

A NZ farmer's guide to soil moisture monitoring



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Why measure soil moisture?

Farmers who use irrigation scheduling services or their own monitoring equipment consistently report higher yields, better crop quality, and lower water use than they achieved without the information. The cost of using a scheduling service or installing monitoring equipment is now low compared to the financial benefits of soil moisture monitoring.



Benefits include:

- Optimum production, increased income
- Reduced energy and water consumption and associated costs
- Improved crop quality
- Increased effectiveness of fertilisers and pesticides
- Better control of diseases
- Optimum root penetration
- Time and labour savings
- Demonstration of good environmental management

When you have a seasonal water limit on your consent, monitoring soil moisture is even more important, since over irrigation in the spring may mean you can't irrigate in autumn.

With some guidance, monitoring equipment can be installed by a farmer, and is generally easy to use.

Some farmers report soil moisture monitoring paying for itself several times over in the first season. Articles from some of these farms are available on the Irrigation New Zealand website (www.irrigationnz.org.nz). Other farmers do little with the information, and consequently receive little benefit. The key is to understand what the information means, and to use that information to irrigate smarter.



How to measure soil moisture

The main options for measuring soil moisture in pasture and crops are:

- (1) Hand-held probes
- (2) Permanently installed probes
- (3) Irrigation scheduling services

Hand-held probes

A hand-held probe offers a good entry level to soil moisture monitoring. They are portable, and with experience can be a valuable tool in managing irrigation. They are widely used for pasture and cropping.

Most hand-held probes use time domain reflectometry (TDR) technology. You push the rods into the soil, wait about 10 seconds, and take a reading. The display tells you the soil moisture as a percentage of the total soil volume.

Soil moisture will vary across a paddock. Therefore measure several different points (4-5) in a paddock and average the results. Some farmers find it helps to have fixed transect lines, and measure at several points along the line.



The maximum rod length is only 200 mm, but the root-zone may be 500 mm or more deep. To measure the moisture at depth, dig a wedge hole with two cuts of a spade at 4-5 different points in the paddock. Push the probe into the bottom of the wedge to take a measurement. Average the results. Don't use the same hole for future measurements.



Beware of stones. The rods on most TDR units bend easily. If they are bent, straighten them up again, as the accuracy depends on the probes being parallel. A plastic or plywood plate, which sits on the ground with two holes for the rods, can help to keep the rods straight when pushing the probe into the soil.

Two suitable hand-held probes are the Campbell Scientific 'Hydrosense' (CS620) (www.scottech.net) and the Spectrum Technologies 'Field Scout' (www.envco.co.nz). **Cost:** \$1,300-\$1,500

Advantages	Disadvantages
<ul style="list-style-type: none">• Portable – can measure any number of locations• Only need one unit for a farm• No on-going seasonal costs• Good accuracy with experience.	<ul style="list-style-type: none">• No regular farm visits by an expert• Takes time to go out and take readings

Other portable soil moisture methods include Sentek's 'Diviner' (see www.sentek.com.au/products/diviner.asp), and the 'feel method' which is no longer recommended.

Permanently installed probes

Permanently installed probes provide a continual measurement of soil moisture at a particular site. Two suitable products for pasture and cropping are AQUAFLEX and Decagon ECH₂O probes.

The AQUAFLEX sensor is a flexible tape 3m long, which is permanently buried in the root-zone. The long sensor means measurements are more accurate. The unit continually records both soil moisture and temperature. The two common installation configurations are single and dual tapes. The dual tape setup provides more information on moisture in the lower root zone, and can highlight when irrigation water is being wasted by draining beyond the root-zone.



With the single tape configuration, the electronic module at the start of the tape is buried about 50-100mm deep. The tape is sloped down so that the end of the tape is at the bottom of the main root zone – typically 400-500 mm for pasture. With the double tape configuration, sometimes a second tape is installed horizontally at the lower root zone, typically 500-600 mm deep. Tapes are buried edge up, so that water does not sit on top. You need to install the probes two to three months before you need measurements to allow time for the sensor to settle.

