Soil Moisture Measurement Notes

SKYE INSTRUMENTS LIMITED
21, DDOLE ENTERPRISE PARK
LLANDRINDOD WELLS
POWYS, LD1 6DF

TEL: 01597 824811
FAX: 01597 824812
EMAIL: skyemail@skyeinstruments.com
WEB: www.skyeinstruments.com

SOIL MOISTURE MEASUREMENT GUIDANCE NOTES

CONTENTS

1. INTRODUCTION

There are many different methods and techniques for measuring soil moisture, and just as many different instruments commercially available. These guidance notes will briefly describe some of the techniques, but concentrate mainly on instrumentation manufactured by Skye Instruments Ltd.

2. WATER AND SOIL

Soil is made up of a mixture of components including mineral and organic particles, with water and air making up the spaces in between. Plants need a combination of all these components for healthy growth.

When the spaces between the soil particles are full of water without any air pockets, the soil is saturated. (See Figure 1a.) This is generally short lived and the surplus water drains downwards and away under gravity.

The surface tension effect on the water around the soil particles holds a certain quantity of water against the pull of gravity, and it is at this stage that the soil is described as being at field capacity. The spaces between the soil particles are now filled with a mixture of water and air pockets (see Figure 1b).

As the soil surface evaporates and a crop removes water, the soil has less water than at field capacity, and is now described as having a soil moisture deficit (SMD).

Every crop has a Critical SMD level, if the soil is allowed to dry out beyond this there will be a resultant decrease in yield and / or quality.

As more and more water is removed, eventually the little water remaining is held by the surface tension too tightly for the crop to extract. The soil is said to be at wilting point. The soil particles are now surrounded by just a thin film of water with large air pockets in between (see Figure 1c).

By measuring soil moisture, crop water needs can be assessed and irrigation controlled to keep the SMD within the boundaries of Field Capacity and Critical SMD, and so maximise crop yield, quality and profitability.

3. TYPES OF SOIL MOISTURE MEASUREMENT TECHNIQUES

3.1 Gravimetric Technique

The classical method of measuring the amount of water in a soil sample is to use the Gravimetric Technique. This method involves taking a volume of soil, accurately weighing it, completely drying it out in an oven, re-weighing the dry sample and calculating soil moisture percentage from the weight loss. This is a time consuming and painstaking procedure.

3.2. Radioactive Technique

A method which uses radioactivity is called the Neutron Probe technique. Because of the radioactive transmissions, these instruments are very expensive and measurements need to be taken by qualified personnel. Usually the services of a Neutron Probe company are employed to take soil moisture percentage readings on a weekly basis. Shafts are permanently installed at the measurement site which the Neutron Probes lowered each time the readings are taken.

This method is expensive and inflexible. Measurement sites are not easily changed, and readings are infrequent.

3.3 Capacitive Technique

There are several instruments which indicate the percentage of water in the soil by measuring its capacitance. These instruments give instantaneous volumetric moisture contents quickly and easily by measuring the dielectric properties of the soil. Probes are inserted into the soil to the required measurement depth and the measurement can either be displayed on a meter or can be recorded using a datalogger.

However, the dielectric property of the soil not only depends on the amount of water present, but also on the type of soil, it's porosity and its organic content. So for accurate volumetric soil water content readings, each measurement site should be individually calibrated.

One example of a technique measuring the capacitance of soils is Time Domain Reflectrometry (TDR). Although the metal probes themselves are inexpensive, generally the electronics to control and interpret the measurements are rather costly.

A lower cost alternative is the ECHO probe which is a robust, flexible probe which can be buried at the required depth and connected to most dataloggers for long term recording.

3.4 Conductivity Technique

Generally, soil conductivity decreases with decreasing soil moisture. Resistance or gypsum block sensors measure soil conductivity and are quite inexpensive. However, conductivity of the soil water is different in different soil types (alkaline or acid soils) and can change according to the sprays or fertilisers applied. So resistance block sensors are generally used for trends in soil moisture changes only.

3.5 Soil Suction Technique

The soil suction technique measures water availability to plants, rather than actual percentage of water in the soil. This water availability measurement is more valuable in agriculture and irrigation of crops than is water percentage values. This measurement is also independent of soil type and gives a measurement of the plant or crop's actual water requirements.

