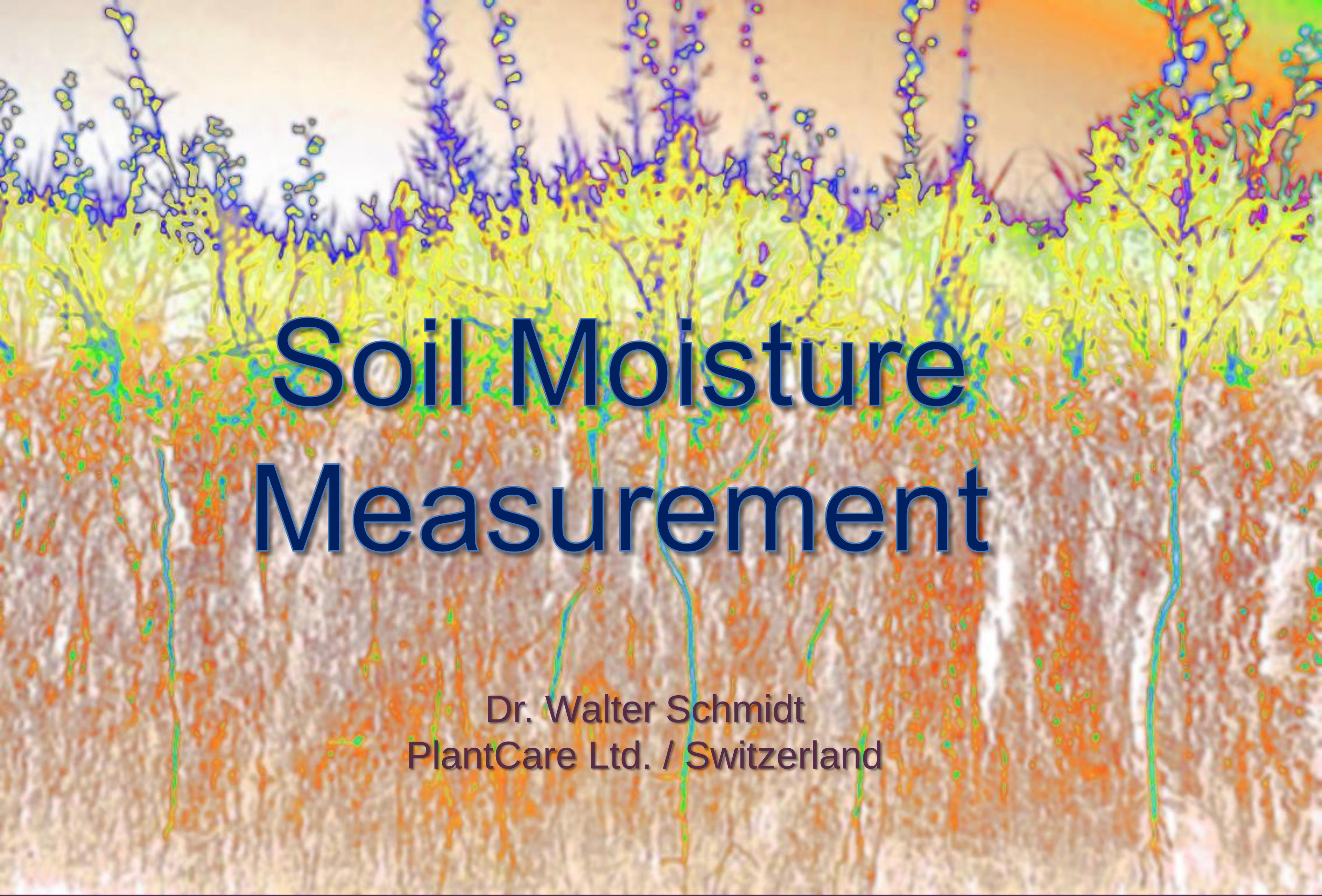

Soil Moisture Measurement

Dr. Walter Schmidt
PlantCare Ltd. / Switzerland

Introduction

- Soil is usually very heterogeneous and consists primarily of:
- Inorganic material (sand, clay, silt, stones….)
- Pores filled with air or water
- Macro-organic material (roots, compost,.)
- Micro-organic material: Microbes and fungus micelles
- In addition, this composition is a function of time:
- Pore size distribution
- Volume of the roots
- Formation of preferential water paths

Soil Moisture Measurement Methods

- **Weighing**
  - There is only one method for determining the absolute proportion of water in the soil: Weighing a soil sample, drying it at 120°C and weighing again.
  - Apart from the disadvantage that this method is not very suitable in practice, it is absolutely not suitable for the automatic control of an irrigation.
- **Measuring the Matrix Potential: (Tensiometer)**
  - This is the oldest method to measure a value (sucking pressure) which is related to the soil moisture content but does not provide a direct percentage information. Usually, the sucking pressure or water tension is understood as the force the roots have to apply to be able to take-up the water from the soil. This explanation is not quite correct, because the Matrix Potential is a measure for the energy which has to be applied to get the water out from the soil against the capillary force. Roots, however, take-up water by osmosis.
- **Measuring the Electrical Conductivity in a porous Gypsum Block**
  - The electrical conductivity is quite dependent on the salinity (fertilizer content) and soil temperature. To compensate the influence of the salinity, the sensors on the market uses a gypsum buffer, which have to be replaced after 2-3 years.
  - One disadvantage of this type of sensor is a slow response to changes in soil moisture which limits the use for automatic irrigation control purposes.

Soil Moisture Measurement Methods

- Measuring the Dielectric Constant ε_r:
  - How effective a dielectric is at allowing a capacitor to store more charge depends on the material the dielectric is made from. Every material has a dielectric constant ε_r. This is the ratio of the field without the dielectric (Eo) to the net field (E) with the dielectric.
  - Because water has a very high ε_r the measuring of it is used to determine the amount of water in the soil.
  - The measuring can be performed by various methods. Most of sensors on the market use a high-frequency pulse traveling along wave guide rods into the soil. The attenuation or the reflection time of the pulse or combinations are used. Other use the shift in the resonance frequency of a resonator which is depended on the ε_r of the surrounding soil.
  - In practice, the measurement is very difficult because the soil is a mixture of several components with very different εr. The measurement result corresponds to the average over a certain soil volume. From this value the percentage of the water has to extracted mathematically.

measured value

2 - 4 1.5 - 3 80 1 20-60 $Vol_{roots} = f(time)$

? ? ? ? ? ? ? ? ? ?

$$\varepsilon_{r\ average} = \frac{Vol_{inorg.} \times \varepsilon_{r1} + Vol_{org.} \times \varepsilon_{r2} + Vol_{free\text{-}water} \times \varepsilon_{r3} + Vol_{air} \times \varepsilon_{r4} + Vol_{bound\ water} \times \varepsilon_{r5} + Vol_{roots} \times \varepsilon_{r6}}{Vol_{total}}$$

The measurement result = Vol% = $Vol_{free\text{-}water} + Vol_{bound\ water}$

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Soil Moisture Measurement Methods

- As a result of these difficulties, suppliers of such sensors recommend to perform an on-site calibration.
- This calibration is done as follows: The sensor is buried at the desired position and depth and the soil is watered until it is saturated. After that, one has to wait 2-3 days until the field capacity has been reached and a first measurement has to be done. The measured value is considered as a reference value. The set-point for the start of an irrigation is chosen as a percentage of the field capacity.
- This freely selected set-point level represents an unknown percentage of water in the soil.

