

MANAGEMENT OF SPRINKLER IRRIGATION SYSTEMS

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ABSTRACT

An efficient sprinkler systems is the result of good system design, proper irrigation scheduling, careful operation, and timely maintenance. This paper presents some general suggestions for wheel move (and hand move) sprinkler management. Good sprinkle irrigation requires an understanding of soil-water-plant relationships and that irrigation timing and amount depends on soil water holding capacity, weather, and crop growth progress. Adequate system design, installation, proper operation and maintenance are important for realizing the benefits of sprinkler irrigation over the system lifetime.

Key Words: wheelmove, hand move, management, sprinkler, alfalfa, evapotranspiration

INTRODUCTION

Sprinkler irrigation has been an important part of agricultural production in the Western United States since the 1950's. About 48 percent (Irrigation Journal, 2000) of the 17 Western States' irrigated acres are watered with sprinklers, including hand move, wheel move, center pivot and other types. Sprinklers can be a good investment when properly designed, installed, maintained and managed. For every acre-foot of water supplied to an efficient sprinkler system a farmer can expect to harvest about 1-3/4 ton of alfalfa and 46 bushels of wheat. In contrast, the expected harvest with a typical surface irrigation system (flood or furrow) is less than 1-1/4 ton of alfalfa or about 30 bushels of wheat for each acre-foot of water supplied to the farm. Sprinklers produce more yield than typical surface irrigation systems per acre-foot because sprinklers apply water more efficiently.

Not all water applied by an irrigation system is used by the crop. Some water is lost to deep percolation, evaporation, or runoff. Application efficiency (Ea) is a term that tells how much of the water applied by the system is actually stored in the root zone for crop use. A good sprinkler system has an Ea of about 70 percent which means that 70 percent of the water applied by the sprinkler heads is actually stored in the soil for crop use. The actual Ea depends upon how evenly the sprinklers distribute water and other factors such as operating pressure, nozzle size and

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spacing, wind, air temperature and humidity (day versus night), irrigation scheduling and maintenance condition. The average efficiency of surface irrigation in the intermountain West is probably less than 50 percent as compared to the higher sprinkler efficiency of 70 percent.

SPRINKLER IRRIGATION MANAGEMENT

An efficient sprinkler system is the result of good system design, proper irrigation scheduling, and careful operation and timely maintenance.

DESIGN

A well designed sprinkler system applies water uniformly to the soil surface and is capable of applying enough water to meet the peak demands of the crop without producing excess runoff. Good design considers such factors as pressure; nozzle size and spacing; wind, air temperature and humidity (day versus night); soil intake rate; crop rooting depth and water use rates.

The flow rate from a sprinkler nozzle depends upon nozzle size and water pressure. Flow rates for selected nozzle sizes and pressures are given in Table 1. Typical sprinkler flow rates may vary from four gallons per minute (gpm) from a 5/32-inch nozzle at 30 pounds pressure to over 11 gpm from a 7/32-inch nozzle at 70 pounds pressure. The nozzle size is usually stamped on the nozzle. Wheelmove systems typically have 3/16-inch nozzles.

Table 1. Sprinkler Pressure and Flowrate.

Nozzle size inch	Nozzle Pressure, psi				
	30	40	50	60	70
	Nozzle flow rate, gallons per minute (gpm)				
5/32	3.9	4.5	5.0	5.4	5.8
11/64	4.7	5.4	6.0	6.6	7.1
3/16	5.5	6.3	7.0	7.7	8.3
13/64	6.4	7.4	8.2	9.0	9.7
7/32	7.4	8.6	9.6	10.5	11.3

Note: Flowrates are for agricultural sprinkler heads with brass nozzles. Sprinkler nozzle flowrate is proportional to the square root of the water pressure at the base of the nozzle.

On sloping fields there may be considerable pressure differences between sprinkler heads on high and low ends of the line. In this situation, flow control nozzles may be used to improve the

uniformity of water application. Flow control nozzles apply water at the same rate, regardless of water pressure.