Inexpensive soil moisture tensiometers measure the availability or water potential of the soil. Readings are in units of pressure, or more exactly negative pressure or suction, expressed as centibars (cbar) or kilo Pascals (kPa).

4. SOIL MOISTURE TENSIOMETERS

Traditionally, readings from a soil moisture tensiometer have been displayed on a dial attached to the top of each instrument. Recent developments in technology have increased the accuracy and versatility of tensiometers by including electronic pressure transducers in the construction, in place of the analogue dial gauge.

This means that electronic tensiometers often read in units of hecto Pascals (hPa - where 1 hPa = 10 kPa) or millibars (mbar - where 1 mbar = 10 cbar), giving more sensitivity with the increased accuracy. Another big advantage is that the electronic signal from the instrument is also available for connection to a datalogger for automatic recording throughout a growing season, or can be linked up to trigger an automatic irrigation system.

If an automatic soil moisture tensiometer system is not required, a low cost, manual system is also available to take advantage of the greater accuracy of the electronic pressure measurement of soil suction.

Tensiometers have sometimes had 'bad press' in the past for being unreliable and problematic. With just a little attention paid to the initial installation within a well irrigated crop, most users find they offer continuous operation with no further maintenance. They are robust and corrosion free instruments, designed to be used for many years. For installation instructions, please see Appendix 1.

4.1 Tensiometer Construction

Tensiometers consist of a porous ceramic tip and a clear acrylic plastic shaft of varying lengths according to the required depth of measurement in the soil, which is usually the rooting depth of the crop. Table 1 shows typical installation depths for different crops.

Tensiometers are also available in different diameters, larger sizes for field grown crops and smaller diameters for containers, pots and growbag monitoring.

Simple 'septum tensiometers' which do not have an attached pressure sensor are installed at very low costs. These are sealed with a rubber stopper and are the basis of a manual system for making soil moisture measurements. A single display meter with electronic pressure transducer can be taken around an unlimited number of septum tensiometers for monitoring moisture levels.

The electronic tensiometers each have a pressure transducer fitted and although are initially more expensive, they can be fully automatic and so a saving can be made on manpower and time.

4.2 Principles of Operation

Before installation into the soil, a tensiometer must be filled with water and sealed. The water is able to flow through the porous ceramic tip in either direction. When the ceramic is in contact with a dry soil, water flows out of the tensiometer leaving a vacuum behind. This vacuum becomes equal to the soil suction, which is then directly measured using the electronic pressure transducer.

If the soil is irrigated or it rains, the soil suction reduces. Water flows back into the tensiometer to reduce the vacuum so that it again equals the soil suction.

If the soil becomes saturated, more water will enter the tensiometer until the vacuum is filled. The pressure transducer will now read zero as there is no soil suction at soil saturation.

As soils or growing mediums dry out and are rewetted by irrigation or rainfall, tensiometers will follow and continue to read the soil suction directly. Low readings nearer zero mean wetter soils while higher suction readings mean drier soils.

See Figure 2 for general observation and interpretation of tensiometer readings.

4.3 Operating Range

Tensiometers operate in the range of 0 to 850 mbar (millibar) or hPa (hectoPascals), where a reading of zero shows saturated soils and higher readings show drier soils. See Figure 3 for conversions between units of pressure measurement.

Some plants can live in soils with soil suction readings of up to 15,000 mbar (15 bar), which is known as the 'Wilting Point'. However, most commercial cash crops use water for efficient growth within the 0-850 mbar tensiometer range. Moisture available for plant growth lies between the Field Capacity and the Wilting Point. In general, soils require irrigation when about 50% of the available water is used up.

See also Table 2 which shows different crops and the soil suction readings at which it is advisable to begin irrigation.

See Table 3 for examples of tensiometer readings against soil type and soil moisture percentages.

Appendix 2 gives an example of tensiometer readings taken with a datalogger over time, and the interpretation and insight to crop water use which can be made.

