Final Report

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COMPARING SOIL MOISTURE SENSORS FOR PEANUT IRRIGATION SCHEDULING

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Introduction

Water availability for agricultural irrigation is a hotly debated topic among interested parties in Georgia, Florida, and Alabama. Yet it is widely known that Southeastern agriculture relies on irrigation to ensure profitability. Ag water use is a major portion of the total water consumed in many critical peanut producing regions of the Southeast. Drought and lawsuits have prompted a renewed interest in water conservation methods by the general public, which is becoming increasingly insistent that agriculture do its part in conserving water.

Better irrigation scheduling is one way that farmers can make more efficient use of their irrigation water. Irrigation scheduling is simply a method of deciding when and how much water to apply to a field to maintain healthy plant growth. Scheduling has been shown to have many benefits to the grower. These benefits include:
- minimize crop water stress and maximize yields.
- increase crop quality.
- maximize water use efficiency.
- reduce surface runoff and leaching of nutrients.
- reduce water pumped and energy used.

One scheduling method that is gaining in popularity is the use of soil moisture sensors that directly sense the soil moisture status of the plant’s root zone. Irrigation is called for when the soil moisture sensors reach some critical level. There are a number of soil moisture sensors on the market, including Watermark sensors, Time Domain Reflectometry (TDR) probes, tensiometers, neutron probes, and ECH2O dielectric/capacitance probes. Each type of probe uses a unique sensing property and responds to changing soil moisture conditions and soil types differently. From an ease-of-use perspective, the new TDR sensors, Watermark sensors, and ECH2O sensors are very popular.

Objectives

The objective of this research project is to compare soil moisture sensor response from TDR, ECH2O, and Watermark sensors over a range of soil moisture conditions using predominant soils from the major peanut producing areas in Georgia, Florida, and Alabama. The response from these sensors will give an indication of their usefulness in peanut irrigation scheduling.

Project Description
Peanut extension specialists in Georgia (John Beasley), Florida (David Wright), and Alabama (Kris Balkcom) were contacted to determine a suitable field site (and 2 soils) in each state. In Georgia, Tifton Loamy Sand soil near Tifton and Greenville Sandy Loam soil near Plains were identified. In Florida, Orangeburg Loamy Sand soil and Norfolk Loamy Fine Sand soil near Quincy were identified. In Alabama, Dothan Fine Sandy Loam soil and Lucy Loamy Sand were selected, both near Headland.

Soil core "liners" were fabricated from PVC pipe (6 in diameter x 20 in long). The lower edge was beveled for easier insertion into the soil. A Giddings hydraulic soil core extraction rig was refurbished and repaired to make it useable for this project and was used to push the PVC core liners into the soil (Figure 1). For each soil type, ten soil cores were extracted by pushing the PVC liner into the soil to a depth of approximately 18 inches. The Giddings rig also was used to pull the core/liner out of the soil profile. As soon as the core/liner was out of the soil, caps were placed on each end to prevent any soil loss during transport. The ten soil cores from each soil type in each state were split into three groups, with a spare core, to be used in triplicate with three different soil moisture sensors. The cores were then transported to the Bio and Ag Engineering Dept building in Tifton for further analysis.

Three cores from each soil type were instrumented with a specific soil moisture sensor. The sensors used for this project consisted of the Watermark Soil Moisture sensor (Irrometer, Riverside, CA), the ECH2O EC-20 Soil Moisture sensor (Decagon Devices, Pullman, WA), and the FieldScout TDR300 Soil Moisture sensor (Spectrum Technologies, Plainfield, IL). The Watermark and ECH2O sensors were installed in the cores as specified by the manufacturer and the TDR was inserted into the soil daily as specified by the manufacturer. The two installed sensors (Watermark and ECH2O) were installed as close to a depth of eight (8) inches as possible. The eight inch depth was chosen to provide a consistent measuring depth since the TDR300 sensing rods were eight inches long and thereby measured the soil moisture to eight inches.

The volumetric soil moisture was measured and calculated daily. This was accomplished by the following procedure:

1. Soil cores were placed in water to within 2 inches of the top, for a minimum of 48 hours. This allowed the column to become saturated with water, thereby providing the best case for a saturated soil.
2. The soil cores were removed from the water bath and weighed after five minutes of drainage. An initial sensor reading was also collected.
3. The soil cores were then placed in a bulk curing tobacco barn and heated air (100°F) was circulated through the barn for eight hours daily to dry the soil columns. The heated barn was used to provide a quicker means of drying the soil columns versus allowing the soil cores to dry naturally. This approach was taken after a "test run" was made on the two Georgia soils. In the "test run", the soils were saturated and allowed to air dry for two weeks. At the end of the two weeks, the soil core had only lost a small fraction of the water. Therefore, it was decided to use the heated barn to force dry the cores and reduce the total testing time to two weeks from approximately two months per sample.
4. The soil cores were weighed daily (weekdays) and a sensor reading was collected daily for two weeks. At the end of two weeks, it was determined that the soil cores were completely dry and the test was stopped.
5. This process was repeated three times for the Georgia and Florida soils and twice for the Alabama soil. The Alabama soil test was only repeated twice as the soil cores from Alabama were collected much later in the project due to scheduling and weather delays.