Costs are approximately \$1,200/site for a single tape and \$2,100/site for a double tape setup. One to six sites per farm are typical. Also required is a palm PDA, adaptors, and software (\$700/farm). Installation, telemetry, radio, and pivot control options are also available at additional cost. For further information refer to www.aquaflex.co.nz.



The Decagon ECH₂O probes use similar technology to AQUAFLEX. Probes are shorter than AQUAFLEX, so it is necessary to have three to five probes per site to accurately measure moisture throughout the profile and over a reasonable area. A soil temperature probe can also be added.

To install the probes, dig a hole through the root zone of the crop and push the sensor into undisturbed material in the side of the hole. Probes should be edge up so that water does not sit on top. Install two to three probes at about 1m horizontal intervals and at different depths in the main root zone (100-400 mm deep). Install a further one to two in the lower root zone (typically 500-600 mm deep). The cost of each probe is \$150-\$200. The per site cost is \$1,000-\$1,500 for three to five probes and a logger. One to six sites per farm are typical. You also need a palm PDA (\$300/farm). Software is free. Installation, telemetry, radio, and pivot control options are also available at additional cost. For further information refer to www.envco.co.nz or www.scottech.net.

Currently most farmers download the data from the AQUAFLEX or ECH₂O loggers in the field onto a PDA, and then onto a computer in the office. However telemetry and radio options, where the data is transferred directly to an office computer, is becoming much cheaper.

Advantages	Disadvantages
<ul style="list-style-type: none"> • Moisture measured throughout the soil profile. • Good accuracy • No on-going seasonal costs. • Continual logging of both moisture and temperature • Data can be remotely down-loaded to an office computer. • Can be used to automate centre pivots. 	<ul style="list-style-type: none"> • No regular farm visits by an expert • Units are not portable

When installing permanent probes, both the location, depth, and how they are installed is important. Some of the benefits of the probes can be lost if installed poorly or at inappropriate locations or depths. Choose a site where soils which are slightly lighter than the average soils of the area that you want the site to be representative of. Don't choose the lightest soils. Avoid high or low points - choose somewhere in the mid-point of a slope. Don't install in high stock or vehicle traffic areas. For example, don't install near gates or within about 8m of a fence. If you can, it is well worth while to get good specific guidance on where and how to install the probes, from someone who knows the equipment well and also understands your farming operation and your type of irrigation system.

Ideally you should install one monitoring site for each irrigation rotation. This generally means you would need one monitoring site for each irrigator (e.g. Rotary boom, Gun, Centre Pivot etc.). Monitoring borders and K-line is a little difference and is discussed latter in the brochure. For long rotations (12+ days) ideally you should install two monitoring sites for each rotation. If you have a couple of very different soils in a rotation you may consider having a monitoring site in each of the soils.

A hand-held probe is a useful complement to permanent monitoring sites. It allows you to check soil moisture anywhere. It is particularly useful if you are irrigating on rolling country, or if you have a lot of variability in your soils since in these situations soil moisture can vary a lot across paddocks.

Other permanently installed methods include the gypsum block electrical resistance method and tensiometers. None of these methods are common for pasture and cropping.

Irrigation scheduling services

If you don't want to measure soil moisture or make irrigation management decisions yourself, you can engage an irrigation scheduling company. The company sends an expert to your farm to measure soil moisture, usually on a weekly basis, and provides specific instructions on when to irrigate and how much water to apply. Generally these companies use a neutron probe to measure soil moisture. Irrigation scheduling services are widely used for pasture, cropping, viticulture, and horticulture.

At key locations, usually on the advice of the expert, several aluminium access tubes are augered into the soil. Typically tubes are of 900 mm for pasture and arable crops. During each site visit a probe is lowered into the tube and readings are taken every 100 mm down the profile. Readings are normally combined to give a representative reading for the main root zone and the lower root zone.

Irrigation is normally managed so that the moisture in the main root zone stays with a certain range, while moisture in the lower root zone does not increase.



Advantages

- Regular on-farm expert advice.
- Moisture measured throughout the soil profile
- Very good accuracy

Disadvantages

- On-going seasonal costs
- Weekly readings may limit effectiveness



An irrigation scheduling service, (e.g. www.hydroservices.co.nz) will generally give direct instructions on what to do with soil moisture information. The cost is typically \$500-700/site/season with 2-6 sites/farm typical. While this is generally the most expensive option (\$1,000-\$3,000/farm/season), depending on the value and type of crop, returns can be well in excess of the monitoring costs.

