WHITE PAPER

A System for Closed-Loop Irrigation: Citrus



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AgriNET · Tuctronics · Walla Walla, Washington

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Abstract

This white paper describes a closed-loop regulation feedback system based on moisture level. It was used to control algorithms for watering a corn field and a lemon tree (see our other white paper). This experiment demonstrates that it is possible to meet a high standard for yield and production by using moisture sensors to maintain moisture level at a particular soil depth. The ideal moisture level was calculated for a growth period from the flood drought method described in this paper, in order to find the extreme of said characteristics. Specifically, we calculated the soil's water holding capacity and the point at which a plant had been watered to a temporary state of wilt.

This system allows a grower to conserve water while also producing the best possible crop.

Introduction

Consumers want their food to appear perfect and pristine, free from insect damage or discoloration. Consumers also want their food to be safe: free of pesticides, herbicides, and polluted water. These two desires are in direct contradiction of each other; the only way to achieve pristine, perfect crops is to use these chemicals. The alternative is organic food. Unfortunately, there is a very serious problem with the production of organic food in the United States; fish parts are used as fertilizer in many cases, and they contain heavy metals like mercury; when organic foods are tested for heavy metals, they are found to contain traces of mercury. High levels of mercury can negatively impact brain development in young children, and in adults, it can cause brain, heart, kidney, lung, or immune system damage. Proof of this can be found in Brian Baker and Diana Tracy's "Heavy Metals in Fertilizers Used in Organic Production."

There is little current regulation governing the heavy metals in organic foods; thus, when one purchases organic food with the hopes of consuming a purer crop, one is possibly doing the opposite and exposing oneself to heavy metals. Minimizing water use to minimize chemical flushing into the water table will become essential in this battle of contradiction for the marketplace.

We have created a system that will prevent loss of quality or quantity, while maintaining the safety and integrity of the crop. The system outlined in this white paper is also intended to minimize the use of water. Conservation of water is an important issue, but specifically, our goal is to minimize chemical flushing, since this practice is the main perpetrator behind fertilization chemicals being pushed below root level and entering into the water table.

It is important to note that rain also pushes these chemicals down into the soil. When creating an irrigation plan, growers need to account for this phenomenon. Our algorithm takes it into consideration, avoiding oversaturation. It works to prevent permanent wilt in crops, conserve water, and refrain from polluting drinking water with fertilization chemicals.

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Validation of the Irrigation Algorithm

Lemon Tree Closed-Loop Irrigation via Moisture Probe

Experiment goal: Test a system for closed-loop irrigation based on moisture monitoring.

