GROW OBSERVATORY

Making Sense of Sensors

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Contents

Introduction

Sensor data can help growers to easily see correlations (relationships) between soil moisture, temperature, and light intensity. A sensor is not essential to see the connection between these three aspects of growing, but the added benefit provided by sensor data is the ability to easily access these measurements across time and seasons. Growers can retrieve historical records and correlate them with weather or soil management events, like irrigation, mulching or fertiliser applications.

Sensor data is for guidance, there are general thresholds for optimal values, but the grower must know his or her site to interpret the measurements. Growers are encouraged to study all measured properties together, because they are related, for example, shading reduces water loss from evaporation.

Soil moisture monitoring for assessing plant stress and irrigation needs. The sensor data can help growers identifying the optimal soil moisture for a specific site, soil type and crop.

Fertiliser some soil sensors measure soil fertility using the electrical conductivity of the soil. Electrical conductivity is a measure of how well an electric current moves through a substance. Fertilisers introduce nutrients and salts into the soil and raise its electrical conductivity. Other factors can also influence electrical conductivity of soil, including pH, soil depth, temperature, soil type and moisture. The reliability of Flower Power sensors for measuring soil fertility has not been tested by the GROW Observatory and is not covered in this guide.

Temperature influences germination, plant growth and soil life, as well as the intensity of evaporation. The Flower Power sensors measure the air temperature rather than soil temperature, which can be 10-15 °C greater than the temperature of the air. A sensor placed in direct sunlight will show higher temperature readings than one in the shade.

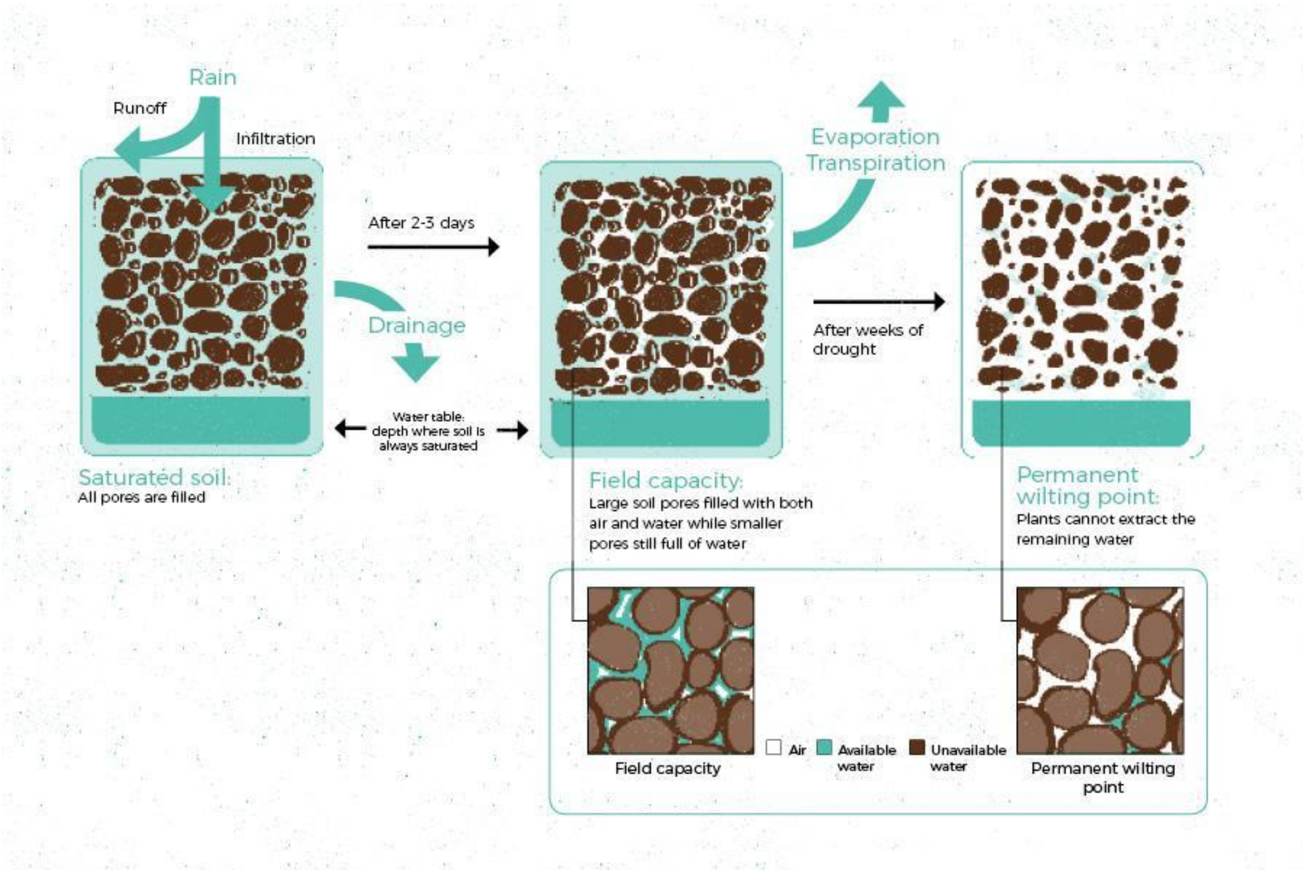
Light influences germination and plant growth, as well as showing changes in light over days and seasons a reduction in light intensity can show that plants are overgrowing the sensor and increase shading.

Understanding soil moisture

Soil moisture was the focus of the GROW Observatory and a key soil measurement. The right soil moisture is not only needed for optimum plant growth but also regulates the exchange of energy, and carbon flows between the soil and the atmosphere, thus strongly affecting the climate. Collectively, soil moisture data collected by citizen scientists could be used to predict the likelihood of drought and flooding events and validate soil moisture data obtained remotely by satellites.

Soil can retain water in two ways: in pore spaces, and as a thin layer around the soil particles. Full saturation is when all pore spaces are filled with water, preventing air entering soil. If this situation exists for a long period, roots cannot breathe and plants die. Roots of most plants will rapidly die in waterlogged soils. As the water drains, air (including oxygen) can enter the pore spaces, which is beneficial for roots. After the drainage has stopped, the large soil pores are filled with both air and water while the medium and smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are ideal for crop growth. This is usually 2-3 days after a major wetting event.

Plant roots can access water in pore spaces but the water coating the soil particles may be too tightly bound for plant roots to access. When the soil reaches permanent wilting point, the remaining water is no longer available to the plant. The amount of water available to the plant (available water capacity, or AWC) is the amount of water stored in the soil at field capacity minus the water that will remain in the soil at permanent wilting point. The field capacity, permanent wilting point and available water content are called soil moisture characteristics. They are constant in undisturbed soil but vary widely from one type of soil to another.



How soil moisture works

There are two ways to measure how much moisture is in your soil and how much of that moisture specific plants can actually absorb:

- Soil moisture content - the amount of water in the soil, usually described as a percentage based on mass or volume, this is what most soil sensors report, including the Flower Power sensor.
- Soil moisture tension - how hard the plant root has to work to extract water from the soil (usually described as kiloPascals (kPa) which are units of pressure measurements).

All soil water which can be taken up by plants is called plant available water and its amount differs from site to site depending on soil texture, soil organic content, stone content, activity of small burying animals, plant rooting depth and root density, and soil management by humans (mostly tillage operation intensity, depth and frequency). Some of these factors are covered in more detail in this document. Actual soil moisture content does not reveal much information on actual growing conditions, it needs to be interpreted with characteristics of the soil and plants to estimate if crops have enough water, if there is stress from lack of water, or stress from lack of oxygen from waterlogging.