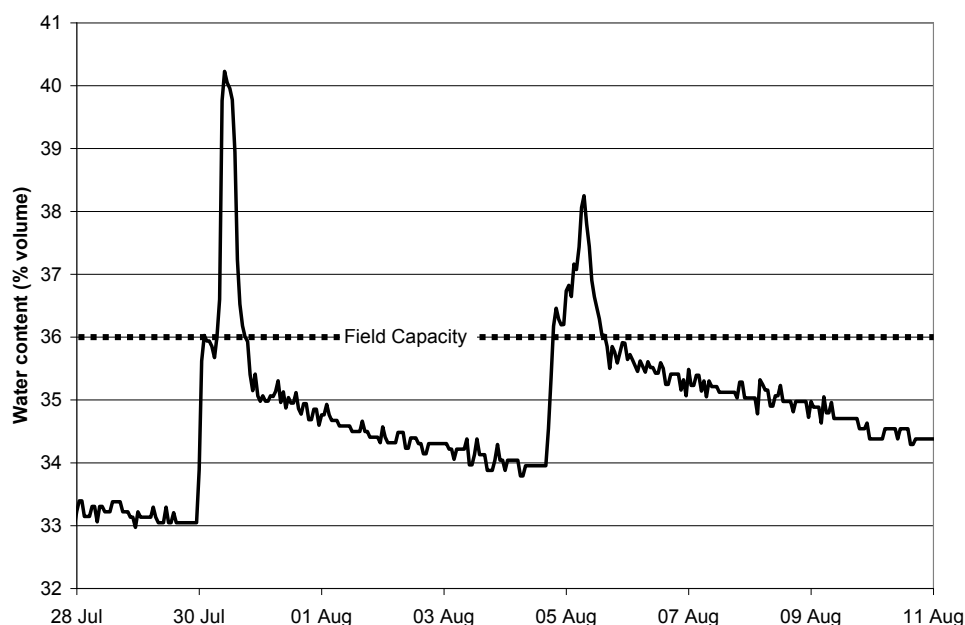
Using measurements to schedule irrigation

Soil moisture monitoring is only useful if you make use of the information to irrigate smarter. Fortunately it is not difficult to use moisture measurements to improve both irrigation efficiency and production.

To best schedule your irrigation you need to know the ‘field capacity’ and the ‘refill point’ of your soils, and the irrigation application depth.

Field capacity

The ‘field capacity’ is the full point of the soil. It is the maximum amounts of water that can be kept in the soil. It does not include the water which drains away quickly after a large rain or irrigation event. For most soils field capacity can be estimated from an AQUAFLEX or ECH₂O trace. After a lot of rain or excess irrigation, which saturates the soil, you should observe soil moisture initially reduces rapidly. For a free draining soil this rapid drainage will only take a few hours. For moderately heavy soils it may take 1-2 days. After this period of rapid drainage soil moisture should begin to decrease at a slower rate, indicating field capacity has been reached.



AQUAFLEX trace following two periods of rain. Field capacity is about 36%. Tape installed from 75-450mm¹

For poorly drained soils you can't directly measure field capacity since excess water doesn't drain away. For these soils you can estimate field capacity from the saturation point. The saturation point is the peak water content following a lot of rain or over-watering. As a rule of simple thumb assume field capacity is about 5% below saturation point. Alternatively contact a soils expert to determine field capacity by taking samples and lab analysis. If you irrigate poorly drained soils up to the saturation point you will loss production because the plant roots will not be able to properly breathe.

If you only have a head-held probe, you can roughly estimate field capacity by measuring soil moisture about a day after the end of heavy rain or excess irrigation. Be sure to take several moisture measurements not only at the surface but also between 200-400mm, by digging a hole. Average the readings.

¹ For example purposes only. Actual installation depth different.

