Irrigation Systems Evaluations

(A Look at Distribution Uniformity)

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1.0 Introduction

Water use efficiency has typically been a priority for produce growers in the United States, but with recently diminishing water resources due to drought conditions and groundwater depletion, there has been a renewed urgency to improve water use efficiency in irrigation systems. An irrigation system’s uniformity of water distribution or distribution uniformity (DU) is a key measurement of a system’s water use efficiency. If water is not distributed evenly or uniformly on a field, areas receiving less acre-feet of water will have poorer plant health and reduced crop yields or to avoid reduced yields, the system must over-irrigate to compensate for unequal distribution.

DU, expressed as a percentage, is considered outstanding above 90%, as good between 70-90%, and poor when it is below 70%. Operating with a DU above 90% makes good economic sense in that DU correlates closely to crop yield and reduces costs related to increased water use. An irrigation system operating at 85% DU uses 22 lbs. of fertilizer/acre and 0.7 acre feet of water with the per-acre energy cost of $16.65. Compare this to an irrigation system operating at 75% DU, where the grower applies more water in drier parts of the field to compensate for the lower DU resulting in the use of 78 lbs. of fertilizer/acre and 1.6 acre feet of water with energy costs of $59.84/acre. In addition to increase costs, poor DU also impacts yield revenue. Assuming an average yield of 2,500 lbs./acre and a crop value of $3.00/lb., a field with 85% DU has a per-acre revenue loss of $188 due to DU degradation while a field with 75% DU has a loss of $563/acre. These numbers increase substantially as DU further degrades below 70%, demonstrating a real impact on the bottom line for growers using poorly designed and maintained irrigation systems.¹

As part of their effort to support members in achieving increased water use efficiency, Western Growers partnered with The Toro Company and Simplot Water Logic Services Group to sponsor a study to evaluate distribution uniformity in drip irrigation systems. The study, conducted from October 23, 2015 through March 7, 2016, included the irrigation systems of four Western Grower grower-shippers.

2.0 Methods

Rich Bernier, Technical Services Project Lead for Simplot’s Water Logic Services Group and Paul McFadden, national accounts manager for the Western Growers, outlined the specific methods used in the study. The results of this study will provide valuable insights for growers looking to optimize their irrigation practices and improve water use efficiency.

Toro Company worked with participating companies to evaluate and improve the DU of their drip irrigation systems. Prior to sampling and treatment, participants filled out an operational questionnaire about their water and power sources, irrigation system, and system maintenance. Observations about the condition of the irrigation system were noted both pre- and post-treatment.

Water samples were collected pre-filter, post-filter, at the end of the tape lines to analyze water quality. Water samples were also collected from three sets of four emitters randomly selected on three separate tape lines or laterals furthest from the pump station to analyze specific flow rates. Sampling locations were marked with flags so that the same emitter could be monitored for comparison purposes throughout the study period. After baseline water samples were taken, the system was treated. Irrigation system treatment consisted of a 24-hour exposure to acid-based microbiocide injected upstream of the filters followed by flushing of the system.2 After the system flush, one-minute “catch can” water samples were again taken from the same emitter locations and analyzed for comparison to pre-treatment measurement values.

3.0 Measurements

In this study, DU was evaluated by calculating the Emission Device Discharge Variation (EDDV), a statistical prediction of irrigation systems water application evenness. To calculate the EDDV, a number of performance measurements (discharge rates) are taken and arranged from high to low. The EDDV is the product of the average of the lowest quarter of these readings divided by the average of all readings. DU is reported as a percentage: the EDDV multiplied by 100.3

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DU = \left( \frac{\text{Average of low quarter discharge rates}}{\text{Average of all discharge rates}} \right) \times 100
\]

In addition to system performance measurements used to calculate the EDDV, the following water quality measurements were taken as part of the system evaluation:

- pH
- Electrical conductivity (EC)

• Sodium adsorption ratio (SAR)
• Organic salts – calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), bicarbonate + carbonate (HCO$_3$ + CO$_3$), chloride ion (Cl$^-$), sulfate (SO$_4$-S)
• Water hardness
• Minerals – boron (B), iron (Fe), manganese (Mn)
• Bacterial counts

These measurements are critical for understanding the performance of the drip irrigation system. The study results discuss how these water quality characteristics affect system performance.