The data from all test runs was plotted on the same graph. The replications of the treatments within each run were averaged (3 replications per run to provide one value per date) and then all runs were plotted to provide additional data for producing correlation information of actual reading versus calculated volumetric soil moisture.

Once the data had been collected, the weight of each soil core over the duration of the test was used to calculate the volumetric soil moisture for each soil core. This data was then compared to the actual sensor reading from the various cores and plotted. These plots can be seen in Appendix A. Analysis of the collected data is provided below. The authors will explain the data by separating the analysis into sensor type and not by state or soil type.

Results

Watermark sensors
Watermark sensors (Figure 2) are granular matrix sensors with wire ends inserted into the matrix during construction. The sensors are installed in the soil profile and as the soil moisture content increases or decreases the resistance across the granular matrix changes. This change in resistance corresponds to a change in soil moisture. The scale for such sensors ranges from 0 (saturated) to 199 (completely dry). These sensors, as mentioned above, were installed in eighteen soil cores (3 cores X 3 states X 2 soil types). The sensors were monitored daily and the measurement was recorded. The authors expected the measurements to form a
plot that was basically linear based on the scale of 0 (wet) to 199 (dry). As can be seen in Figure 3 (one of the six plots for the Watermark sensor data) the watermark sensor readings did not follow the expected 0 to 199 line as would be expected for a soil that was getting drier as time elapsed. Some of the sensors reached a dry state (199 reading), but this was only 2 times of the 16 different runs. These dry states were not gradual increases as would be expected as the soil dried, but was actually an increase from 19 to 132 or 39 to 199. This indicates that the soil cores were not getting dry in the center as the cores were dried in the heated barn. Based on this information, the last run of drying the soil cores was monitored and immediately after completion of the run, the soil cores were cut in half and the soil moisture was analyzed for the upper, lower and middle sections of the soil cores (Figure 4). The collected data is presented in Figure 5. It can be seen that there was some difference in the soil moisture in the soil core sampling locations. The difference as seen in the different depths of the soil cores indicates that the cores were not dried equally. This difference helps explain why the Watermark sensors did not register a dry (199) reading when they should have been dry. The Watermark also had a disadvantage in that the soil moisture was monitored at one location within the soil profile whereas the other sensors measured a larger section of soil depth.

![Figure 3. Data plot of the watermark sensor data collected from the Tifton soil. The data represents the average of three replications per date and three different run times.](image_url)
Figure 4. (a) cutting cores in half to analyze soil moisture within the soil core, (b) split soil core showing the placement of the watermark sensor and the color change in the soil profile.

Figure 5. Soil moisture of various depths of the soil cores as analyzed after the last run of sensor analysis. The orange bars are the samples collected from the center location of the cores.
Decagon Devices ECH2O sensors

The Decagon Devices ECH2O sensors are capacitance sensors that use the dielectric property of the soil to indirectly measure the soil moisture of a soil. The sensor as seen in Figure 6 sends an electric signal through the sensor and the amount of charge stored in the soil profile is measured. This stored charge is an indirect measurement of the soil moisture. The ECH2O soil moisture sensors were installed in the soil cores as described earlier. Since the soil moisture is averaged over the length of the sensor, the center of the sensor was placed at the eight inch depth as was the Watermark sensor.

![ECH2O sensor used in soil core test.]

The sensor measurements are reported in units of cubic meters per cubic meters (m³/m³). This states that there is some amount of water (in cubic meters) per cubic meter of soil. The readings of ECH2O sensors range from a dry soil reading of 0 to a saturated soil value of 0.45 or 45%. The 0.45 or 45% reading for saturated soil is due to the dielectric properties of the soil and water. Soil has a dielectric constant of 3-7 and water has a value of 80. In the calibration of the sensor and within the programming of the measurement devices, the manufacturer caps the readings at 0.45 which represents a saturated soil type for most soils.

