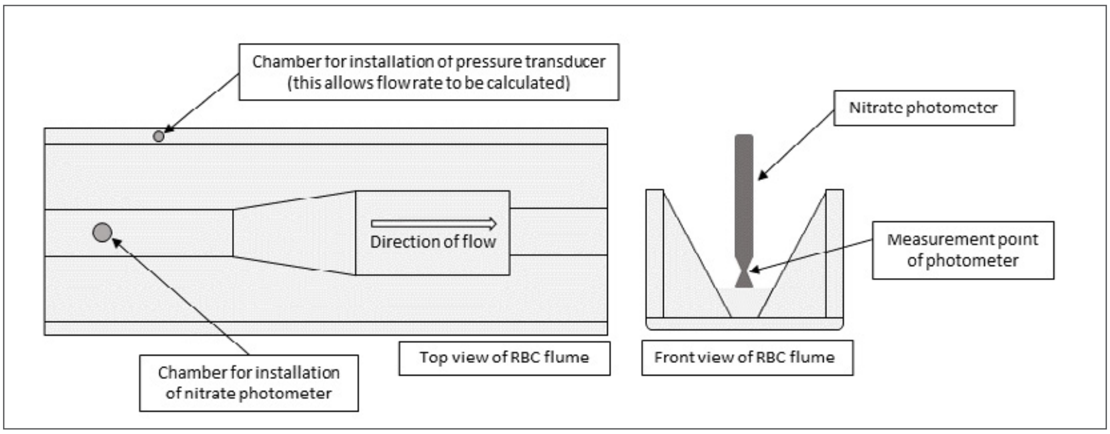


Figure 37. Diagram of a runoff flume with photometer.

Nitrate runoff and leaching

Water containing high concentrations of nitrate is unfit for human consumption and, if discharging to freshwater or marine habitats, can contribute to algal blooms and eutrophication. Nitrate pollution of groundwaters in coastal north-eastern Australia is of particular concern because of its proximity to environmentally sensitive areas (e.g. the Great Barrier Reef). Nitrate can leave a farm through surface water runoff (also known as wastewater) or through leaching through the soil profile to groundwater to drainage channels.

Nitrate can be measured inexpensively with test strips (Hach 2745425) or with a portable photometer (Hanna HI83306). Runoff samples can be collected with self-sealing bottles mounted at the soil surface (ThermoFisher 1100-1000) and leachate samples can be collected with subsurface collectors (CSIRO FullStop Wetting Front Detector).

- The housing used to secure the sensor should allow good water flow, so that the sensor is measuring a representative sample of the water body

Maintenance

The calibration of a TriOS photometer should be checked regularly with nitrate standards and pure water (e.g., reverse osmosis water). A minimum three-point calibration is recommended, which will need to be designed with consideration of the expected concentration of nitrate in water. The measurement range of the TriOS NICO is dependent on the pathlength of the lens, which needs to be specified. A recommended range is 0-30ppm ± 0.5 NO3-N.

Managing the data

Excessive nitrate in the water leaving farms through subsurface runoff or subsurface leaching is primarily due to nitrogen fertiliser use. There are no government guidelines on acceptable nitrate concentrations or loads in runoff or leaching. There is however regulation on the amount of nitrogen fertiliser that can used in the banana industry (400 kg / N / ha / yr).

Nitrate concentration data can be used to detect fertiliser loss events, which are usually caused by rain or over irrigation after fertiliser application. Patterns of increased nitrate loss through water can be used to refine fertiliser application rates and practices.

Using an EC sensor is a much cheaper, yet less accurate way to continuously measure fertiliser loss in runoff and leaching water.