FIGURE 1

Water and soil conditions

Figure 1a – Saturated soil

Spaces between the soil particles totally filled with water

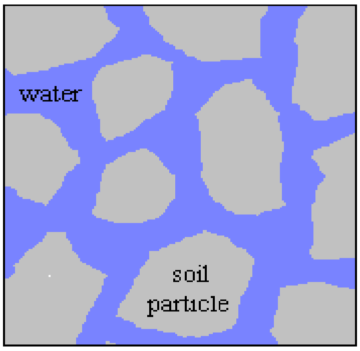


Figure 1b – Soil at field capacity

Spaces between the soil particles filled with water and air

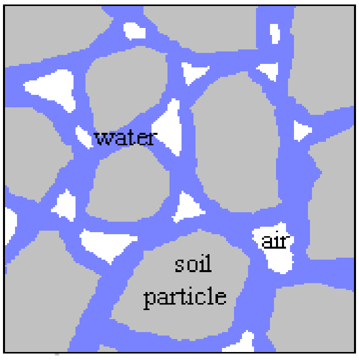


Figure 1c – Soil at wilting point

Spaces mostly filled with air, with a small amount of water held tightly around the soil particles

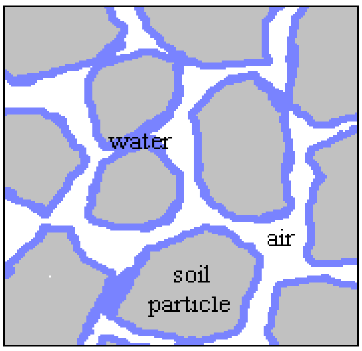


FIGURE 2

Interpretation of Soil Suction Readings

0 hPa (mbar)	A reading of zero means that the soil is completely saturated with water. A zero reading for long periods indicates poor drainage conditions and may cause disease development.
10-100 hPa (mbar)	There is a surplus of water in the soil. Persistent low readings may indicate poor drainage conditions.
100-200 hPa (mbar)	There is plenty of both water and air in the soil for healthy plant growth. It is advisable to stop irrigation when these readings are reached, as additional water may drain away and be wasted.
200-400 hPa (mbar)	There is adequate water and air in the soil for plant growth. In sandy soils, irrigation may be advisable.
400-600 hPa (mbar)	There is adequate water and air in fine or clay soils for plant growth. In medium soils, irrigation may be advisable. In sandy soils irrigation is required.
600-800 hPa (mbar)	Readily available water is scarce except in heavy clay soils. Irrigation is required for fine and medium soils. Plant damage may occur in sandy soils.
800-1000 hPa (mbar)	It is not advised to let soils get this dry, as plant damage may not be reversible.

Note: These interpretations must be regarded as advisory only, and may be crop dependant.

FIGURE 3

Conversions between Units of Pressure or Suction

1 bar = 0.9869 atmosphere (atm)

1 bar = 100 centibar (cbar)

1 bar = 1000 millibar (mbar)

1 centibar (cbar) = 10 millibar (mbar)

1 millibar (mbar) = 1 hectoPascal (hPa)

1 kiloPascal (kPa) = 10 hectoPascal (hPa)

1 atmosphere (atm) x 1013.25 = 1 millibar (mbar)

1 pounds / square inch (psi) x 68.946 = 1 millibar (mbar)

1 millimetres of mercury (mmHg) x 1.33322 = 1 millibar (mbar)

1 inches of mercury (inHg) x 33.864 = 1 millibar (mbar)

TABLE 1

Suggested tensiometer installation depths (cms)

CROP TYPE	TENSIOMETER 1	TENSIOMETER 2	TENSIOMETER 3
Apples	50	100	150
Bananas	30	60	
Broccoli	30	50	
Brussel sprouts	30	50	
Cabbage	30	50	
Carrots	30	50	
Cauliflower	30	60	
Celery	20	40	
Cherries	60	120	
Citrus fruits	40	80	
Coffee	50	100	
Cotton	40	80	120
Cucumber	40	80	
Grapes	60	120	150
Hops	60	120	150
Lettuce	30		
Maize	40	80	
Melons	40	80	
Olives	60	120	150
Onions	20	30	
Parsnips	40	80	
Peas	40	80	
Pears	40	80	120
Potatoes	20	30	50
Raspberries	40	80	
Sorghum	40	80	
Spinach	30	60	
Strawberries	15	30	
Sugar beet	40	80	
Sugar cane	40	80	
Sunflowers	60	120	150
Tea	30	60	
Tobacco	20	40	70
Tomatoes	40	80	
Turnips	40	80	