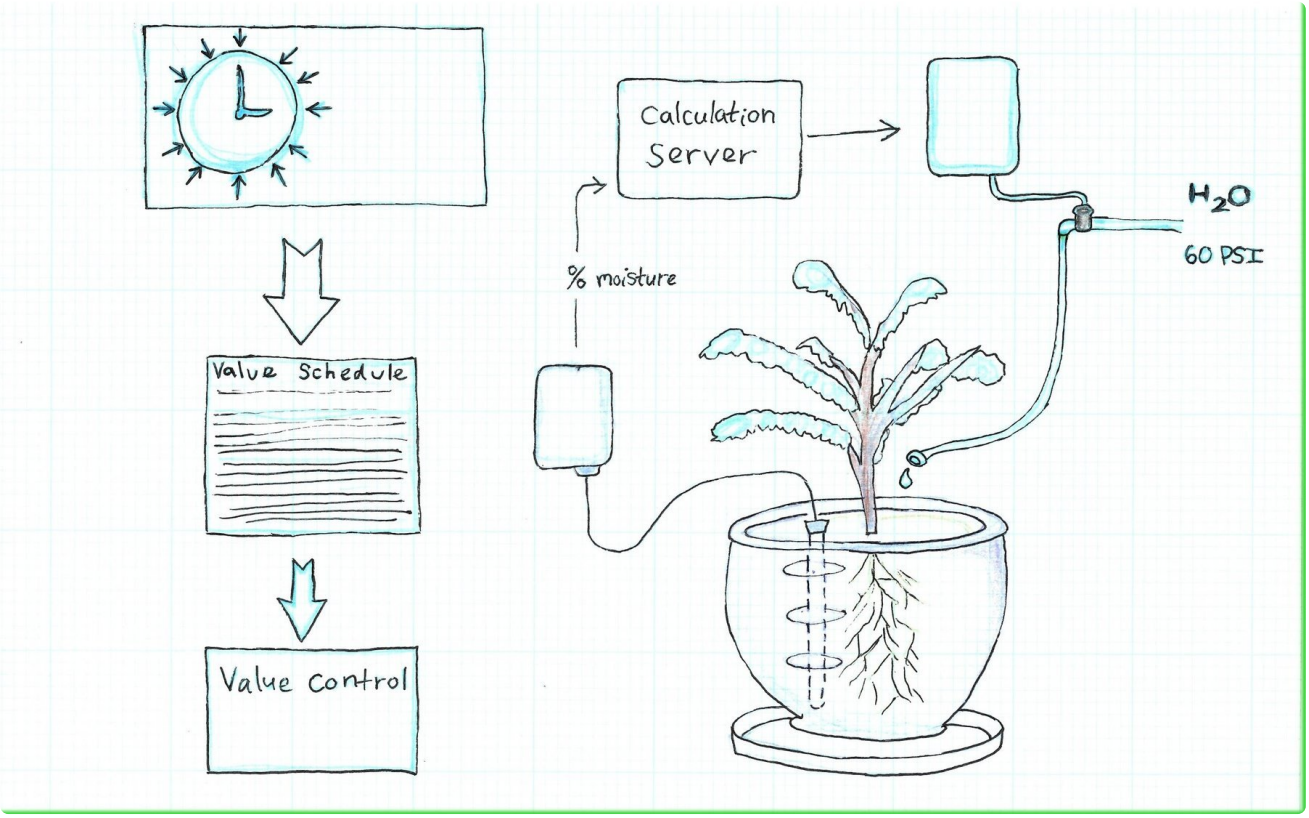


Figure 1. System overview: the moisture probe in the potted tree reports % moisture to the calculation server, which writes the valve schedule; valve control opens the drip valve from the 60 PSI water supply.

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Figure 2. The research setup: the lemon tree, valve control equipment, plumbing and the live moisture display.

Equipment Necessary

Lemon tree experiment components and local field equipment:

- Improved Meyer lemon tree (the monitored tree)
- Approximately 5 gallons of soil in a 7 gallon pot
- 1 overflow drip tray
- 1 valve control unit (12 volt, 2 wire latching, LTE cellular radio for communications)
- Probe in the plant: 3-sensor Sentek SDI-12 probe, with sensors every 10 cm (4 inches)
- Water delivery system at 60 PSI
- Control valve from a 60 PSI water source to the lemon tree through a drip emitter
- LTE modem connected to the valve, controlled by the valve algorithm on the Saturn server
- Weather station via WiFi to the database on the Saturn server
- LTE or WiFi telemetry to the Saturn database and from the Saturn back end server valve system

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Our research environment was climate-controlled and stable. The climate in this room was held at a constant 70° F with full spectrum fluorescent lights above the plants. The light level was insufficient to increase growth; its purpose was to maintain the tree as during winter. The Improved Meyer lemon tree is hardy in cold weather.

The lemon tree is approximately 4 ft tall (1.2 meters) and was planted in a 7 gallon vessel with approximately 5 gallons of media soil. The lemon tree was monitored with a Sentek moisture monitoring device using the SDI-12 protocol, which sends a digital number out so there is no question of the value of the sensor. The following is a description of the algorithm used to irrigate the lemon tree by using the moisture sensor.



Figure 3. The Sentek SDI-12 moisture probe and drip line in the lemon tree's pot.