To convert from % volume to mm of water, multiply by the deep of soil which you monitor moisture. For the example above,

Aquaflex tape measures soil moisture to a depth of 450mm
Field capacity (in mm) = 36% × 450mm = 162mm

The field capacity value above includes water which the plant cannot use, and should not be confused with ‘Plant Available Water’ (PAW) or ‘Water Holding Capacity’ (WHC) values, which *do not* include water the plant can’t use.

Irrigation depth

You need to know the average depth of irrigation in mm. For newer systems such as centre pivot the depth will be displayed on the control panel. For other systems, the supplier may have calculated the application depth when the system was installed. Be aware that any changes to sprinklers or nozzles would have changed the application depth.

If you don’t know the depth, you can measure it using a number of buckets in a line, or you can calculate it if you know the flow rate of the system. For further information contact a local irrigation supplier or see the “New Zealand Irrigation Manual” (www.irrigationnz.co.nz).

The refill point

The refill point is the target soil moisture level at which you aim to irrigate.

For crops which don’t benefit from water stress, such as pasture, a basic rule of thumb for moderate to deep soils is the refill point should be the field capacity (in mm) – the irrigation depth (in mm) – 5 mm. For the example above, assuming the irrigation depth is 50mm, the refill point should be:

Refill point (in mm) = 162mm – 50mm – 5mm = 107mm

To convert to % volume, divide by the deep of soil which you monitor moisture

Refill point (% volume) = 107mm/450mm = 24%

If you have light soils, or have a low system capacity so that you can’t keep up with crop demands in December to February, you may need a higher refill point. If you have specialist crops which benefit from water stress at certain times of the irrigation season, or if you have high pumping costs and want to maximise the production for the volume of water you use each year, consider engaging a soils expert to more accurately determine an appropriate refill point. Plants are affected by how hard the plants need to suck to get water – the water pressure. However, what you measure in the paddock is not the water pressure, but the % of water. A soils expert can take samples and analysis them in the lab to determine the relationship between % water to water pressure for your particular soil. Sometimes they may estimate the soil properties only from a visual survey. You, or your farm advisor, can find published target water pressures for a particular crop at a particular stage of growth. You can then convert these target pressures to a % or mm of water.

Deciding whether to irrigate

The aim is to irrigate when the soil moisture reaches the refill point.

If you have the same crops and similar soils in all paddocks in a irrigation rotation, irrigate the paddocks in the same sequence each time. The paddock you are about to irrigate will always be the paddock with the lowest soil moisture. Start the irrigator in the paddock which has the soil moisture monitoring site. If the soil moisture is below the refill point, start irrigating. If not, wait until soil moisture reaches the refill point. Continue to irrigate until you get back to the start of the rotation, unless it rains. If it rains, use a hand-held probe to measure the soil moisture in the paddock about to be irrigated. If the soil moisture in that paddock is below the refill point, continue

to irrigate. If not, keep measuring the soil moisture and start irrigating when that paddock drops below the refill point. If your irrigator can't keep up with the crop requirements (i.e. when you started the rotation the soil moisture was already well below the refill point) unless you get a lot of rain you will probably need to keep irrigating. If however your irrigator was not getting behind before it rained, you should be able to stop irrigating for:

$$\text{Days to stop irrigating} = \text{Depth of rain (in mm)} \div \text{Expected ET (in mm/day)}$$

For example, if you got 15mm of rain in December and you are near Christchurch and irrigating pasture (average ET/day for pasture = 4.8mm), you should be able to stop irrigating for $15\text{mm}/4.8\text{mm/day} = 3$ days. Information on measuring rainfall and calculating the expected ET is given latter in this booklet.

If you have more than one monitoring site in a rotation, re-evaluate whether you can delay irrigation before you irrigate each monitored paddock. If you only use a hand-held probe measure soil moisture about once a week, or following rain. As above start irrigating when the soil moisture drops below the refill point.

If you have different crops or soils in an irrigation rotation it may not be best to irrigate paddocks always in the same sequence. Some paddocks will have higher water requirements than others. Each different crop and soil combination is called an irrigation unit. Within an irrigation unit there will be one or more paddocks/irrigation runs. Ideally you should monitor soil moisture in each irrigation unit, either with one permanent monitoring site for each irrigation unit, or with a hand-held probe. Within an irrigation unit, when the soil moisture drops below the refill point, in the monitored paddock, irrigate all the paddocks in that irrigation unit in a regular sequence. When more than one irrigation unit monitoring sites is below the refill point, irrigate your high value crops and your shallow soils first.