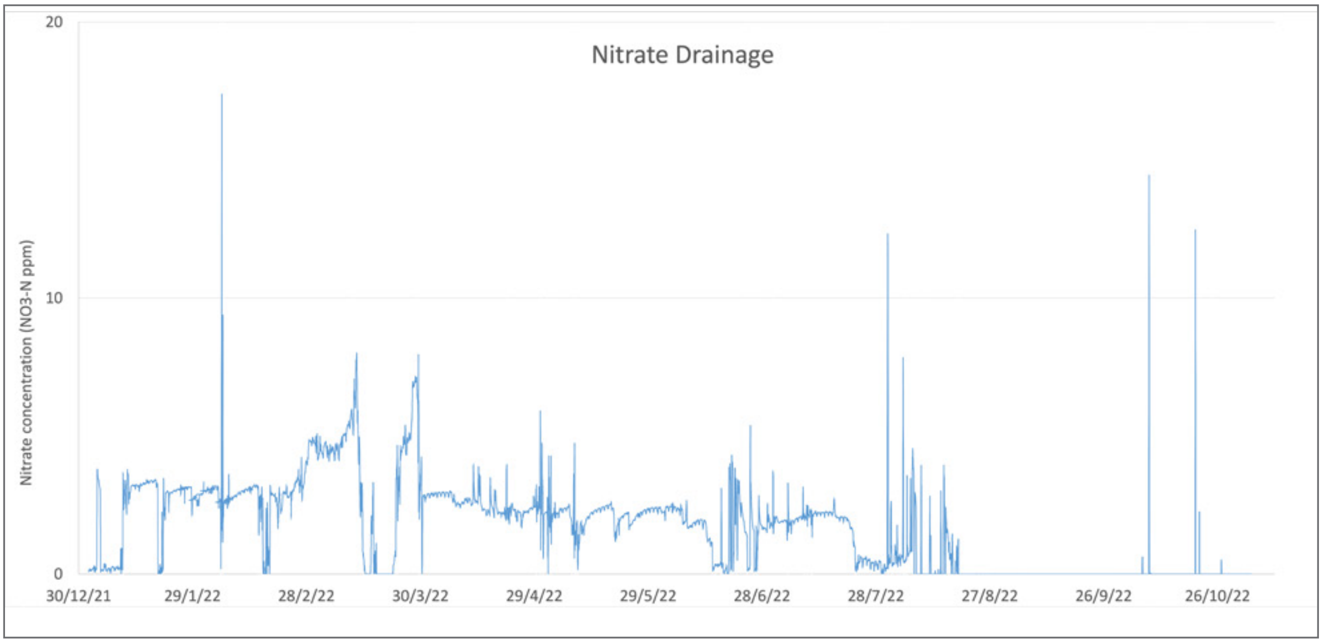


Figure 38. High resolution nitrate concentration data from TriOS NICO

Runoff flumes

Runoff flumes combine a rated flume with a pressure transducer to measure the runoff rate at a single point on a farm. These flumes are especially effective when paired with an in-situ photometer, as the concentration and flow rate of a specific parameter can be used to calculate total loads.

RBC flumes are portable, long-throated flumes designed to measure flows. RBC flumes can be manufactured and calibrated so that the optimum flow rate range of the flume is suited to the site.

There are a few key things to consider when installing RBC flumes:

- The flume should be well secured so that it stays in place and remains level during periods of high flow
- It should be positioned in the centre of the predicted flow
- It should not be installed in an area of high traffic and should be marked as a hazard

DESKTOP PHOTOMETERS

Desktop photometers conduct on-site analysis of water samples. The results from these analyses can then be exported to databases for recordkeeping purposes. The flexibility of the desktop photometer facilitates water analysis at any point on the farm. Samples can be analysed for a range of parameters such as pH, nitrate, and phosphorus. The disadvantage of the desktop photometer is the labour required for the analysis of each sample.

An example of such a photometer is the Hanna Instruments HI83399 benchtop photometer. This photometer can measure 40 water and wastewater quality parameters. A digital electrode allows pH to be measured. The HI83399 is equipped with USB ports to allow data transfer.

Figure 39. Desktop photometer used to measure nitrate, phosphate, chlorine and alkalinity of water samples. Results are used for EcoHort reporting.

