5.5 Improving accuracy

Good data are needed for good decision-making. And because no sensor is perfect, it is worthwhile to consider different ways in which accuracy can be improved. Calibration was discussed above. Another topic to consider is how much spatial variability there is in the parameter you're trying to measure. For example, greenhouses often have temperature gradients, especially when pad and fan cooling systems are used. If accurate temperature data are needed in such a greenhouse, it may be necessary to place thermometers in several different locations. That would allow users to quantify the temperature gradient that is present in the greenhouse. If users only want to know the average temperature, the temperature readings from multiple thermometers can be averaged.

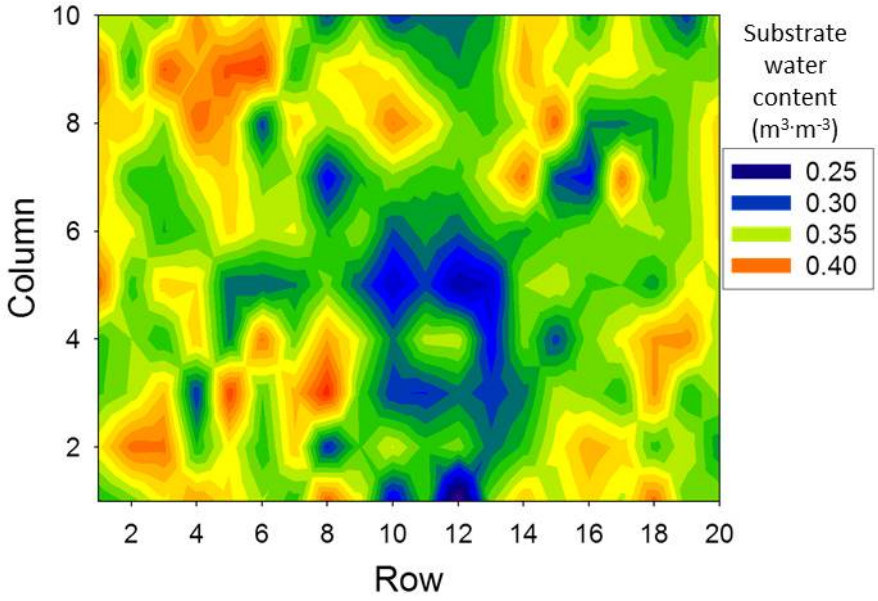

Figure 8. Spatial variability in substrate water content in a group of 200 plants (arranged in 20 rows of 10 plants each. Adapted from: van Iersel, Dove, and Burnett, 2011, *Acta Horticulturae* 893:1049-1056.

Alternatively, a single thermometer could be placed in a location that is representative for the entire greenhouse. In many cases, a central location is chosen. But keep in mind that this is not always representative. To truly find a representative location, it is necessary to first quantify the spatial variability. Spatial variability is also important when using soil moisture sensors. Soil/substrate moisture content is rarely, if ever, uniform throughout and within a single container, let alone an entire crop or a whole greenhouse or nursery. Spatial variability in soil or substrate moisture content can be the result of non-uniform irrigation (see learning module x.x), differences in plant size, or different micro-environments within a growing area (for

example, plants on the edge of a production block or bench typically dry out faster than those in the middle).

The greater the spatial variability, the more sensors are needed to get truly representative measurements. That said, we have had good success irrigating thousands of plants based on soil moisture sensor readings using only five soil moisture sensors. And at times, we have irrigated up to 2,000 plants using a single soil moisture sensor. With that single sensor, users cannot determine how much variability there is, but a single sensor can be indicative of changes in soil/substrate moisture over time. Note that the example here refers to differences in temperature or soil moisture content at different locations within a production area. But typically there are also spatial gradients within a container: the top part of the substrate normally is drier than the bottom part. To minimize variability, placing all sensors at the same depth is important.

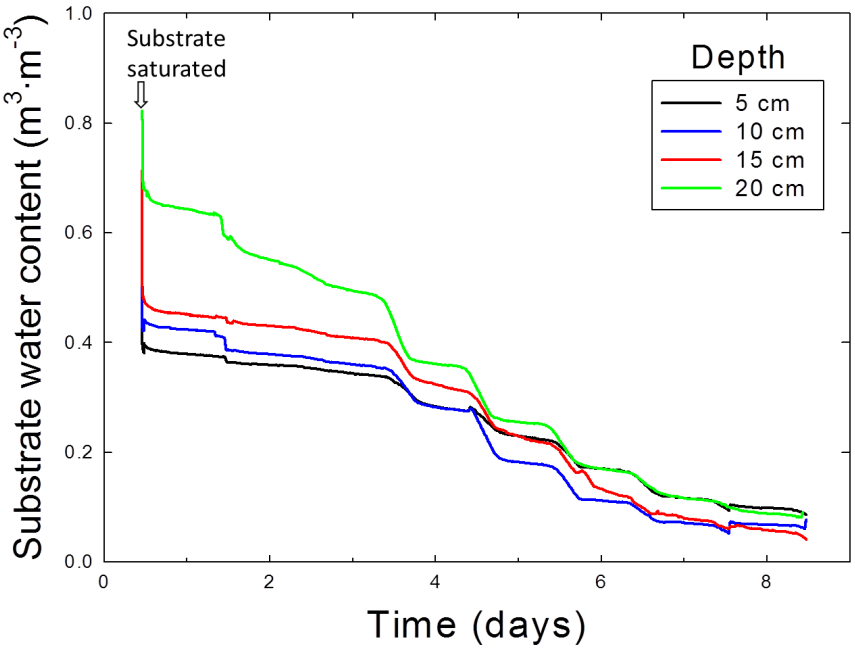

Figure 9. Temporal and spatial variability within a #2 container with a coleus plant. The container was watered thoroughly on day 0 and allowed to dry out after that. Initially, there is a largely spatial gradient within the container, with more water in the bottom. As the substrate dries out, the spatial gradient decreases and water content at all four depths becomes more similar. There also is temporal variability: the substrate water content at all depths decreases in a stepwise manner, because the plant uses more water during the day than at night. Adapted from: van Iersel, Dove, and Burnett, 2011, *Acta Horticulturae* 893:1049-1056.

We do not have specific guidelines for how many sensors are needed in a specific situation; it depends on spatial variability and the level of accuracy that is required. In principle, more sensors are likely to provide better data, but this comes at a higher cost and the need for more maintenance.

In addition to spatial variability, there can also be temporal variability because the things we measure change over time. In the case of substrate water content, we typically see it decrease more rapidly during the day than at night and more rapidly on sunny, dry days than on overcast, humid days. Changes in substrate water content immediately after irrigation can be used to detect leaching: a very rapid decrease in substrate water content generally means that water is running out of the bottom of the container (or at least below the location of the sensor). If such information is important, data should be collected at short time intervals.

Using multiple sensors can often improve accuracy if the sensors are noisy (i.e., have poor precision). In such cases, multiple measurements can be averaged, reducing the noise and increasing the accuracy. One example is the measurement of light level in a greenhouse. There are many structures in a greenhouse that can shade a light sensor or may reflect light onto the light sensor. That can make light data quite noisy. Averaging multiple measurements can reduce the noise in the data and provide more representative data.