The method above will generally not be suitable if you have borders, wild flooding, or contour flooding, since with these systems you generally can only irrigate on certain days. For these types of systems you need to predict how low the soil moisture will be when the water is next available, if you don't irrigate. This is explained further in the section "What about borders?"

Common questions

What should my irrigation depth be?

Some irrigation systems are more flexible in the depth of irrigation than others. If your system does have flexibility, frequent irrigation and a small application depth (ideally 20mm) increases production and water use efficiency. Small application depths are more important on light soils than heavy soils. If you have light soils and irrigate using K-lines or guns you can reduce the application depth by shifting the irrigators twice a day.

What about borders?

For borders, wild flooding, and contour flooding, water is generally not available every day. For these types of systems you need to predict how low the soil moisture will get by the time water is next available, if you don't irrigate. Irrigate if the soil moisture would get below the refill point when water is next available. To make this decision you need to know how many days until you can next irrigate? What is the expected ET? Is any rain forecast? What is the current soil moisture? Irrigate if:

Current soil moisture (in mm) - Expected ET (mm/day) × Days till next irrigation + Expected rainfall (in mm) is less than Refill point (in mm).

Information for calculating the expected ET is given later in this booklet.

On light and medium soils usually you have drainage beyond the root zone. This reduces the irrigation efficiency. The long return periods also means you will probably be losing production due to water stress. Generally lack of flexibility in surface irrigation system means you will get less benefit out of soil moisture monitoring.

What about K-lines and guns when its windy.

Windy conditions can cause guns and k-lines to put a lot of water on some places and little water in others. At your soil moisture monitoring site this will mean sometimes the sensor says the soil moisture is higher than the average for the paddock, and sometimes it will say the soil moisture is less than the average. In windy conditions you can make an adjustment to the soil moisture reading, based on how much soil moisture normally increases following irrigation. For example if soil moisture on average increases by 11% after irrigation, but following irrigation on a windy day it increases by 15%, take 4% off the soil moisture reading. Also take steps to minimise this non-uniform application of water. If you can, close up gun lane spacings on windy days. Move guns and k-lines twice daily. If you can, avoid irrigating on very windy days. Staggering K-lines so pods in adjacent lines do not end up being directly opposite each other, and off-setting lines every second shift so the same areas do not always get over and under watered, can help to improve efficiency. GPS tracking software such as Tracmap (www.tracmap.co.nz/irrigation--effluent/) can also help to irrigate with K-lines more uniformly and efficiently.

Even when it is not windy the pattern of watering is quite non-uniform under k-lines. Sometimes the sensor will record soil moisture higher and sometimes lower than the average for the paddock, depending on exactly where the pods are placed each time. As described above you can make an adjustment to the soil moisture reading, based on how much soil moisture normally increases following irrigation. Hand-held probes are also useful since you can measure several different points in the paddock.

What can I do if my irrigator can't keep up with crops water demands?

This is mainly an irrigation system design issue; although there are some management changes you can make which will help. Most irrigation systems are not designed to always meet the peak crop

water demands. Some loss of production is often tolerated in order to reduce the initial capital cost of the system. However some systems cannot keep up with the crop requirements because of low efficiency due to poor design. The biggest problem is usually irrigators apply too much water for the type of soil. The second biggest problem is usually irrigators do not apply the water uniformly meaning some parts of the paddock are over-watered while others are under-watered. You may consider getting an expert to evaluate your system. Refer to Irrigation New Zealand's website (www.irrigationnz.org.nz) for more information on the evaluation of irrigation systems. Once the system has been evaluated you may consider making changes to improve the efficiency of the system.

If you have light soils and irrigate using a K-lines or guns you can increase efficiency by shifting the irrigators twice a day.

Measuring rainfall



Rainfall is a major soil moisture deposit. Without rainfall, most irrigation systems could not cope with the crop demands. Rainfall is highly variable – the amount will vary from farm to farm. Therefore recording your own measurements is better than relying on a neighbour's measurement, or using a climate station which may be some distance from your farm. Rain gauges are inexpensive.