Precipitation Rate (How hard is it raining?):

The Precipitation Rate (Pr) is the rate at which water is delivered from the nozzle, averaged as inches per hour, over the area covered by one nozzle. It is important to consider the Precipitation Rate when designing a sprinkler system, since water will run off if applied faster than the soil can absorb it. Precipitation rate can be calculated using the following formula:

$$\text{Pr (inches/hr)} = 96.3 \times \text{nozzle flow rate (gpm)/area covered (ft}^2\text{)} \quad (1)$$

Precipitation Rate can be calculated as follows: In a typical wheelmove system, each sprinkler covers 2400 square feet. This is based on a spacing of 40 feet between sprinklers on the line, and a 60 foot move (40' x 60' = 2400 square feet). With 3/16 inch nozzles that are operating at 50 pounds pressure, the nozzle flowrate is 7.0 gpm (from Table 1). The Precipitation rate would be:

$$\text{Pr} = 96.3 (7.0 \text{ gpm})/2400 \text{ ft}^2 = 0.28 \text{ inches per hour} \quad (2)$$

Application Rate (How much of the rain stays in the soil?):

The Application Rate (Ar) is the average rate at which water is stored in the soil, in inches per hour.

$$\text{Ar} = \text{Application Efficiency (Ea)} \times \text{Precipitation rate (Pr)} \quad (3)$$

While sprinkler application efficiency varies with field conditions, 70 percent is a reasonable value.

Example:

$$\text{Ar} = (70/100) \times 0.28 = 0.20 \text{ inches per hour}$$

How Long to Irrigate (Duration):

The duration of irrigation needed to store the crop irrigation requirements in the root zone is:

$$\text{Irrigation Duration (hours)} = \text{Crop Irrigation requirements (inches)/Ar} \quad (4)$$

Example:

Determine how many hours to irrigate in July with a crop irrigation requirement of 8.5 inches, 3/16 inch diameter nozzles at 50 psi and 40' x 60' spacing (use results of previous examples).

$$\text{Hours to irrigate in July} = 8.5 \text{ inches} / 0.20 \text{ inches/hour} = 43 \text{ hours}$$

Assuming that the sprinklers were moved twice per day, about 11 ½ hour sets, then about four irrigations ($4 = 43/11.5$) are needed in July. This is equivalent to one 11 ½ hour irrigation about every 8 days [$8 = 31/(43/11.5)$].

Calculated irrigation duration for nozzle sizes of 5/32 to 7/32 and pressures of 50 and 60 psi are given in Table 2. The durations shown in Table 2 were obtained from the use of Table 1 and Equations 1, 2, and 3, assuming sprinkler spacing of 40' by 60' and 70 percent application efficiency. The Table 2 duration value corresponding to the above examples is 43.2 hours, which is found at the intersection under the 3/16, 50 psi column and the 8.5 inch row.

OPERATION AND MAINTENANCE

General

To realize the full benefit of the sprinkler system, it must be operated according to design and properly maintained throughout the irrigation season. This may involve special operating techniques such as using an offset hose or alternating between day and night on successive irrigation cycles to improve distribution uniformity. Where pressure differences within a sprinkler system result in low uniformity of water application, special hardware such as flow control nozzles or pressure regulators may be required.

Typical hand move and wheelmove sprinklers use impact sprinklers with 3/16" diameter nozzles operating at 45 to 50 psi pressure. Unfortunately, some systems are operating at pressures somewhat below this which lead to problems with distribution uniformity.

Several years back, in a program funded in part by the Utah Department of Agriculture and the Utah Agricultural Experiment Station, numerous sprinkler irrigation systems around the state were evaluated. Irrigation application efficiencies (water stored in the root zone divided by a water delivered to the field) for wheel moves varied from 39 percent to 75 percent. With reasonable good management, the wheelmove application efficiencies averaged nearly 70 percent (Hill, 1994). The lower application efficiencies were from lower pressures than designed or, perhaps, a greater distance in the move than is desirable. One such system we evaluated had a coefficient of uniformity (CU) of 62 percent on the 40 foot by 60 foot sprinkler spacing. The uniformity improved to 87 percent when a 20 foot offset was used on alternate irrigations. The 20 foot offset, in this case, was equivalent to one revolution of the wheel move to either the right or the left of the previous irrigation lateral position.