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The Irrigation Algorithm

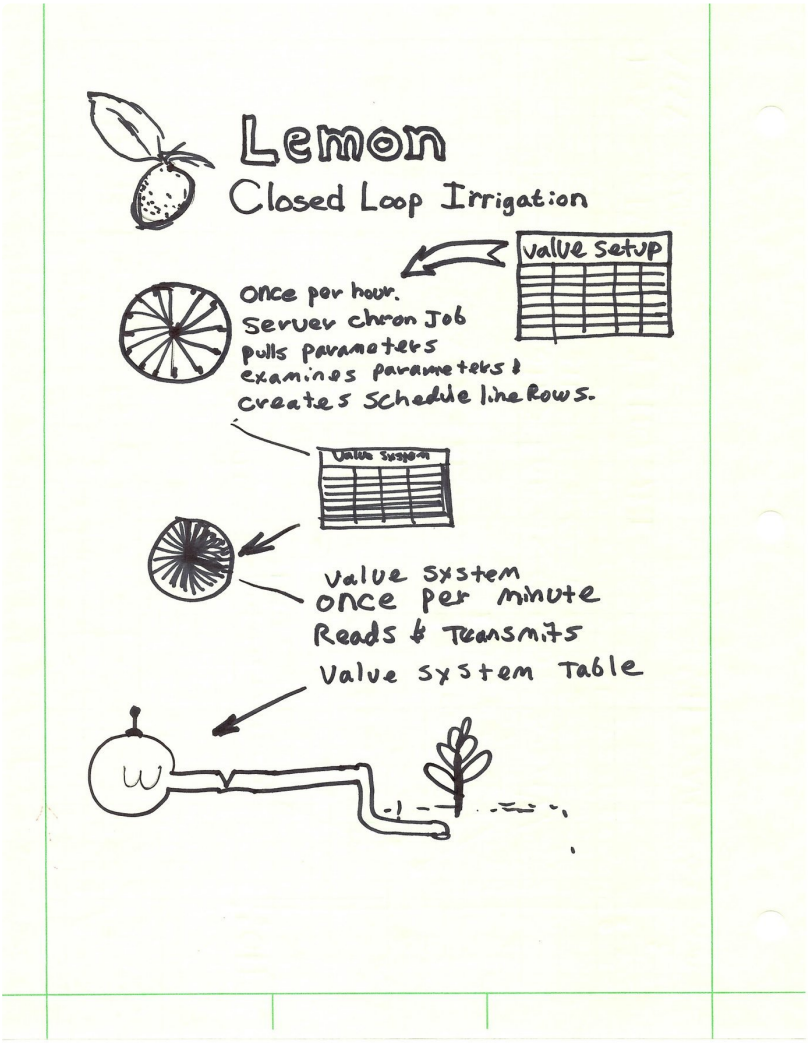


Figure 4. Lemon closed-loop irrigation: once per hour a server job pulls the valve setup parameters, examines the moisture data and creates schedule line rows; the valve system reads the valve system table once per minute and transmits commands to the valve.

There are various parameters that control when and how long the irrigation occurs. There is also a post-irrigation parameter to keep the system inactive for a period of time to allow the water to percolate down and possibly drop below the trigger moisture point level.

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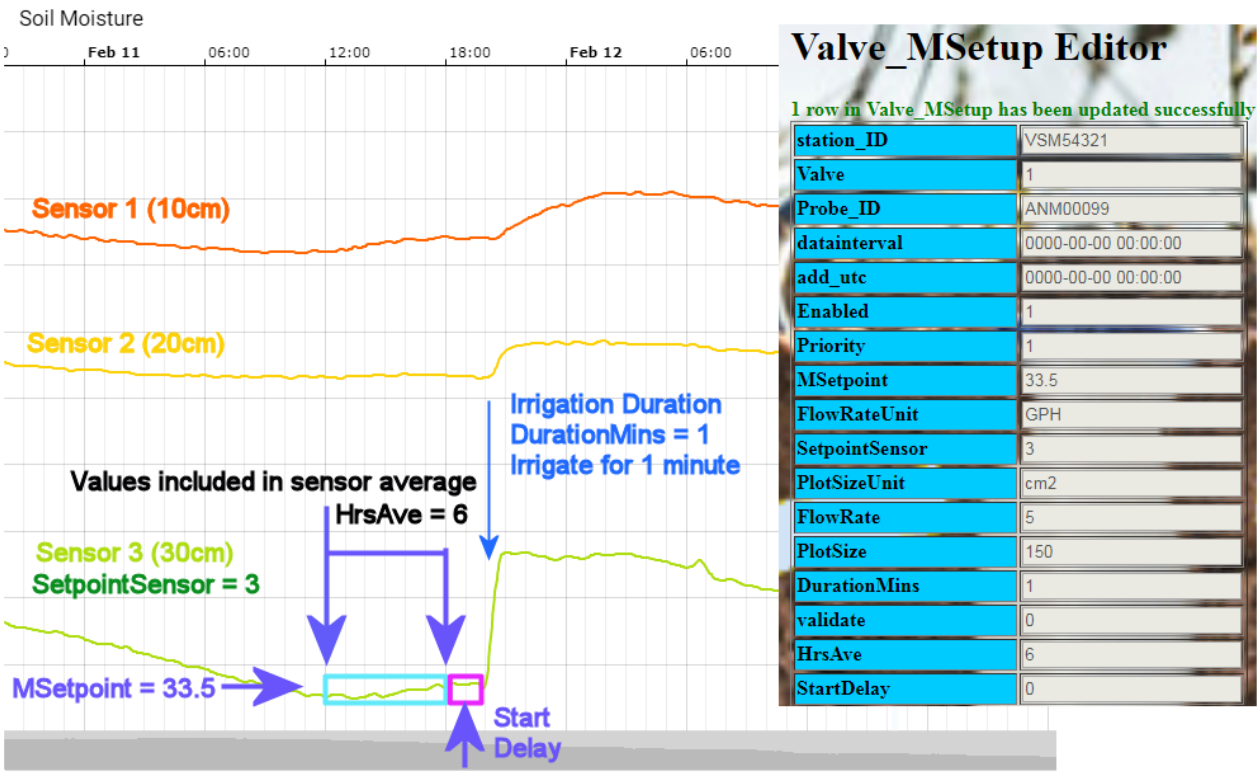