There are two types of rain gauges – manual and automatic. Both are quite cheap.

Rainfall measurements are only of value when they are recorded. Committing them to memory is not acceptable practice. The location is also important. Many rain

gauges are in poor locations that do not provide a representative measure of rainfall.



Taking records

- Record the amount of rainfall on a rainfall chart.
- Record at least to the nearest 0.5mm.
- The accepted standard is to read rainfall at 9:00am each day. The rainfall is recorded on the chart for the previous day; for example, if you read 10 mm at 9am on 10 January, record this amount for 9 January.
- Note the general form of the rainfall (e.g. thunderstorm, easterly drizzle etc. Long gentle rainfalls can be more effective and beneficial than short intense storms because there is less runoff.

Where to put the rain gauge

- Ideally the gauge is set on the ground, but it is usually more practical on a farm to fix it to the top of a post or other object so it will not be blown over or tilted by strong winds.
 - Choose a location where stock cannot damage or rub against the gauge.
 - Site the gauge away from obstacles such as trees, houses, sheds, etc. The distance from an obstacle should be at least twice and ideally four times the height of the obstacle. If it is too close, the gauge will be under-exposed and will result in an incorrect estimate.
 - If the gauge is over-exposed (on a rooftop, on the crest of a hill, etc) the rainfall measurement will be incorrect.
 - Avoid siting the gauge on a slope where the ground falls away steeply.
-

Calculating the expected evapotranspiration

Evapotranspiration (ET) is a combination of the water that evaporates from the soil and the water that plants use (transpiration). If you need to predict future crop water requirements you need to know the 'expected ET'. Most the time the expected ET should be the average for that month. However if the forecast is for unusually hotter or colder than normal conditions, your expected ET should be 10-15% higher or lower than the average. Average ET values for pasture by month for a few locations in Canterbury and Otago are given in the table below. For other locations anywhere in NZ evapotranspiration data is available from <http://cliflo.niwa.co.nz/> and sometimes from your local news paper.

For crops other than pasture, reference ET needs to be adjusted proportionally by the crop coefficient. The crop coefficient depends on the type of crop and changes with the different growth stages.

$$\text{ET} = \text{Crop coefficient} \times \text{ET for pasture}$$

Refer to "Crop evapotranspiration - Guidelines for computing crop water requirements" <http://www.fao.org/docrep/X0490E/X0490E00.htm> for crop coefficients.

Using this method to calculate expected ET you will find for some parts of your farm the estimate is consistently a bit higher or a bit lower than what you observe from your moisture monitoring. For instance, north facing paddocks will have higher ET than south facing paddocks. You can use your experience to make your own minor adjustments to the expected ET estimates.

Canterbury						
Month	Cheviot	Darfield	Christchurch	Winchmore	Timaru	Waimate
September	2.1	1.8	2.0	1.7	1.8	1.7
October	3.1	2.7	3.1	2.7	2.9	2.7
November	3.9	3.5	4.1	3.5	3.8	3.6
December	4.4	3.9	4.8	3.9	4.4	4.2
January	4.5	4.2	4.9	4.1	4.5	4.3
February	3.9	3.6	4.1	3.6	3.8	3.6
March	2.9	2.6	3.0	2.5	2.6	2.5
April	1.9	1.5	1.8	1.4	1.5	1.3
May	1.2	0.9	1.0	0.8	0.8	0.7
Otago						
Month	Oamaru	Alexandra	Tarras	Taieri		
September	1.5	1.9	2.0	1.9		
October	2.6	3.0	3.2	2.7		
November	3.4	4.1	4.4	3.6		
December	3.8	4.7	5.1	4.0		
January	4.0	4.9	5.3	4.0		
February	3.4	4.2	4.5	3.4		
March	2.3	2.8	3.1	2.5		
April	1.2	1.5	1.6	1.5		
May	0.6	0.7	0.8	0.8		

Average ET (mm/day) for pasture by month. Most the time your expected ET should be the average for that month. However if the forecast is for unusually hotter or colder than normal conditions, your expected ET should be 10-15% higher or lower than the average.