Protecting Water Quality through Improvements in Irrigation Efficiency

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Introduction

Efficient irrigation management maximizes water use for crop production and minimizes water lost through runoff, deep percolation, and evaporation. A portion of water applied during an irrigation benefits crop growth by providing moisture for transpiration and by leaching salts from the root zone. The remainder of the applied water that is lost through run-off and deep percolation not only wastes water, energy, and fertilizer, but can also transport nutrients and pesticides into ground and surface water supplies. With increased pressure on the agricultural community to lessen the loading of nutrients and pesticides into surface and ground water supplies, implementing practices that increase irrigation efficiency can significantly improve water quality.

Though improving irrigation efficiency makes good economic and environmental sense, there are limitations to both evaluating and increasing irrigation efficiency. One of the main limitations is that each field and irrigation system is unique, and requires careful assessment of efficiency as well as the implementation of solutions that fit within the cropping pattern and farming operations. The purpose of this article is to outline some general steps that growers can follow for both evaluating and improving irrigation efficiency.

Defining irrigation efficiency

Irrigation efficiency (IE) is the amount of water that is used to grow a crop compared as a ratio to the total amount of water applied:

$$IE = \frac{Amount\ of\ water\ used\ for\ crop\ production}{Total\ water\ applied}$$

An irrigation efficiency greater than 0.9 or 90% is considered high, and an IE of less than 0.6 or 60% is considered low. An IE of 0.6 would mean that 60% of the applied water is used in the production of the crop, and that 40% of the applied water is lost to evaporation, deep percolation and run-off. In most cases deep percolation and run-off represent a majority of these losses.

Estimating irrigation efficiency

Factors influencing irrigation efficiency

The main factors that influence irrigation efficiency are: 1. distribution uniformity, 2. irrigation scheduling, 3. maintenance and management, and 4. soil variability.

Addressing any or all of these factors can lead to a more efficient use of water, but it is important to consider which of these factors most influences IE and which can be addressed most affordably. For example, converting from a sprinkler to a drip system can be a costly, but effective strategy to improve distribution uniformity. However, improving the maintenance and operation of a sprinkler system might also provide as much improvement in irrigation efficiency as switching to drip irrigation, but for much less cost.

Distribution Uniformity: A well designed and maintained irrigation system will uniformly distribute water to a crop. Furrow, sprinkler, and drip systems can be designed and operated to maximize distribution uniformity (DU), but often poor management or design limitations reduce the uniformity of these systems. The DU of a system is often evaluated by measuring the application rate at 20 or more locations in a field. These data are used to calculate the distribution uniformity of the lowest quarter (DU_{lq}), which is the average application rate of the lowest 25% of the measurements divided by the average of all the application rates measured:

$$DU_{lq} = \frac{\text{average of lowest } 25\% \text{ of application rates measured}}{\text{average of all application rates measured}}$$

Much like irrigation efficiency, a high DU_{lq} (>0.9 or 90%) indicates that a system has a high distribution uniformity. An evaluation of sprinkler and drip irrigation systems conducted by the Monterey County RCD in 2002 showed that the distribution uniformity of sprinkler systems ranged from 0.4 to 0.9 (Figure 1) and the uniformity of drip irrigation systems ranged from 0.6 to > 0.9 (Figure 2). Common reasons for fields with low DU values were poor system designs, and insufficient maintenance.

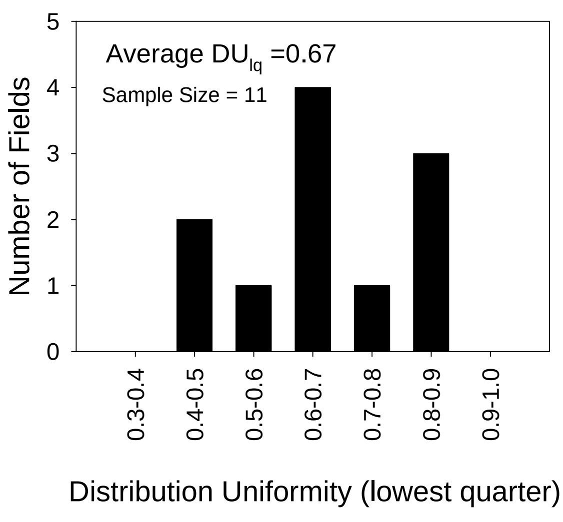

Figure 1. Distribution uniformity of sprinkler irrigated fields in Monterey County measured by the Resource Conservation District, Irrigation Mobile Lab during 2002.