Figure 5. Irrigation algorithm parameters in the AgriNET valve setup editor: setpoint sensor 3 (30 cm), moisture setpoint 33.5%, a 6 hour sensor average, a 1 minute irrigation and the start delay.

Finding the Wilting Point and the Saturation Point

The lemon tree was first allowed to wilt somewhat; the moisture level of the bottom sensor at 30 cm deep was noted during this wilt event. The wilt was not allowed to progress to a permanent wilt, but rather a temporary and recoverable wilt.



This moisture level was determined to be the low end because of the correlation with the leaf wilt of new leaves. Following this event, the lemon tree was then irrigated to saturation. Saturation is defined by water collecting in the bottom pan below the pot containing the lemon tree, and also by the moisture chart flattening, indicating the inability to take more water.

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Figure 6. Onset of temporary wilt in the new leaves.



After determining the wilting point moisture level and the saturation point moisture level, a moisture value in between these two extremes was chosen as the target value for the lemon tree. The irrigation algorithm was initiated on a server and runs to this day. The target value chosen has been set for 10 months and continues to this day. The moisture levels on all three sensors have completely stabilized, and the plant neither wilts nor produces any water in the bottom pan below the pot. After a period of 6 months, the entire system stabilized to somewhat constant values aligned with the irrigation provided.

Figure 7. Healthy leaves with the target moisture maintained.

Formal Tuning Algorithm Procedure

The tuning algorithm is used to determine the ideal set point, or the ideal set point range, for the moisture average parameter of the moisture irrigation algorithm. Tuning proceeds in the following manner:

1. The irrigation moisture target is set at a realistic number for the soil, for example 33–35% moisture.
2. The plant is examined daily for the onset of wilt in the leaf.
3. The irrigation set point target is decreased daily until wilt is observed.
4. Cause the onset of oversaturation and note the % moisture when the value stabilizes.

The response of wilt in the Improved Meyer lemon tree is rather rapid, in that over half a day, the leaf can wilt if the soil is sufficiently dry. The photo of the leaf clearly shows the onset of wilt. The photographs of the leaves in those periods can be used as a reference for the wilt qualification level of this tuning procedure. After the wilting point (i.e., the onset of non-permanent wilt) is determined by the moisture target value, the next step is to perform an oversaturation of the soil in a manner slow enough to not

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destroy the integrity of the soil (i.e., tunneling, collapse, or anything causing violent change in bulk density). At 11.5 oz per minute, this is not an irrigation delivery speed that risks over-watering or would cause any problems.

