Application Note: Soil Humidity Measurements (WORK IN PROGRESS)

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Outline

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Figure 1 Agroforestry in Missouri, USA

Introduction

There are various types of soil (sandy, loam, silt, clay) and these soils can store different amounts of water. They also release this water differently to the plants (see Table 1). For example, plant roots can extract water from sandy soil with less effort than clay soil. This is reflected by the lower soil tension value of sand when it has lost 50% of its water, compared to clay soil.

Table 1 Soil water properties by textural class (Extract from (Sanford and Panuska 2015))

SOIL TEXTURE	Total Pore Space (% by volume)	Field Capacity (% by volume)	Permanent Wilting Point (% by volume)	Total Available Water (% by volume)
SANDY	38	15	7	8
SANDY LOAM	43	21	9	12
LOAM	47	31	14	17
CLAY LOAM	49	36	18	18
SILTY CLAY	51	40	20	20
CLAY	53	44	21	23

SOURCE: Campbell and Norman, 1998, and Fangmeier et al., 2006

Each plant species also has a different root depth. Irrigation management aims at irrigating the root zone, while avoiding providing water below the root zone, which is considered a loss.

Soil moisture monitoring can help identify problems such as excessive intervals between irrigation, inadequate wetting, too frequent irrigation, and differences in moisture extraction patterns of different crops. Solving these issues can lead to increased crop yields and/or water usage reductions. Soil water content measurements are an efficient way to reduce water usage in agriculture (e.g., 25-50%).

Moisture monitoring can reduce energy use through reduced water pumping as well as reduced fertilizer and pesticide use. Continuous measurements can help identify trends that can be difficult to detect with weekly manual measurements (Hanson, Orloff, and Peters 2000).

A significant portion of the world's producers still do not use water sensors. For example, Afghan rural farmers were only introduced to Watermark soil water content sensors in 2006 by US. Air Force (Varble and Chávez 2011).

Soil humidity is a complex and still evolving science. For example, soil temperature affects the hydraulic conductivity and water movement capability, and thus may have an indirect impact on moisture measurement (Evett 2008; Evett, Tolk, and Howell 2006; Toth and Maule 1998).

The goal of this short document is to give an introduction to some of the core concepts of soil humidity measurements, describe the applicable methods for the RDL and how the user can start making measurements.

VARIABLES OF INTEREST

A- Soil water tension

Soil water tension is also called 'soil water potential'. It provides an indication of how difficult it is for a plant to absorb water from the soil. It is a very important measure of the soil. Traditionally, soil tension is expressed in units of pressure (centibar) and is measured by a tensiometer. As the soil dries, the soil water tension value increases.

B- Water content

Water content simply represents the amount of water in a given soil volume, without consideration for the ease with which the plant can access that water. It can be expressed by unit of weight (gravimetric water content) [kg/m3] or volume (volumetric water content) [m3/m3]. At saturation, the water content is maximal for a given soil texture and type.

The relationship between soil water tension (A) and volumetric water content (B) in a given soil in a given condition is given by a release curve.
(https://open.library.okstate.edu/rainorshine/chapter/3-3-soil-water-retention/)

MEASUREMENT DEVICES

1- Tensiometer

The tensiometer is the only device able to directly measure soil water tension described previously. A mechanical sensor that measures the partial vacuum created by moisture absorption at the tip of the instrument. Measurements are usually not continuous but rather done manually every few days, at two different depths.