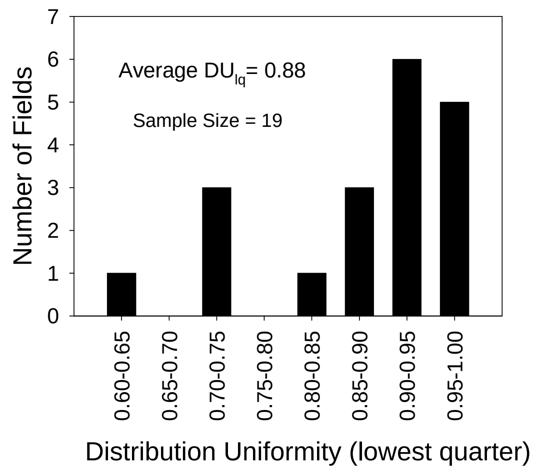

Figure 2. Distribution uniformity of drip irrigated fields in Monterey County measured by the Resource Conservation District, Irrigation Mobile Lab during 2002.

With simple changes in design or operation, many growers can achieve significantly higher distribution uniformities. In distribution pattern studies of solid set sprinklers, we found the spacing of the lateral-lines has a large influence on distribution uniformity (Figure 3). In contrast, offsetting the sprinkler lines into diagonal patterns had a minimal effect on distribution uniformity. Poor regulation of pressure in lateral lines and plugging of emitters can greatly limit the uniformity of drip systems. Using pressure regulators, appropriate diameter drip tape, and tape with pressure compensating emitters can help improve the distribution uniformity of systems designed for fields with significant slopes. Using appropriate filters and performing regular flushing of lines can minimize the plugging of emitters.

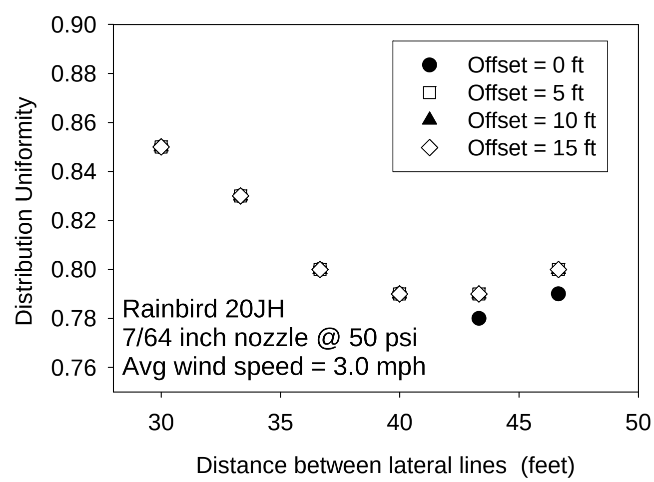

Figure 3. Effect of lateral spacing and head offset on distribution uniformity of impact sprinklers.

<u>Irrigation Scheduling</u>: Systems with high distribution uniformities can have low irrigation efficiencies if they are operated for too long or too frequently. For instance, applying twice the amount of water needed for crop evapotranspiration would reduce the irrigation efficiency to less than 50%. Irrigation schedules can often be improved by estimating the evapotranspiration water-use of the crop using CIMIS (California Irrigation Management Information System) data and by monitoring soil moisture. Daily estimates of evapotranspiration water use can be used to calculate a close approximation of how long and frequent to irrigate, and soil moisture monitoring can serve as a cross-check for fine-tuning the irrigation schedule.