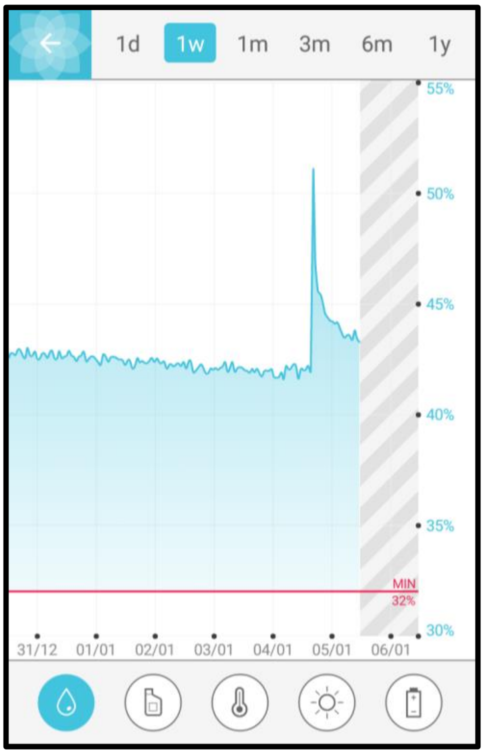
The GROW Observatory developed a Soil Water Content tool available for growers of any scale to learn more about the availability of water in their soil. The visualisation shows when plants will have too much or not enough water, and can help growers decide which crops to plant, and when to plant.

Getting started

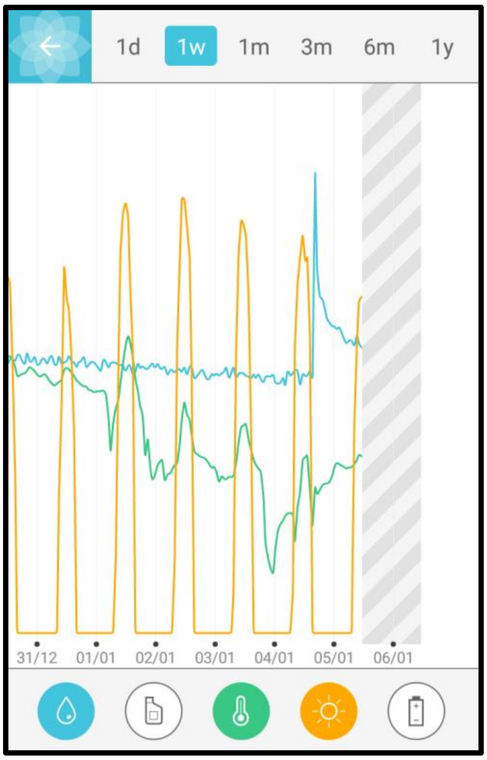
If you are using a Parrot Flower Power sensor, the app displays your sensor measurements over time, other sensors may have similar apps and the patterns of light, temperature and soil moisture will be similar.

In the Flower Power app, from the My Garden screen select the sensor icon bottom right. There are four measurements to choose from: moisture, fertiliser, temperature and light. If you are connected to your sensor the app will display the current reading. To view measurements over time, select the graph icon on the bottom right.

Click the four symbols at the bottom of the screen to display or remove measurements from the display. You can select to view measurements by day, week or other time periods from the top menu bar or by pinching and zooming in and out. If you display more than one measurement the values on the vertical (y) axis are not displayed, select a single measurement if you wish to see the recorded values.



Soil moisture over one week



Soil moisture, temperature and light over one week

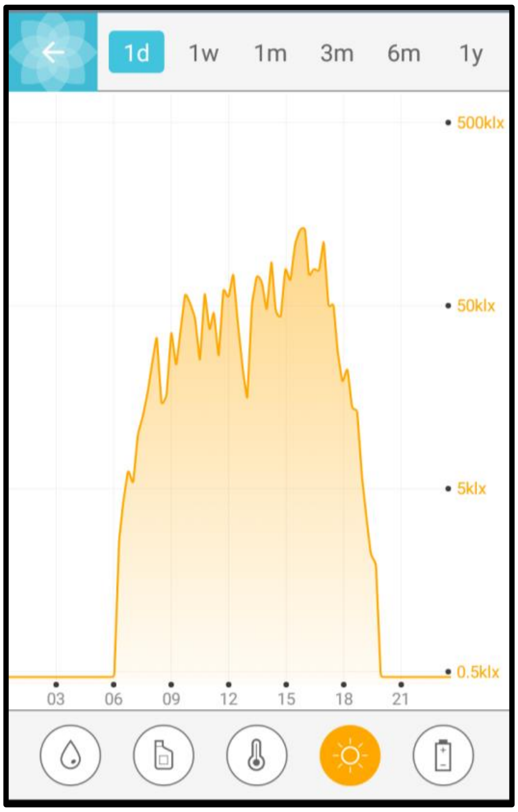
Daily patterns

Light

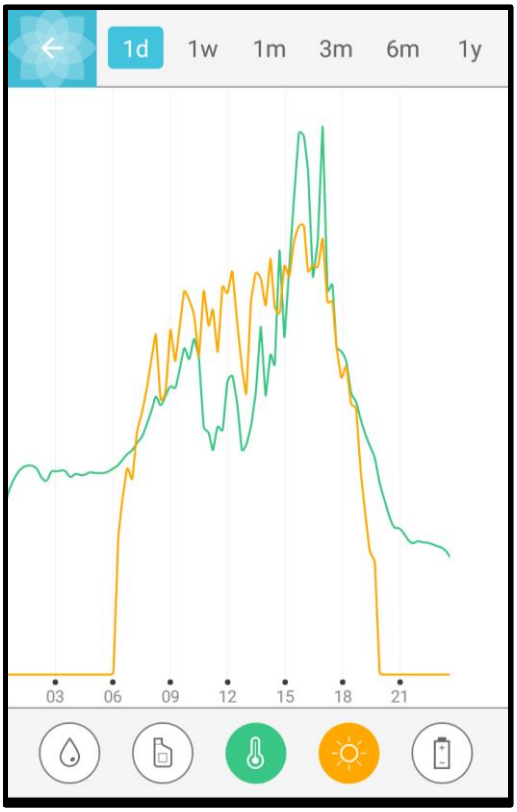
The change between night and day can clearly be seen. In this example sunrise occurs around 06:00 and sunset about 20:00, but there are fluctuations during the day. These fluctuations can be due to movement of clouds or shadows, e.g. from vegetation, where the sensor is located.

Temperature

The sun provides both light and heat and the relationship between these two important factors for plant growth can be seen clearly in the graph. As light levels increase during the day, so does temperature. However, heat can accumulate, and the temperature does not drop off as sharply as light because the sensor retains heat.