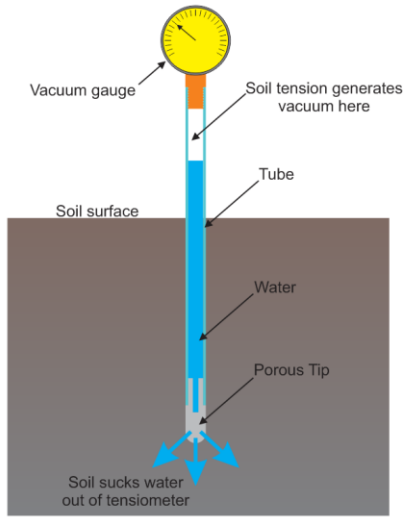

Figure 2 Principle of action for a traditional tensiometer (reproduced from smartfarming.co.za)

2- Gypsum block measurements

Gypsum blocks have been used since the 1940s (Bouyoucos and Mick 1940). They are small solid blocks made of porous material and two electrodes. Their electric resistance varies with the humidity level of the blocks. Commercial gypsum blocks are usually made of Plaster of Paris. Commercial gypsum probes for moisture measurements cost around US$1.25 per probe (UMass 2015). The gypsum probe is not an ideal resistor. Due to the electrochemical cell nature of plaster, the electric resistance cannot be measured with a direct current (DC). It otherwise become polarized and does not provide a stable or reliable measurement (UCDavis 2008). Alternating current (AC) avoids this problem but requires a more sophisticated measurement circuit. Jericho uses very short DC pulse every 15 sec to avoid the problem.

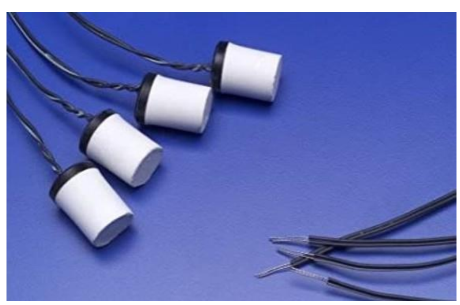

Figure 3 Example of commercial gypsum probes for moisture measurements

For a given soil moisture tension, soil moisture content depends on soil texture (Hanson et al. 2000). Therefore, to convert the resulting electrical resistance value to *soil water tension*, a *calibration curve* is required. To convert the resulting electrical resistance value to *water content,* a different calibration curve is required.

Gypsum blocks react quickly to rising humidity in the soil, but tend to react slowly to drying events. It might react within a minute to irrigation, but will not detect properly the soil moisture levels in the week following the irrigation event. This delay effect called hysteresis is the reason why gypsum blocks are most useful to detect if irrigation has reached a specific depth. The effect is stronger in medium- to coarse-textured soils. For that reason, you must wait a week before taking measurements, once put in the soil (adjustment to the soil).

Gypsum blocks readings are affected by temperature. The readings must be temperature compensated. Gypsum blocks are also affected by highly saline/alkaline soils (Hoseini and Albaji 2016). If the soil or irrigation water is highly saline the readings will not be reliable. There is plenty of material online about the growing problem of salt in agriculture (Meter Group 2021)

Gypsum blocks dissolve overtime and must be replaced every 1 to 3 years.

Watermark is a popular US brand of granular matrix sensor. It uses a material similar to gypsum and has an inner matrix to reduce degradation and improve lifespan. They are also designed to automatically estimate soil water tension from due to the calibration curve being integrated in the Watermark data logger. The manufacturer claim that the calibration curve of the Watermark probe is not dependent on the soil properties, but (Varble and Chávez 2011) have found otherwise.

An example of meter available for gypsum blocks is 1510-A Psychrometer by Soil Moisture company.

It is typical for a producer to install blocks in multiple locations at 3 or 4 heights to determine the humidity and temperature profile of the soil. Four measurements is more useful than three to manage irrigation.

3- Other soil humidity methods

Other methods such as Time Domain Reflectometry (TDR) allows the measurements of soil humidity (UMass 2015). Wet soil transmits the electric signal more slowly than dry soil, which can be used to infer soil water content. This technique is not perfect either. According to studies, even in dielectric soil moisture sensors, the measured moisture depends greatly on the soil salinity, temperature, and clay content (Evett et al. 2008).

4- Electric conductivity

To be written

Bulk EC

Bulk EC (σ_b) is the electrical conductivity of the bulk soil (soil, water, and air). Soil moisture sensors installed into the soil all measure bulk EC. Empirical or theoretical equations can be used to determine pore water EC and saturation extract EC (σ_e) from measured bulk EC values. Bulk EC is the only EC measure that can be continuously monitored in situ.