TABLE 2

Suggested tensiometer readings at which to start irrigation

(or Critical Soil Moisture Deficit)

(taken as reading of uppermost tensiometer)

CROP TYPE	Reading in hPa
Broccoli	250
Brussel sprouts	250
Cabbage	350
Carrots	450
Cauliflower	350
Celery	250
Grapes	350
Lettuce	350
Maize	450
Onions	250
Parsnips	700
Peas	700
Potatoes	250
Spinach	250
Strawberries	200
Tomatoes	450
Turnips	450

TABLE 3

Tensiometer readings compared to soil moisture water content percentage (by dry weight) in different soil types

TENSIOMETER READING	WATER CONTENT CLAY SOIL	WATER CONTENT SANDY SOIL
hPa	%	%
0	58	32
100	40	15
200	30	10
300	26	9
400	23	8
500	21	7.5
600	20	7
700	19	6.5
800	18	6
900	17.5	5.5
1000	17	5

APPENDIX 1

INSTALLATION OF TENSIOMETERS

Once carefully installed, a tensiometer should be left in place throughout the whole growing season, and will give accurate readings of soil suction with very little or no maintenance.

1. Choosing the installation site

In an ideal situation, the soil within a crop field is uniform in consistency and so one tensiometer measurement station is often sufficient to represent the entire area.

In reality, fields vary in topography or soil consistency and have some areas which are wetter or drier than the rest. In these cases some common sense is used to judge how many tensiometer measurement stations are required to allow the crop water usage to be monitored over the different areas of the field.

Container, pot and growbag monitoring are more like the ideal situation, but under glasshouse conditions, variations in water use are often seen at edges or in the middle of large arrays.

In any case, the tensiometer(s) should be installed within the rooting area of an actual plant, typical of the main crop.

2. Filling the tensiometer with water

In order to equilibrate with the moisture in the soil, the tensiometer must be filled with water before inserting in the soil. When a vacuum is applied to a water surface, (as happens inside a tensiometer installed in dry soils) the vacuum draws out any gas which is dissolved in the water. So a tensiometer will work more efficiently if the water it is filled with is gas-free to begin with.

Water straight from the tap is quite full with dissolved air. A glass of water left standing for some time often develops gas bubbles on its sides as the air comes out of solution. The simplest way of 'de-gassing' water is to boil it hard for several minutes. (If you have an automatic kettle, boil with the lid off for 4-5 minutes - but don't forget it and let it boil dry!) When the water has cooled slightly, completely fill a bottle or container - make sure there are no air bubbles which can consequently redissolve back into the water - and this can be stored for a day or so. Ideally the water you boil will be de-ionised as used in car batteries or household irons.

The porous ceramic at the tip of the tensiometer is also filled with entrapped air. To ensure a free flow of water between the soil and the tensiometer, these ceramic pores must be filled with water. To do this, immerse the tensiometer in a little of the prepared water to a level just above the top of the ceramic. Air pressure will force water through the ceramic into the tensiometer to its own level, removing the entrapped air (and dissolving it) on its way. This may take a couple of hours. Discard the small amount of water which has been forced through the ceramic into the tensiometer, and fill with the prepared water.

Alternatively, suspend the empty tensiometer so that the ceramic tip is not touching anything and fill with the prepared water. Let the water drip through the ceramic tip under gravity, so removing the entrapped air. When the water level has dropped about half way down the tensiometer length, refill again to the top.

If there are any small air bubbles stuck to the clear sides of the tensiometer shaft, flick gently with a finger and these will be dislodged and rise to the surface. Top up again and seal the tensiometer, with the rubber septum seal, 'O' ring and screw or sensor cap as appropriate. It is advisable to wrap the ceramic tip in clingfilm (plastic foodwrap) temporarily until installation into the soil can be completed, which will prevent further water leakage for a short time.

