

2.7 Calibrating soil water monitoring devices

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Key points

- Calibration of soil water monitoring equipment is not required to undertake basic irrigation scheduling of crops but is required for advanced tasks such as determining a soil water balance.
- Uncalibrated and calibrated probes will give similar trends, but the real values provided may differ by 40% or more
- The setup, calibration and operation of neutron and capacitance soil water probes is discussed.

Soil moisture sensors, particularly capacitance probes and neutron moisture meters (NMM) have been used for some time in the cotton industry, mostly for irrigation scheduling. These probes are usually used without site specific calibration, and it is important to understand the limitations of probe use under these conditions.

Is Calibration Necessary?

Soil moisture information from capacitance probes and NMMs is usually presented in terms of per cent volumetric water content or 'millimetres' of soil moisture. However, these tools do not directly measure how many 'millimetres' of water is contained within the soil. They instead measure another indicator (electrical conductivity or neutron scattering) and employ a default calibration equation to convert the raw readings into a form that is more recognisable by irrigation managers. The characteristics of the soil in which the readings are taken will determine how accurately the default calibration reflects the actual soil moisture.

For general irrigation management, the accuracy of these readings is less important. What is usually most important is how the current soil moisture compares to the acceptable soil moisture range for optimum crop growth. However, accuracy does become important when soil moisture data is used for some other purposes. Listed below are some common uses for soil moisture tools and some general comments about the need for probe calibration for each of these uses.

Determine when to irrigate (General Irrigation Scheduling)

- Does not require a calibrated probe. Trends of soil moisture extraction can indicate when a plant is beginning to stress. Analysis of soil moisture trends for irrigation scheduling is discussed in WATERpak Chapter 2.1.

Regulated deficit irrigation scheduling (precise scheduling where the soil profile may not be filled)

- Does not require a calibrated probe, although a calibrated probe may provide some additional value. Under deficit conditions, soil moisture can vary spatially, even over short distances (less than 1 metre), so even a calibrated probe may not give a good indication of average soil moisture. A Neutron probe may provide an improved

average value under these conditions as it samples a larger soil volume.

Determine volume of water applied/Calculate a soil water balance

- Does require a calibrated probe, although even a calibrated probe may still be inaccurate, particularly under deficit conditions (as mentioned above) or saturated conditions (when probe readings will not increase even though water may still be applied).

Determine actual deficit (e.g. to calculate application efficiency)

- Does require a calibrated probe. Spatial variability may still be problematic under deficit irrigation conditions. Determining accurate crop coefficients and using evapotranspiration data to determine a soil water balance is probably a less labour intensive solution. See WATERpak chapter 2.8 for more information.

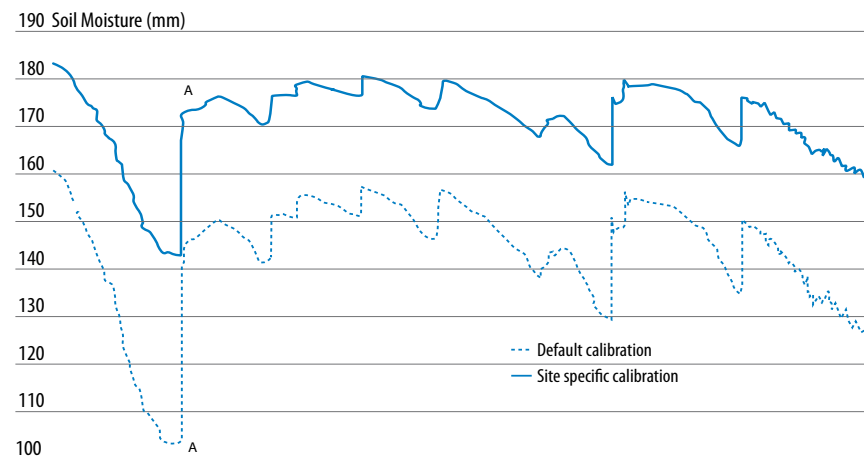
Determine effective rainfall.

- Does require a calibrated probe. Don't forget about the spatial variability of rainfall.

Determine deep drainage

- Even calibrated probes are unlikely to be able to measure deep drainage as this often occurs under saturated conditions. Probe readings will not change under saturated conditions even though drainage may be occurring.