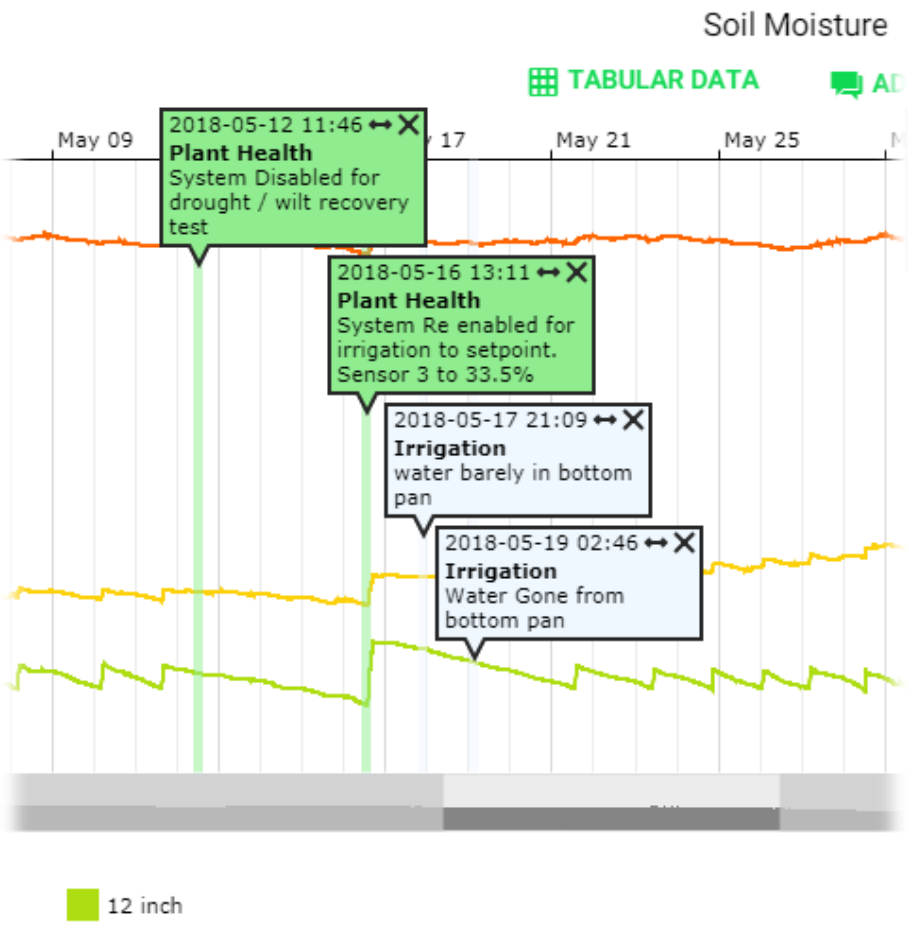


Figure 8. Maximum allowed wilt at 5/16/2018 13:11. The chart notes show the system disabled for the drought and wilt recovery test, then re-enabled for irrigation to setpoint with sensor 3 at 33.5%.

How to Evaluate the Onset of Oversaturation

Oversaturation is defined in this experiment as both the flattening of the moisture sensor curve over time and the presence of water in the pan below the main ceramic container holding the lemon tree. For this document, the holding capacity is defined as the flat portion of the moisture percentage curve for lemon tree sensor 3, for a period of time during which there is water in the pan under the lemon tree. This may vary slightly from traditional holding capacity, but for the purpose of this document, the concepts of saturation and holding capacity are one and the same. The moisture percentage that indicates this is determined by the presence of water in the bottom evaporation pan along with the flattening of the moisture curve.

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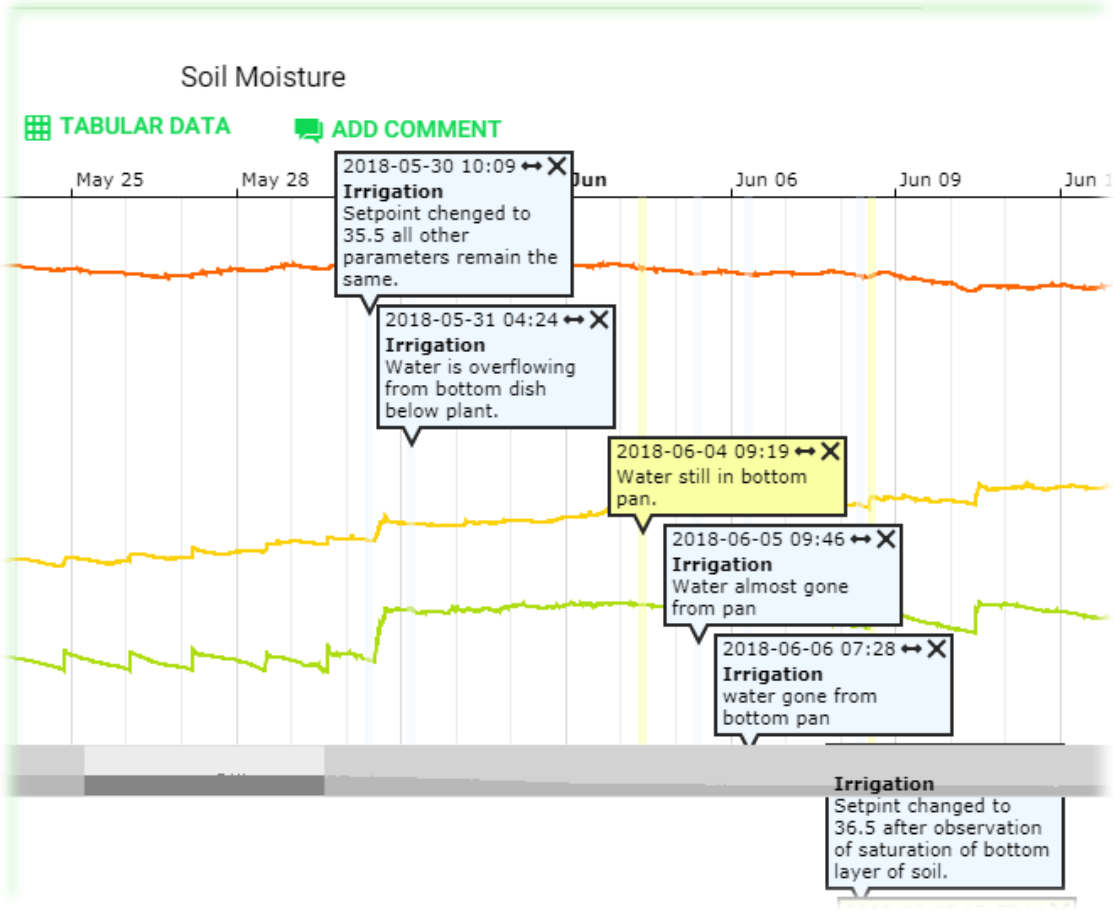


