Evaluating Sprinkler Operational Efficiency using SMS

Authors

Gary Klinefelter

CEO and Founder, IrriGreen Inc.
gary.klinefelter@irrigreen.com

Michael D. Dukes, PhD., P.E.

University of Florida, Agricultural and Biological Engineering Dept.
mddukes@ufl.edu

Abstract. *Evaluating irrigation sprinkler operational efficiency with catch cups is a labor-intensive process that provides data regarding the output of the irrigation system using mechanical spray and rotary sprinklers. Catch cups are a proxy for the available moisture in the soil due to many factors such as: soil saturation, soil type, run-off, etc. While soil moisture sensing (SMS) can automate the measurement process, much needs to be learned about the limits and benefits of using soil moisture to measure irrigation sprinkler operational efficiency. This presentation will cover examples of using soil moisture to measure sprinkler operational efficiency; limits in making before and after soil moisture measurements; advantages in using soil moisture sensing and what we still need to learn.*

Keywords. SMS, sprinkler, irrigation, efficiency, soil, moisture, measure.

Introduction

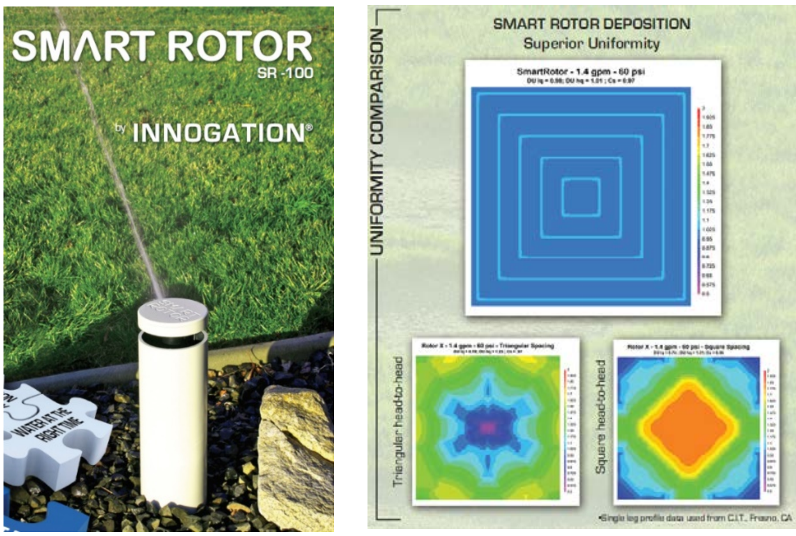
For many years, the irrigation industry has used catch-cups to sample water output from irrigation sprays and rotors to evaluate water application efficiency. The most common method is to compute distribution uniformity lower quartile (DULQ). DULQ is computed from a set of data by taking the average of the lower 25% of the data set compared to the average of the entire data set. More recently, the industry has defined the SWAT protocol which defines methods of placing catch-cups along with calculations for operational efficiency. SWAT operational efficiency is computed by subtracting percolation losses and overspray losses. The percolation loss is computed by taking sum of the differences of the upper 75% of the data points minus the 75% data point divided by the sum of the entire data set. For this paper, the term *efficiency* will simply mean how efficiently a sprinkler is applying water in the field. The term *digital* refers to controlling a sprinkler rotation and throw distance using digital electronics.

Smart Water Application Technologies (SWAT)

According to the Irrigation Association website: "*Smart Water Application Technologies is a partnership of water providers and irrigation companies, working to promote landscape water-use efficiency through innovative technology.*" The SWAT *Spray Head Sprinkler Nozzles Performance Characteristics* testing protocol defines test methods, test shapes and calculations such as: precipitation rate, distribution uniformity, overspray losses, percolation losses and operational efficiency.

New Technology Influence on Sprinkler Measurement

In 2013, IrriGreen began offering a digital irrigation sprinkler that used multiple streams of water to uniformly water the soil by setting stream volumes that match the area at each stream distance. This new technology created challenges using catch-cup measurements to measure water application efficiency because some streams miss the catch-cups while others are deflected by the catch-cups. Like previous digital irrigation sprinklers (Figure 1) which used digitally adjusted spray or streams, catch-cups did not tell us what is happening in soil when the sprinkler output is streaming and moving. Do we need an alternative measurement of digital sprinkler efficiency that uses soil moisture measurements?



