THE UNIVERSITY OF ARIZONA
Cooperative Extension

az2102 January 2025

Understanding Distribution Uniformity in Gravity Drip Irrigation Systems

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Introduction

Adopting micro-irrigation systems has become a promising strategy for increasing water productivity through accurately delivering irrigation water in the root zone (Elnemr et al., 2019; Elsadek, 2018). Pressurized drip irrigation can be used to grow crops under limited water supplies with the possibility of maintaining the exact yield and improving water productivity (Cheng et al., 2021; Elshikha et al., 2023; Hunsaker et al., 2019; Hunsaker and Bronson, 2021). However, changing from flood to drip can be impractical in some areas due to a lack of infrastructure, funding, or energy. Gravity drip (GD) could be an alternative to pressurized drip systems because it does not require any pumping while providing an appropriate soil moisture level to the crop rhizosphere (Omodei and Koech, 2016).

Distribution uniformity (DU, %), defined as a water supply measure relating to the average flow discharge of 25% of the emitters with the lowest flow discharge and the average flow discharge of all the tested emitters, is crucial for gravity drip systems operating at low pressure to achieve optimal water distribution uniformity (Bernardo et al., 2006). Poor DU indicates that some irrigated areas could receive more water and fertilizer than others. Moreover, several pesticides, including insecticides and fungicides, would also be impacted by the distribution uniformity of the irrigation system, which would have implications for pest control efficacy. This would cause irregular plant growth (Gil et al., 2008), development, and affect the final yield (El-Nemr, 2010). Therefore, our objective was to assess the N-Drip gravity irrigation system regarding DU. This will guide growers in efficiently managing their gravity drip (N-Drip) system under the arid climate in Arizona.

N-Drip gravity irrigation system

The N-Drip gravity irrigation system was introduced as a system to precisely and efficiently irrigate field crops, optimizing yields without requiring expensive pumps or filters (Elshikha et al., 2024). The System provides an easy-to-install economic solution that uses the field's existing infrastructure and operates using gravity. Consequently, it is designed to lower initial costs, water use, and money spent on labor and fertilizers (https://ndrip.com/, last accessed October 10, 2024).

Distribution uniformity test

Distribution uniformity (DU) is one of the most widely used indicators to evaluate drip irrigation systems. Therefore, data were collected from three cotton fields distributed across Arizona, as shown in Figure 1, to assess the DU of the N-Drip irrigation systems. For the University of Arizona Maricopa Agricultural Center location, Pinal County, 20 samples were collected along each dripline (112 m or 367 ft) with five replicates, covering a total area of 1.5 ha. The test was conducted three times, representing the beginning, middle, and end of the cotton season. However, at the field in Parker, AZ, La Paz County, the test was carried out during the middle and end of the cotton season, whereas 28 samples were collected from each dripline (189 m or 620 ft) with three replicates, covering a total area of 12.9 ha. At the Safford location, Graham County, the test was only conducted at the end of the cotton season. Like the Parker location, 28 samples were collected along each dripline (387 m or 1270 ft) with three replicates, covering a total area of 4.9 ha.

The DU was calculated following the approach of the On-Farm Irrigation Committee of the Irrigation and Drainage Division (1978), as follows:

$$DU = \frac{qlq^{-}}{q^{-}} x100$$

where qlq^{-} is the average flow discharge of 25% of the emitters with the lowest flow discharge, and q^{-} is the average flow discharge of all the tested emitters (all units