Whilst soil moisture values will differ between a calibrated and uncalibrated probe, the pattern of the soil water trends will be similar. However the magnitude of difference can be significant, which is why calibration is important for some of the uses in the list above. Figure 2.7.1 shows capacitance probe soil moisture data collected from a calibrated site which is then compared to the same data using the default calibration equation.



In this figure, it is clear that the data represents the same trends, regardless of the default or site specific calibration. However if we look at the first irrigation event at point A:

- The calibrated soil moisture (solid line) goes from 144 mm to 173 mm – a change of 29 mm
- The default calibration soil moisture (dashed line) goes from 105 mm to 146 mm – a change of 41 mm

If the default calibration were to be used and assumed to be correct, the change in soil moisture would be overestimated by 40%.

Should calibration be required, it should be understood that the calibration process does require considerable effort. Furthermore, the potential for calibration to change over time in the shrink-swell soils which comprise much of the northern cotton and grain regions should be recognised. This is because probe calibration may vary according to changes in soil bulk density, which might be caused by deep ripping, deep drying or changes to stubble retention practices.

It should be remembered that without calibration these tools have a demonstrated ability to support and improve the process of day-to-day irrigation management, but for other uses the value of uncalibrated data must be considered

Figure 2.7.1 - A single data set using a default and site specific calibration (Sentek, 2001)

Normalisation

It is important at this point to understand the difference between normalisation and calibration. Normalisation (also called the standard count for NMMs) is a process that sets the maximum and minimum readings that a soil probe will encounter. This is done by taking readings in air (i.e. 0% water content) and in water (i.e. 100% water content). The probe can then interpolate readings between these extremes to determine the proportion of water in the medium it is measuring. Normalisation is a standard operating procedure for these tools and should be performed regularly.

The neutron moisture meter

How does a neutron moisture meter work?

The neutron moisture meter (NMM) uses the 'neutron moderation method'. Neutrons are emitted from the probe's radioactive source and are slowed down by collision with hydrogen in the soil water molecules. The meter counts the slow returning neutrons which are related to the amount of water in the soil. The measurement sphere is about a 15 cm radius around the neutron source.

Setting up the NMM

Cable and stops

When cable stops are spaced 10 cm apart, starting 40 cm from the source end of the cable, soil moisture measurements will be taken at 20, 30, 40, 50, 60 cm intervals, and so on, down the soil profile. (These measurements refer to the NMM Hydroprobe® 503DR.) Often from 60 cm depth the cable stops are set every 20 cm apart, giving readings at 60, 80, 100 and 120 cm depths as required.

Standard count

The counts read by the meter are usually divided by a standard count to give a count ratio. A standard count is determined by installing an access tube (sealed at the bottom) into a 44-gallon drum of water and inserting the NMM source probe into the access tube so it is suspended in the middle of the drum. The use of the standard count guards against changes in the count rate brought about by the ageing of the meter's components. The NMM owner's manual explains the procedure for determining the standard count.

Access tubes and installation

Aluminium access tubes sealed at the lower end of the desired length can be installed in the soil by hand or powered augers. Ensure that there is minimal space between the tube and soil. Tubes are installed wherever desired. This could be between rows or on the plant line. Where the irrigation method is drip irrigation, ensure that the location of tube is near a drip emitter so that the site will be watered by the system.

Reading and processing data

Calculating count ratio

The counts read by the meter are divided by the standard count to give a count ratio. The meter counts are usually determined over a 16 second period (if three tubes at one site are averaged) at each position down the profile (see NMM manual to set the count time). It is recommended (but not always undertaken) to determine a new standard count prior to each field NMM soil moisture reading session.

Using calibration curves to calculate 'probe' mm water

When a formal calibration is determined for a neutron probe, a relationship between the count ratio (NMM reading/standard count) and volumetric water content (**volumetric soil water = % water in the soil × bulk density**) is established for each layer of the soil type in question. This calibration is then site-specific and cannot be used at other sites without errors.

In most on-farm situations the relationship between soil type and count ratio is not assessed, and a default calibration data set is used by most unsuspecting operators.

This relationship might be a straight line of the form:

$$(a) \quad y = a + bx$$

where

y is the volumetric soil water content

x is the count ratio

a and b are the regression parameters.

By simply substituting the count ratio for x, volumetric soil moisture content can be calculated.