Table 2. Required Irrigation Duration for Selected Irrigation Water Requirement Values

Irrigation. Water Req'd, inches	Nozzle size, inches									
	5/32		11/64		3/16		13/64		7/32	
	Pressure psi									
	50	60	50	60	50	60	50	60	50	60
Irrigation Duration, Hours										
0.5	3.6	3.3	3.0	2.7	2.5	2.3	2.2	2.0	1.9	1.7
1.0	7.1	6.6	5.9	5.4	5.1	4.6	4.3	4.0	3.7	3.4
1.5	10.7	9.9	8.9	8.1	7.6	6.9	6.5	5.9	5.6	5.1
2.0	14.2	13.2	11.9	10.8	10.2	9.2	8.7	7.9	7.4	6.8
2.5	17.8	16.5	14.8	13.5	12.7	11.6	10.9	9.9	9.3	8.5
3.0	21.4	19.8	17.8	16.2	15.3	13.9	13.0	11.9	11.1	10.2
3.5	24.9	23.1	20.8	18.9	17.8	16.2	15.2	13.8	13.0	11.9
4.0	28.5	26.4	23.7	21.6	20.3	18.5	17.4	15.8	14.8	13.6
4.5	32.0	29.7	26.7	24.3	22.9	20.8	19.5	17.8	16.7	15.3
5.0	35.6	33.0	29.7	27.0	25.4	23.1	21.7	19.8	18.5	17.0
5.5	39.2	36.3	32.6	29.7	28.0	25.4	23.9	21.8	20.4	18.6
6.0	42.7	39.6	35.6	32.4	30.5	27.7	26.1	23.7	22.3	20.3
6.5	46.3	42.9	38.6	35.1	33.1	30.1	28.2	25.7	24.1	22.0
7.0	49.8	46.2	41.5	37.8	35.6	32.4	30.4	27.7	26.0	23.7
7.5	53.4	49.4	44.5	40.5	38.1	34.7	32.6	29.7	27.8	25.4
8.0	57.0	52.7	47.5	43.2	40.7	37.0	34.7	31.6	29.7	27.1
8.5	60.5	56.0	50.4	45.9	43.2	39.3	36.9	33.6	31.5	28.8
9.0	64.1	59.3	53.4	48.5	45.8	41.6	39.1	35.6	33.4	30.5
9.5	67.6	62.6	56.4	51.2	48.3	43.9	41.2	37.6	35.2	32.2

Note: Irrigation duration, hours, calculated from flowrate in Table 1 and from Equations (1), (3), and (3) assuming sprinkler spacing of 40' by 60' and 70% application efficiency.

An audit or evaluation of the irrigation system is recommended if you suspect that the system is not as efficient as it might be. An audit determines application depth, distribution uniformity, and hydraulic performance of the supply system. If a pump is used, it is tested to determine fuel or energy use efficiency. An audit may also identify steps to improve system operation and maintenance.

Good operation also includes matching the set time (or rotation time with a center pivot) with the applied water depth and application rate to maximize the fraction of water stored in the root zone. Field irrigation (application) efficiency is the water stored in the root zone divided by the water delivered to the field. If a field is under-irrigated, a high irrigation efficiency could result with a

low uniformity. Conversely, an over-irrigated field will have a low irrigation efficiency even with a high uniformity because of the deep percolation. Thus, a knowledge of the soil moisture content prior to irrigation is essential to maintaining a high application efficiency while providing for optimum crop water use and growth.