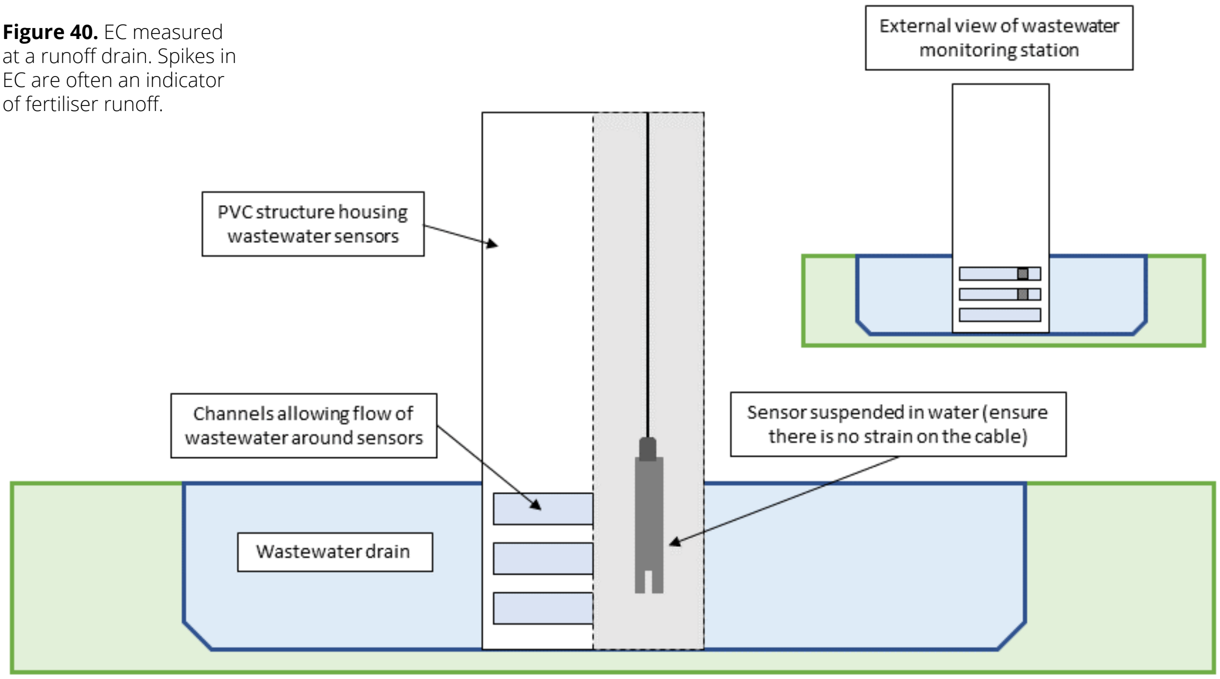
ELECTRICAL CONDUCTIVITY OF WASTEWATER

Electrical conductivity (EC) can be measured in runoff and container leachate as an indicator of dissolved salts, such as fertilisers. Continuous monitoring of EC can provide an efficient indicator of excessive fertiliser loss in water.

Managing the data

When leachate EC is monitored in conjunction with fertiliser applications and runoff water quality, the irrigation timing and duration can be manipulated to reduce the infiltration rate of the water, prolonging the time nutrients remain in the root zone. It can also be used to determine when fertiliser should be applied after a rain event.

Figure 40. EC measured at a runoff drain. Spikes in EC are often an indicator of fertiliser runoff.