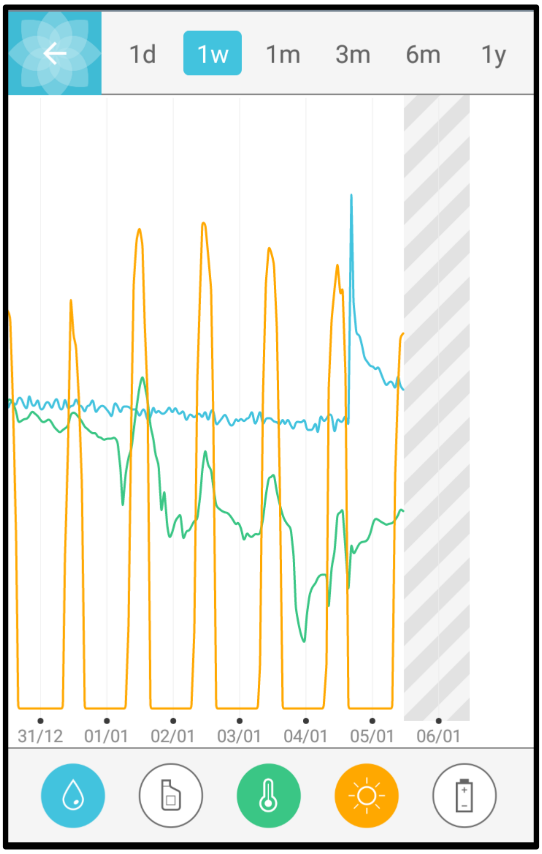
Light measurements over one day



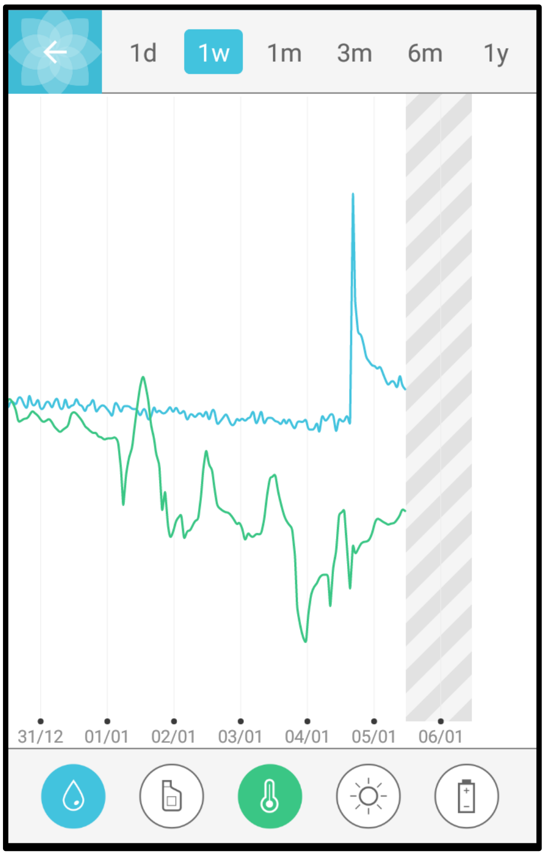
Light and temperature measurements over the same day

Weekly patterns

The daily patterns in light can be clearly seen as peaks and troughs as we look over a whole week. Interestingly, the patterns of temperature and soil moisture are more variable.



Moisture, temperature and light over one week



Moisture and temperature over the same week

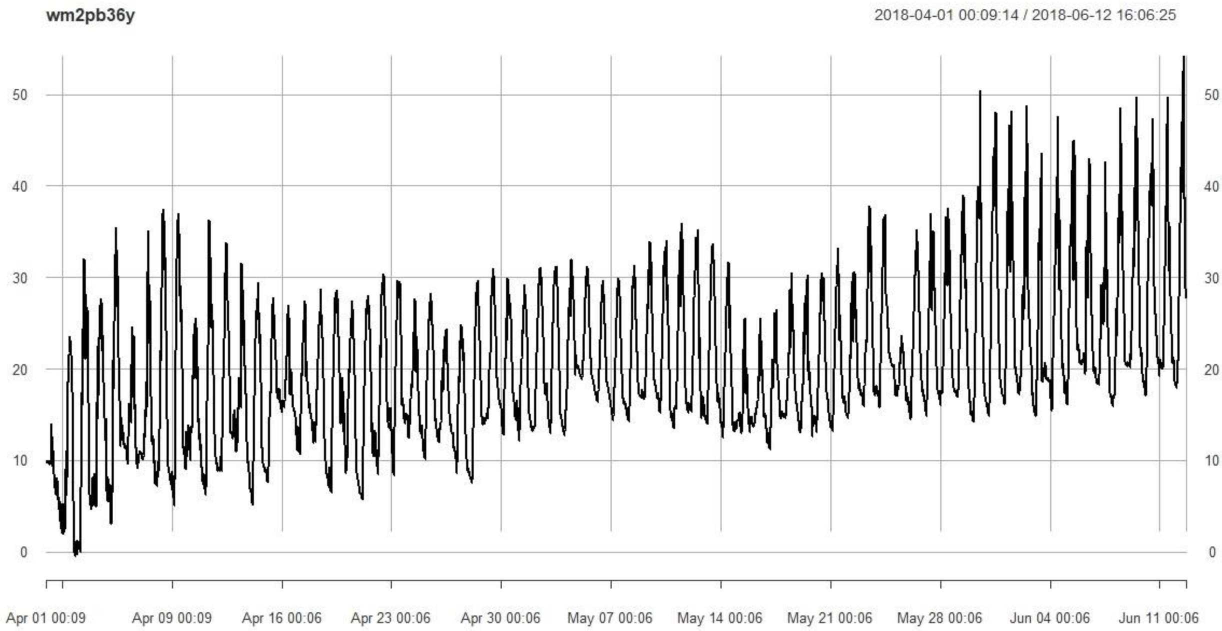
In the data for the week shown above, we still see the peaks in temperature (green) correspond to those in light (orange) as they did in the diurnal (daily) pattern. However, over the week those temperature peaks fall and we get some quite cool temperatures overnight near the end of the week. This can affect how well your plants grow, particularly those that are susceptible to cooler temperatures. Seeing a decline in maximum temperature can indicate potential periods where you might need to protect your crops from cold, so you could predict what might happen in your own growing space and be prepared to take action (e.g. bring pots indoors, cover crops with horticultural fleece, postpone planting seedlings out).

Soil moisture (blue) gradually declines over the week until a spike on the 05/01 corresponding to a precipitation or watering event, and then declines again. The slow decline over most of the week shows that water in the soil is being gradually lost. This can be through evaporation from the soil surface, and/or through uptake by the plants - together this is called 'evapotranspiration'. It is worth keeping an eye on this to see when you might most efficiently add water if needed.

After the rain or a watering event, most of the extra water is lost quickly (the rapid drop after the peak), suggesting well-drained soils or high evaporation (if high temperatures). However, the overall soil water level afterwards is higher than at the start of the week, suggesting that the moisture lost each day is more than replenished by the rainfall or watering.

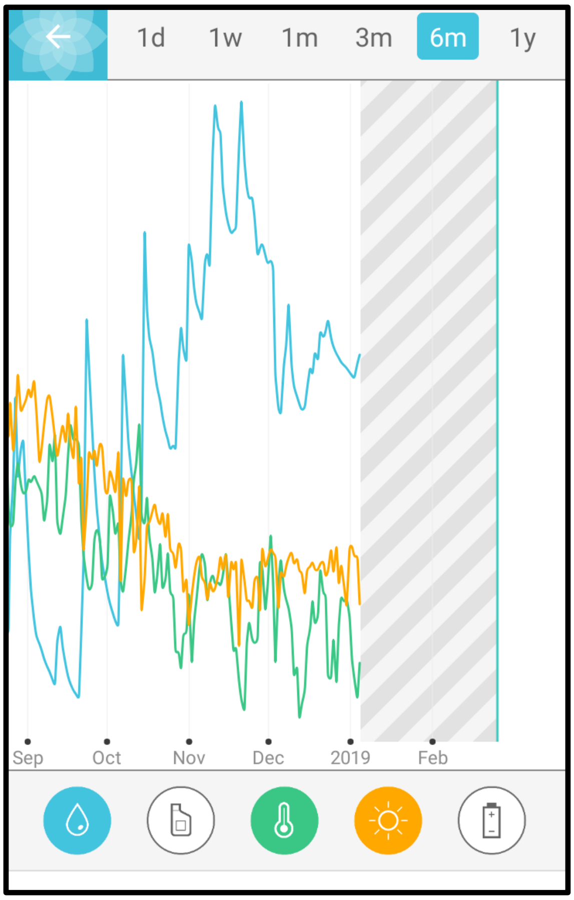
Longer time patterns

Collecting measurements over a longer time period gives insights into seasonal changes. In this graph of temperature readings, you can clearly see the daily patterns of night and day, but also the more gradual increase in temperature between April and June.