The plotted data collected for one soil type (Tifton) is shown in Figure 7. The measured data was plotted against the calculated volumetric soil moisture as determined from the weights of the soil cores. A you can see in Figure 7, there is a 70% correlation for a best fit line and a 67% correlation if the best fit model is forced to intercept at zero. Either model (equation) indicates that there is some discrepancy in the collected and calculated data. This could be related to the data as shown in Figure 5 where the soil moisture was not constant across the length of the soil core. Likewise, since the ECH2O sensors are 20 cm in length, the sensor is measuring across the length of the 20 cm which crosses different soil moisture areas within the soil core.

The other plots can be seen in Appendix B. The correlations for the different soil types are presented in Table 1. The data for the Alabama soils was also plotted with a polynomial regression curve. This actually gave a better fit that either the linear or a linear forced to zero. The other soils (Georgia and Florida) had a very good response to both a linear and linear forced to zero curve. The only soil that did not have a good fit was the Georgia Greenville soil ($R^2 = 0.367$).
Figure 7. The plot of measured volumetric soil moisture verses calculated volumetric soil moisture in a Tifton soil as measured with the ECH2O. The linear regression lines are best fit and forced to zero intersection.

Table 1. Regression curve correlations for the different soils used in the soil moisture test as measured with the ECH2O.

<table>
<thead>
<tr>
<th>State</th>
<th>Soil Type</th>
<th>Linear fit</th>
<th>Linear fit forced to zero</th>
<th>Polynomial fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>Tifton</td>
<td>0.673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>Greenville</td>
<td>0.367</td>
<td>0.581</td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>Orangeburg</td>
<td>0.792</td>
<td>0.816</td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>Norfolk</td>
<td>0.729</td>
<td>0.751</td>
<td></td>
</tr>
<tr>
<td>Alabama</td>
<td>Dothan</td>
<td>0.228</td>
<td>0.34</td>
<td>0.575*</td>
</tr>
<tr>
<td>Alabama</td>
<td>Lucy2</td>
<td>0.375</td>
<td>0.279</td>
<td>0.615*</td>
</tr>
</tbody>
</table>

The collected data and the regression for most of the soils indicate that the ECH2O sensors will provide a good means of measuring the soil moisture as represented by this test.
TDR300

The TDR300 sensor operates by sending a pulse of electricity through two metal rods and the time domain of the signal measurement is measured. This measurement of a high-frequency electromagnetic pulse is indirectly related to the volumetric soil moisture. Like the ECH2O, the volumetric soil moisture is measured in units of cubic meters per cubic meters (i.e. cubic meters of water per cubic meter of soil). The TDR300 used for this test is shown in Figure 8.

The plotted data collected for one soil type (Tifton) is shown in Figure 9. The measured data was plotted against the calculated volumetric soil moisture as determined from the weights of the soil cores. As you can see in Figure 9, there is a 95% correlation for a best fit line and an 88% correlation if the best fit model is forced to intercept at zero. Either model (equation) indicates that there is some discrepancy in the collected and calculated data. This could be related to the data as shown in Figure 5 where the soil moisture was not constant across the length of the soil core. Likewise, since the TDR300 sensors are eight inches in length, the sensor is measuring across the length of the eight inches which crosses different soil moisture areas within the soil core. One other difference in this data used for fitting a curve and the ECH2O is that there are not as many points for plotting. Since the TDR300 has to be inserted into the soil daily, there is some disturbance and potentially greater drying. Also, the soil moisture in the top few inches of the soil core tended to get very dry (almost brick consistency) which did not allow the TDR300 to be inserted into the soil profile completely and thereby no measurement as the soil got drier.

The other plots can be seen in Appendix C. The correlations for the different soil types are presented in Table 2. All soils have very good fits to the data with the lowest regression being $R^2 = 0.656$ (Greenville soil, Linear Fit). From this data the TDR300 is a very good instrument to use for monitoring soil moisture for peanuts and any crop.
Figure 9. The plot of measured volumetric soil moisture versus calculated volumetric soil moisture in a Tifton soil as measured with the TDR300. The linear regression lines are best fit and forced to zero intersection.

Table 2. Regression curve correlations for the different soils used in the soil moisture test as measured with the TDR300.

<table>
<thead>
<tr>
<th>State</th>
<th>Soil Type</th>
<th>Linear fit</th>
<th>Linear fit forced to zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>Tifton</td>
<td>0.876</td>
<td>0.951</td>
</tr>
<tr>
<td>Georgia</td>
<td>Greenville</td>
<td>0.656</td>
<td>0.821</td>
</tr>
<tr>
<td>Florida</td>
<td>Orangeburg</td>
<td>0.881</td>
<td>0.9</td>
</tr>
<tr>
<td>Florida</td>
<td>Norfolk</td>
<td>0.83</td>
<td>0.904</td>
</tr>
<tr>
<td>Alabama</td>
<td>Dothan</td>
<td>0.774</td>
<td>0.907</td>
</tr>
<tr>
<td>Alabama</td>
<td>Lucy2</td>
<td>0.832</td>
<td>0.949</td>
</tr>
</tbody>
</table>

Cost Analysis of Sensor Systems
The cost of any one of these systems used in our test will depend on what the farmer wants and needs in a particular situation. The information in Table 3 is a starting point for installation and use of any of the sensor systems we tested.