- The following slides show the result of a comparison measurement of different types of soil moisture sensors at identical conditions. These tests were performed by *Paschold, Peter-J.; Kleber, Jürgen; Geisenheim Research Center - Department Vegetable Crops; www.fa-gm.de*

Soil Moisture Measurement Methods

In 2008, Prof. P. J. Paschold and J. Kleber from Geisenheim Research Center - Department Vegetable Crops (Germany) have performed comparative tests between various soil moisture sensors.

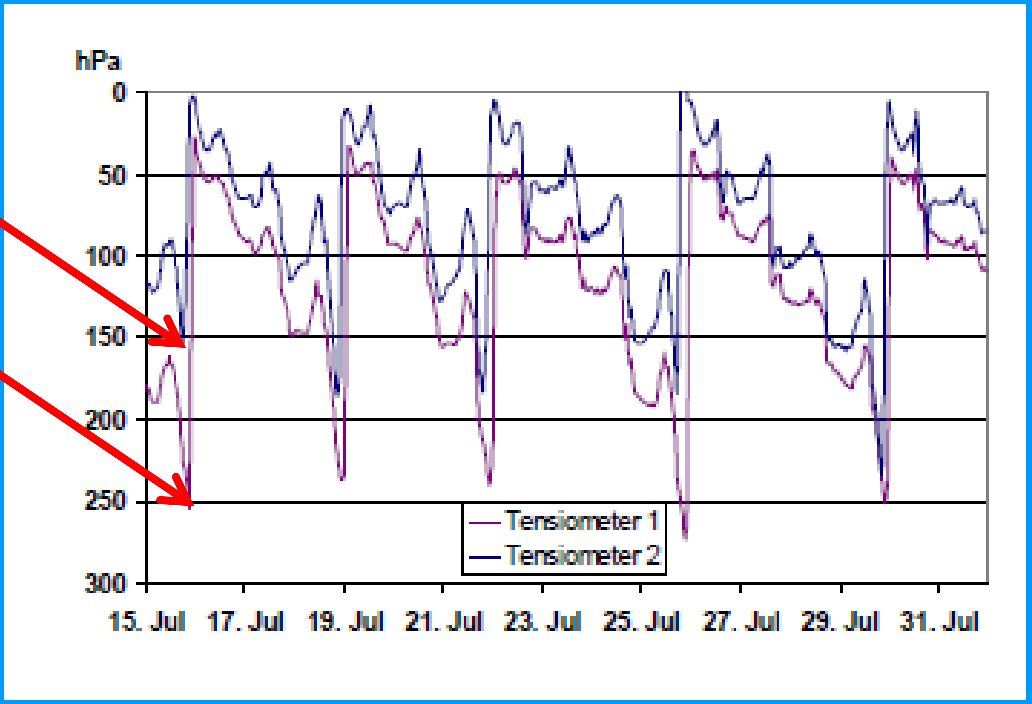



They placed the sensors - narrow spaced - in one bigger plant pot filled with a standard soil and measured several wet-dry cycles.

Tensiometer

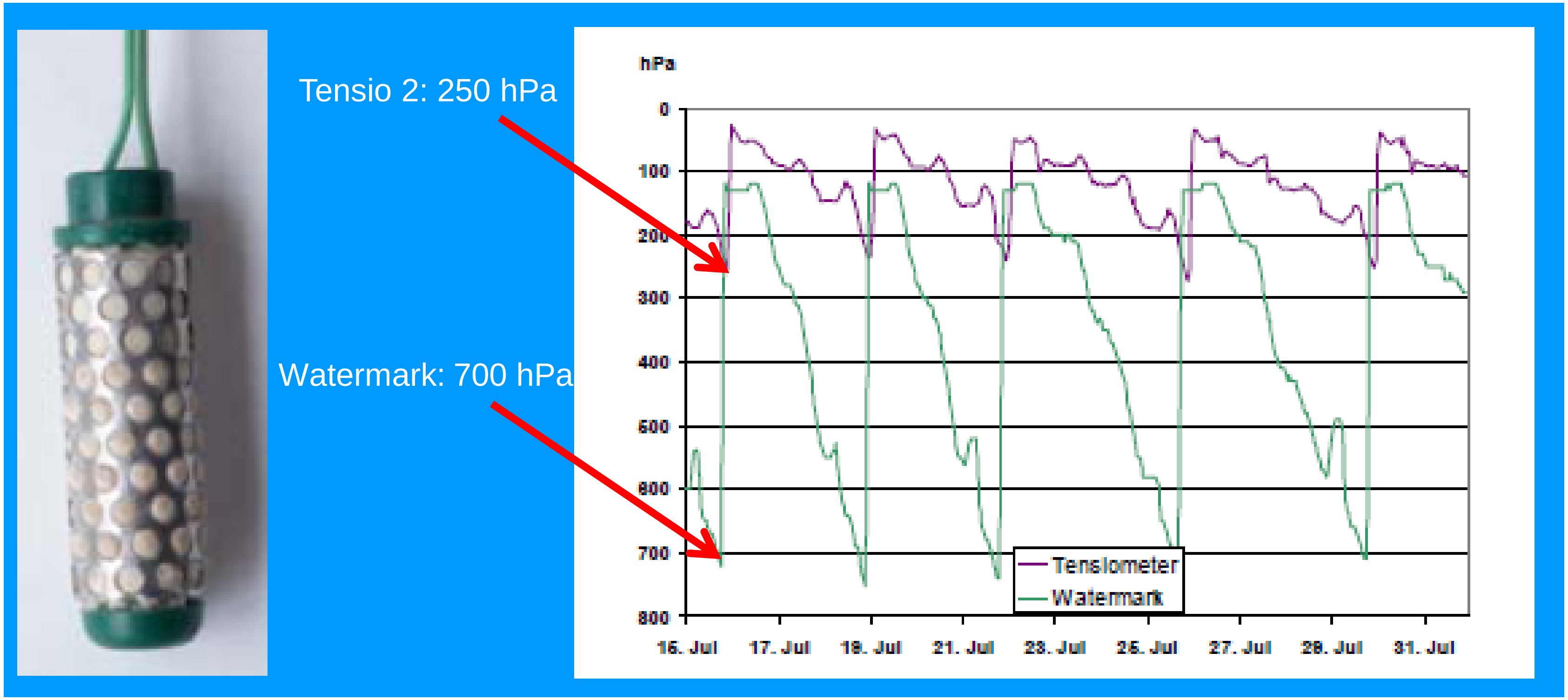
Tensio 1: 150 hPa

Tensio 2: 250 hPa



Even two tensiometers placed side-by-side in the same soil sample show considerable different results.

Electrical Conductivity



The Watermark®-Sensor measures the electrical conductivity (mS) and converts it to hPa. When the tensiometer measures approx. 250 hPa, the sensors output is approx. 700 hPa.