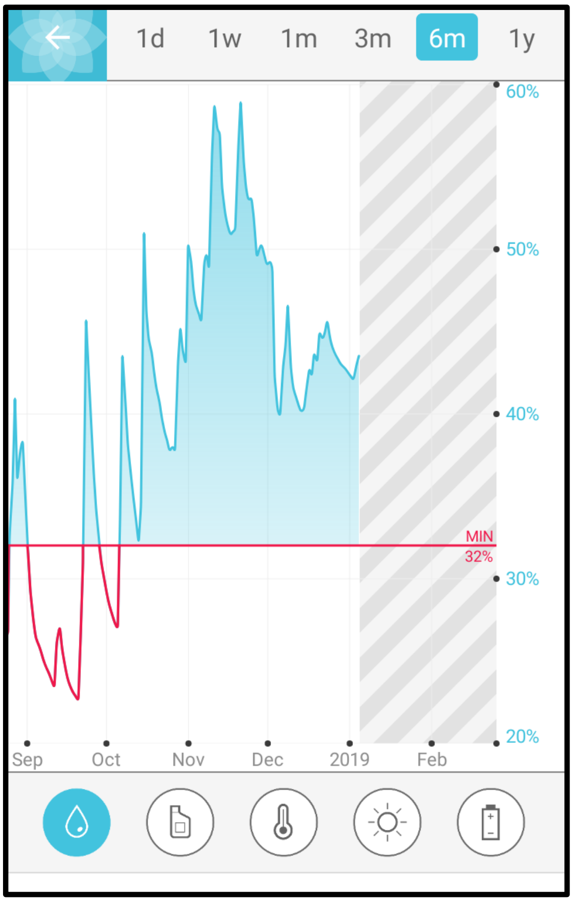


Credit: Jody Thornton

In the following Flower Power app screenshots, you can see how light and temperature decrease from September to January and that rainfall tends to be higher in the winter months.

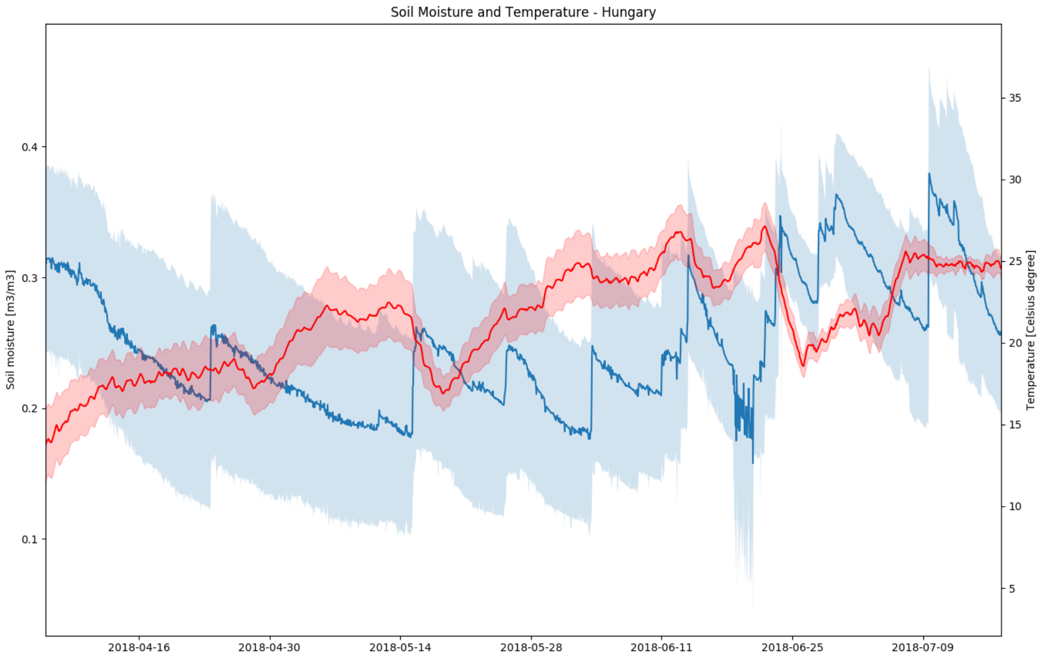


Moisture, temperature and light over six months



Moisture over the same six months

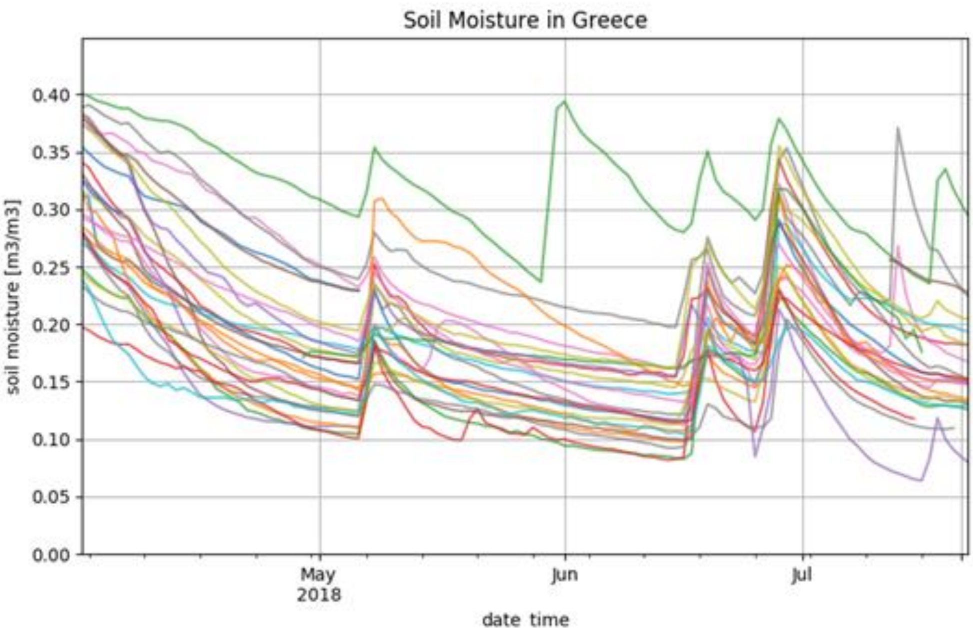
The next graph shows the changes in soil moisture (blue) and temperature (red) over four months using data from multiple Flower Power sensors. The central bold line depicts the average value among locations in the same region and the shaded area is the variability among sensors (standard deviation). How are soil moisture, temperature, and precipitation related?



We can see the impact of precipitation on both soil moisture and temperature. When heavy precipitation events occur (corresponding to steep increases in soil moisture), temperature changes accordingly. In particular, the heavier the rainfall the stronger the drop of temperature. You can clearly see it happening around the end of June. There is usually a lag of few hours or days between the precipitation event and the drop in temperature.

