Water Distribution Under Sprinkler Irrigation

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WATER is being applied to millions of acres of irrigated lands by many types of sprinkler and surface-irrigation systems. Uniform water distribution by these systems is necessary to maximize crop yield and quality. Also, uniform water distribution is necessary for more efficient use of the available irrigation-water supplies. For these reasons, improvement in water distribution by both sprinkler and surface irrigation systems is very important to irrigated agriculture.

To gather more information on water distribution by agricultural sprinkler systems under southern Idaho conditions, studies were made of the water distribution from a handmove sprinkler system during a normal irrigation season, from five types of sprinkler systems operating individually, and from three types of systems operating simultaneously with the same type sprinkler heads, nozzle sizes, sprinkler spacing on the lateral, nozzle pressure, and wind conditions. The maximum average rate at which these systems applied water to the soil surface was determined since this is a factor to be considered in the final distribution of water on the soil. The effect of low and high windspeeds on the application rate of a side-roll sprinkler system, and the effect of compaction by farm machinery on the infiltration rate of the soil in a potato field were measured. Both soil compaction and wind can cause water to accumulate on the soil surface and result in poor water distribution.

The distribution of water by a sprinkler irrigation system is a two-part job – distribution from the sprinkler nozzles to the soil or crop surface and distribution in the soil profile from the soil surface.

Water is distributed to the soil or crop surface mechanically. Deviations from a pattern obtained under zero windspeed can be considered random since they are influenced by varying wind speed and direction, both of which tend to be randomly distributed. Therefore, the cumulative pattern during a long time interval or from two or more irrigations would be expected to be more uniform than most individual irrigations during the irrigation season.

If the application rate of the sprinkler system is less than the infiltration rate of the soil, the water will enter the soil near the spot where it was applied by the sprinkler. If the application rate is greater than the infiltration rate of the soil, runoff occurs and water distribution is poor.

Factors Affecting Water Distribution

Many factors affect the distribution of water to the soil or crop from the sprinkler system. These can be grouped under sprinkler heads, distribution system, climatic and management factors.

Sprinkler head factors include nozzle size, nozzle angle, rotation speed, pressure at nozzle, number and type of nozzles.

Distribution system factors include sprinkler head spacing on the lateral, spacing of laterals along the main pipeline, height of sprinkler above the soil or crop, stability of the sprinkler riser, and pressures variation in the sprinkler system.

Climatic factors are windspeed and direction.

Management factors are duration of system operation, velocity of lateral or sprinkler movement over the ground in self-propelled laterals and sprinkler machines, alignment of laterals, and alignment of sprinkler risers with the vertical.

Water-distribution tests of individual springler heads have been reported in numerous publications (1, 2, 3, 4, and 5)*. However, information is lacking on water distribution under many types of operating sprinkler systems. Therefore, the present study was conducted to determine the water distribution for handmove, side roll, sequencing solid set, center pivot self-propelled, straight lateral self-propelled, and side move with trailer lines systems under climatic conditions of southern Idaho. The seasonal cumulative water distribution, as well as individual irrigation water distributions, were determined for a handmove system typical of those used to irrigate crops in the Snake River valley of Idaho. Water-application rates were determined for all systems tested.

Procedure and Results

All water-distribution patterns were complied from data obtained by using spray catch cans set to collect the spray from each operating sprinkler system. The catch cans were made from quart oil cans and were placed in a rectangular grid pattern over the area between lateral settings. Cans were spaced 10 ft apart, beginning 5 ft from the sprinkler in each direction. Depths of water caught were measured volumetrically using a 100 or 250-cc graduate. Kerosene was used to suppress evaporation from the spray catch cans.

The average application rate for each catch-can location in a plot was calculated by dividing the inches of water caught by the number of hours the sprinkler lateral was in operation. For moving laterals, the time was that which elapsed between the first drop collected in a catch can to the last drop into the can as the lateral passed overhead. The rate at the catch-can location in a pattern having the greatest depth of water was reported as the maximum average application rate for that system.

Sprinkler-system operating pressure was measured at the sprinkler nozzle with a pitot tube and pressure gage. Wind speed was determined from a standard U.S. Weather Bureau recording anemometer or from a portable weather station located near the test site.

Christiansen's coefficient of uniformity (Cu) was calculated using the formula:

$$Cu = 100\ (1.0 - \frac{\Sigma x}{mn})$$

where x is the deviation of individual observations from the mean value, m, and n is the number of observations.

The infiltration rate of the soil for sprinkler design was measured using the Tovey method (8). This infiltration rate equals the average application rate at which water does not accumulate on the soil surface when the soil moisture in the soil profile is at field capacity. The water applied by the sprinkler at one point just disappears from the soil surface by the time the sprinkler head completes one revolution and is ready to apply water to the same point again.