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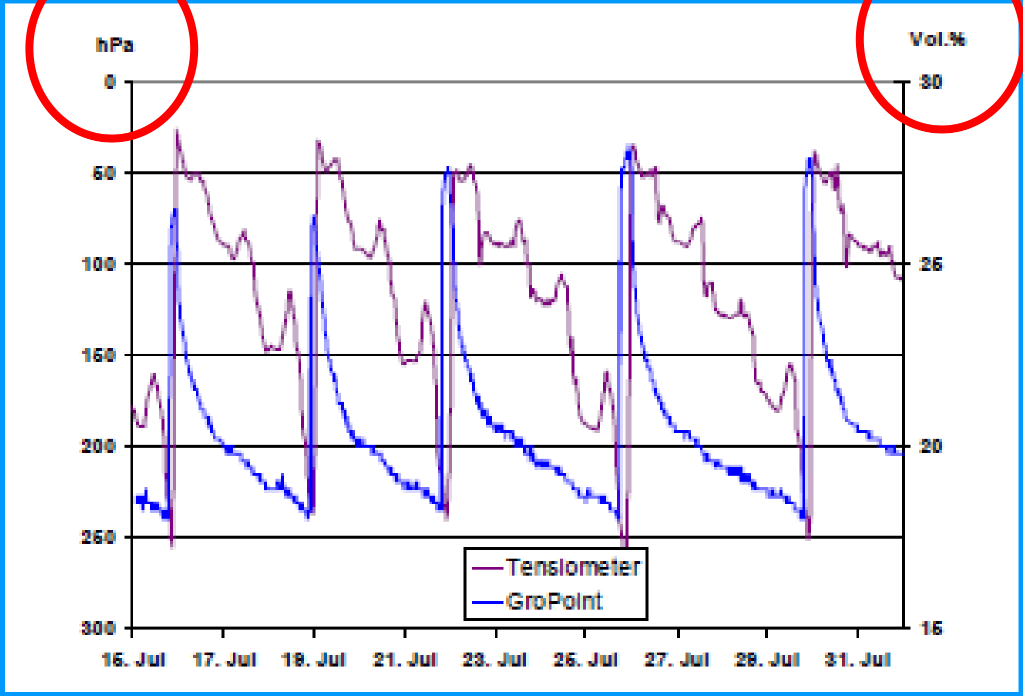
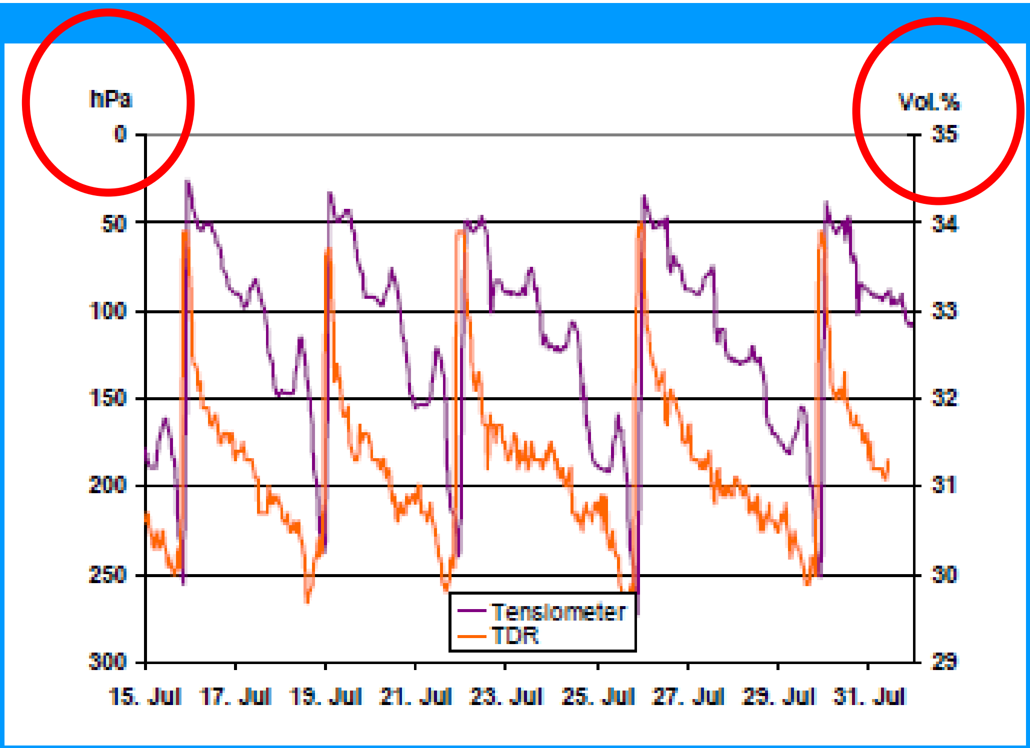
Time-Domain-Transmission (TDT)



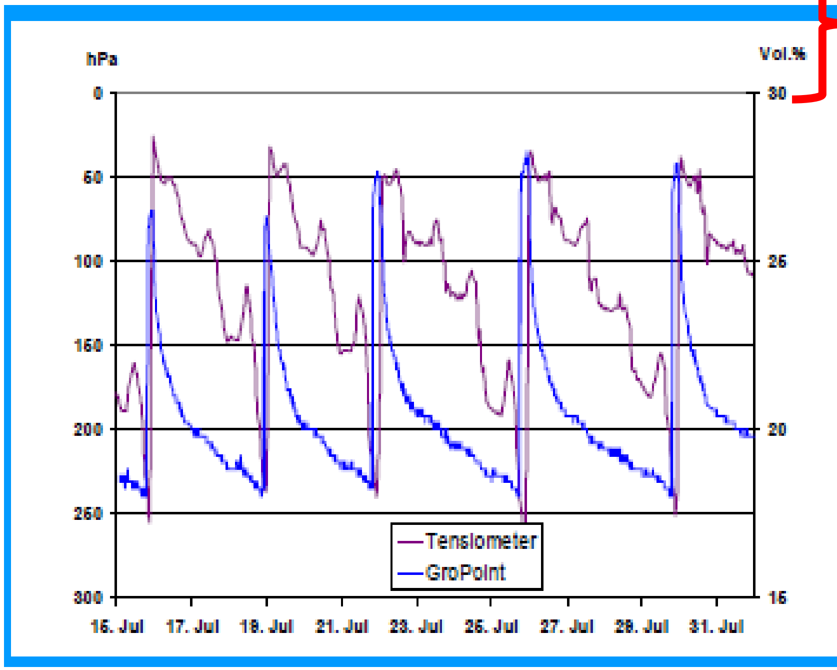
The sensor output is usually volumetric water content (%) derived from an εr measurement. There is no direct comparison between hPa and Vol% possible.