Saturation extract EC: the traditional method

Saturation extract EC (σ_e) tells exactly how much salt is in the soil and can be converted to soil salinity. This is the traditional way to measure EC. It is measured by taking a soil sample, making a saturated paste of soil and deionized water, extracting the water, and then measuring the EC of the extracted solution. Published EC values reported in the literature are almost always saturation extract EC.

Figure 4 Metergroup.com

Soil humidity terminology

#soil water content [mm3/mm3]
#soil moisture content [inches of water per foot of soil]
#soil water tension [centibar or Pa]
#soil moisture tension [centibars or Pa]
#soil water potential [centibar or Pa]
#soil dielectric permittivity (see Chavez et al. 2011)
#soil water release curve (water content = f(soil tension, soil type))
#soil water characteristic curve (SWCC) : synonym of “release curve” and “retension curve”
#soil suction change [bar or centibar]
#volumetric water content [m3/m3]
#gravimetric moisture content [kg/m3]
#allowable depletion [%]: each crop has a recommended maximum water depletion (e.g., 50%).
#soil salinity (dS m-1).
#weight moisture (amount of water per weight of soil) [kg/m3]
#spatial moisture (amount of water per volume of soil) [m3/m3]
#neutron moisture meter: water content measurement device based on radioactivity

Jericho soil humidity measurements

With its 16 channels dedicated to resistive measurements, the RDL can operate simultaneously up to:

- 16 gypsum block measurements, without temperature compensation; OR
- 8 gypsum block measurements with individual temperature compensation; OR
- 16 EC measurements, without temperature compensation.

Prototypes of ultra-low-cost gypsum blocks were manufactured and tested. The compatibility of commercial gypsum probes with the RDL will be evaluated in the near future.

Instructions for Do-It-Yourself Gypsum blocks

1. Prepare a few 2-pin screw terminals with lead wires (see picture)
2. Create a small batch of Plaster of Paris. It should be liquid enough to allow the insertion of screw terminals.
3. Pour the liquid in the ice cube rack
4. Insert the screw terminals in the center of each cube
5. Support the lead wire weight to ensure that the screw terminals remain centered until the block is solid (see picture)
6. After 48h, remove the dried blocks and let thoroughly dry..

Figure 5 Screw terminals used as electrodes inside the gypsum blocks

Figure 6 Gypsum blocks during the drying process

"The gypsum blocks also responded to soil moisture changes, but they changed little during the week following an irrigation. By the time they started responding, soil moisture tensions were nearly 60 to 70 centibars. The Watermark blocks responded well throughout the wetting and drying cycles, indicating that they function more consistently over a wider range of soil moisture contents compared with tensiometers and gypsum blocks."

