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Sprinklers, Crop Water Use, and Irrigation Time: San Juan County

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SPRINKLERS, CROP WATER USE, AND IRRIGATION TIME
SAN JUAN COUNTY

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Sprinkler irrigation has been an important part of Utah's agricultural production since the early 1950s. About 40% of Utah's 1.3 million 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 tons 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 tons of alfalfa or about 30 bushels of wheat for each acre-foot of water applied. Sprinklers apply water more efficiently and uniformly than typical surface irrigation systems, thus they produce more yield for each acre-foot of water.

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. In Utah a typical sprinkler system has an Ea of 70% which means that 70% of the water applied by the sprinkler heads is actually stored in the soil for crop use. The actual Ea depends on how evenly the sprinklers distribute water as well as other factors such as operating pressure, nozzle size and spacing, sprinkler maintenance condition, wind, air temperature and humidity (day versus night), and irrigation scheduling. In Utah, the average efficiency of surface irrigation is less than 50% as compared to the higher sprinkler efficiency values of more than 65% for well managed systems.

SPRINKLER IRRIGATION MANAGEMENT

An efficient sprinkler system is the result of good system design, proper irrigation scheduling, 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 on 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 4 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 side of the nozzle. Wheelmove systems typically have 3/16-inch nozzles.

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 nearly the same rate when operated within the rated pressure range of the nozzle.

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 Pr 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:

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

Table 1. Sprinkler Pressure and Flow Rate.

Nozzle size	Nozzle Pressure, psi				
	30	40	50	60	70
Inch	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: Flow rates are for agricultural sprinkler heads with brass nozzles. Sprinkler nozzle flow rate is proportional to the square root of the water pressure at the base of the nozzle, thus doubling the pressure does not double the flow rate.

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' × 60' = 2400 square feet). With 3/16 inch nozzles that are operating at 50 pounds pressure, the nozzle flow rate is 7.0 gpm (from Table 1). The precipitation rate would be:

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

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.

$$Ar = \text{Application Efficiency (Ea)} \times \text{Precipitation rate (Pr)} \quad (2)$$

Typical sprinkler application efficiency values vary from 60% to 80%, with 70% a reasonable average.

Example:

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

How Long to Irrigate (Duration):

The duration of irrigation needed to store the crop irrigation requirement (evapotranspiration, Et) in the root zone is:

$$\text{Irrigation Duration (hours)} = \text{Crop Irrigation requirement (inches)}/Ar \quad (3)$$

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

Hours to irrigate in July = 8.5 inches/ 0.20 inches/hour ≅ 43 hours
Assuming that the sprinklers were moved twice per day (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% application efficiency. The Table 2 duration value corresponding to the above example is 43.2 hours, which is found at the intersection under the 3/16 nozzle, 50 psi column and the 8.5 inches of water required row. Crop water use estimates for Utah are given in Hill (1994).

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 evaporation, 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. Following a soil-water budget based on weather data and/or pan evaporation.
6. Some combination of the above.

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 flow rate in Table 1 and from Equations (1), (2), and (3) assuming sprinkler spacing of 40' by 60' and 70% application efficiency. Irrigation water required is equivalent to crop evapotranspiration, if rainfall is ignored (see Table 3).

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.

Operation and Maintenance

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.

An audit or evaluation of the irrigation system is recommended if you suspect that the system is not as efficient as it should 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 irrigation water depth and application rate to maximize the fraction of water stored in the root zone. Field irrigation (application) efficiency is the ratio of water stored in the root zone divided by the water delivered to the field. For example, if 50 acre inches of water are delivered to a 10 acre field during an irrigation and 30 acre inches are stored in the root zone, then the application efficiency (Ea) is 60% ($60 = 100 \times 30/50$). 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, regardless of the 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.

Crop Water Use

The single most important factor influencing plant growth and crop yields is soil water availability. A good understanding of how water influences crop growth is essential for good water management. Water is the most massive of the inputs to crop yield. It takes 120 pounds of water (evapotranspiration only) to produce 1 pound of potatoes, 560 pounds of water for 1 pound of alfalfa hay and 790 pounds of water for 1 pound of wheat.

Soil water availability is affected by infiltrated irrigation water and rainfall, drainage and evapotranspiration. The crop irrigation requirement, or evapotranspiration (Et), is the combination of transpiration from plant leaves plus evaporation from adjacent soil surfaces. While crop Et can be measured, it is most often estimated with equations from weather data collected locally. Estimated average monthly crop water use (Et) for alfalfa, pasture, spring grain, and turf in Blanding, Bluff, and Monticello are given in Table 3. Seasonal Et is higher in Bluff than in Monticello and Blanding for all crops. Alfalfa Et is higher in July at Blanding and Monticello and is also higher in August at Blanding. In the case of spring grains, Monticello's Et is much higher in July than Blanding or Bluff. Although, the peak monthly Et of spring grain at

Bluff, 8.51 inches in June, exceeds peak monthly Et values of other crops and sites. These differences reflect variations in crop growth dates at the three locations.

Assuming that the soil water depletion is completely replenished with each irrigation, the irrigation requirement is equal to Et minus effective rainfall. As a general rule, field crops should be irrigated whenever the soil water depletion approaches 50% of the available water in the root zone (see Appendix). This minimizes crop stress and keeps yields high. In the peak crop water use period in an arid area, the occurrence of rain is often neglected in determining an irrigation schedule.