4.0 Study Results

Water quality is critical to achieving uniform water distribution in a field. There is a 1:1 correlation between DU and crop yield. Irrigation water that comes from municipal, surface, or well sources may have very different water quality profiles. It must also be noted that water quality can change dramatically throughout the year depending on the water source or quantity available. Many substances in irrigation water can damage drip irrigation system components. Analyzing water quality prior to irrigating with a drip system will best ensure system maintenance is tailored to appropriately mitigate potential problems that may occur due to the water quality profile. Proper system maintenance to maximize DU is critical for maximizing crop yields.

4.1 Distribution Uniformity

DUs for three of the four participants were compared for pre- and post-treatment measurements. Two companies saw significant improvements in their systems after treatment, 7 and 10 percentage points, respectively. Both of these companies ended up with DUs above 90%, which is considered optimal. One company did not see any improvement in their system (DU remained at 83%) while the fourth company did not complete the post treatment analysis. The company that didn’t see any DU improvements, used irrigation tape that needed to be replaced, which greatly affected the system’s performance.

Table 1. Distribution uniformity for participating companies

<table>
<thead>
<tr>
<th>Company</th>
<th>Before Treatment</th>
<th>After Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>83%</td>
<td>83%</td>
</tr>
<tr>
<td>2</td>
<td>73%</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>88%</td>
<td>95%</td>
</tr>
<tr>
<td>4</td>
<td>81%</td>
<td>91%</td>
</tr>
</tbody>
</table>
4.2 pH

It is important to know the pH of the water used in a drip irrigation system for proper system maintenance. Drip irrigation systems are easier to maintain when the pH of the water is slightly acidic. Organic salts and minerals such as iron and manganese are more soluble at lower pH, but will fall out of water (precipitate) and form deposits if the pH is above 7.0 or even above 4.0 for some organic salts. Mineral deposits can contribute to clogging and decreased DU if the water pH is not properly maintained.

The pH of the irrigation water evaluated in the study was mostly alkaline (pH > 7.0): the average pH was 7.7 with a range of 6.95 – 8.2 during the study period.

4.3 Organic salts

Dissolved organic salts or minerals add to the solids content of irrigation water. The most common dissolved salts are calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), sodium (Na$^+$), bicarbonate (HCO$_3^-$), chloride (Cl$^-$), carbonate (CO$_3^{2-}$), and sulfate (SO$_4^{2-}$). Many organic salts are very reactive meaning they will readily combine with other minerals under various conditions to form solids that may then fall out of solution (precipitation). For example, under the right conditions CO$_3^{2-}$ will combine with Ca$^{2+}$ or Mg$^{2+}$, both of which are insoluble in water. These reactions depend on the relative salt concentrations, the water’s pH, among other factors and affect the water chemistry to further perpetuate the potential for precipitation of solids and system clogging. As shown in Table 2, many organic salts are present in the participants’ irrigation water in significant amounts. These amounts, coupled with the tendency of the irrigation water pH toward alkaline conditions (i.e., pH > 7.0) as reported above, creates the potential for dissolved solids to form insoluble compounds and fall out of solution. Some salts (e.g., chloride) are also corrosive when present in high enough concentrations. Maintaining an appropriate water pH will reduce the likelihood that organic salts will precipitate out of solution and cause clogging.

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### Table 2. Organic salts in irrigation water samples

<table>
<thead>
<tr>
<th></th>
<th>Avg (ppm)</th>
<th>Max (ppm)</th>
<th>Min (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca+</td>
<td>79.7</td>
<td>224</td>
<td>54</td>
</tr>
<tr>
<td>Mg+</td>
<td>26.3</td>
<td>37.0</td>
<td>15.0</td>
</tr>
<tr>
<td>K+</td>
<td>8.1</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Na+</td>
<td>128.7</td>
<td>150</td>
<td>111</td>
</tr>
<tr>
<td>$\text{HCO}_3^-+\text{CO}_3^-$</td>
<td>217.8</td>
<td>290</td>
<td>183</td>
</tr>
<tr>
<td>Cl-</td>
<td>126.6</td>
<td>181</td>
<td>68</td>
</tr>
<tr>
<td>$\text{SO}_4^-\text{S}$</td>
<td>65.6</td>
<td>87</td>
<td>39</td>
</tr>
</tbody>
</table>