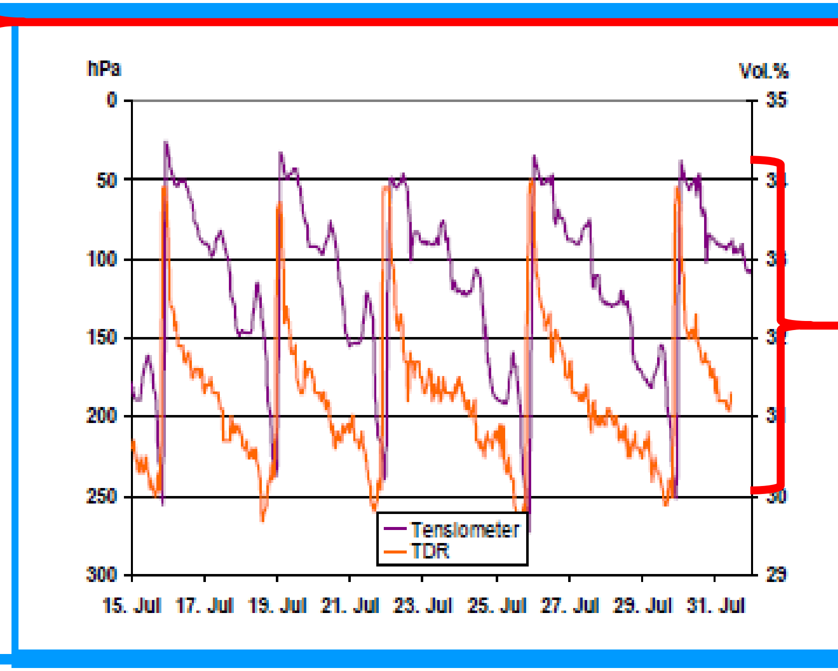
Time-Domain-Reflection (TDR)



The sensor output is usually volumetric water content (%) derived from an εr measurement.

Conversion εr > Vol.%





Both systems (TDT as well as TDR) measure the εr and convert it to Vol.%. The results differ considerably.

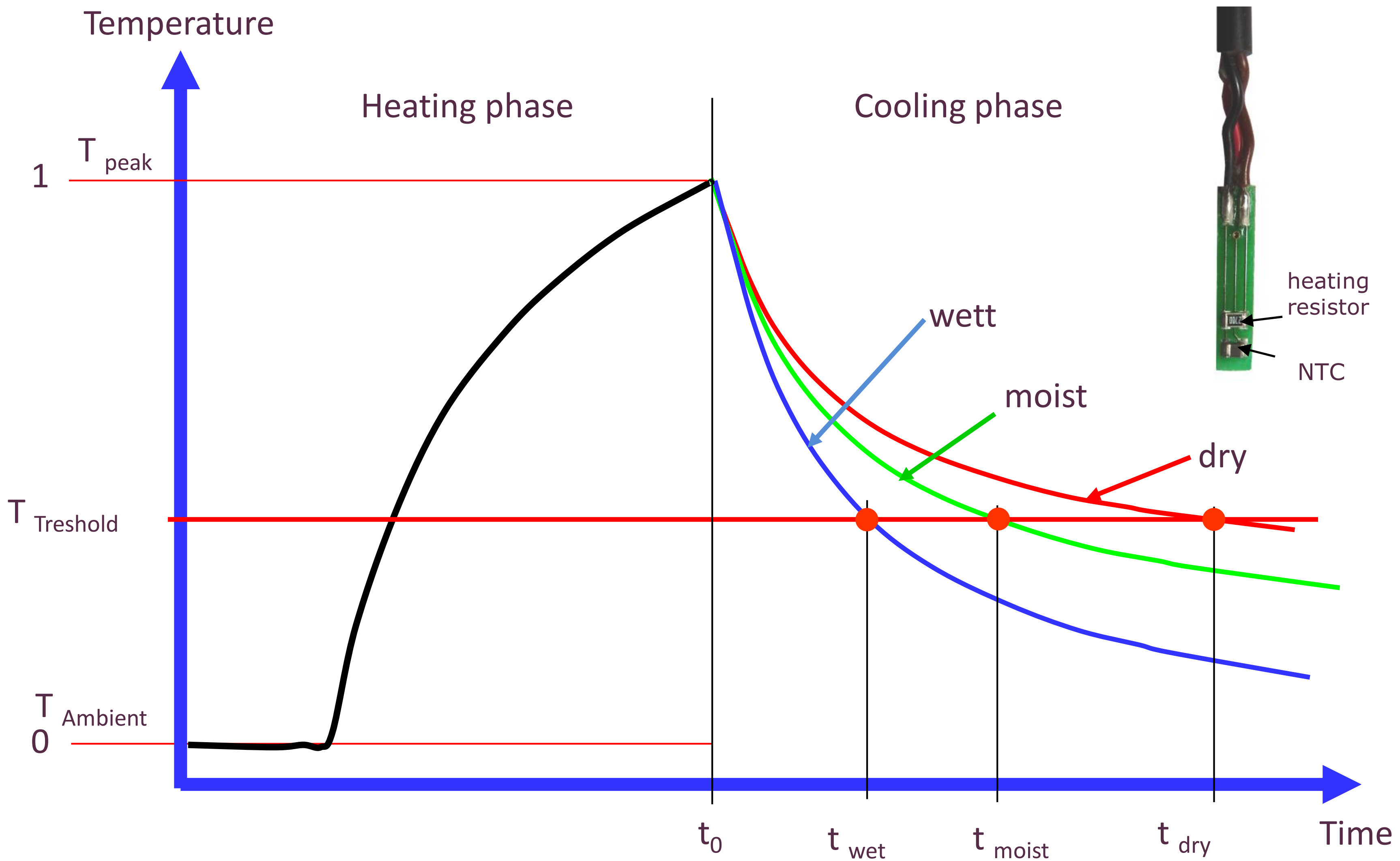
Characteristics of an „ideal“ Sensor

- **Technical**
  - Measures plant-available water only
  - High sensitivity, accuracy and repetition accuracy
  - Applicable to any soil type
  - No influence of fertilizers and salinity content
  - Short response time
  - Independent from ambient temperature
  - Simple conversion into electronic signal
  - Low power consumption
  - Small outline
  - No maintenance required
  - High reliability
  - Simple application
- **Commercial**
  - Low production cost