However for some soil types the relationship might not be linear and could be represented by a more complex equation which introduces a third parameter 'c', for example:

$$(b) \quad y = a + bxc$$

To convert this to mm water, simply multiply volumetric water content (y) by the depth interval, which will be 100 mm (10 cm) if readings are taken at 10 cm intervals down the profile:

$$\text{mm water} = \text{volumetric water} \times \text{depth interval}$$

By adding the mm of water in each depth interval, the total mm of water in the profile is calculated.

Further explanation of these points and of determination of soil bulk density can be found in Dalglish, N and Foale, M 1998, *Soil Matters*.

How to get a NMM calibration

Insert NMM access probe tubes into the soil, take NMM readings at intervals (usually 10 cm) down the profile and calculate the count ratio.

Extract soil cores close to the access tube and calculate the gravimetric soil moisture content (see details in *Soil matters*) for each interval corresponding to the NMM interval readings. These readings and cores need to be taken at the soil's upper limit, lower limit and at various moisture contents (intermediate moisture contents) between these limits so that you get a good curve.

Upper limit is the amount of water that a soil holds following drainage for about 48 hours. It can be determined following rainfall or irrigation.

Lower limit is the amount of water left in the soil after a particular crop has extracted as much as it can. This is determined following harvest.

Soil bulk density is required to convert gravimetric soil moisture to volumetric soil moisture. Be aware that although this process seems straightforward, soil samples are required for each depth interval, for multiple soil moisture contents and that bulk density must also be measured.

Calibration for irrigation use

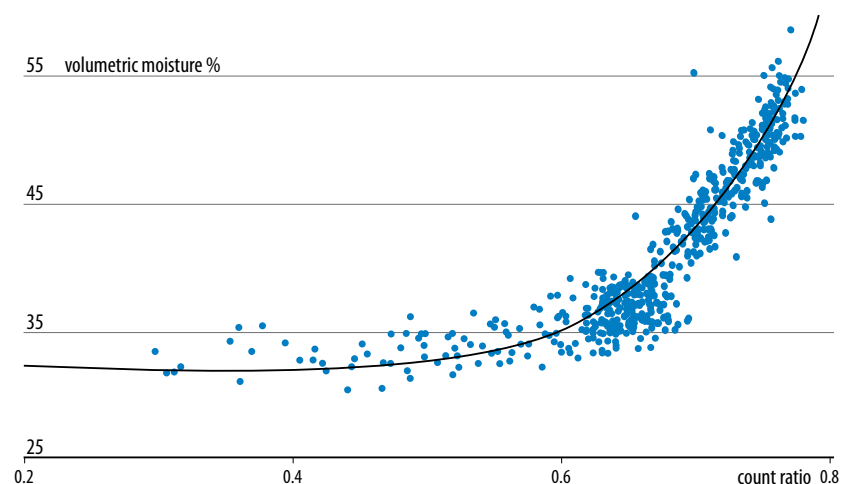
The relationship between the NMM ratio and soil moisture content need only be determined from the upper limit to a moisture content just below the predetermined refill point. Following conversion to volumetric moisture content, the relationship will most likely conform to equation (a) above.

Calibration for rain grown cropping

The relationship between the NMM ratio and soil moisture content will need to be determined from the upper limit to the lower limit and as many points as possible between these. The volumetric moisture content/NMM ratio relationship will most likely conform to equation (b) above, because the relationship between the count ratio and soil moisture content might not be linear as the soil dries to low values.

The volumetric water data are plotted against the NMM count ratio and the relationship calculated for either equations (a) or (b). An example of the relationship for equation (b) is shown in Figure 2.7.2.

Figure 2.7.2. Non-linear relationship of volumetric moisture and count ratio



Capacitance soil water devices

How do capacitance soil water devices work?

Capacitance probes such as the C-probe™ and Enviroscan® systems work by measuring the dielectric constant of soil. Charlesworth (2000) describes the dielectric constant as 'a measure of the capacity of non-conducting material to transmit electromagnetic waves or pulses'. He adds:

The dielectric of dry soil is much lower than that of water, and small changes in the quantity of free water in the soil have a large effect on the electromagnetic properties of the soil water media.