Comparing water use data from flow meter or pumping-hour records with an estimate of evapotranspiration water-use can help determine if an irrigation schedule needs to be improved. For example a 70-day head lettuce crop planted in South Salinas on July 1st of 2004 needed only 12-inches of water for evapotranspiration and to leach salts from the root zone assuming that the distribution uniformity of the sprinkler system was 75%. If water-use records indicated that significantly more water was applied to this field (*ie.* > 16 inches), then it may be worthwhile to evaluate if the irrigations sets were excessively long or too frequent.

For sprinkler systems, understanding the relationship between the nozzle discharge rate, the lateral line spacing and the application rate of the system (Table 1) can help with deciding if the irrigation sets were too long. For instance, a sprinkler system that applies 0.25-inches of water per hour may only need to be operated 2.5 hours to satisfy the 3-day water-use of a 60-day-old head lettuce crop, while a system that has an application rate of 0.17 inches per hour may need to be operated 3.5 hours to apply the same amount of water.

Table 1. Application rates for impact sprinkler systems* of varying nozzle discharge rates** and lateral line spacings.

Lateral	nozzle discharge rate (gallons/minute)							
Spacing	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5
(feet)	Sprinkler Application Rate (inches/hour)							
30.0	0.22	0.25	0.27	0.29	0.31	0.33	0.35	0.37
33.3	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34
36.7	0.18	0.20	0.22	0.24	0.25	0.27	0.29	0.31
40.0	0.17	0.18	0.20	0.22	0.23	0.25	0.26	0.28
43.3	0.15	0.17	0.18	0.20	0.21	0.23	0.24	0.26
46.7	0.14	0.16	0.17	0.19	0.20	0.21	0.23	0.24
50.0	0.13	0.15	0.16	0.17	0.19	0.20	0.21	0.22

* sprinkler head spacing is 30 feet along the lateral lines.

** 7/64” nozzles at 45-50 psi have discharge rates of approximately 2.5 gallons/minute and 1/8” nozzles in the same pressure range have a discharge rate of approximately 3.3 gallons/minute.

Maintenance and management: As mentioned earlier, maintenance and proper operation of an irrigation system are required to optimize distribution uniformity. A check list of some practices to improve the maintenance and operation of drip, sprinkler, and furrow systems is presented in Table 2. The clogging of nozzles, drip emitters, and leaks in lateral lines and submains, all reduce irrigation efficiency. Also, operating sprinklers with too high of an application rate for the soil type, or under windy conditions will reduce irrigation efficiency. Figure 4 shows that sprinkler distribution profile is dramatically altered even in winds below 7 mph. Our field tests also demonstrated that as wind speed increased from 4 to 10 mph, the distribution uniformity of solid set sprinklers decreased from 89% to 57% (Figure 5) with the highest application rates measured near the lateral lines and lowest application rates occurring between the lateral lines.

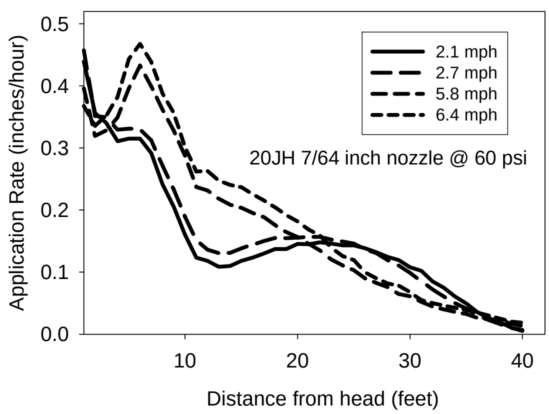

Figure 4. Effect of wind speed on the distribution pattern of impact sprinklers.