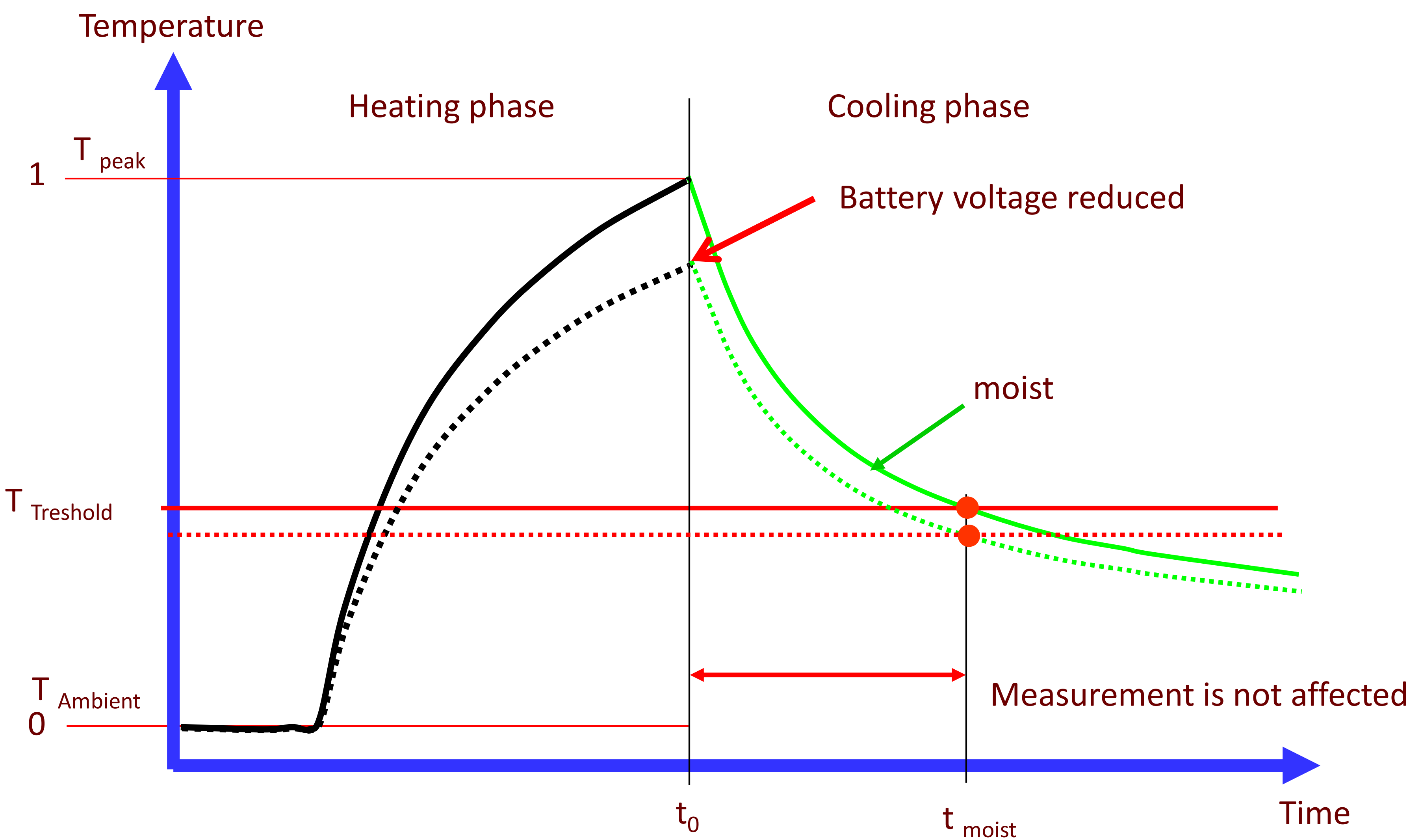
Farmer‘s desires

- Easy to install and operate
- No cabling
- It should be possible to place the sensors anywhere on a field
- No maintenance required
- No signal drift over time (no manual adjustment necessary)
- Measurement not influenced by fertilizer or temperature
- Multi-sensor measurement with automatic averaging
- Long battery life time
- Use of cheap, readily available batteries
- Easy replacement of batteries
- Reasonable price

Measuring Method PlantCare

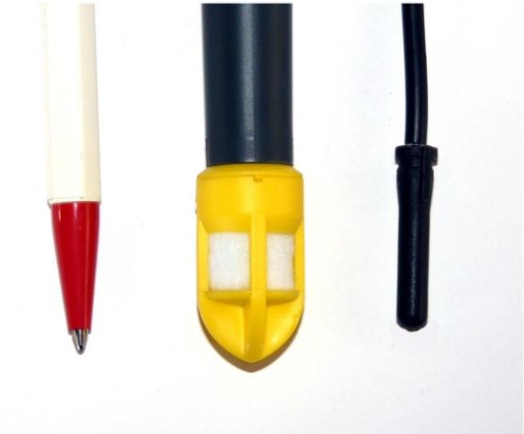


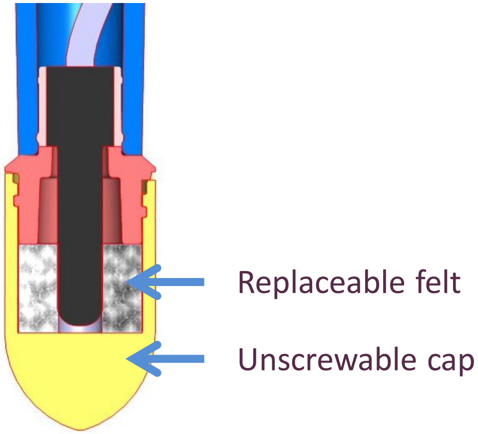
Measuring Method PlantCare



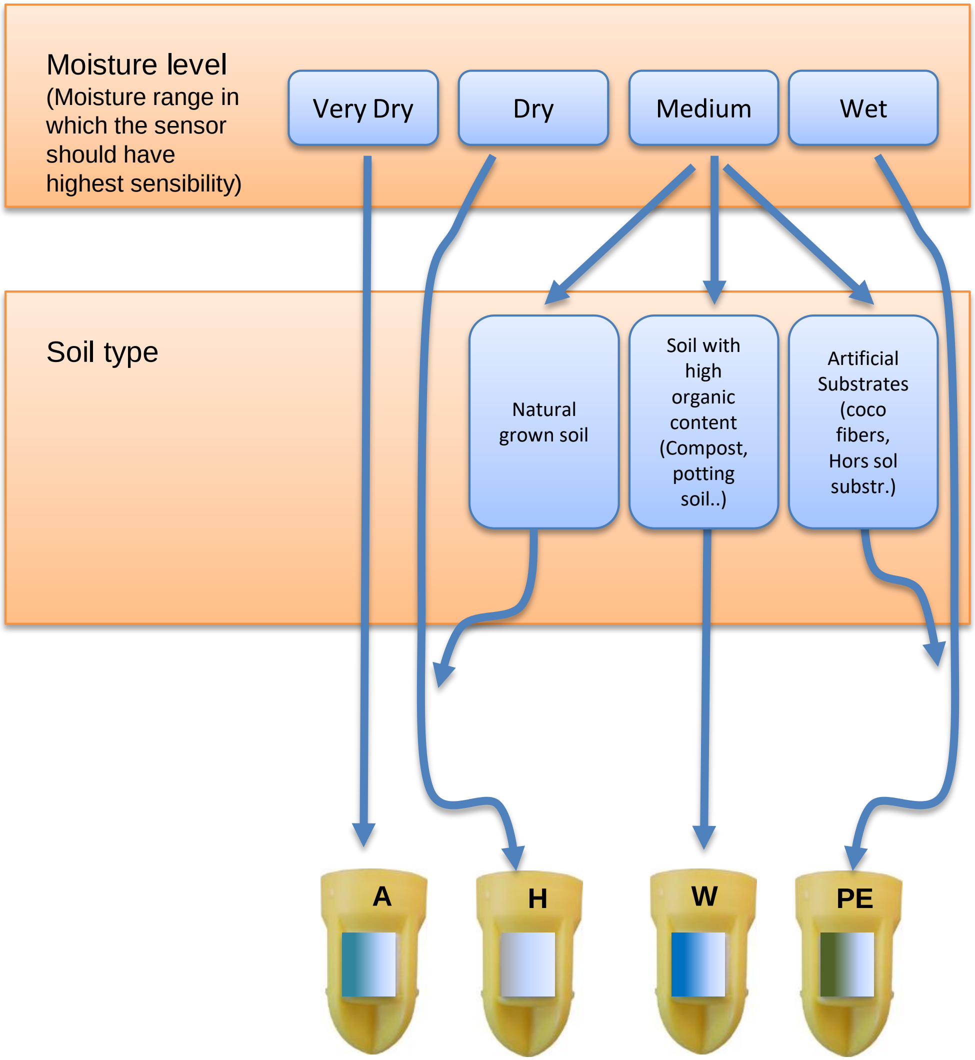
Measuring Method PlantCare

- The actual sensing element has no direct contact with water, humic-acid, fertilizer etc.
- Small outline results in fast response, spotty measurement and low power consumption.
- Felt doesn’t decompose even after long exposure to soil.
- Felt composition can be tailored to type of substrate:
  - Felt Type A: High Matrix Potential
  - Felt Type H: Medium to high Matrix Potential
  - Felt Type W: Low Matrix Potential
  - Felt Type PE: Very low Matrix Potential
- This allows to cover the complete range of applications from extremely wet very dry.