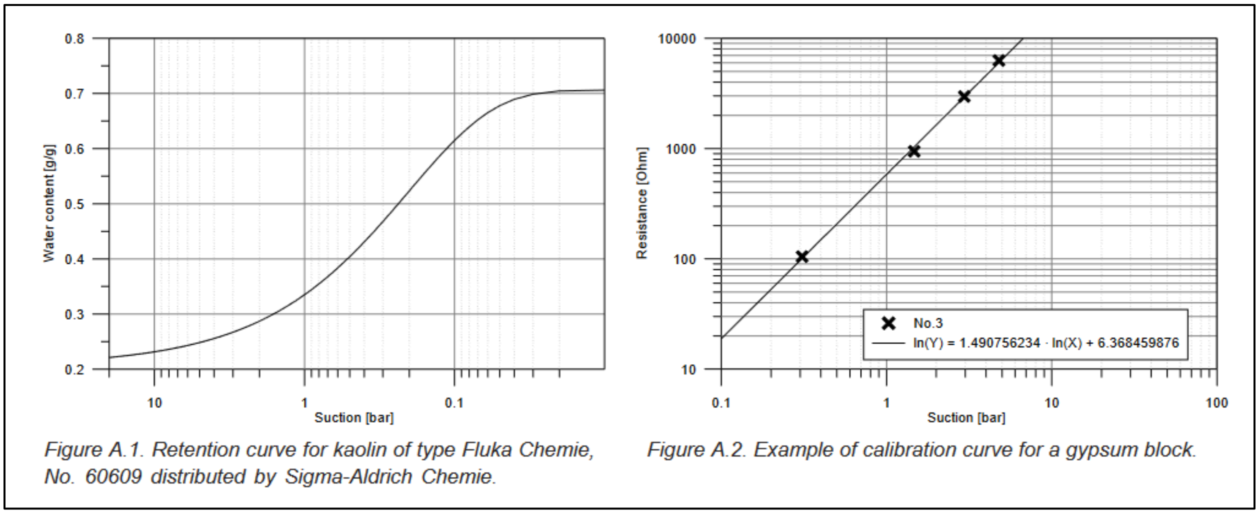

Figure 7 Soil retention curve (left) and block calibration curve (right) example from (Nordtest 2001) for kaolin clay

To establish the relationship between a given gypsum block resistance and a soil suction tension, one must have access to the release curve of a given soil (for example kaolin, on the left). This allows us to convert a resistance/water content curve into a resistance/suction curve without using a tensiometer. However, the final curve will only be an approximation tied to the type of soil used to obtain the characterization curve.

F3 = F1 X F2

F1 = Resistance/Water Content curve
F2 = Water content/Suction curve
F3 => Resistance /Suction curve

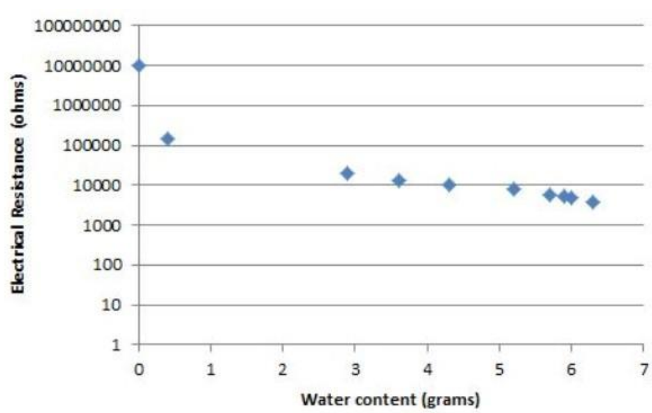

Figure 8 Jericho relationship between the water content (grams) and electrical resistance of the plaster block

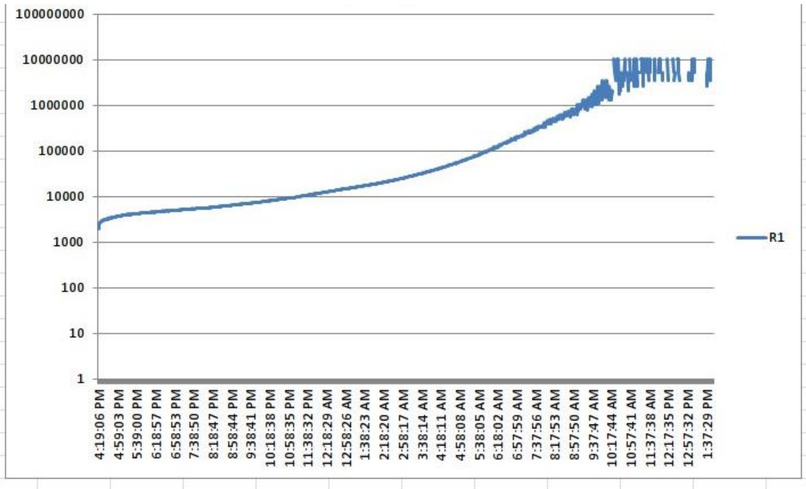

Figure 9 Jericho experiment of the evolution of resistance as the plaster block dries in the air

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