Table 3. Monthly Crop Evapotranspiration for Blanding, Monticello, and Bluff.

Site	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Season Total
Alfalfa Water Use, Inches									
Blanding		2.80	6.31	5.61	7.54	6.49	3.86	1.70	34.30
Bluff	0.31	3.43	6.70	6.41	6.78	5.96	5.13	2.01	36.71
Monticello		1.00	5.37	5.77	7.18	5.37	3.77	0.12	28.57
Pasture Water Use, Inches									
Blanding	0.29	2.05	4.11	4.97	5.62	4.79	3.33	1.44	26.59
Bluff	0.62	2.47	4.36	5.55	5.94	5.03	3.81	2.03	29.81
Monticello	1.36	3.66	4.68	5.23	4.49	3.19	0.58		23.19
Sp Grain Water Use, Inches									
Blanding		1.17	5.37	7.64	5.54				19.72
Bluff	0.21	1.70	6.18	8.51	3.98				20.57
Monticello		0.26	2.79	6.97	7.77	1.89			19.66
Turf Water Use, Inches									
Blanding	0.30	2.22	3.55	4.28	4.85	4.12	2.87	1.24	23.43
Bluff	0.72	2.41	3.75	4.78	5.12	4.33	3.29	1.75	26.15
Monticello		1.56	3.27	4.04	4.51	3.87	2.75	0.29	20.28

Adapted from: Consumptive Use of Irrigated Crops in Utah, Utah Agricultural Experiment Station Research Report No. 145. Oct. 1994.

CALCULATING AN IRRIGATION INTERVAL

The information needed to determine the interval between irrigations is available soil water in the root zone, crop water use (Et) rate (inches per day), and allowable soil water depletion at irrigation. Conversely, the irrigation system applied water depth (if fixed for all irrigations) could be used in place of the allowable depletion.

Example A: Simple Irrigation Calendar. Determine the irrigation interval and application depth for alfalfa on sandy loam at Bluff. Use July Et and a root depth of 5 ft. Irrigate when one half of the available soil water has been depleted, i.e., when the management allowed depletion

(MAD) is 50%.

From Table 3, July Alfalfa Et at Blanding is 7.54 inches.
Average daily Et rate = 7.54 inches/31 days = 0.24 inches/day.

Soil water holding capacity (sandy loam) is1.5 inches/ft (from Appendix).
Root zone available water = 5 ft × 1.5 inches of water/ft = 7.5 inches of water.

At a MAD of 50% depletion between irrigations, the irrigation amount is 7.5 × .5 = 3.8 inches for each irrigation.
Irrigation interval = Irrigation amount/daily Et rate = 3.8 inches/0.24 inches per day ≅16 days.

Summary: Irrigate every 16 days, storing 3.8 inches of irrigation water in the root zone.

Example B: Alternate irrigation interval if wheelmove sprinklers are moved twice per day. Assume 3/16 inch nozzles at 50 psi and 40 ft by 60 ft spacing (see examples with Equations 1, 2, and 3 previously), and the same situation as in Example A above.

The net irrigation is 2.3 inches stored in the soil (2.3 inches = an application rate of 0.20 inches per hour x 11.5 hours per set).
The irrigation interval = 2.3 inches/0.24 inches per day = about 9 1/2 days.

Summary: Irrigate every 9 1/2 days, storing 2.3 inches of irrigation water in the root zone.

Both of these examples use the average daily Et rate for the month to illustrate the calculations. If a real time soil water budget method of irrigation scheduling were used, it would account for the day to day variations in Et and rain. This would result in varying the irrigation interval as needed.

SUMMARY

Good sprinkle irrigation requires:

- Understanding of Soil-Water-Plant Relationships
- Proper 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)

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APPENDIX

Available Water-holding Capacity of Soils			**Typical Crop Rooting Depths**	
Soil Texture	Inches of available water per foot of moist soil	Permeability rate[1] Inches/Hour	Crop	Typical active root Zone depth, feet
Sands and fine sands	0.5 - 0.75	1.0 - 10	Alfalfa	5
Very fine sands, loamy sand	.8 - 1.0	1.0 - 3	Corn	4 - 5
Sandy Loam	1.2 - 1.5	0.5 - 3	Small Grains	3 - 4
Loam	1.9 - 2.0	0.3 - 0.8	Dry Beans	3
Silt loam, silt	2.0	0.2 - 0.4	Pasture	1.5 - 2.5
Silty clay loam	1.9 - 2.0	0.01 - 0.2	Potatoes	2 - 3
Sandy clay loam, Clay loam	1.7 - 2.0	0.1 - 0.6	Turf	1 - 2
			Vegetables	1.5 - 3

Note: Allowable depletion to avoid crop water stress is usually about 50% of available water holding capacity for most field crops.
[1]Normal ranges. Intake rates vary greatly with soil structure and structural stability.

The web site address for "Consumptive Use of Irrigated Crops in Utah," UAES Research Report #145, and the data tables used in Table 3 herein is found by going to the Utah Division of Water Rights home page at: http://nrwrtl.nr.state.ut.us/

Then select "Publications" and then select "Consumptive Use Tables."

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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.*

Additional information on wheel move sprinkler management is available on the Utah State University web site at:

http://extension.usu.edu/publica/engrpub2.htm

BIE/WM-05 “Maintenance of Wheelmove Irrigation Systems”
BIE/WM-08 “Wheelmove Sprinkler Irrigation Operation and Management”

WHERE CAN YOU GET HELP?

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