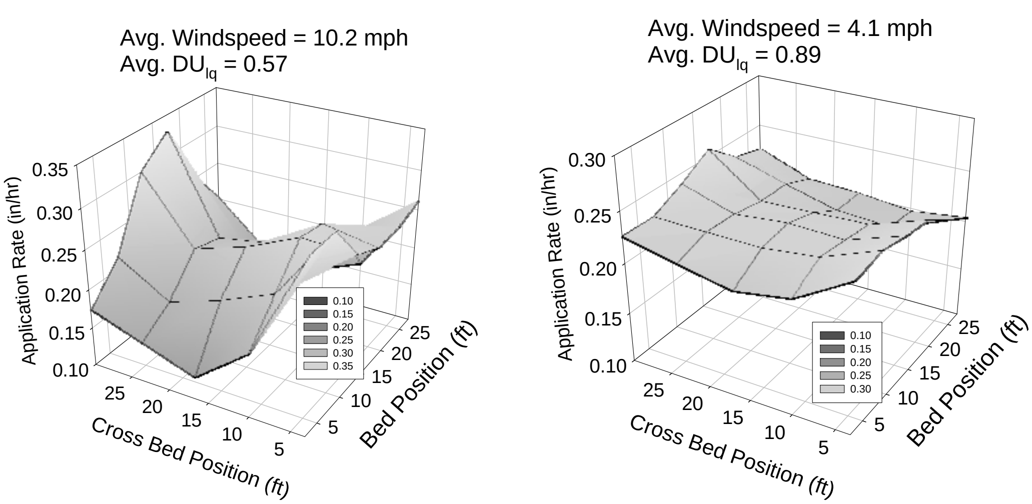

Figure 5. Effect of wind speed on the distribution uniformity of impact sprinklers.

Table 2. Maintenance and management checklist for drip, sprinkler and furrow systems.

Drip Irrigation:
- Fix leaks on main and laterals
- Use filters appropriate for water quality
- Flush filters and drip lines
- Regulate pressure
- Chlorinate lines

Sprinkler Irrigation:
- Operate in low-wind conditions
- Fix leaks on main and lateral lines
- Replace worn gaskets
- Use optimal lateral spacing
- Maintain sprinkler heads
- Use appropriate nozzle size lateral and head spacing
- Use a uniform nozzle size
- Offset hand-move lines
- Maintain appropriate pressure in lateral lines
- Reduce the time of irrigation sets to minimize run-off

Furrow Systems
- Improve uniformity of slope (laser grade/level, plane)
- Smooth furrows prior to irrigating (torpedo)
- Recirculate/reuse tail water
- Short irrigation sets to reduce tail water
- Split field to shorten furrow lengths
- Use amendments to improve infiltration (organic material, gypsum, PAM)
- Use a surge valve
- Irrigate alternate furrows

Soil variability: Soil properties can vary greatly across a field. Though water can be uniformly applied, areas with course textured soil may be more prone to deep percolation and leaching of nitrate and areas with poor drainage may have significant runoff. Managing irrigations for soil variability is generally difficult unless there are clear delineations in soil properties so that the system can be designed and managed differently in each area of the field. In some cases, managing an irrigation system for the most problematic area of the field may be a reasonable strategy. For instance, if run-off occurs at the lower end of a field after 2 hours of irrigating with sprinklers then irrigation sets may need to be reduced to 2 hours. In fields with highly variable soils, converting to drip systems may be the best strategy to increase irrigation efficiency. By frequently applying small amounts of water to match the evapotranspiration demand of the crop, a well managed drip system avoids creating excess run-off and deep percolation.

Summary

Estimates of irrigation efficiency can help growers judge the portion of applied water that is beneficially used for growing the crop and the portion that could potentially impact the quality of ground and surface water. Improving irrigation efficiency will help reduce water usage and production costs as well as address water quality issues by reducing run-off and deep percolation. Growers need to consider four factors in improving irrigation efficiency: distribution uniformity, irrigation scheduling, maintenance and operation, and the variability of soil properties. With the help of irrigation consultants and advisors, growers should aim at adopting the lowest cost improvements that have the most effect on irrigation efficiency.