IMPORTANT: When filled with water, keep the tensiometer upright to prevent the small air bubble reaching the ceramic. Do not allow to be shaken violently otherwise the force of the water could damage the pressure transducer.

3. Installing the tensiometer

The ceramic tip of the tensiometer is easily cracked and broken if the instrument is forcibly driven into the soil. So a core of soil is first removed to allow the tensiometer to be placed to the required depth.

In tilled soil which is fairly loose and free of stones down to the required measurement depths, then a simple piece of copper plumbing pipe can be used to make the borehole. (Please see the instruction manual supplied with the instrument for the diameter required.)

If the soil is compact and stony, then it is advisable to use a soil auger to remove the soil core and create the borehole ready for insertion of the tensiometer. Again, check the instruction manual for the correct size auger to use.

Mark the pipe or auger with the measurement depth required and remove the soil core. Keep a small amount of the removed soil and mix with water to make a fine slurry. Pour the slurry down the borehole just enough to be able to cover the ceramic tip when inserted. This slurry will soon drain away leaving a close contact of soil with the ceramic, ensuring trouble free measurements.

Unwrap the clingfilm from the tensiometer tip and gently lower down into the borehole, until it reaches the measurement depth – there should be at least 5 cms still protruding. Take care not to disturb the sides of the borehole, so that there is a good fit to the tensiometer all the way down its length. Pat down the soil around the top of the tensiometer to ensure that rainwater or irrigation cannot easily run down the side of the instrument, leading to false measurements.

If the tensiometer is an electronic type, attach its cable and connector to a Skye DataHog or other datalogger, or fit a blank cap to its connector to ensure the system is water tight.

APPENDIX 2

INTERPRETATION OF TENSIOMETER GRAPHS

Using tensiometers with automatic dataloggers enables regular soil moisture readings to be plotted against time on a graph. This allows an overview of the crop water use at a glance, for quick and easy interpretation and decision making.

Graph 1 shows the readings taken from 2 tensiometers placed at 30 cms and 50 cms depth in a potato crop, over a 2.5 week period. As the crop uses up the available water, tensiometer readings increase steadily, and then drop dramatically as water is applied either by rainfall or irrigation.

The shallow tensiometer at 30 cms is clearly more responsive to the irrigation / rain events than the deeper 50 cm tensiometer. Events 1 and 3 apply only light surface water reflected by just the 30 cm tensiometer readings. Event 2 application goes deep enough to be detected by the tensiometer (and so the crop roots) down at 50 cms depth. This type of graph can be used to assess how much irrigation to apply, to ensure enough is applied to reach the rooting zone, but not too much to prevent wastage due to run off.