Figure 9. Determination of saturation. The chart notes record water overflowing into the bottom dish, then the setpoint changed to 36.5 after observing saturation of the bottom layer of soil.

After performing these two steps, we now have a moisture value that indicates saturation and one that indicates the onset of wilt. For the remainder of the experiment, the target for the moisture level of the lemon tree was set between the wilting point and the saturation point.

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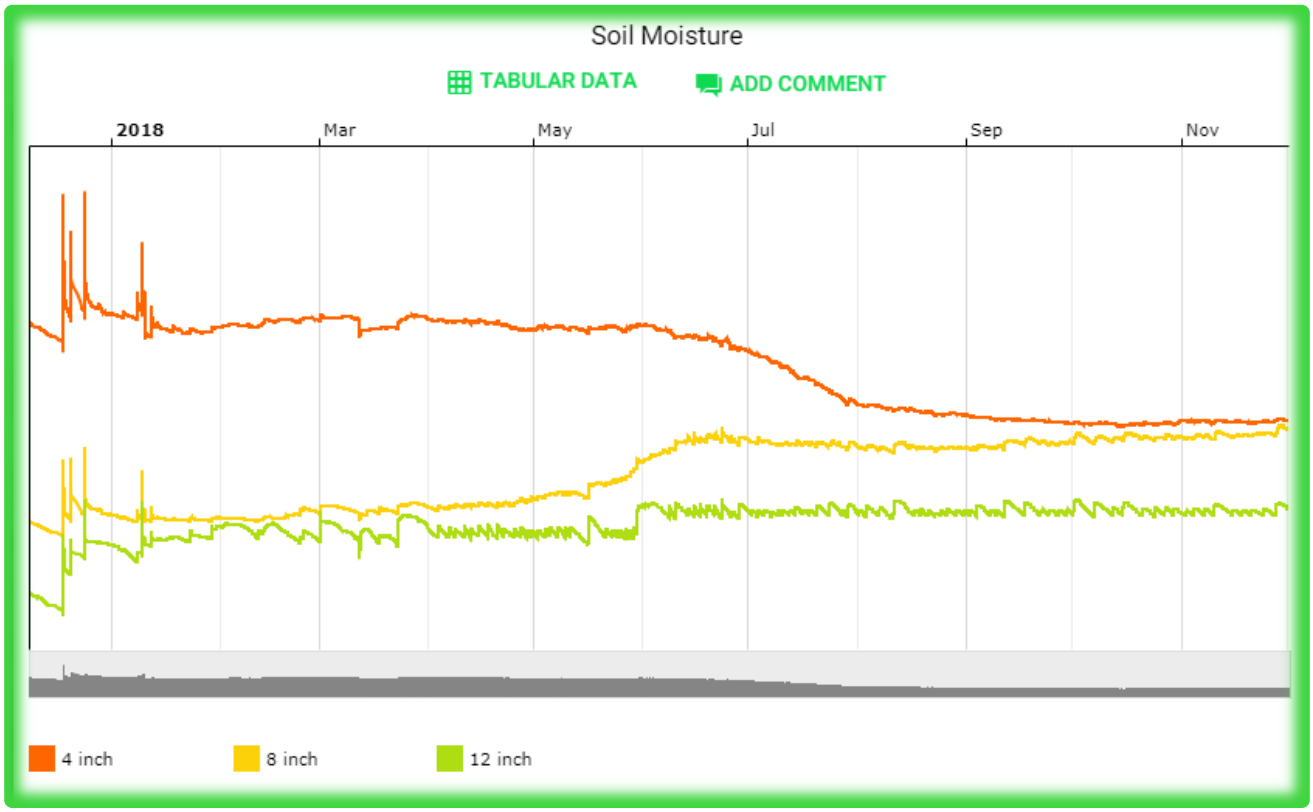


Figure 10. Lemon tree soil moisture for almost one year, at 4, 8 and 12 inches.