Wheelmove Sequencing

The objective of the moving sequence is to maintain adequate soil water for best crop growth, while not causing excess deep percolation. Deep percolation is detrimental to water conservation and salinity reduction goals. Various wheel move sequencing scenarios have been tried and/or suggested:

- A. Irrigate every move across the block and then roll it back empty. This move sequence is similar to the way hand move lines were used. But a major disadvantage is the long distance the empty line is rolled back.
- B. Skip irrigate every other move across the block and then on return irrigate the skipped sets on the way back instead of rolling back empty.
- C. Irrigate every set across and then start, say twelve hours later, and irrigate every set coming back.

This avoids rolling the line empty all the way back, it also avoids some of the concern about the skip irrigation having alternating unirrigated spots on either side that may bother people. However, irrigating so soon after the previous irrigation causes extra deep percolation losses on the wet side of the field. There is also a longer than needed interval between irrigations on the opposite (or “dry”) side. This mode is not recommended due to the alternate over irrigation followed by soil water shortage.

- D. Irrigate every set across, roll the line empty for about three sets back and then irrigate the rest of the way back. Roll the line empty for three sets or so and then irrigate across again.

This reduces the effect mentioned in Part C above, but does not eliminate it.

- E. Other possible variations exist and depend upon soil, crop and field characteristics.

Wheelmove Maintenance Concerns

Much of the maintenance is related to the single cylinder air-cooled engine and associated hydraulics, gears, and chain drive for moving the system. It is important to follow the engine

manufacturers' recommendations for oil viscosity and change intervals and for air filter, spark plug, and other service requirements. The wheelmove manufacturers provide adequate operation and maintenance instructions to fit their particular drive system. It is important that the owner/operator read and be familiar with and follow the instructions that match the equipment he/she is using (for more information details see USU Extension Fact Sheet WM 05).

Check all nozzles and impact sprinklers for plugging, mismatched sizes, breakage, corrosion or other damage caused by wear or winter weather. Couplers and connections should be checked for leaks and repairs/replacements should be done early. It is a good practice to identify problem components at the end of the previous irrigation season and to have the replacement parts on hand for spring installation. If water leaks occur at joints or drain plugs during irrigation, check the gaskets and pipeline connections for wear or cracks and replace them as needed. Check and tighten the couplers and connectors as required.

In those places where an open ditch water supply is used, adequate screening and sediment removal are essential for minimum trouble operation. This is particularly a problem in the spring and early fall with more trash in the ditches and canals at those times.

There are quite a few anecdotal stories about runaway wheelmoves in high winds. Anytime the wheelmove is empty, and particularly during the off season, it is essential that it be anchored to prevent wind damage. Often this is as simple as moving the system over to a fence and tying it down in three or four places to sturdy posts. However, special wind anchors are available which attach to the lateral pipe and act like a brace to prevent movement.

Gravity Pressure Sprinklers

Wheelmoves and hand moves are used on almost all of the more than 300 gravity pressurized sprinkler systems in Utah. Utah's mountain valley topography is favorable to developing gravity pressurized pipelines. Much of our irrigated area is in mountain valleys in close proximity to canyon streams. Thus, it is often economic to install a pipeline up the canyon to gain about 110 feet or so of elevation induced head. This also has the advantage of reducing open channel water seepage losses in the canyon mouth alluvium and extends the available water supply.

Many previously surface irrigated systems (private irrigation companies as well as individuals) have converted over to gravity pressure wheelmove irrigation. This switch from the traditional (often pioneer built) surface irrigation to gravity pressurized sprinkler has created some interesting situations. The value of "head end" water access opportunities in preference to a "tail end" location in multiple user surface irrigation systems is well known. However, when a conversion to gravity pressure sprinklers occurs, the historically "tail end" irrigators become switched to the "head end" position in that they now have the highest pressure. For some, this is the first time ever that they have had access to abundant water instead of the tail end dribble they are used to. These advantages are often short-lived as the irrigation company board of directors have responded by requiring pressure or flow regulated nozzles and strict adherence to water deliveries proportionate to water stock shares owned.