### 4.4 Water hardness

Water hardness is a collective measurement of dissolved organic salts and other minerals. Hardness is primarily a measurement of calcium and magnesium compounds (e.g., calcium bicarbonate, magnesium bicarbonate), but is also influenced by the presence of other metals such as iron. Hard water may be softened by adding water conditioners that remove dissolved calcium and magnesium. In order to minimize the potential for clogging, water hardness should be less than 150 ppm. Readings >300 ppm are considered to have severe clogging potential. Water hardness for participating companies averaged 288.5 ppm with maximum and minimum measurements of 684 and 196 ppm, respectively. The maximum measurement came from a water sample that was collected from the end of the line before the acid treatment and system flush. The irrigation system had a pre-treatment DU of 81%. This pre-treatment water sample also had the highest measured total dissolved solids (1,600 ppm) and highest EC (2.5 dS/m). In contrast, the water with the lowest level of hardness also had the lowest levels of Ca+ and Mg+, low EC (1.07 dS/m), and a post-treatment DU of 95%.

### 4.5 Other minerals

Other minerals measured in the study were boron, iron (Fe), and manganese (Mn). Some forms of iron are completely water soluble and are not a concern for a drip irrigation system. Iron is very reactive (i.e., easily oxidized) and levels greater than 0.1 ppm can be problematic while levels of 0.4 ppm can cause severe problems. Oxidized iron precipitates out of water and can attach to tubing and completely block emitters. Iron levels in the water evaluated in the
study ranged from 0 to 0.08 ppm with an average concentration of 0.02, well below 0.1 ppm – the level where problems with the irrigation system may begin to occur. Manganese behaves similarly to iron in water, but is much less abundant than iron. The irrigation water under evaluation did not contain any measureable manganese. Boron, although essential to plant growth in minute amounts, can quickly become phytotoxic at higher levels; however, boron does not have any negative effects on the irrigation system itself, and is only included in the water analysis for phytotoxicity purposes.

Table 3. Mineral concentrations in water samples

<table>
<thead>
<tr>
<th></th>
<th>Avg (ppm)</th>
<th>Max (ppm)</th>
<th>Min (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>0.3</td>
<td>0.35</td>
<td>0.13</td>
</tr>
<tr>
<td>Iron</td>
<td>0.02</td>
<td>0.08</td>
<td>0</td>
</tr>
<tr>
<td>Manganese</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

4.6 Bacterial counts

Bacteria in irrigation water cause decreased DU when they form biofilms and slimes that clog emitters and filters. Once bacteria enter the system they rapidly grow in the protective polysaccharide layer they produce in an environment that provides optimal growing conditions (i.e., moisture, warmth, nutrients, etc.). Bacterial populations in drip irrigation systems vary with irrigation water quality – cleaner water sources such as municipal water or well water have less microbial populations than reclaimed water sources that often contain large microbial loads.

There were no obvious trends in the bacterial count data. Bacterial counts in water samples taken at the end of the line were generally higher than counts taken before and after filters suggesting that bacteria in the drip system may be transported by water flowing through the system. One pre-filter and two post-filter water samples had the lowest measured count of 1.00 CFU/mL. The highest level measured 10^7 CFU/mL in a post-filter water sample.
In addition to effects on DU, high bacterial counts potentially have food safety implications as well. Although water was not tested for pathogenic bacteria, bacterial counts in the water indicate that populations were high in the system, which causes some concern for potential pathogenic contamination. Keeping irrigation system components clean is a recommendation in many good agricultural practices guidelines, and this data would indicate that there is a need for implementation of irrigation equipment cleaning procedures.

4.7 Electrical conductivity

Electrical conductivity (EC) is directly related to the salt content of the water and is measured to characterize the salinity of irrigation water. Since an electrical current is transported by ions in solution, in this case – irrigation water, the EC increases as ion concentrations increase. EC is not a measurement directly related to irrigation system performance, but as a water quality parameter, it relates to the health of the soil and crops. Water salinity affects soil and ultimately crop productions with reduced yields when salinity levels approach crop tolerance levels. The appropriate threshold is crop dependent since produce crops vary in their salt tolerance. However, many tree fruit and vine crops are more sensitive to soil salinity than are vegetable and row crops. For tree fruit and vine crops an EC around 1.5 deciSiemens/meter (dS/m) will affect yields while for vegetable and row crops, there may be no effect on yield until EC is 2.0 dS/m.\(^5\) EC of the irrigation water evaluated in this study ranged from 1.02 to 2.50 dS/m with an average reading of 1.20 dS/m.