"Based on the dryness distribution plot in Figure 3, an intelligent system can reduce water use by 40% to 50% in most cases."
- Robert Walters

Figure 1 – Adjustable Spray Sprinkler by Innogation

Multi-Volume, Multi-Stream Nozzle Catch-Cup Measurements

In 2012 and 2013, IrriGreen did extensive catch-cup testing to refine the performance of a multi-volume, multi-stream nozzle. Figure 2 shows an example of how early testing was performed using 6-inch catch-cups. The catch-cups close to the nozzle lost water due to stream deflection while the catch-cups farther away missed water falling between the catch-cups. To improve the result, measurements were done with catch-cups adjacent to one another. While this works fine for research, it is not very practical in the field.

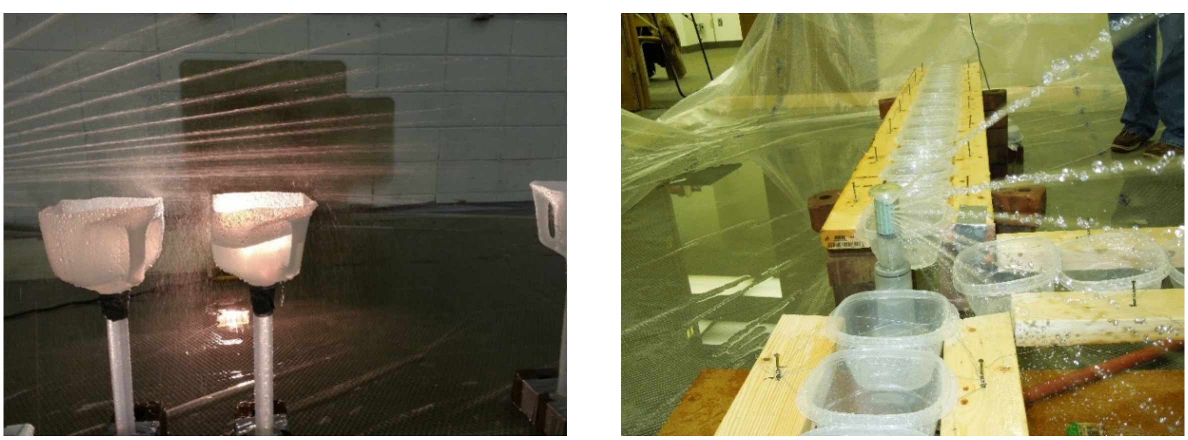


Figure 2 – Multi-Stream, Multi-Volume Nozzle

The resulting data from this early development was used to refine the IrriGreen nozzle to design the distance between the streams so the soil would be able to fill in the gaps like drip irrigation. Figure 3 shows how the water volume changes with distance for the multi-stream nozzle.