Patterns in space

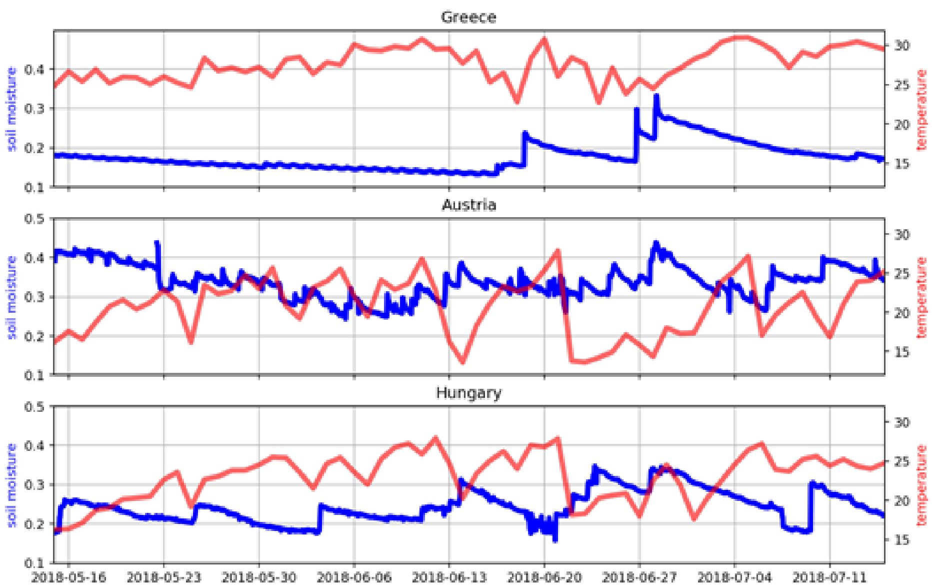
Having several soil sensors allows patterns in space as well as time to be identified. The next graph shows soil moisture measured near Alexandroupoli, Greece, over a three and half month period during summer 2018. Each line depicts a single sensor (approximately 30 in total).



Even though the sensors are closely located, there are significant differences in soil moisture values. This is because soil moisture can vary at small scales, due to changes in soil texture, organic matter content, vegetation and topography. There is more about influences on sensor readings here. If you are experimenting with different land management techniques you could use soil sensors to monitor differences between them.

Patterns in time and space

The next graph shows patterns on a larger scale, showing average temperature (red line) and moisture (blue line) for all the sensors in three locations characterised by different climates: Austria, Greece, and Hungary.



Greece (top graph) has the highest temperature and lowest soil moisture levels, especially up to mid-June. The typical trend of the dry Mediterranean climate (as of Greece) is clearly visible, with very dry conditions coupled with high temperatures. However, in the second half of this period, a rainfall event led to an increase in soil moisture and a slight decrease in temperature.

Austria and Hungary show similar patterns to each other, with higher moisture levels and precipitation - in particular, the temperature trends are very alike. This highlights the similarity of climatic conditions among these two areas, especially the solar radiation (energy from the sun), which is one of the main controls of temperature.

We can also observe that in Austria soil moisture is marked by continuous increases, corresponding to light rain and/or isolated showers, as expected from the Austrian climate (a warm temperate humid climate) where the precipitation is quite evenly distributed over the year.

Another noticeable pattern is the relationship between temperature and precipitation (corresponding to peaks in soil moisture) - after a big rainfall event the temperature tends to drop, and the more precipitation there is, the greater the decrease in temperature.

What influences sensor readings?

Soil moisture is affected by many different factors, most obviously rainfall and temperature, but also the type of soil, vegetation cover, slope, and aspect of the land. To make sense of the data coming from sensors we need more information about where the sensor is placed - known as metadata (data about data).

Canopy cover

Compare a Flower Power sensor under some trees with one in a field of cereals, how might the differences in vegetation influence readings of soil moisture, temperature and light from the soil sensor?

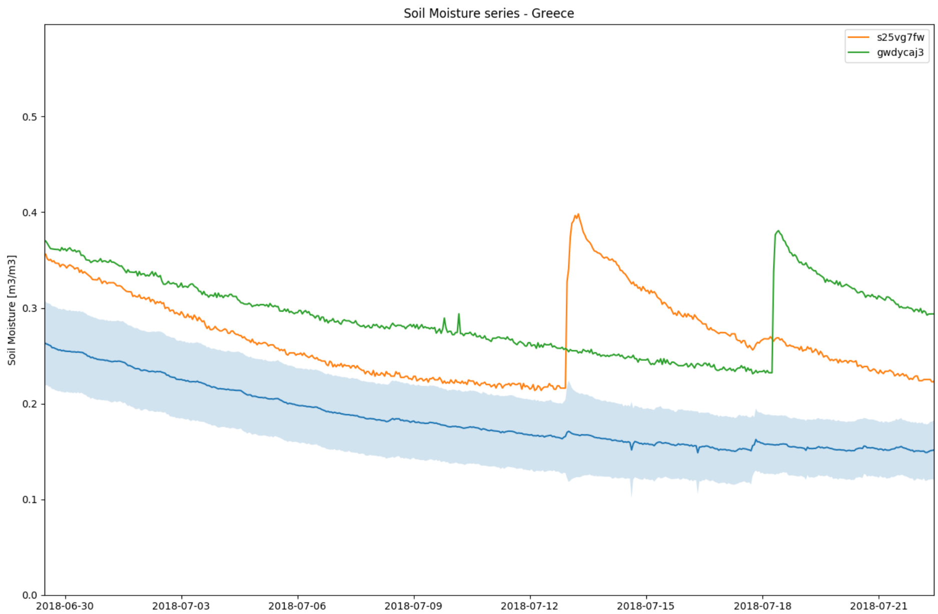
The denser canopy under trees reduces light to the sensor so it will be cooler and shadier. The canopy also intercepts some of the rainfall before it reaches the soil, so moisture levels will rise more gradually than if there was no canopy present. Soil under a canopy also dries out more slowly after rain due to the lower temperature and sunlight, and resultant decrease in evaporation. An area with less, or no canopy cover dries out faster and wets quicker.

Land use

We see above that the type of vegetation and canopy cover affects soil moisture, but there are other influences of land use. Observing and describing all visible components of the land surface, for example, trees, shrubs, water bodies, crops and other plants, buildings, roads, greenhouses can help you understand how they affect conditions of your site, such as sunshine, moisture, temperature or overall plant growth. For example, a paved area near the sensor may cause rain may run off quicker causing sharp increases in soil moisture and retain heat in summer but be colder in winter.