4.8 Sodium absorption ratio

The sodium absorption ratio (SAR), the measurement of the concentration of solids dissolved in water, is used as one of several general indicators for the suitability of water to be used for irrigation. Similarly to EC, it is not a measurement that is directly related to performance of the irrigation system. The SAR is used to evaluate the sodium hazard associated with irrigation water supplies by comparing the sodium (Na+) ion concentration to calcium and magnesium ion concentrations. The SAR is evaluated in combination with EC to determine whether or not irrigation water will present a permeability problem. With ECs in the study range (1.02 to 2.5 dS/m), SARs below 12 would not be considered problematic.5 Use of irrigation water with a high SAR and incompatible EC can damage soil and create water infiltration problems that affect crop production. SAR in this study ranged from 4.34 to 1.99 with an average ratio of 3.33.

In irrigation water with high levels of bicarbonate ions, the SAR may be adjusted since the bicarbonate can affect the calcium and magnesium concentrations. The water samples in this study had high amounts of bicarbonate so the adjusted SAR was also calculated: the range was 2.62 to 4.97 with an average of 3.86.

5.0 Concluding Study Observations

The lack of system cleaning was observed in all the study systems. Routine cleaning is essential to maximizing performance – even when new parts are added to a system. When new parts are added to a dirty system, the condition and subsequent functioning of the new parts quickly become equivalent to the old parts. When drip tape is not cleaned, buildup of algae, bacterial and fungal slime, biofilms, and mineral deposits rapidly reduce the water flow through the system resulting in unevenness in distribution and decreased water use efficiency. Drip tape and upstream components need to be regularly flushed with antimicrobials and/or cleaning solutions in order to maximize their performance. Due to the reduced water quality of surface water sources, especially reclaimed water, drip irrigation systems using this water have significantly more problems with reduced DU than systems sourcing from wells or municipal water providers. Use of poor quality water requires additional cleaning and maintenance efforts to maintain system performance.

Water pressure also plays a significant part in achieving good DU. All of the systems involved in the study needed to improve pressure by installing pressure gauges and regulating valves.

It is important to choose parts that are appropriately designed for your drip irrigation system and the area to be irrigated. For example, not all drip tape is equal. Some systems did not use drip tape that was well-suited for the area that was to be irrigated. These systems had very long runs and would have benefitted from using a different type of tape that is better suited for systems with longer runs. Some systems were especially leaking and would benefit from installation of insert tape fittings to improve connections and reduce leakage. Several of the
study participants lacked flow meters on their systems or although they installed flow meters, they neglected to use them. Flow meters provide valuable information for understanding how much water is being used and how fast it is being pumped. These numbers are key factors in determining water use efficiency.

Overall there was a general lack of communication between irrigators and others on the operational team. In order to have optimal water use efficiency, it is important that everyone understands the elements of a well-managed irrigation system. Managers need to understand what components are necessary to make the system run efficiently and irrigators need to report equipment problems in a timely manner. With the increasing cost and decreasing availability of water, it is in a grower’s best interest to ensure irrigators are equipped with the resources to effectively manage irrigation.

6.0 Study Recommendations

Mr. McFadden and Mr. Bernier both emphasized the importance of using proper equipment and appropriately maintaining that equipment for achieving optimal DU in drip irrigation systems. Proper use and maintenance of irrigation systems may be time-consuming, but absolutely critical for achieving maximum water distribution uniformity, an essential factor for maximizing water use efficiency and crop yield.

A summary of their recommendations to better manage your irrigation system include:

- Ensure your system components are well suited for the size of the field being irrigated.
- Establish SOPs for system cleaning and schedule system cleaning on a routine basis based on water quality profile.
- Flush system with antimicrobials and/or cleaning solutions to prevent biofilm and slime formation and to dislodge any that is already established.
- Install flow meters and regularly use them to monitor water use efficiency.
- To reduce/prevent leakage, install tape fittings to improve connections.
- Install injection ports and filters at appropriate places in the system for cleaning purposes and to reduce particulate buildup.
• Install pressure gauges and regulating valves to ensure water pressure is sufficient to support a suitable DU.

• Routinely discuss system performance with irrigators and the field operations management team.

7.0 Resources


DripTips Newsletter for Drip Irrigation, Toro: http://driptips.toro.com/


Maintenance of Microirrigation Systems, University of California: http://micromaintain.ucanr.edu/


SmartFarm, precision agriculture, Simplot: http://www.simplot.com/farmers/products/smartfarm