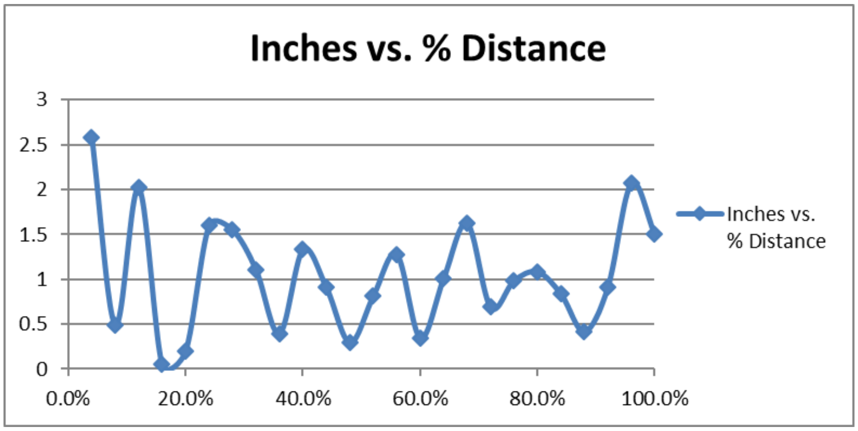


Figure 3 – Multi-Volume, Multi-Stream Digital Sprinkler

Uniformity Testing with Brian Horgan, PhD. University of Minnesota

In 2014, IrriGreen worked with Brian Horgan, PhD. from the University of Minnesota to perform catch-cup and soil moisture testing on turf. He used both catch-cups and a Spectrum TDR-300 soil moisture probe to make measurements. The goal was to sample test areas of turf grass where 3 mechanical rotors overlapped versus one IrriGreen digital sprinkler. He tested three 10 x 10 plots of turf grass. In his report, the coefficient of uniformity for catch-cups was 0.91 for a mechanical rotor and 0.68 for IrriGreen. When using TDR soil moisture measurements both mechanical and IrriGreen had 0.85 coefficient of uniformity. (Full report available at www.irrigreen.com)

Mark A. Crookston, P.E., D.WRE, Northern Water, Berthoud, CO 80513

Mark Crookston, Irrigation Management Department Manager at Northern Water heard about the IrriGreen system in 2016 and took the approach of using very large catch-cups (5-gallon pails) to overcome the difficulty of measuring streams. This yielded a DULQ of 0.58 and a SWAT sprinkler operational efficiency of 67%, not a very practical method to use in the field.

Figure 4 – Digital Sprinkler Test, Northern Water

Digital Sprinkler Testing at the Center for Irrigation Technology (CIT)

In 2016, IrriGreen worked with the Center for Irrigation Technology at Fresno State to test the IrriGreen digital sprinkler. We ran 3 tests: 30 x 60 rectangle, 30-foot square and 30-foot circle with the latter 2 tests defined by the SWAT protocol. CIT selected best-in-class mechanical irrigation sprinklers to be tested on the same plots as digital sprinklers. In each case there was one digital sprinkler in the center compared to 6-9 mechanical sprinklers around the edge. We tested on turf so we could perform catch-cup testing and soil moisture testing side by side.

Figure 5 – CIT Testing Digital Sprinkler

CIT Testing Considerations

The team at CIT used mechanical rotor sprinklers in the 30 x 60 rectangle to water the turf for 58 minutes using 2 GPM nozzles. Using mechanical rotors sprinklers as a reference, the IrriGreen team calculated the mechanical sprinklers low quarter and set the IrriGreen system to match at 5 revolutions, about .275 inches. At the time, we asked several experts including Dr. Michael Dukes about when to make SMS measurements and decided to make them immediately after making catch-cup measurements and at 3 hours. We wanted to make sure we did not over saturate the soil for either mechanical or digital sprinklers. For instance, the center areas of Figure 6 represent areas of high precipitation for mechanical sprinklers.

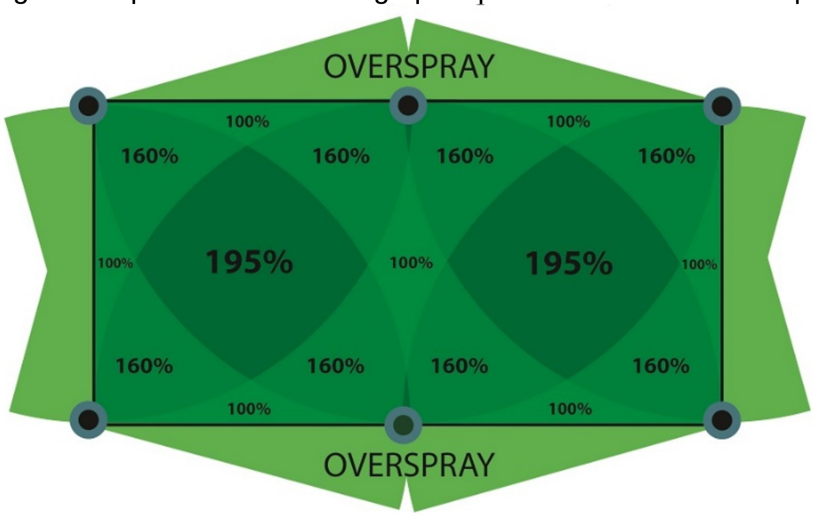


Figure 6 – Overlap and Overspray from Mechanical Sprinklers (0.65 DULQ)

Unlike a mechanical sprinkler that overlaps and is positioned head-to-head, a digital sprinkler is placed in the center of the landscape and waters uniformly from the inside out. For the digital sprinkler, areas of high and low soil moisture measurement occur between the streams as shown in Figure 3.