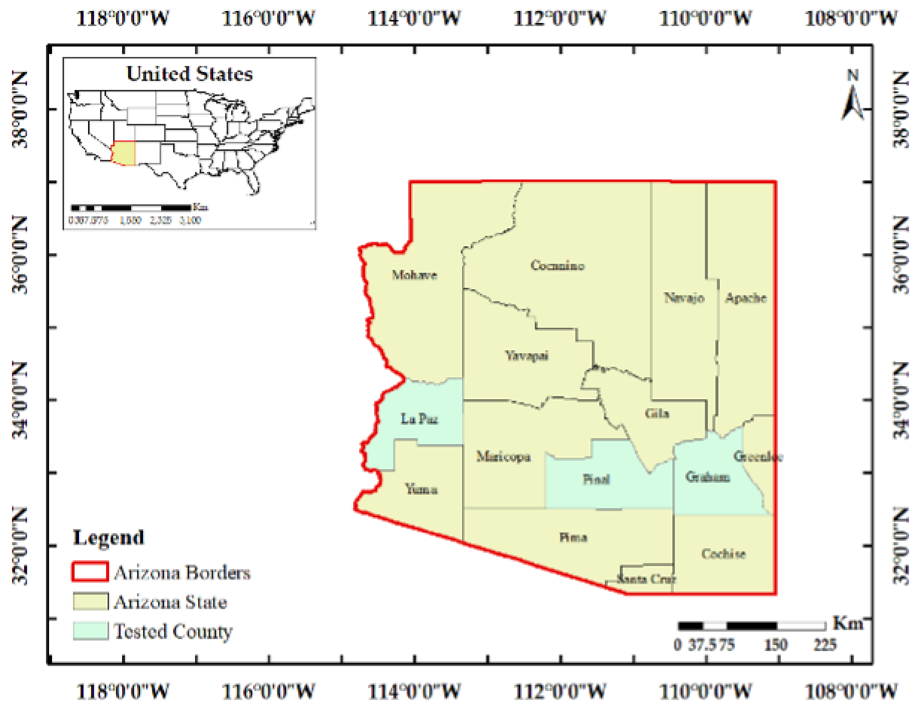

Figure 1. The geographic location of the tested systems in Arizona, US.

are in l hr-1). According to the standards of ASAE EP 458, DU between 87 and 100% is excellent, 75-87% is good, 62-75% is reasonable, 50-62% is bad, and DU < 50% is unacceptable (American Society of Agricultural Engineers (ASAE), 1988).

Results and Discussion

Table 1 summarizes the distribution uniformity (DU) results of the N-Drip gravity irrigation system as the 2024 cotton season progressed. Overall, the N-Drip gravity irrigation system showed unacceptable uniformity in distributing irrigation water along the dripline (field length), especially in the middle and end of the cotton season. For the Maricopa location, the system initially performed well, with DU at 78.1% at the beginning of the cotton season. However, the system's performance declined throughout the evaluation period, where the DU value dropped to 45.8% and 38.9% in July (three months after planting) and September (five months after planting), respectively, reflecting unacceptable DU. This decline was primarily due to emitter clogging, which reduced the average emitter flow rate from 1.87 liters per hour to 1.21 liters per hour by mid-July (-35.3%) and to 1.14 liters per hour by mid-September (-39%).

Similarly, at the Parker location, the flow rate dropped from 1.5 liters per hour (designed flow printed on the tape) to 0.99 and 0.63 liters per hour by July and September, representing 34% and 58% reductions, respectively. Despite this significant reduction in the average flow rate, the DU remained relatively stable, around 42.5-43%. It is possible that higher-than-intended irrigation amounts were applied to compensate for the declining flow rates, masking the full impact of emitter clogging on distribution uniformity.

In contrast, at the Safford location, the measured flow rate during September was 2.16 liters per hour, higher than the design flow rate (1.5 liters per hour, printed on the tape). Despite this, the DU was still low at 59.1%, indicating bad DU across the field. The increase in measured flow rate might result from using a feeding pump delivering the water to the irrigation tanks, maintaining at least 4 feet of water level above the soil surface. This may maintain a steady water level in the gravity drip tank and mitigate the effects of clogged emitters by increasing the flow rate. However, despite the bad DU across the cotton field, this resulted in over-irrigation.