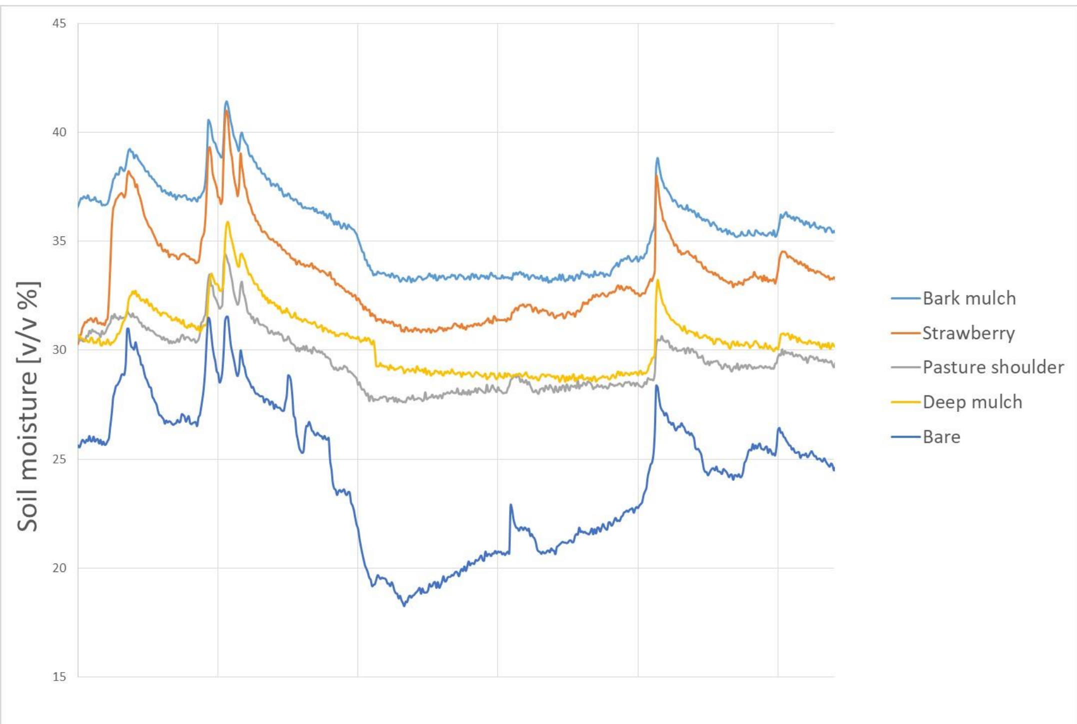
Land management

The land management practices you use around sensors, for example adding fertiliser, tillage or digging, irrigation, and mulching can influence sensor readings. To illustrate this, look at this graph of average soil moisture (blue line) and standard deviation (shaded area) of sensors located in Greece and two individual sensors (orange and green lines).



The sensors represented by the orange and green lines show a different pattern from the average soil moisture, with rapid increases in soil moisture, rather than ongoing drying, so must be responding to another source of water. As the sensors are only a few hundred metres apart this is unlikely to be rain and more likely because they are close to an irrigation system. Keeping records of your land management around each sensor can help to identify and interpret anomalies like this.

Here is another example showing how different mulches can influence soil moisture readings. Mulches tend to retain moisture in the soil by decreasing the maximum soil temperature and creating a barrier for evaporation of water.



Slope

Whether land has a slope or a flat plain has major effects on water movement, soil composition and available sunlight. Changes across slopes in a hilly area, or even small changes across a site which can influence whether water will pool or run off, which can in turn, influence the availability of nutrients and water to plants. If you look at your country or region, you will likely find that the flatter areas tend to be used for agriculture. Slightly steeper areas might be more suitable for animal pasture, and the steepest areas are most often used for forestry. Sometimes growers create flat areas to improve their growing conditions, like many rice terraces in Asia.

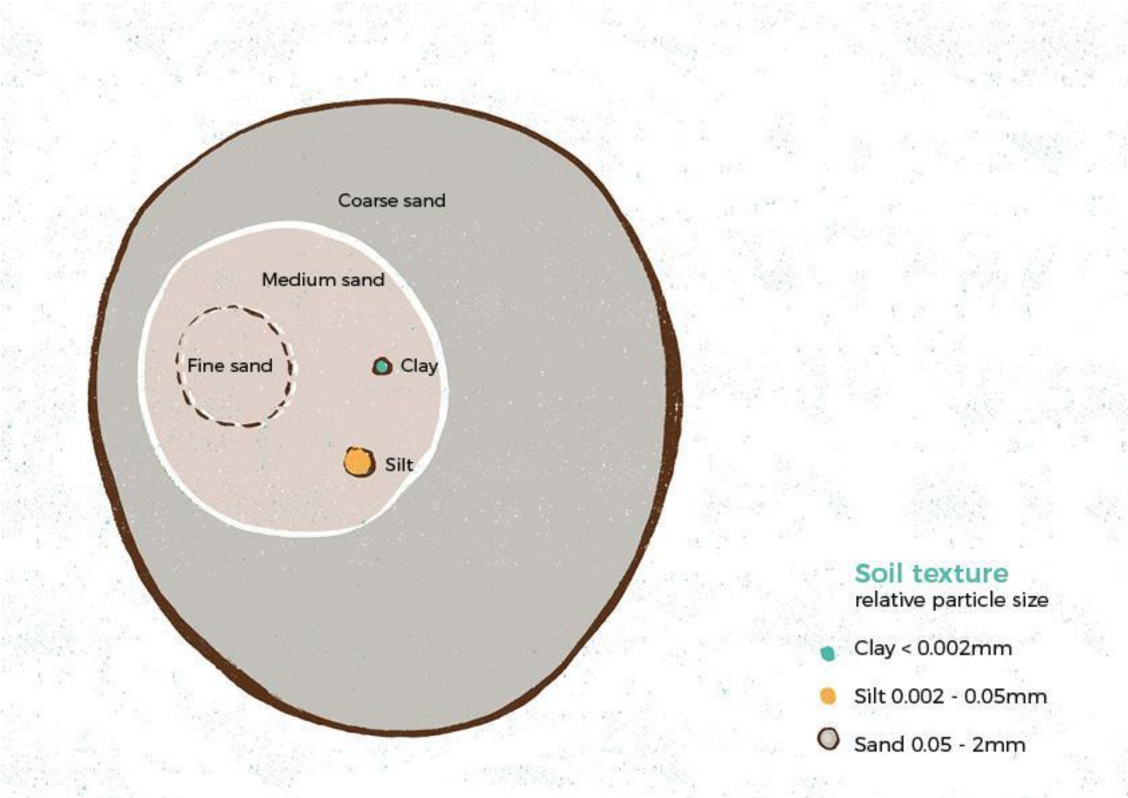
Slope aspect is the compass or cardinal direction a slope faces. It affects temperature, light levels, weather and thus processes that influence soil formation (such as erosion, deposition, and rock weathering). All of these factors have a great impact on the growing environment and conditions for plants. You can learn how to measure slope aspect and steepness using simple tools in this video: https://youtu.be/yxpYmcP7RsQ.

Soil type

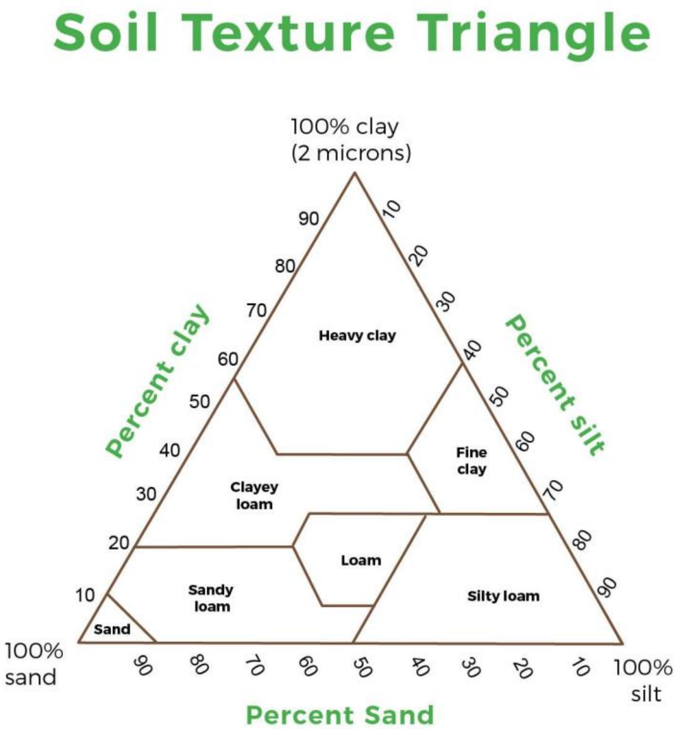
Soils are composed of mineral (weathered rock) and organic (dead plants and animals) components. Soils can be entirely mineral, for example many desert soils, or entirely organic, for example peats, but most are somewhere in between. Soils with more organic material generally hold more water than those with a higher mineral component as water adheres more tightly to organic material than minerals.