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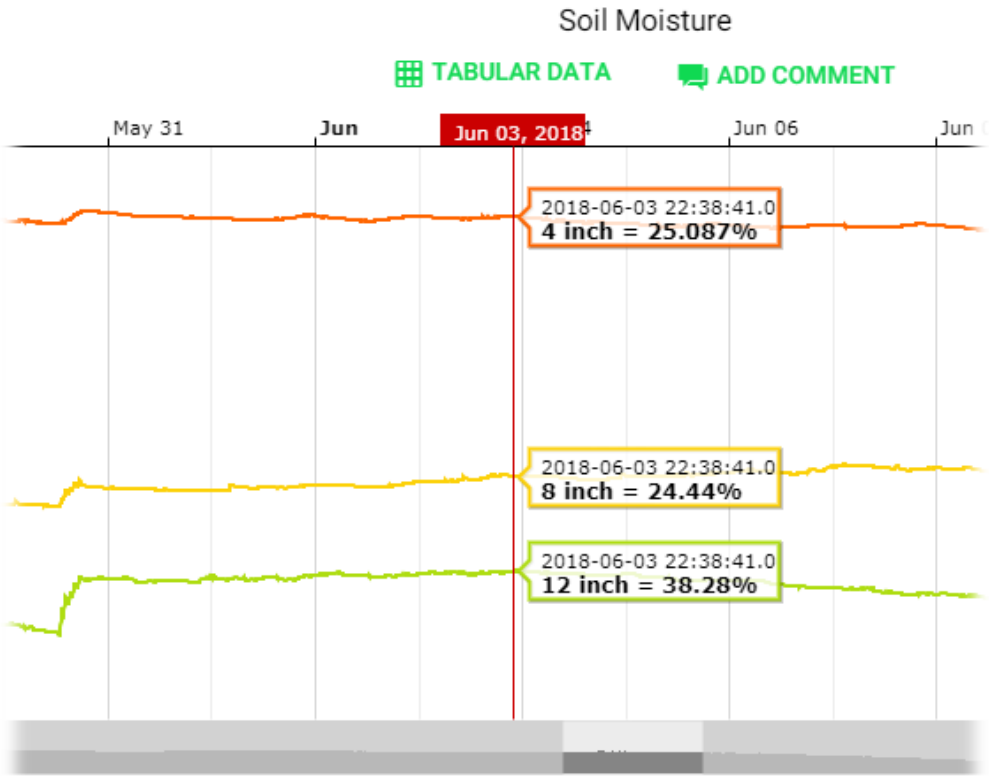


Figure 11. Lemon tree soil moisture at 4, 8 and 12 inches, June 2018.



Figure 12. Lemon blossom on the monitored tree.



Figure 13. Lemon fruit.

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Summary

The results of the lemon tree experiment suggest that the design of using moisture monitoring to control irrigation is a valid way to maintain a constant soil moisture level. Control zones will be used to monitor the uniformity of the irrigations as compared to the monitored zone.

It is possible to maintain a soil moisture condition that leads to neither eventual wilt nor eventual over-watering, defined as water lost to the evaporation pan below the pot.

There was no wilt observed during the 3 month period of the test. The weather was kept uniform to minimize variation due to climate. There was never water in the evaporation pan through the entire experiment. The leaves remained dark green and healthy, as can be observed in the photographs of these leaves.

The moisture level at the 3rd sensor in this lemon tree was kept within a very narrow range for 6 months, as can be seen in the moisture data chart.