The hand-move system operated during an entire season consisted of 500 ft of 3-in. aluminum lateral with sprinklers spaced 40 ft apart along the pipe-

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* Numbers in parentheses refer to the appended references.

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TABLE 1. CHRISTIANSEN'S COEFFICIENT OF UNIFORMITY FOR EACH IRRIGATION AND FOR ACCUMULATIVE IRRIGATIONS DURING THE 1965 SEASON FOR A HANDMOVE SPRINKLER LATERAL HAVING A 40 × 60 FT SPRINKLER SPACING

Irrigation	Plot number										
number	1	2	3	4	5	6	7	8	9	10	11
1	49	56	57	48	31	52	52	56	63	59	36
2	85	90	89	87	88	89	87	88	86	87	88
3	73	77	71	75	76	77	77	80	73	81	73
4	75	77	59	71	76	78	72	70	80	73	72
5	81	85	86	84	83	83	86	86	85	82	77
1-2	86	89	88	87	86	86	87	90	89	90	80
1-3	88	89	84	87	86	89	88	90	87	90	86
1-4	87	87	84	85	86	88	88	86	90	90	86
1-5	88	88	85	87	86	88	88	87	89	92	87

line. Conventional single-nozzle sprinkler heads having a 5/32-in. nozzle were used. Operating pressure was maintained at 35 psi. The sprinkler lateral was moved 60 ft on the main pipeline and operated for the same length of time at each irrigation.

Time to start an irrigation was determined using gypsum-soil moisture blocks to avoid bias in selecting climatic conditions. These blocks were installed at three locations in the spray catch-can area at 12 and 18-in. depths. When a majority of the soil moisture blocks reached a predetermined resistance reading, the grain crop was irrigated. Four irrigations were applied in 1964, five in 1965, and four in 1966. Results obtained each year showed the same trend, so data from the 1965 season were selected for this report.

The water distribution for adjacent settings of the lateral and the total water for each can location in the area between lateral settings were determined for each irrigation. Cumulative water distribution patterns were obtained by summing the depth of water caught in the same can location from each of two or more irrigations.

The area between sprinkler laterals was divided into eleven plots, each bounded by four sprinklers, for computing the Christiansen coefficient of uniformity and determining the maximum average rate of water application.

Christiansen's coefficient of uniformity (2) for each irrigation and for accumulative irrigations on each plot during the 1965 season for a handmove sprinkler lateral having a 40 x 60-foot spacing are presented in Table 1. The maximum variation in the coefficient of uniformity for individual irrigations of any one plot was from 31 to 88, while the minimum variation was from 63 to 86. The maximum variation in the uniformity coefficients for the accumulative distribution from two to five irrigations on individual plots was from 80 to 88, while one plot had no variation, the coefficient of uniformity being 86 for all accumulated irrigations.

The maximum average rate of water applied to the soil during each lateral set is shown in Table 2. The rate varied from 0.09 to 0.50 in. per hr. No water accumulated on the soil surface using any of these rates.

Five sprinkler systems, using manufacturer-supplied equipment or field systems operated under southern Idaho conditions, were tested for water distribution and maximum averagė application rates at the soil or crop surface for single irrigations. These types of systems were side roll, sequencing solid set, center pivot self-propelled, straight lateral self-propelled, and side move with trailer lines.

The side roll system had a 1/4-mile lateral length and the nozzle pressure was 40 psi. Sprinkler heads were spaced 40 ft apart on the lateral and the lateral move was 50 ft on the main pipeline. Sprinkler nozzle sizes were 5/32 in. for one series of tests, and 11/64 in. for the second series of tests. Windspeed for the first series of tests averaged 1.9 mph, and 13 mph for the second series.

The sequencing, solid-set system was portable with two-nozzle sprinklers spaced at 70-ft intervals along the lateral. Sprinklers on alternate laterals were offset to give a triangular spacing of 70 ft between sprinklers. Sprinkler nozzle sizes were 7/32 and 3/32-inch., and the operating pressure was 76 psi.

The center-pivot, self-propelled system had a 1485-ft lateral length. Nozzle pressure at the pivot point was 80 psi. Sprinkler nozzle sizes on this system varied from 1/8 to 1/2 inch in diameter and speed of lateral movement was one revolution in 48 hr.

The straight lateral, self-propelled system had single-nozzle sprinkler heads with 5/32-in. nozzles operated at 50 psi. Sprinklers were spaced 40 ft apart along the lateral. Lateral speed of movement was varied from 8.3 to 12.8 ft per hr.