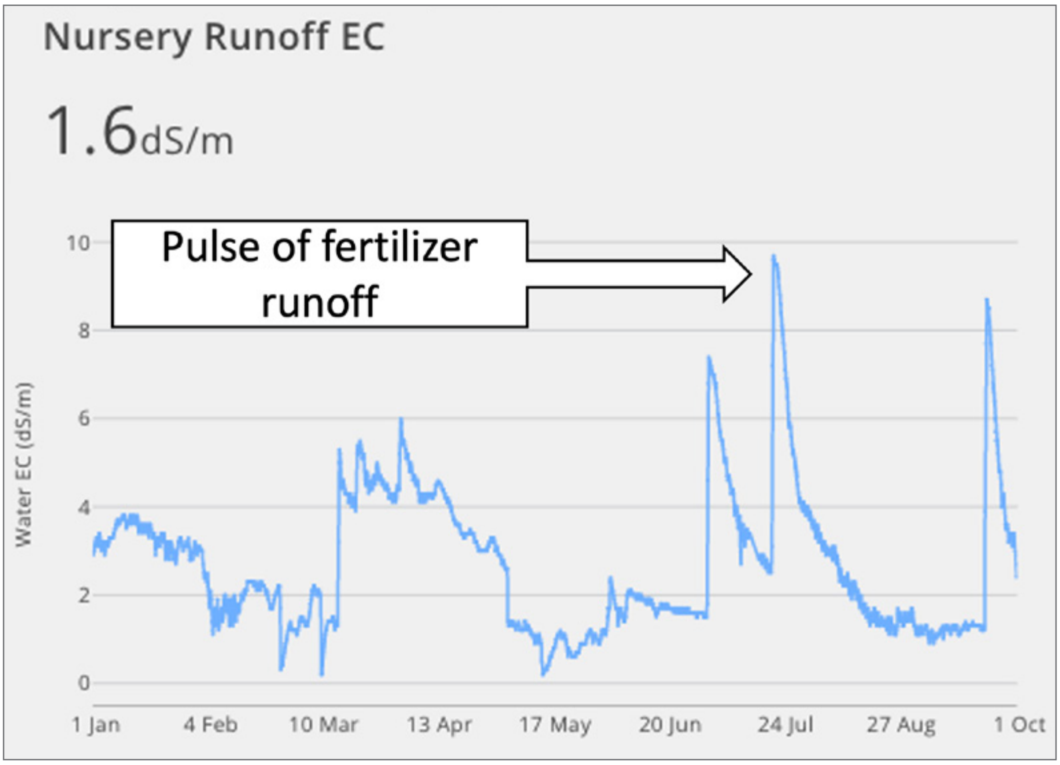


Figure 41. EC measured at a runoff drain. Spikes in EC are often an indicator of fertiliser runoff.

EC in leachate (measured directly under a container as shown in Figure 42) and runoff (measured in a drain as shown in Figure 40) will reduce with prolonged rain events and an application of fertiliser may be required to maintain plant quality. Monitoring EC can help to reduce the amount of fertiliser applied, the amount of nutrients lost, and reduce costs.

Maintenance

EC sensors need to be checked and cleaned on a regular basis to maintain accurate readings, especially if installed in an area of stagnant or dirty water. The sensor can be cleaned with a microfibre cloth and clean water. Check the calibration of EC sensors annually, with an EC standard.

Figure 42. EC and pH sensor installed to measure pot leachate for EcoHort reporting and nursery management.

REFERENCES AND FURTHER READING

Adeyemi, O., Grove, I., Peets, S. and Norton, T., 2017. Advanced monitoring and management systems for improving sustainability in precision irrigation. Sustainability, 9(3), p.353.

Agriculture Victoria (2017), Soil Moisture Monitoring

Agriculture Victoria (2019), Plant-based sensors for irrigation management

Department of Primary Industries Farm Services Victoria (2010), Soil Moisture Monitoring, Choosing the right device

Dumroese, R.K., Pinto, J.R. and Montville, M.E., 2015. Using container weights to determine irrigation needs: a simple method. Native Plants Journal, 16(1), pp.67-71.

Fernández, J.E., 2017. Plant-based methods for irrigation scheduling of woody crops. Horticulturae, 3(2), p.35.

Freebairn, D.M., Cutajar, J.L. and Thornton, C.M., Estimating hydrology and water quality leaving Australian agricultural systems.

Kawashima, S., Ueyama, M., Okamura, M., Harazono, Y., Iwata, H. and Kobayashi, H., 2021. Spring onsets of a young forest in interior Alaska determined based on timelapse camera and eddy covariance measurements. Journal of Agricultural Meteorology, 77(3)

Martín-Palomo, M.J., Andreu, L., Pérez-López, D., Centeno, A., Galindo, A., Moriana, A. and Corell, M., 2022. Trunk growth rate frequencies as water stress indicator in almond trees. Agricultural Water Management, 271, p.107765.

Meinhardt, F., 2021. TriOS Water Quality Monitoring. The Chemical Monitoring Station of the Future

Miller, P., Lanier, W. and Brandt, S., 2001. Using growing degree days to predict plant stages. Ag/Extension Communications Coordinator, Communications Services, Montana State University-Bozeman, Bozeman, MO, 59717(406)

Miyamoto, T., Kameyama, K. and Iwata, Y., 2015. Monitoring electrical conductivity and nitrate concentrations in an Andisol field using time domain reflectometry. Japan Agricultural Research Quarterly: JARQ, 49(3)

Nursery and Garden Industry Australia (2013), Automating Irrigation Scheduling in Nursery Production

Nursery and Garden Industry Queensland (2018), Soil Moisture Sensors for Nursery Production

Preti, M., Verheggen, F. and Angeli, S., 2021. Insect pest monitoring with camera-equipped traps: strengths and limitations. Journal of pest science, 94(2)

Steppe, K., Vandegehuchte, M.W., Tognetti, R. and Mencuccini, M., 2015. Sap flow as a key trait in the understanding of plant hydraulic functioning. Tree Physiology, 35(4), pp.341-345.

University of Florida, Institute of Food and Agricultural Sciences Extension (2021), Monitoring Leaching Fraction for Irrigation Scheduling in Container Nurseries

Washington State University Extension (2013), Practical Use of Soil Moisture Sensors and Their Data for Irrigation Scheduling