CROP RESPONSE TO SOIL MOISTURE MANAGEMENT

Agricultural researchers in the Western U.S. have studied the effect of soil water availability on crop yield through the use of such techniques as sprinkler line source field research plots. In this research the irrigation water is varied from none to excessive amounts. Results of such a field study is shown in Fig.1 for alfalfa at Kimberly, Idaho. The relationship between evapotranspiration and corresponding yield is readily apparent. As shown in Fig. 1, alfalfa yields were less than 4.0 ton/acre with deficit irrigation, whereas with adequate water, yields in excess of 9.5 ton/acre were obtained at crop water use values (ET) of 8 and 28 inches, respectively. Results of a farm field study in Utah (Hill, 1983) are similar as shown in Fig. 2.

Based on these and similar studies (see also Bauder, 1998) it is estimated that alfalfa produces about 0.2 ton/acre yield for each inch of consumptive water use (ET) in intermountain U.S. farm fields. This is expressed in the following simple yield model based on water:

$$\text{Alfalfa Yield: } Y = ET \times 0.2 \text{ tons/ac}$$

where Y is alfalfa yield field dry (12 percent moisture), tons/acre, and ET is evapotranspiration, inches. Evapotranspiration is equal to seasonal soil water depletion plus effective growing season rainfall plus irrigation water stored in the root zone.

IRRIGATION SCHEDULING

Irrigation scheduling is the process of determining when to irrigate and how much water to apply. It depends upon design, maintenance, and operation of the irrigation system and the availability of water. The objective of irrigation scheduling is to apply only the water that the crop needs, taking into account seepage, runoff losses, and leaching requirements. Scheduling is especially important to pump irrigators if power costs are high. Common irrigation scheduling approaches include the following:

1. Irrigation on fixed intervals or following a simple calendar, i.e., when a water turn occurs or according to a predetermined schedule.
2. Irrigating when the neighbor irrigates.
3. Observation of visual plant stress indicators.
4. Measuring (or estimating) soil water by use of instruments or sampling techniques such as probes.
5. By following a soil-water budget based on weather data and/or pan evaporation.
6. Some combination of the above.

Figure 1. Yield versus Et for Alfalfa at Kimberly, Idaho (1982).

Figure 2. Alfalfa yield and evapotranspiration - Millard and Iron counties, Utah (1979 - 1981).

For irrigation scheduling to be most useful at a specific location, the following should be done:

1. Evaluate the irrigation system. Determine application depth, efficiency, and operating capabilities and constraints.
2. Select an appropriate irrigation scheduling method.
3. Monitor performance at intervals during the growing season.
4. Perform a post-season evaluation and determine changes for next year.

As a general rule, field crops should be irrigated whenever the soil water depletion approaches 50 percent of the available water in the root zone (see Appendix). In the peak crop water use period in an arid area, the occurrence of rain is often neglected in determining an irrigation schedule. Figure 3 shows the root zone soil water content for an alfalfa field throughout the growing season. This field did not receive sufficient irrigation from the third week of June through late July and again in late August. The soil water content was below 50 percent of available (Field Capacity - Wilting Point) soil moisture prior to and following the first cutting on July 6 and prior to the second cutting on August 30. Consequently, the crop was water stressed and the yield was reduced about 3/4 ton/acre below what could have been realized with better irrigation scheduling.

Figure 3. Calculated (solid line) and measured (triangles) soil water content for a commercial alfalfa field in Rich County, Utah, 1983, irrigated by wheel move sprinkler.