The side-move type with trailer line system had trailer lines spaced 40 ft apart on the 5-in.-diameter carriage lateral. Each trailer line had three sprinkler heads spaced 50 ft apart. Sprinkler heads were the 2-nozzle type with 1/8 and 3/32-in. nozzles. Nozzle pressure was 50 psi.

Christiansen's coefficient of uniformity and maximum average application rates under various windspeeds for five mechanical-move and solid-set systems operated for one irrigation are shown in Table 3. The average application rates for the circular, self-propelled system are shown in Table 4.

A comparison was made of three types of sprinkler systems operating simultaneously for water distribution and maximum average application rates. The systems were handmove portable lateral, straight lateral self-propelled, and side move with trailer lines. For these tests, all systems had the same type of sprinkler heads, sprinkler-nozzle size, nozzle pressure, and wind pattern. Sprinkler heads were single-nozzle, medium-pressure type with 5/32-in. nozzles operated at 50 lb per sq in. Speed of movement of the self-propelled lateral was 25 ft per hr.

The coefficients of uniformity, maximum average application rates, and average wind speeds for two tests of three systems operated simultaneously under the same operating and climatic conditions are shown in Table 5.

The effect of low and high wind speeds on the application rate of the side-roller sprinkler lateral was determined at the same time the water distribution pattern and maximum average application rate were determined. The infiltration rate for sprinkler design was measured on the soils in the sprinkled areas. Those can locations having average application rates in excess of the measured infiltration rate for sprinkler design were used to determine the percentage of area to which water was applied faster than the soil could absorb it.

The coefficients of uniformity, maxi-

TABLE 2. MAXIMUM AVERAGE RATE OF WATER APPLICATION IN INCHES PER HOUR MEASURED AT THE SOIL OF CROP SURFACE (Handmove SprinklerSystem)

Irrigation and lateral	Plot number										
set No.*	1	2	3	4	5	6	7	8	9	10	11
1a	0.17	0.18	0.17	0.17	0.14	0.15	0.15	0.17	0.14	0.18	0.50
1b	0.17	0.19	0.19	0.17	0.16	0.18	0.19	0.19	0.19	0.22	0.27
2a	0.20	0.19	0.20	0.20	0.18	0.21	0.19	0.18	0.20	0.21	0.22
2b	0.18	0.19	0.18	0.18	0.18	0.18	0.19	0.18	0.19	0.20	0.19
3a	0.18	0.19	0.25	0.20	0.16	0.16	0.13	0.14	0.13	0.13	0.18
3b	0.13	0.17	0.19	0.16	0.16	0.18	0.16	0.19	0.18	0.17	0.09
4a	0.18	0.16	0.12	0.19	0.13	0.15	0.19	0.21	0.17	0.16	0.20
4b	0.13	0.17	0.16	0.20	0.16	0.16	0.16	0.16	0.11	0.12	0.23
5a	0.17	0.20	0.20	0.19	0.24	0.22	0.18	0.20	0.21	0.17	0.20
5b	0.14	0.17	0.17	0.18	0.20	0.18	0.18	0.19	0.20	0.16	0.17

* a, first lateral set, and b, second lateral set for indicated irrigations.

TABLE 3. INDIVIDUAL SYSTEM COEFFICIENTS OF UNIFORMITY, MAXIMUM AVERAGE APPLICATION RATES AND WINDSPEEDS

Type system	Christiansen's coefficient of uniformity	Maximum average application rate, in. per hr	Average wind speed during test, mi per hr	Speed of lateral travel
Side roll	71	0.38	13.0	----
	76	0.32	13.0	----
	86	0.19	1.9	----
	89	0.18	1.9	----
Sequencing solid set	75	0.22	6.0	----
	75	0.22	5.5	----
	78	0.24	4.3	----
Self-propelled center pivot	81	(See Table 4)	7.1	1 rev per 48-hr
	86		5.0	1 rev per 48-hr
Straight lateral self-propelled	89	0.17	6.0	11.1 ft per hr
	89	0.18	3.2	8.3 ft per hr
	90	0.16	2.9	12.8 ft per hr
Side move with three sprinklers on each trailer line	84	0.31	2.8	----
	86	0.37	3.9	----
	87	0.42	4.1	----
	88	0.38	2.9	----

TABLE 4. AVERAGE WATER APPLICATION RATES FROM PIVOT POINT TO OUTER END OF A CENTER PIVOT, SELF-PROPELLED SPRINKLER LATERAL

Distance from pivot, ft	Average application rate, in. per hr
0 + 95	0.21
1 + 85	0.22
2 + 75	0.25
3 + 65	0.35
4 + 55	0.35
5 + 45	0.43
6 + 35	0.39
7 + 25	0.45
8 + 15	0.45
9 + 05	0.53
9 + 95	0.65
10 + 85	0.72
11 + 75	0.81
12 + 65	0.83
13 + 55	0.73
14 + 45	1.01

mum average application rates, average wind speeds, and percentage of area that the average application rate exceeded the measured sprinkler design infiltration rate of the soil for a side roll sprinkler system are shown in Table 6. The measured sprinkler-design infiltration rate for the soil at this test site was 0.19 in. per hr. Under light wind conditions, the water stayed where distributed by sprinkler. Under high-wind conditions, water was applied faster than the soil could absorb it over from 40 to 50 percent of the wetted area. This resulted in runoff which changed the water distribution that the sprinkler system applied.