Figure 7 – Example Mechanical and Digital Sprinklers

CIT Test Results

As expected due to the challenge of using catch-cups with streams, the distribution uniformity and operational efficiency numbers for the digital sprinkler catch-cup measurements are lower than mechanical measurements in Table 1. The same uniformity and efficiency measurements for the digital sprinkler using SMS data are closer to mechanical measurements. Assuming SMS readings are valid measurements for operational efficiency, then the digital sprinkler performed nearly as well as the mechanical sprinkler. (Full CIT report is available at www.irrigreen.com)

CIT Test	SWAT Operational Efficiency	DULQ
Mechanical Sprinkler CC	80%	0.71
Digital Sprinkler CC	54%	0.43
Mechanical Sprinkler SMS	70%	0.37
Digital Sprinkler SMS	65%	0.55

Table 1 – CIT 30 x 60 Test Result Summary Mechanical and Digital Sprinklers

Differences in gallons collected

What is even more dramatic than the differences in SMS versus catch-cups measurements, is the difference in the volume of water collected given a similar change in soil moisture, about 40% less volume (gallons) for digital versus mechanical sprinklers. (With catch-cups it is unnecessary to collect volume because the cup is a volume measurement). Volume and SMS measurements may tell us more accurately what is happening in the soil. These results led IrriGreen to plan additional research into using SMS as a measurement for sprinkler efficiency.

Working with Dr. Dukes, University of Florida on SMS measurements

It became clear from the work done at CIT that in the future the irrigation industry may need an alternative way to measure sprinkler performance using soil moisture measurements. Given Dr. Michael Dukes past research in soil moisture measurements in the field, IrriGreen chose to work with Dr. Dukes and the University of Florida to perform further research into using soil moisture as a performance measurement and use the resulting protocol to test mechanical and digital sprinklers with more replication.

What SMS Measurements Are Needed

Since there are physical boundaries for using SMS as a measurement tool, we decided to define what those are. Like a catch-cup, soil can only hold so much water so we needed to define those measurement boundaries. Here is the process we chose for doing the research:

1. Installation and set-up of 1 IrriGreen Genius® Sprinkler (30 x 60 ft. turf plot).
2. Installation and set-up of a conventional 6 rotor system (same 30 x 60 ft. turf plot).
3. Estimate Volumetric Water Content (VWC) range based on starting an irrigation event at 8% VWC (maximum allowable depletion) and ending it at 12% VWC (field capacity).
4. Calculate and run 1 IrriGreen Sprinkler from 8% VWC (maximum allowable depletion) and ending it at 12% (field capacity).
5. Calculate and run 6 mechanical rotors from 8% VWC (maximum allowable depletion) and ending it at 12% (field capacity).
6. Compare results from 4 & 5 above, and re-calculate and re-run if necessary.
7. **INTERIM RESULT:** Have a good idea of which is the maximum allowable depletion point and which is the average field capacity of the area.
8. Run 1st set of comparative tests for delta VWC percentages based on the designed irrigation event determined in Step 7 above (includes tests for catch-cup results – immediately after irrigation, SMS probe – immediately, SMS – 3 hours after and SMS – 24 hours after).
9. Run 2nd set of comparative tests for delta VWC percentages based on insufficient water than designed irrigation event determined in Step 7 above (includes tests for catch-cup results – immediately after irrigation, SMS – immediately, SMS – 3 hours after and SMS – 24 hours after).
10. Run 3rd set of comparative tests for delta VWC percentages based on excess water than the designed irrigation event determined in Step 7 above (includes tests for catch-cup results – immediately after irrigation, SMS – immediately, SMS – 3 hours after and SMS – 24 hours after).
11. **FINAL RESULT:** Write a report that can be distributed by UF and IrriGreen showing study results.