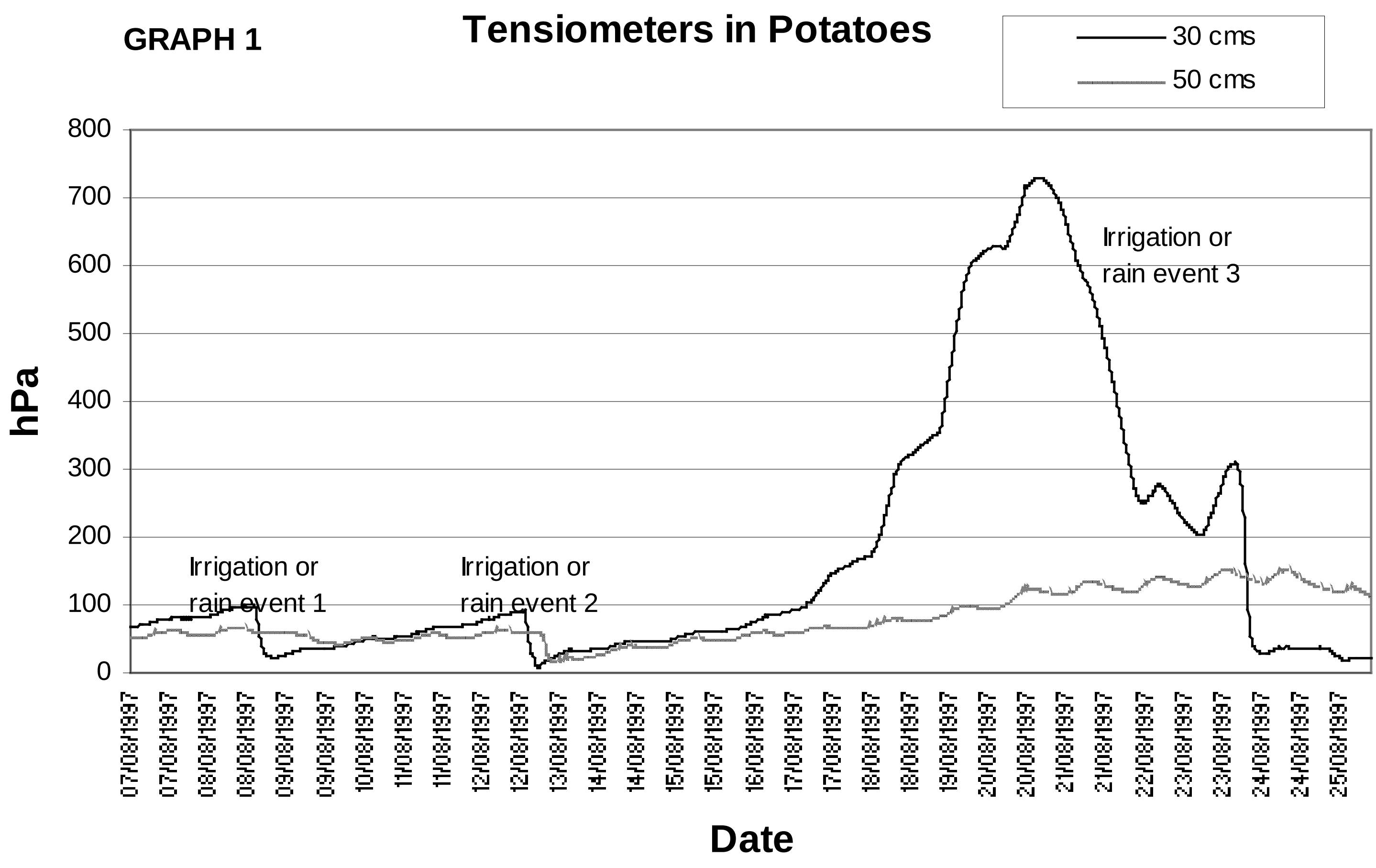
The high peak to over 700 hPa shown by the 30 cm tensiometer before Event 3, would have caused severe water stress damage to a young crop with roots only reaching 30 cms. However, a mature crop with plenty of deeper roots at 50 cms would still be growing healthily, with a maximum tensiometer reading of 150 hPa. Here the graph can be used to assess when the crop requires irrigation. If the mature crop has roots at the deeper level, then it is not necessary to keep the top surface irrigated, as long as the rooting zone has a low suction reading.