Soil texture

Soil texture refers to the relative amounts of three particle sizes: sand (the largest), silt, and clay (the smallest). A soil texture triangle shows the proportions of each particle size and the name of the resulting soil texture. Soil texture influences water drainage and therefore nutrient levels and susceptibility to erosion.



Relative soil particle sizes



Soil texture triangle

In a soil laboratory, soil texture is measured by calculating the proportions of each particle size by passing dry soil through a series of sieves of standard mesh sizes, or by suspending soil in water and measuring how long it takes to settle out. For growers, soil texture can be estimated easily using the hand texturing method. Manipulating soil in your hand and observing what shapes you can form gives an estimate of soil texture.

Loam soils are ideal for growing food as they have a good balance of smaller and larger particles, which means they have space between for water. Water does drain in loam soils, but not too quickly, so they do not get too wet or too dry, and hold nutrients well. Sandy soils tend to be drier and lower in nutrients, as water drains away quickly washing nutrients away with it. The very fine particles in clay soils make it difficult for water to penetrate so they can become waterlogged. When clay soils dry out, they become very hard which makes it difficult for plant roots to penetrate them, and water tends to run off the surface.

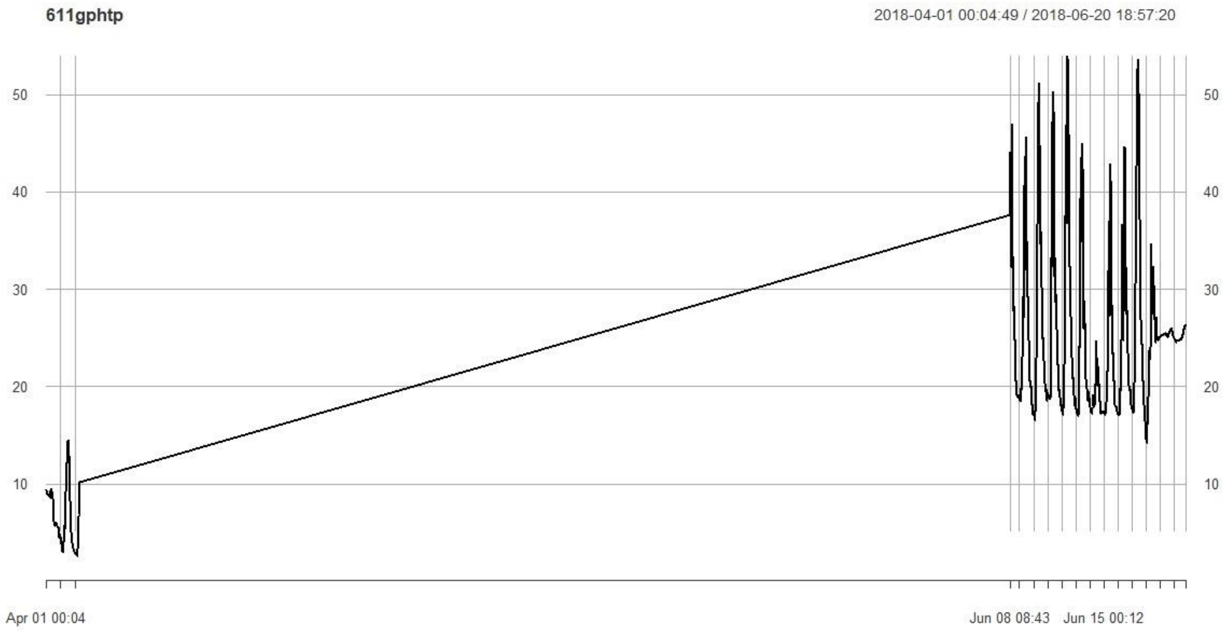
Porosity and bulk density

Soil porosity refers to the number of gaps (or pores) between soil particles. Pores can be filled with air or water and vary in size from micropores (5-30 microns), mesopores (30-75 microns) to macropores (more than 75 microns). Pores can be created by physical soil processes, for example soil cracking due to drought or frost, and biological soil processes, such as plant roots and earthworm burrows. Porosity is also affected by soil texture. Clay soils tend to have low porosity, as soil particles are smaller and pack more tightly than larger particles in sandy soils. More porous soil have more pores and drain water faster than less porous soils. Bulk density is the mass of soil particles in a given volume and depends on soil type, porosity and the level of soil compaction. If soils become compacted the spaces between particles are compressed so porosity decreases, and bulk density increases. This can cause problems for growing, as growth of plant roots, and movement of soil animals, air and water are restricted.

Measurement errors

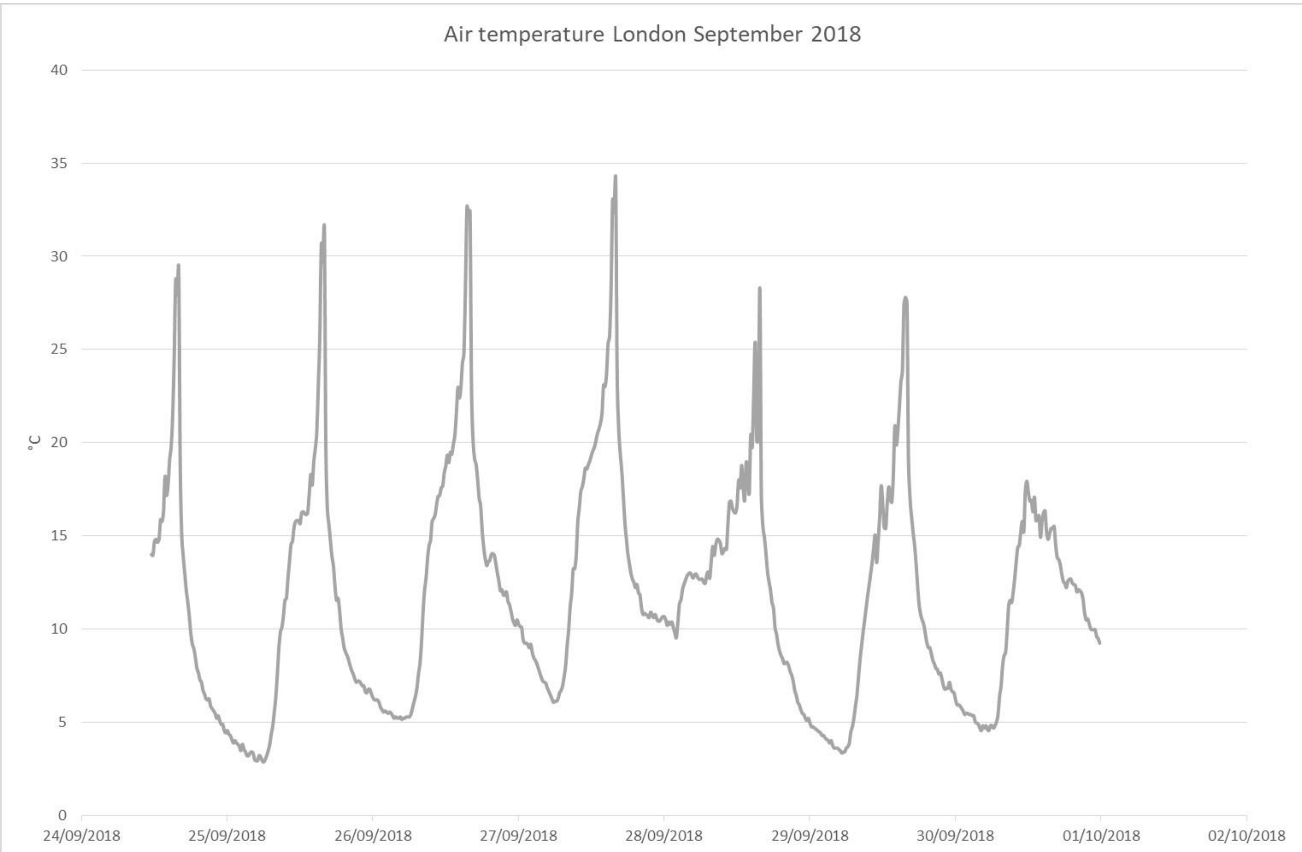
As we have seen, sensors can be influenced by many factors. Choosing a suitable location for your sensor can help minimise some of these and improve the accuracy of the measurements it takes. The GROW Training Manual gives guidance on how to place sensors to give the most accurate readings or you could view this video where Daniel Kibirige, PhD Student from the University of Miskolc gives some useful tips for placing a soil sensor: https://www.youtube.com/watch?v=0_Y0RZgXEMU