University of Florida Field Measurements Steps 1 – 6

Figure 8 Test Areas of Turf Grass at the University of Florida

The first half of the research process has been performed by the University of Florida yielding the results shown in Figures 9 and Table 2. Figure 9 shows the average VWC at 0, 3 and 24 hours. Figure 9 shows that making immediate measurements will yield better results because the water is rapidly draining and redistributing in the soil. Table 2 shows mechanical and digital sprinkler measurements at 0.5-inch application yielding 8%-10% change in VWC and 1-inch application yielding 15%-16% rise in VWC.

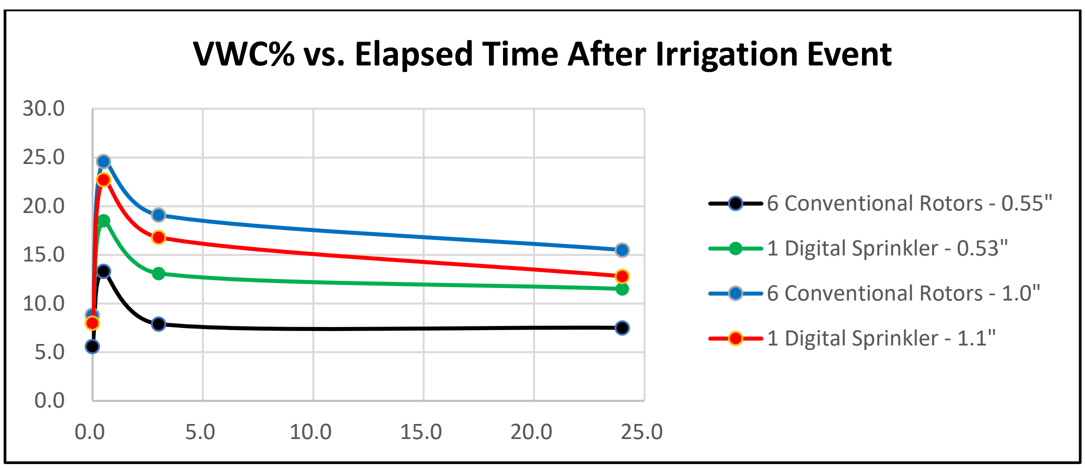


Figure 9 – Soil Volumetric Water Content Over Time

UF SMS Test	Delta VWC	SWAT Operational Efficiency	DULQ
Mechanical Sprinkler 0.5 in.	8%	53%	0.45
Digital Sprinkler 0.5 in.	10%	67%	0.38
Mechanical Sprinkler 1 in.	16%	83%	0.74
Digital Sprinkler 1.1 in.	15%	77%	0.66

Table 2 – UF 30 x 60 Test Result Summary Mechanical and Digital Sprinklers

Figure 10 graphs the data for the results in Table 2. While the curves are similar between digital and mechanical sprinklers, the digital sprinkler has more low and high data points, possibly due to using streams instead of sprays. Both mechanical and digital sprinkler curves become flatter at high soil saturation.