Felt Selection: Decision Matrix

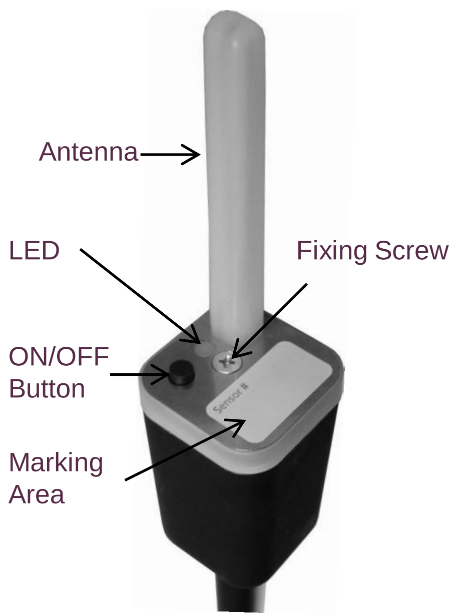


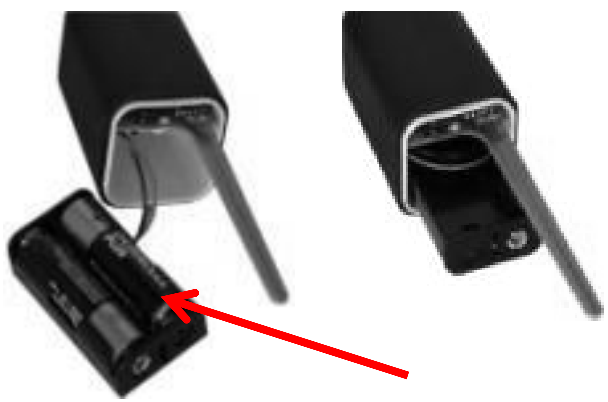
The sensitivity of the sensor can be optimized for the application:

Hors sol, berries
Horticulture, nurseries
Greenhouse and field farming
Viniculture

Range of designs to suit a variety of field applications

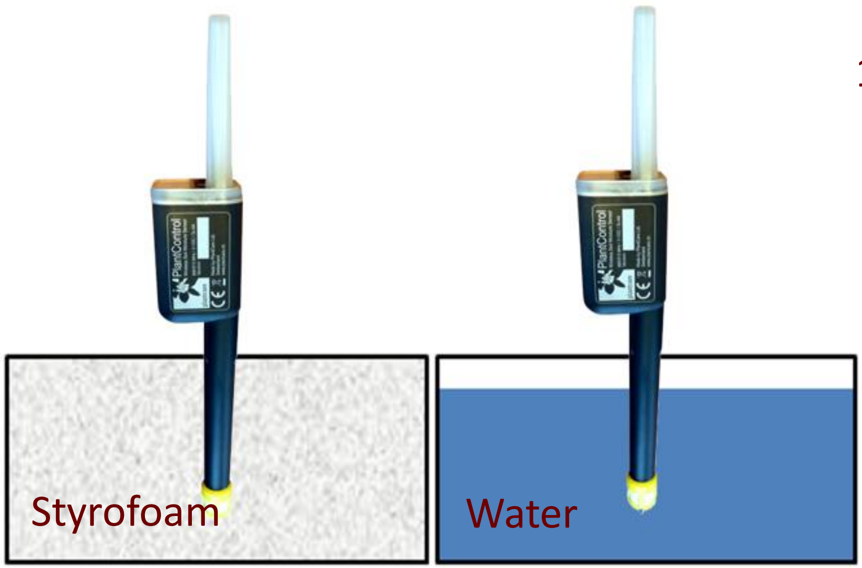
Sensors are available in stiff versions with lengths up to 1 m (more possible) and in a cable-version. The length of the cable can be 300 m without adversely effecting measurements.





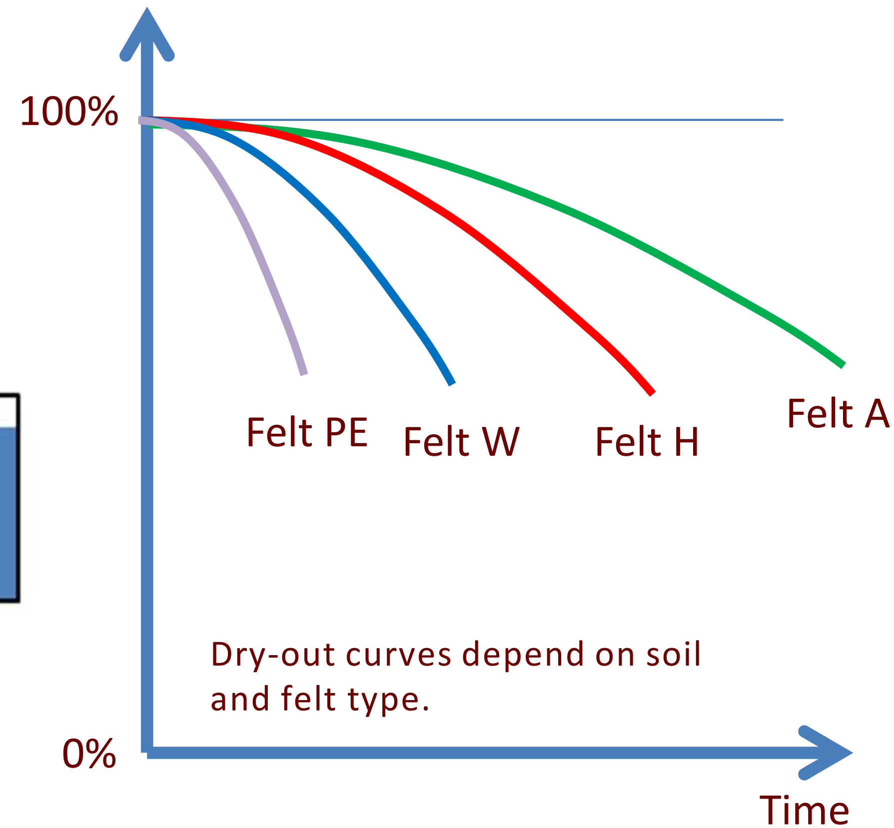
2x AA Batteries

Sensor Calibration



5 measurements
Average = 0 %

5 measurements
Average = 100 %



Calibration eliminates all manufacturing variations between sensors. It does result in an absolute calibration on the endpoints 0% and 100% but does not result in absolute calibrated values between.