**Table 3. Cost of Sensor Packages**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Additional Equipment for System</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watermark</td>
<td></td>
<td>$60.00</td>
</tr>
<tr>
<td></td>
<td>sensor monitor</td>
<td>$219.00</td>
</tr>
<tr>
<td></td>
<td>Datalogger (w/ sensors)</td>
<td>$550.00</td>
</tr>
<tr>
<td><strong>TOTAL SYSTEM (Manual)</strong></td>
<td></td>
<td>$279.00</td>
</tr>
<tr>
<td><strong>TOTAL SYSTEM (Continuous)</strong></td>
<td></td>
<td>$550.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDR300</td>
<td>$1,195.00</td>
</tr>
<tr>
<td>Extra rods</td>
<td>$48.00</td>
</tr>
<tr>
<td><strong>TOTAL SYSTEM</strong></td>
<td>$1,243.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECH2O</td>
<td>$70.00</td>
</tr>
<tr>
<td>Data logger</td>
<td>$440.00</td>
</tr>
<tr>
<td>Hand monitor</td>
<td>$450.00</td>
</tr>
<tr>
<td>Datalogger w/ remote monitoring</td>
<td>$675.00</td>
</tr>
<tr>
<td>Radio receiver</td>
<td>$650.00</td>
</tr>
<tr>
<td><strong>TOTAL SYSTEM manual</strong></td>
<td>$520.00</td>
</tr>
<tr>
<td><strong>TOTAL SYSTEM w/o Remote</strong></td>
<td>$510.00</td>
</tr>
<tr>
<td><strong>TOTAL SYSTEM w/ Remote</strong></td>
<td>$1,395.00</td>
</tr>
</tbody>
</table>

The systems presented above can be further explained through the following examples.
**Watermark system:**

To install a datalogger and seven sensors at one location it will cost $550 dollars. If however, you would like to install 2 sensors at a given location and manually monitor the sites, the cost for such a system will be $339.00 (2 sensors and a monitor). Additional sites with two monitors will then only cost $120.00 and the monitor can be used at various sites.

**ECH2O system:**

To install a monitoring station and manually check the soil moisture the cost will be $520.00 for one sensor with an additional $70.00 for every sensor you install. The handheld reader can be used for various and multiple sensors. To install a datalogging system, the cost will be $510.00 and $70.00 for every additional sensor. To download data the person will have to hook a computer into the datalogger at the monitoring location. To remotely monitor the systems from a nearby location, the system will cost $1395.00 for the first system. An additional $745.00 would be needed for additional monitoring locations (datalogger and sensor). These costs do not include additional sensors at $70.00 each. As a note, each datalogger can handle 5 sensors.

**TDR300 system**

The TDR system is a manual system and as the values in the Table show, a system will cost $1243.00. The TDR300 will have to be used manually at every location of interest.

**Cost Disclaimer**

The costs presented here are the values from contacting the distributor or manufacturer at time the report was drafted. The prices may be different or can change without the knowledge of the authors.

**Conclusions**

This project was designed to compare three commonly used soil moisture sensors for use in measuring soil moisture during peanut production. The use of such sensors would allow the farmer to better monitor the amount of water being applied to his/her peanut crop without over or under watering the crop. This has the potential of being very important in the future of Georgia agriculture.

The three different sensors tested were the Watermark soil moisture sensor, the ECH2O soil moisture sensor and the TDR300 soil moisture sensor. The three chosen sensors have three different means of indirectly measuring soil moisture. The Watermark is a resistance measurement, the ECH2O is a capacitance measurement and the TD300 is a time-domain reflectometry sensor.
To test the sensors, soil cores were collected from two different soil types in three different states (GA, AL, FL). The soils represent the major peanut-producing soils of each state. Sensors were installed in the saturated cores and then cores were dried in a heated tobacco barn. The collected data was then plotted against the calculated volumetric soil moisture to provide a correlation and best way to compare the sensors.