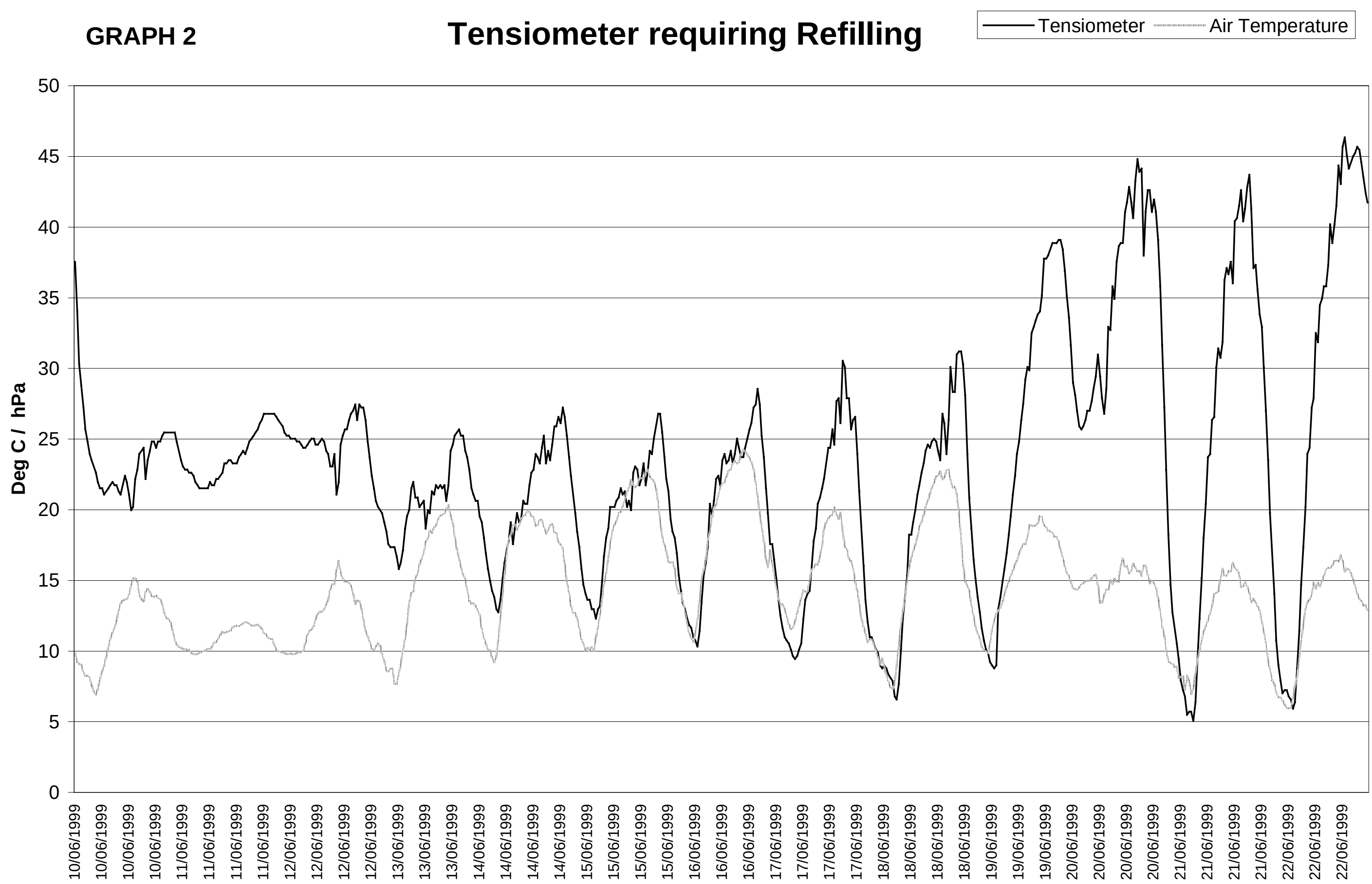
If examined carefully, it can be seen that the graph has a diurnal variation (daily peak and trough shape). This is partly due to the faster uptake of water by the crop in the day than at night, and partly due to the temperature fluctuation of the tensiometer electronics. In a correctly installed tensiometer, the diurnal variation is usually 5-10 hPa.

Graph 2 shows this diurnal variation on a bigger scale. The tensiometer is behaving normally with a variation of 5-10 hPa for the first 2-3 days. This variation then increases each day getting larger and larger. By the end of the week it is getting difficult to determine what is the exact reading. Plotted alongside the tensiometer reading on this graph is air temperature. It is clear that the tensiometer variation matches the day / night temperature cycle. Even when the temperature variation is not very large at the end of the week, the variation in tensiometer readings get increasingly bigger.

The reason for the continual increase in variation is that the water level inside the tensiometer is gradually going down, so increasing the 'air' bubble size. Gases expand and contract with temperature to a much greater extent than do liquids, so giving a greater variation in pressure.

So, if you see this large daily variation in tensiometer reading, it is an indication that the instruments require topping up with water (of the boiled and de-ionised type!).


GRAPH 1
Tensiometers in Potatoes
30 cms
50 cms
hPa
800
700
600
500
400
300
200
100
0
Irrigation or rain event 1
Irrigation or rain event 2
Irrigation or rain event 3
Date


GRAPH 2
Tensiometer requiring Refilling
Tensiometer
Air Temperature
Deg C / hPa
50
45
40
35
30
25
20
15
10
5
0