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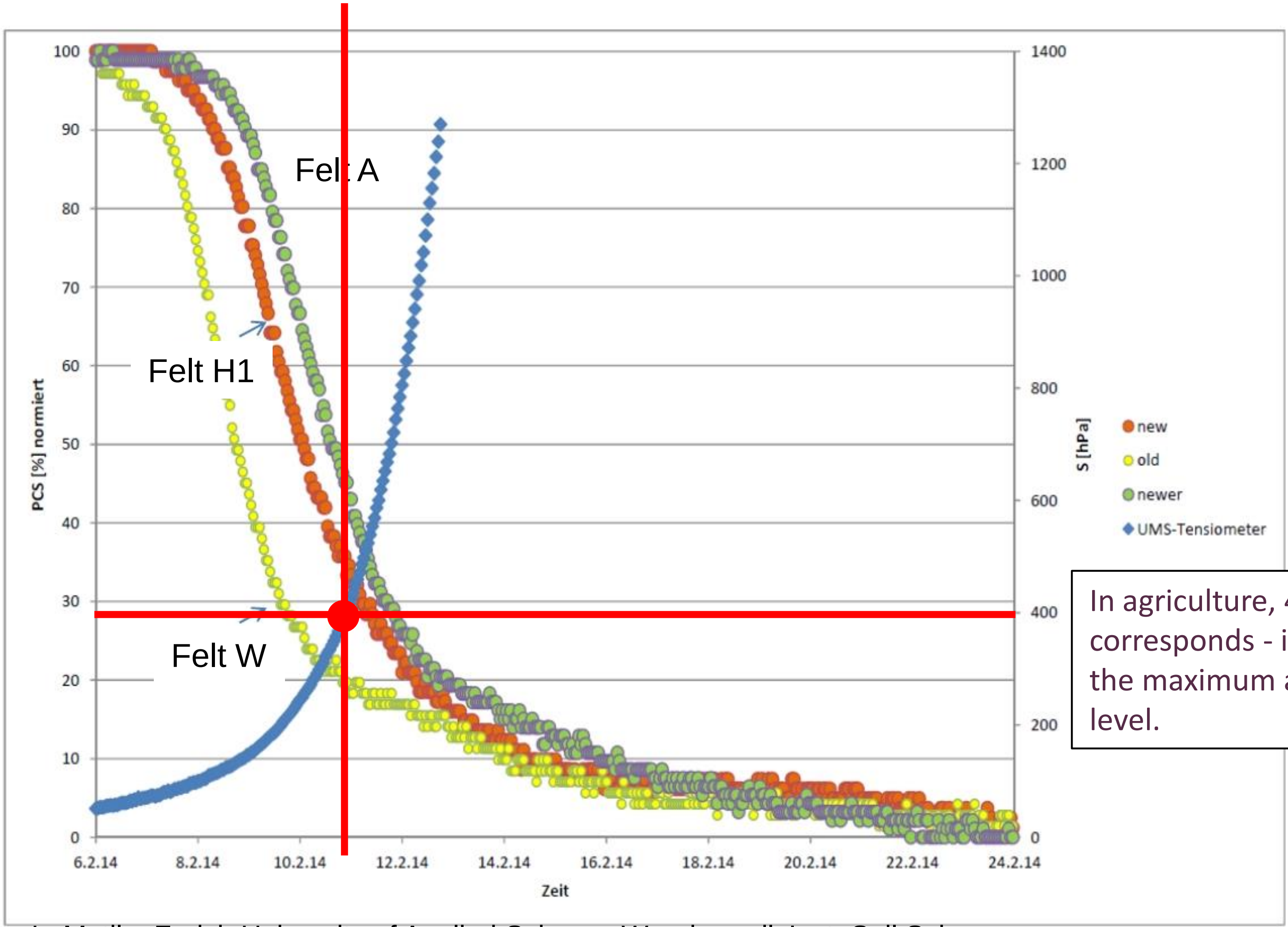
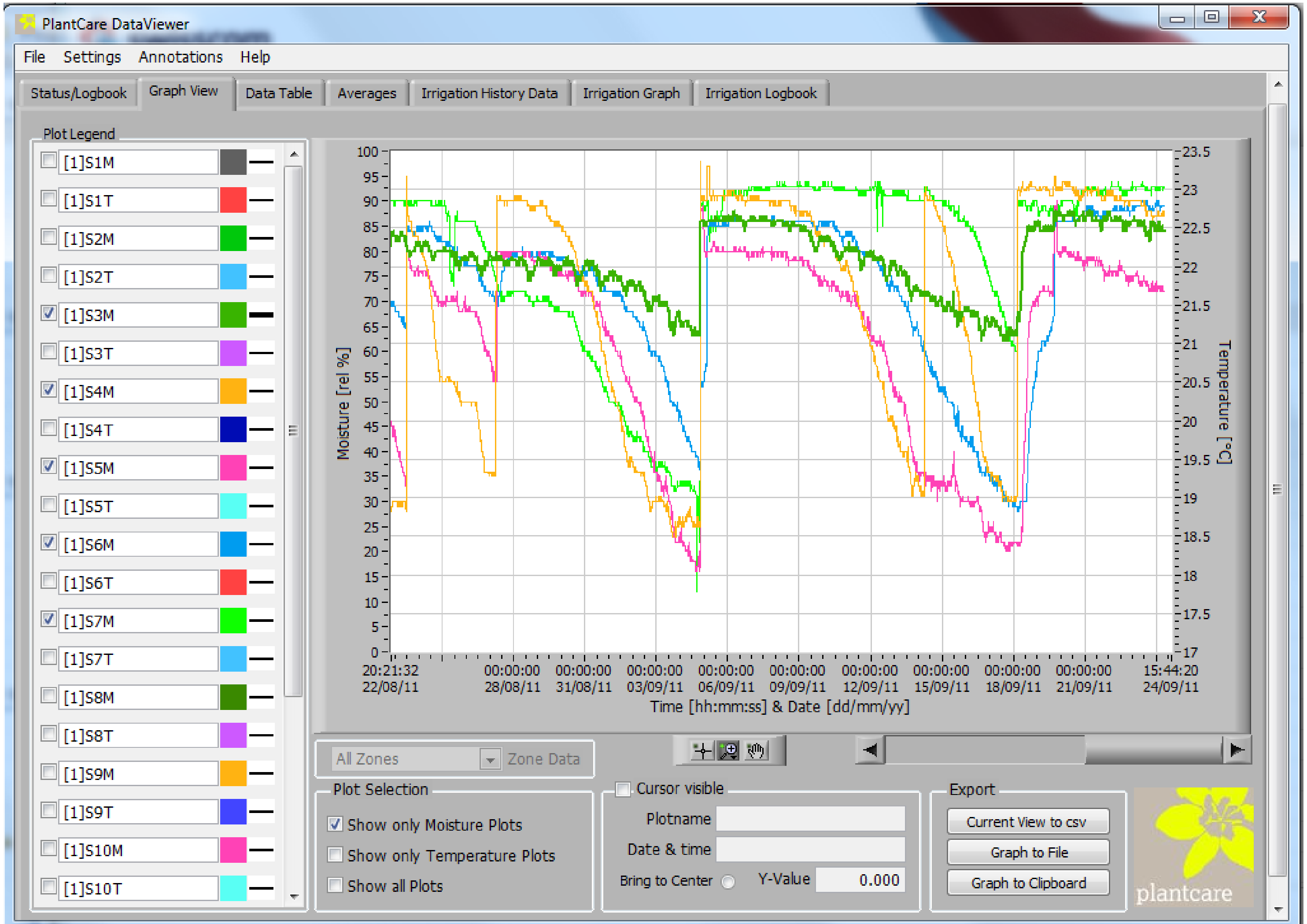
Comparison Tensiometer / PlantCare Method