From the data collected, the TDR300 provided the best data with the soil cores used. The TDR300 has two negative attributes: it cannot be used if the soil crust is very dry and cannot be easily automated. If the soil moisture in the top inch is very low, the crust formed will impede the penetration of the probe and therefore, not be useful. One good point of the TDR system is that it is portable and will only require a small initial outlay of funds to purchase a system. Unlike the TDR300, the ECH2O sensors can be used to collect continuous data. This would be helpful if monitoring soil moisture daily is of concern to the farmer. The system also is permanently installed (not portable) and costs a little more than the TDR300. If multiple sites are of interest then separate sets of sensors and dataloggers will be required.

From our testing, the Watermark sensors did not perform as expected, but this could be due to the tendency for the center of the soil cores (where the sensor was located) not to completely dry out while in the heated barn. The sensors are used routinely for monitoring soil moisture and are relatively cheap if needed for multiple locations in a field.

Based solely on the results from this project, the TDR and ECH2O sensors performed well in the test and had good correlation between the measured and calculated volumetric soil moisture. Either sensor could be used in an irrigation scheduling application in a peanut crop. Other studies have shown the accuracy and ease of use of Watermark sensors and thus these sensors should not be excluded from consideration. Clearly the testing method used in this project was not optimal for properly comparing the three types of sensors.

Acknowledgements

The authors greatly appreciate funding to support this project from the National Peanut Board via the Southeast Peanut Research Initiative and the Georgia Peanut Commission. The authors wish to thank Kris Balkcom (AL), John Beasley (GA) and David Wright (FL) for their assistance in locating representative soils in each state. This project would not have been possible without the exceptional technical support from Gary Murphy of the UGA Bio & Ag Engineering Dept., Tifton Campus.
Appendix A

Regression plots for all soil types using the Watermark soil moisture sensors. Each graph is titled as [State] [Soil Type] [Sensor type], so the first one is GA Tifton Watermark.

GA Tifton Watermark

GA Greenville Watermark
Appendix B

Regression plots for all soil types using the Decagon Devices ECH2O soil moisture sensors. Each graph is titled as [State] [Soil Type] [Sensor type], so the first one is GA Tifton ECH2O.

**GA Tifton ECH2O**

\[ y = 0.865x \quad y = 1.037x - 2.001 \]

\[ R^2 = 0.673 \quad R^2 = 0.699 \]

**GA Greenville ECH2O**

\[ y = 0.335x \quad y = 0.815x - 10.98 \]

\[ R^2 = 0.367 \quad R^2 = 0.581 \]
FL Orangeburg ECH2O

\[ y = 0.664x \quad y = 0.781x - 1.723 \]

\[ R^2 = 0.792 \quad R^2 = 0.816 \]

FL Norfolk ECH2O

\[ y = 0.745x - 2.073 \quad y = 0.632x \]

\[ R^2 = 0.751 \quad R^2 = 0.729 \]
**AL Dothan ECH2O**

- \( y = 0.705x \)
- \( R^2 = 0.228 \)

- \( y = 0.509x + 2.519 \)
- \( R^2 = 0.340 \)

- \( y = 0.112x^2 - 1.135x + 3.678 \)
- \( R^2 = 0.575 \)

**AL LUCY2 ECH2O**

- \( y = 0.709x \)
- \( R^2 = 0.279 \)

- \( y = 0.529x + 2.407 \)
- \( R^2 = 0.375 \)

- \( y = 0.104x^2 - 1.068x + 3.611 \)
- \( R^2 = 0.615 \)
Appendix C

Regression plots for all soil types using the TDR300 soil moisture sensors. Each graph is titled as [State] [Soil Type] [Sensor type], so the first one is GA Tifton TDR.

**GA Tifton TDR**

\[ y = 0.730x \]
\[ R^2 = 0.876 \]

\[ y = 0.976x - 3.874 \]
\[ R^2 = 0.951 \]

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**GA Greenville TDR**

\[ y = 0.377x \]
\[ R^2 = 0.656 \]

\[ y = 0.666x - 7.277 \]
\[ R^2 = 0.821 \]
FL Orangeburg TDR

$y = 0.601x$
$R^2 = 0.881$

$y = 0.691x - 1.656$
$R^2 = 0.900$

FL Norfolk TDR

$y = 0.551x$
$R^2 = 0.830$

$y = 0.751x - 3.631$
$R^2 = 0.904$
**AL Dothan TDR**

- \( y = 0.625x \)
- \( R^2 = 0.774 \)

- \( y = 0.963x - 4.759 \)
- \( R^2 = 0.907 \)

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**AL LUCY2 TDR**

- \( y = 0.635x \)
- \( R^2 = 0.832 \)

- \( y = 0.933x - 4.344 \)
- \( R^2 = 0.949 \)