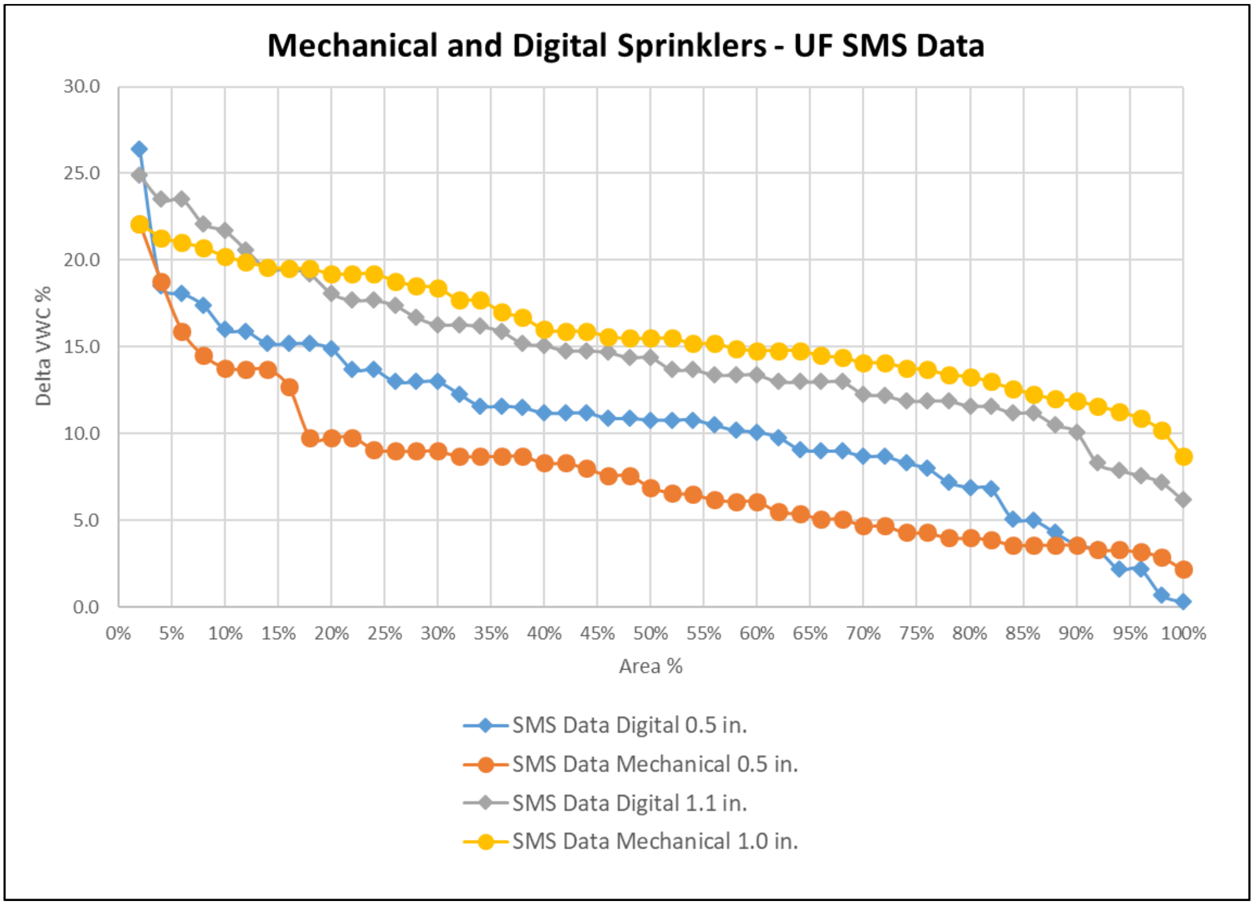


Figure 10 – UF 30 x 60 Test Results Mechanical and Digital Sprinklers

University of Florida Field Measurements Steps 7 - 11

Based on the interim results in steps 1-6, the final testing will be run at 0.25-inch, 0.5-inch and 1-inch of water application to give us a range in which to determine the optimal test result. Catch-cup tests will be taken alongside of soil moisture tests for reference. These results will be reported when available.

Conclusion Using SMS Data to Measure Sprinkler Efficiency

Volume and soil moisture measurements show promise as an alternative way to measure sprinkler efficiency. There is more to be learned about how the application rate and volume affect SMS measurement results. After we complete our research and based on our findings, IrriGreen and the University of Florida will run additional turf grass tests with both digital and mechanical rotors adding more replication to better understand the use of SMS data to measure sprinkler efficiency. We will publish these results in 2018.

Acknowledgements

www.innogation.com

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Dr. Michael D. Dukes, PhD., P.E., University of Florida, Agricultural and Biological Engineering Dept.

Jeffrey Woodson, Director of Operations, IrriGreen, Inc, Edina, MN.