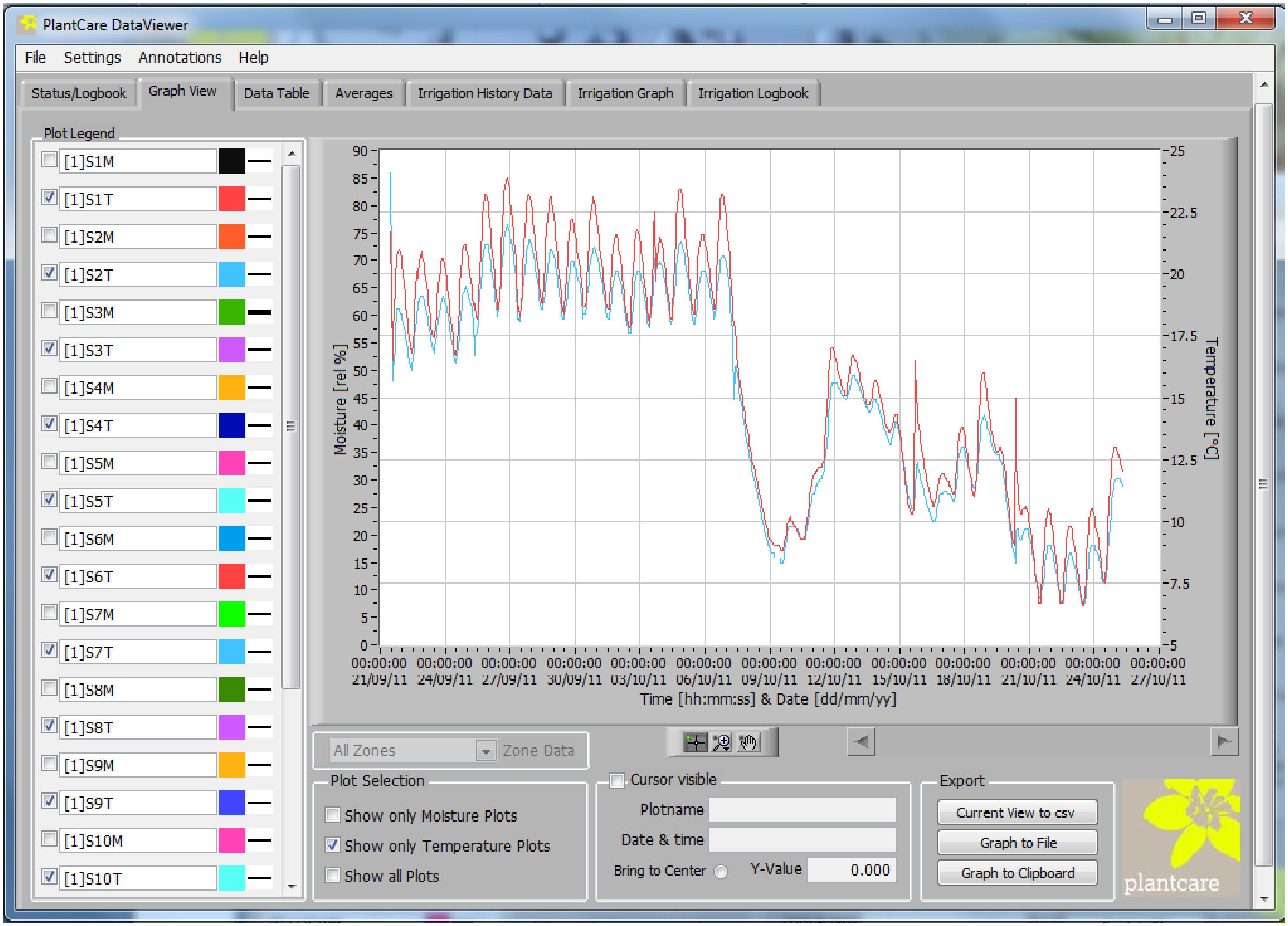
In agriculture, 400 hPa corresponds - in most cases - to the maximum allowed dryness level.

L. Matile, Zurich University of Applied Science, Waedenswil, Inst. Soil Science

Example Soil Moisture



Example Soil Temperature



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Sensor Placement

- How many sensors are needed?
  - The number of sensors depends on
    - the number of different crops
    - the homogeneity of the soil or substrate
    - the terrain
    - the homogeneity of the climatic conditions within a culture
    - **The number does not depend on the area of an irrigation plot!**
  - Experience has shown:
    - In greenhouses 1 to max. 2 sensors per culture
    - In the field, 1 to max. 3 sensors per culture
    - If several sensors are placed in a zone the PlantControl takes the average for irrigation control.

Sensor Placement

- Where the sensors are placed?: Where we want to know how moist it is!
  - In root balls
  - Where the sensor can feel the water
  - Not too far away from drippers
  - When sprinkler irrigation is performed, not below leaves
  - At a position where it cannot be mechanically destroyed
  - Where the sensor has radio link to controller
- How the sensors are inserted?
  - Prior to insertion, the sensor tip is immersed for a few seconds in water. Why? This ensures that the moisture equilibrium between felt and soil adjusts quickly.
  - Depending on the soil (dry and hard or wet and loose-packed) and the depth, the sensor can simply pushed into the ground or one have to pre-form a corresponding hole in which the sensor tip can be pushed in.

An air-gap between sensor and soil does not affect the measurement

Mounting the Sensor Electronics

In order to ensure an optimal radio link, the electronics with the antenna should be attached above the leaves.

Mounting the electronics on slalom flex poles.

Advantages PlantCare Soil Moisture Sensor

- Sensor measures plant-available water only!
- Signal is not effected by fertilizer or temperature.
- Simultaneous measurement of soil moisture and temperature.
- Measuring range from 0 to 2000 hPa
- Measuring sensitivity can be adjusted to specific applications (from very wet to very dry).
- Totally maintenance free.
- Low power consumption (2 AA mono-cells, 1y when measuring cycle = 1 h)
- Small outline. Sensor can easily be placed in small pre-drilled holes or near to the soil surface.
- Length of the connection cable between sensor-tip and electronics is virtually not limited.
- PlantCare's sensor have been qualified by Syngenta Corp. and a number of highly renowned agricultural research institutes like Max Planck Institute for Molecular Plant Physiology, Potsdam, Germany, BASF Cropdesign, Belgium, Julius Kühn Institute, Sanitz Germany and others.
- Over the last 5 years more than 250'000 sensors have been sold and are in service all over the world.