The following graphs show some of the measurement errors that can occur using sensors. The first graph shows temperature readings from a single sensor. There is an obvious break in data collection between April and June, this could have been caused by a battery failure.



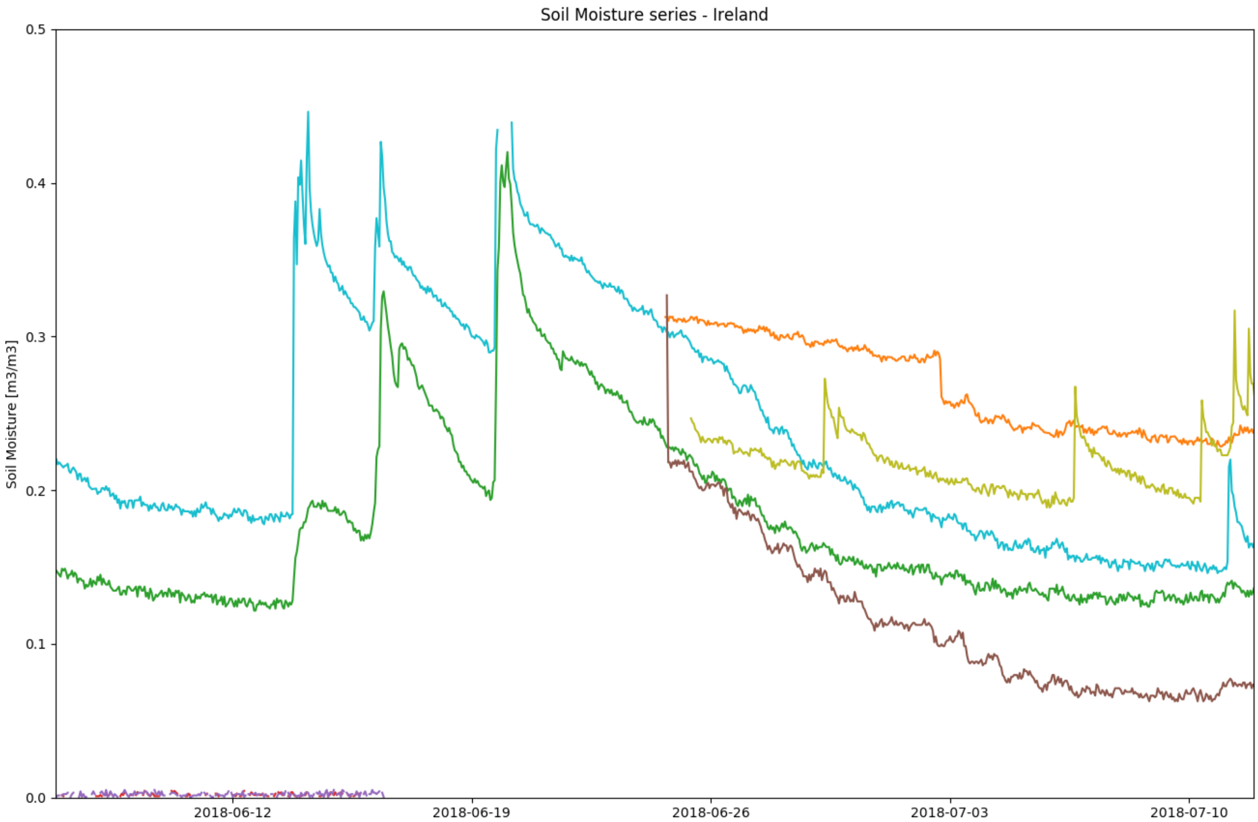
Credit: Jody Thornton

The next graph shows air temperature readings from a Flower Power sensor for London, UK in September 2018. Look at what temperature the peaks reach, do you see anything unexpected?



The temperature peaks are anomalously high. Although this month was unusually warm for the UK the maximum recorded temperature from official weather records was 25 °C. This graph illustrates how the temperature sensor of the Flower Power sensor can heat up when in direct sunlight and give readings higher than the air temperature. Checking data against external sources and using your own experience is useful.

The next graph shows soil moisture changes over time, recorded by a few sensors located in Ireland - represented by different coloured lines. Examine each line, do any look problematic?



The purple line is erroneous - data recorded at the beginning of the period shows soil moisture values very close to 0. This is almost impossible as even in extremely dry conditions some water is still retained by the soil although it may not be available to plants. Such low values of soil moisture can be due to measurements before the sensor was placed in the soil. It is important to identify and exclude such data from further analysis, as these erroneous observations can lead to misleading results and conclusions.

Case studies

Pavlos Georgiadis

Ethnobotanist. Sustainable Development Consultant. Agrifood Entrepreneur.

“I am a fourth generation olive grower, passionate about reviving my family’s farm through regenerative agricultural practices. In September 2018 we had an average temperature of 12 degrees higher than previous years, which led to the multiplication of a fungus that eventually caused a 70% loss in our production. Through GROW I am able to combine soil moisture and soil temperature data in order to better control pests in my family’s organic olive grove, for better adaptation to climate change.”

In this video, Pavlos Georgiadis, GROW’s Community Manager based in Greece, explains how, despite our changing climate having very different impacts in each of these countries, sensor data is helping the growers they collaborate with come together to adapt to new growing and weather conditions.

Kiki Chatzisavva

Biologist. Organic winemaker. Mother of two.

“Taking part in the GROW Changing Climate mission has allowed me to understand the levels of humidity across my vineyard, which directly affect the taste and quality of my wine. I was surprised to discover that the soil moisture levels are higher at the top of the slope, while lower vineyards are drier. I was hence able to adapt the irrigation regime and closely monitor the use of water in the vineyard. Growing can be lonely, but GROW Place Greece has enabled me to connect with other GROWers, exchange know-how and take collective action at local level”

Downloading your sensor data

You can download your own Flower Power raw sensor data in a comma-separated values (.csv) file using a simple program developed by the GROW Observatory. Visit the GROW Observatory GitHub https://github.com/growobservatory/MyData and choose appropriate MyData program for you operating system. CSV files can be imported into most spreadsheet or other data analysis programs to summarise, create graphs and analyse data.