Frequency domain reflectometry (FDR) measures the soil dielectric by placing the soil (in effect) between two electrical plates to form a capacitor. Hence 'capacitance' is the term commonly used to describe what the instruments measure. When a voltage is applied to the electric plates, a frequency can be measured. This frequency varies with the soil dielectric.

(Charlesworth 2000)

Capacitance devices have been shown to deliver repeatability of readings with acute sensitivity to changes in soil water content.

Normalisation is critical for capacitance probes. Without normalising, these devices would only provide a range of irrelevant raw data that varies slightly with each sensor. By matching the raw reading from each sensor to both 0% and 100% water levels, a comparison of readings taken by different sensors can be made on a common scale. This simple action allows raw readings to be seen as either graphics or text permitting irrigators to monitor their soil water levels based on change trends.

Setting up capacitance soil water devices

A number of sensors are allocated to depths within the active root zone of the crop. The number can vary from a couple to eight or more, depending of the level of detail required from the site. Once the location of the sensors has been determined, the sensors are located at their assigned positions on a circuit board that will be installed in an access tube in the field.

Researchers or users seeking absolute values must carry out calibration of the sensors by obtaining a range of values, which are used to produce a calibration curve. A calibration equation can then be determined and described mathematically. This can be done for every sensor and can be done to suit a specific site or soil. This is rarely done for day to day irrigation management, and usually only occurs in the area of research.

The correct siting and installation of access tubes is critical for capacitance devices. As with all devices, capacitance probes need to be installed in a position that is representative of crop type, density and vigour, soil type, irrigation system uniformity and application. Additional care should be taken to locate access tubes where they will not be damaged by machinery. More information on locating probes is included in WATERpak chapter 2.6.

Capacitance probes and cracking soils

Capacitance probes are perceived as being susceptible in clay soils that crack as they dry. This is due to the relatively small soil volume from which capacitance probes source their readings. In practice, this is rarely an issue, and when cracking does occur, the resulting airgaps are easily identified in the software when the soil water content of the airgaps heads towards zero levels. This is well below refill points, and stands out well.

Calibrating capacitance probes

The procedure for calibrating capacitance probes is very similar to that for the NMM:

- As calibration is required across the range of moisture contents from field capacity to crop lower limit (or just below refill point for irrigated crops), a number of sites will be required; one for each moisture content.
- Probe readings should be obtained at each depth for each site.
- Soil cores should be taken close to the access tube and gravimetric moisture content and bulk density determined for each depth at each site.
- Determine volumetric water content as the sum of the gravimetric water content and the bulk density.
- Plot the probe readings against volumetric water content and fit a regression curve. Probe readings should be scaled to take into account the normalisation process. Manufacturers should be able to provide more information on this part of the process.

Sentek provide a very useful [calibration guide](#) for their soil moisture probes: check with your manufacturer for further information for your specific device.

Conclusion

Both the neutron and capacitance probes will show changes in soil water content over time and will easily satisfy the requirements of an irrigator seeking to schedule irrigations based on variation in plant water use. Neither probe requires a calibrated unit of measurement in order to achieve this task, as the change in rate of water extraction is used instead. This could in reality be done on raw data alone.

Both types of probes have software that converts raw counts to either a volumetric percentage reading or to a 'millimetre' reading. If this conversion process is not supported with the relevant soil data then the resulting 'millimetre' readings need to be treated with caution.

Where a more accurate unit of measurement is required, there are higher order calibration methods available to correlate the relationship between the raw data counts, actual soil water content levels and the water-holding capacity of the specific soil. This calibration is rarely done in a commercial agricultural situation.

What is the device being used for? Is it being used to schedule irrigation events based on trends in plant water use, or is the device to be used to calculate a full soil water balance?

The calibration of soil water monitoring devices and the comparison of the resulting data are areas where much more work is required. The devices are currently very strong in the scheduling of irrigation events based on changes in soil water levels over time. This is evident in the way most irrigators with scheduling devices determine irrigation events based on graphed data depicting actual plant water use over time.

The debate over calibration should not detract from this ability to support the process of day-to-day irrigation management.

References

- Charlesworth P. 2000 'Soil Water Monitoring': [National Program for Irrigation Research and Development Irrigation Insights Number 1](#)
- Sentek Pty Ltd. 2001 '[Calibration of Sentek Pty Ltd Soil Moisture Sensors](#)' Calibration Manual, 8:27-30.