SUMMARY

Good sprinkle irrigation requires:

- Understanding of Soil-Water-Relationships
Irrigation timing and amount depends on soil water holding capacity, weather, and crop growth progress.
- Adequate Design and Installation
- Proper Operation and Maintenance
- Dedication and Commitment of Resources to Manage
(i.e., the **WILL** to manage)

BIBLIOGRAPHY

- Bauder, J.W. 1998. Simple Yield Models Based on Water. Montana State University, Bozeman. Personal communication (e-mail).
- Hill, R.W. 1991. Irrigation Scheduling. Chapter 12 in Modeling Plant and Soil Systems, John Hangs and J.T. Ritchie (eds.), American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc., Madison, WI. 491-509.
- Hill, R.W. 1994. Consumptive Use of Irrigated Crops in Utah. Utah Agr. Exp. Stn. Res. Report No. 145, Utah State University, Logan, UT. Oct. 370 pp. Revised and reprinted Feb. 1998.
- Hill, R.W. 1997. Utah Topography Favors Wheelmoves. Irrigation Business and Technology. November. Vol. V. No. 6, pp. 30-35, 59.
- Hill, R.W. and R.G. Allen. 1996. Simple Irrigation Scheduling Calendars. Journal Irrigation and Drainage Division. ASCE. 122:2, March/April.
- Hill, R.W. , R.J. Hanks, and J.L. Wright. 1984. Crop Yield Models Adapted to Irrigation Scheduling Programs. Utah Agr. Exp. Stn. Res. Report 99.
- 2000, 1999 Annual Irrigation Survey, Irrigation Journal, Jan/Feb 2000.

For additional reading/resource material see:

- Larsen, D.C. and T.S. Longley. "Nozzle Management and Leak Prevention for Sprinkler Irrigation." Current Info. Series No. 569. University of Idaho Coop. Extension Service, Moscow, ID 83843.
- MSU Agronomy Notes Series numbers 44, 47, 49, 53, 102, and 122. J.W. Bauder. Soil and Water Specialist; Plant, Soils and Environmental Science Department, Montana State University, Bozeman, MT 59717. Telephone (406) 944-5685; email: jbauder@montana.edu.
- Pacific Northwest Extension Publication, PNW Series numbers 286-292. Jan. 1986. Available from University of Idaho Cooperative Extension Service, Moscow, ID 83843. Titles in this series include: *Pumping Plant Efficiencies, Offsets for Stationary Sprinkler Systems, Irrigation Runoff Control Strategies, Irrigation Scheduling, Converting Sprinkler Systems to Lower Pressure, Sizing Irrigation Mainlines and Fittings, Electrical Demand Charges-How to Keep them Low, Extending Electric Motor Life.*

APPENDIX

<u>Available Water-holding Capacity of Soils</u>		<u>Typical Crop Rooting Depths</u>	
Soil Texture	Inches of available water per foot of moist soil	Crop	Typical active root Zone depth, feet
Sands and fine sands	0.5 - 0.75	Alfalfa	5
Very fine sands, loamy sand	.8 - 1.0	Corn	4 - 5
Sandy Loam	1.2 - 1.5	Small Grains	3 - 4
Loam	1.9 - 2.0	Dry Beans	3
Silt loam, silt	2.0	Pasture	1.5 - 2.5
Silty clay loam	1.9 - 2.0	Potatoes	2 - 3
Sandy clay loam, Clay loam	1.7 - 2.0	Turf	1 - 2
		Vegetables	1.5 - 3

Allowable depletion to avoid crop water stress is usually about 50% of available water holding capacity for most field crops.

INTERNET SITES FOR ADDITIONAL INFORMATION

The web site address for UAES Research Report #145 data tables used in Table 3 herein is found by going to the Utah Division of Water Rights home page at: <http://nrwrt1.nr.state.ut.us/>

Select "Publications" and then select "Consumptive Use Tables"

The direct URL is: <http://nrwrt1.nr.state.ut.us/techinfo/consumpt/default.htm>

The web site address for USU Extension electronic fact sheets can be located at: <http://www.ext.usu.edu>

Select "Publications" and then select "Irrigation Engineering"

- ENGRBIE/WM/05 - Maintenance of Wheelmove Irrigation Systems
- ENGRBIE/WM/07 - Sprinklers, Crop Water Use, and Irrigation Time
- ENGRBIE/WM/08 - Wheelmove Sprinkler Irrigation Operation and Management