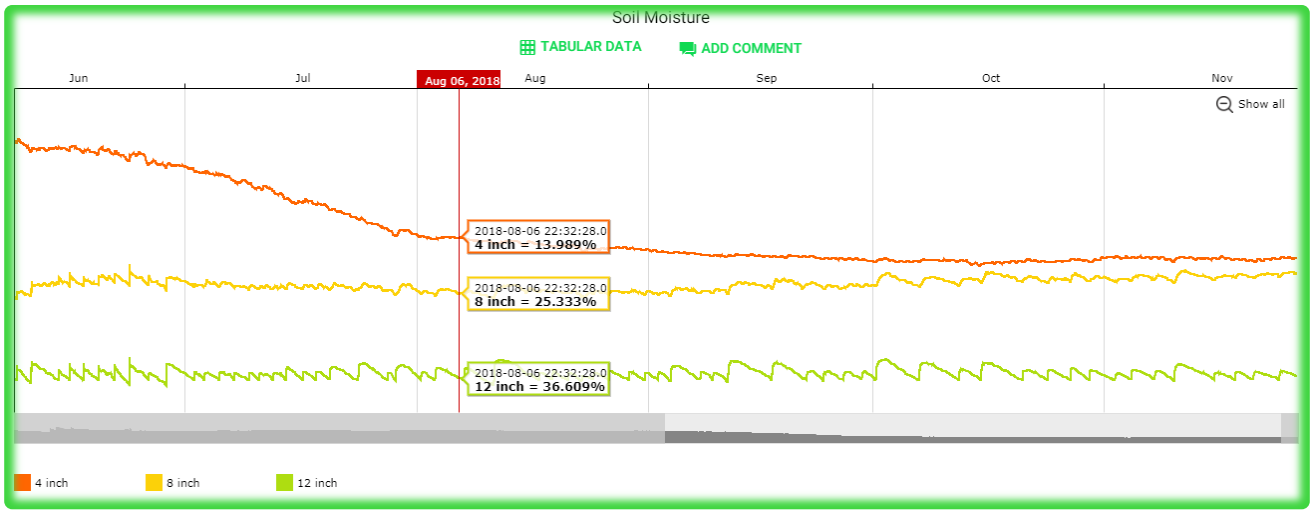


Figure 14. Moisture data chart: soil moisture held in a narrow range at each depth.

This condition of maintaining soil moisture between the wilt and flood values is the AgriNET definition of a **balanced closed-loop irrigation system**.

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Back End Services

The lemon tree sends several transmissions of multi-depth moisture data per hour. The back end server, or the Saturn server, looks at the moisture monitoring data from the lemon tree moisture probe hourly. It compares that value, or series of values, and averages them together according to the parameters set by the irrigation control algorithm.

Once per hour, the moisture information is uploaded from the database into the server algorithm for a particular lemon tree. This data is then averaged based on the averaging period parameter in the database for that lemon tree. Each lemon tree system has its own set of parameters for the irrigation algorithm. The back end server considers the moisture average for a particular lemon tree against the set of parameters specific to that lemon tree or group of trees.

Every hour, each lemon tree registered in the valve setup database table will be evaluated by the server moisture algorithm. If the valve for that tree is set up as “on demand,” then the valve will open as soon as the condition of moisture level is met for the algorithm for that tree. If the valve is set as “priority based,” then the irrigation will occur according to a schedule created by the resource mitigation system, starting at 6 in the morning.

The valve control system will examine the valve schedule table once a minute for valves that need to be turned on. Essentially, the schedule table includes the valve name, when to turn the valve on, and how long to leave it on. The valve control system running on the AgriNET Saturn server sends a command through a static IP and port. All the field equipment connects regularly as TCP/IP clients. The valve control system is a TCP/IP server that remains connected to all the remote valve control boxes as the valve control system examines the valve schedule every minute. As it finds valves that need to be turned on, it sends a control message to that valve. The valve will respond with a validation. If the valve does not respond, it will trigger a maintenance call to a technician through email SMS, which is simply sending an email to a mobile phone’s SMS service by using a particular email suffix provided by the particular mobile carrier. For example, Verizon SMS can be sent as an email from a computer by using the (phone number)@v3g.com suffix. If the valve unit responds correctly, then the valve control will open the valve and then close that particular valve at the appointed time. In this citrus tree experiment, the valves were opened for a one minute interval, yielding 11.5 oz of water per minute.

Resource Mitigation

The original system has a resource mitigation subsystem that decides the amount of available water distributed according to priority to the needed irrigations for that day. The priority is determined by the proximity of current average moisture to the wilt point moisture. Lemon trees that are closer to triggering irrigation (according to their target moisture average) will have higher priority, and will be scheduled before trees which have an average moisture level that is above the target.

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The system decides the order in which the plants will be irrigated, and the priority is simply determined by the threat of wilt. The threat of wilt is quantified by how close the current average moisture is to the irrigation target for that particular lemon tree.

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