Based on the results, the N-Drip gravity system can perform well initially, but emitter clogging and reduced flow rates can severely impact uniformity over time. Higher emitter flow rates, or irrigation duration, may offset some of these issues but at the expense of efficiency and water savings, undermining the system's potential benefits. The low distribution uniformity observed in the gravity drip irrigation systems is likely due to the system's low operating pressure, which limits its ability to distribute water evenly across the field. Low pressure reduces the driving force necessary to push water uniformly through the emitters, particularly in longer driplines, leading to inconsistent water application, especially toward the end of the field. Frequent acid and chlorine applications may be necessary to prevent clogging and maintain proper emitter flow. However, the low-pressure

Table1. N-Drip, gravity, irrigation system distribution uniformity during the 2024 cotton season in Arizona.

Field 1	**Maricopa Agricultural Center Location, Pinal County, Arizona**		
Designed flowrate, l hr^{-1}	1.5		
Date	May 24, 2024	July 12, 2024	September 13, 2024
qlq^{-}, l hr^{-1}	1.46	0.54	0.44
q^{-}, l hr^{-1}	1.87	1.21	1.14
DU, %	78.1	45.8	38.9
Classification	Good	Unacceptable	Unacceptable
Field 2	**Parker Location, La Paz County, Arizona**		
Designed flowrate, l hr^{-1}	1.5		
Date	-	July 10, 2024	September 04, 2024
qlq^{-}, l hr^{-1}	-	0.42	0.27
q^{-}, l hr^{-1}	-	0.99	0.63
DU, %	-	42.5	43.0
Classification	-	Unacceptable	Unacceptable
Field 3	**Safford Location, Graham County, Arizona**		
Designed flowrate, l hr^{-1}	1.5		
Date	-	-	September 10, 2024
qlq^{-}, l hr^{-1}	-	-	1.28
q^{-}, l hr^{-1}	-	-	2.16
DU, %	-	-	59.1
Classification	-	-	Bad

Note: DU refers to distribution uniformity. According to the standards of ASAE EP 458, DU between 87 and 100% is Excellent, 75-87% is Good, 62-75% is Reasonable, 50-62% is Bad, and DU < 50% is Unacceptable (American Society of Agricultural Engineers (ASAE), 1988). *qlq*$^{-}$ is the average flow discharge of 25% of the emitters with the lowest flow discharge, and □$^{-}$ is the average flow discharge of all the tested emitters.

nature of gravity systems may make these treatments less effective. Therefore, one potential improvement could involve pressurizing the system during acid applications. This would allow the acid to be distributed more effectively throughout the system, helping to reduce emitter clogging and thereby improve distribution uniformity over time. Moreover, improving operational practices, such as regular maintenance, could significantly enhance the performance of gravity drip irrigation systems, reducing irrigation losses and improving crop uniformity.

Conclusions

Across the three tested fields, the N-Drip gravity irrigation system showed good distribution uniformity at the start of the season, which declined to unacceptable by the middle of the 2024 cotton growing season. The decline in uniformity was primarily due to emitter clogging, which is particularly evident at the Maricopa and Parker locations. Over time, sediments and mineral deposits can accumulate in the emitters, especially with the low-pressure of gravity drip systems, restricting water flow and reducing system efficiency. Regular acid treatments are crucial for dissolving buildups and preventing clogging, ensuring consistent flow. Chlorination also effectively manages root intrusion and controls bacteria, algae, and other microorganisms. To enhance the cleaning process, it may be necessary to periodically apply both acid and chlorine under pressure and allow the system to sit overnight with these treatments before flushing. While these approaches may reduce clogging, further investigation is needed to identify the most effective protocol.

In response to poor distribution uniformity, some growers may be tempted to apply more water than the emitter designed, responding to the distribution uniformity challenge to achieve better cotton growth and yield. However, this approach is inefficient and unsustainable, especially given the ongoing water crisis in the U.S. Southwest. Applying more water than necessary undermines the potential water-saving benefits of gravity irrigation systems. Instead, implementing proper maintenance practices, such as timely acid and chlorination treatments and system monitoring, could improve the performance of gravity drip irrigation, ensuring efficient water use while enhancing crop growth.

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