The change in infiltration rate for sprinkler design due to compaction by farm machinery in a potato field during a season was measured using the Tovey method (8). Infiltration measurements were made in the bottom and the top of potato furrows until foliage growth prevented further measurements. Measurements were made after the first, third, and fourth irrigations.

The measured changes in infiltration in a potato field during the season are shown in Table 7. The infiltration rate in the tractor-wheel furrow declined from 0.41 in. per hr after the first irrigation to 0.25 in. per hr after the fourth irrigation, and the middle furrow rate declined from 0.47 to 0.37 in. per hr after the same number of irrigations. The potato field was cultivated after each irrigation, and the tractor pulling a 4-row cultivator passed down the wheel furrow during each cultivation. The middle furrow was free from wheel compaction. Water from the sprinkler system accumulated on the surface of the wheel furrow, but not in the middle furrow. Movement of the accumulated water to lower ground changed the water distribution applied by the hand-move sprinkler system.

Discussion

The sequencing soil-set system tested gave individual plot coefficients of uniformity lower than acceptable. This could be improved by closer spacing of the sprinklers. Maximum average application rates were within the range of all but the slowest infiltration rate soils.

The center-pivot, self-propelled sprinkler system gave good uniformity of water distribution to the soil surface. Average application rates varied from 0.21 in. per hr at the first tower from the pivot point to 1.01 in. per hr at the last tower on the outer end of the lateral. The application rate by the larger nozzles was so high that the water could be absorbed as rapidly as applied only by high infiltration-rate soils. Many soils under irrigation today have infiltration rates of less than 0.35 in. per hr, so the average application rate of part of this lateral would exceed the infiltration rate of the soil. Surface movement of water on all but level lands may cause poor water distribution. It should be emphasized that application rates under self-propelled systems are much higher than the maximum average application rates listed for them in Tables 3, 4, and 5. The rate of water accumulation in the test cans follows a normal or Gaussian type of distribution, with finite ends limited by the times at which the first and last drops enter the cans as the lateral passed. The maximum average application rate is the height of a square curve with the same area and base length. As a result, actual instantaneous rates exceed the maximum average rate of application.

The straight lateral, self-propelled sprinkler system had excellent water distribution in individual irrigations. Maximum average application rates were low enough for most soils.

The side move with trailer line system gave good uniformity of water distribution. The application rate, because of the solid set nature of operation, was moderate. This is caused by the overlap from the discharge of adjacent sprinklers.

The comparison of water distribution from three types of sprinkler systems operating simultaneously shows that the straight-lateral, self-propelled sprinkler gave higher coefficient of uniformity than the handmove or side move with trailer line systems. However, the instantaneous water-application rate of any movable sprinkler system a t a point in the pattern will vary from zero through a maximum, then back to zero as the movable lateral passes over the point. Under the handmove and side move with trailer-line systems, the instantaneous application rate does not have the wide variation caused by the moving lateral, and this results in a higher average maximum, water-application rate for these systems.

Under high wind conditions, the average water-application rate exceeded the measured sprinkler design infiltration rate over 40 percent of the wetted soil surface under a side roll system. This caused runoff which distorted the water distribution as applied by the system.

Soil compaction by tractor wheels changed the infiltration characteristics of a soil in alternate rows of a potato field so that the handmove sprinkler system being used applied water faster than the compacted soil could absorb the water. Surface runoff occurring in the compacted alternate rows distorted

TABLE 5. CHRISTIANSEN'S COEFFICIENTS OF UNIFORMITY AND MAXIMUM APPLICATION RATES FOR STRAIGHT LATERAL SELF-PROPELLED, SIDE MOVE WITH THREE SPRINKLER TRAILER LINES, AND HAND-MOVE SPRINKLER LATERALS OPERATED UNDER SAME CONDITIONS

Type system	Christiansen's coefficient of uniformity	Maximum average application rate, in per hr	Average wind speed during test, mi per hr
Handmove,	79	0.26	4.9
40 × 50	92	0.26	5.2
Straight lateral	90	0.14	4.9
self-propelled	95	0.14	5.2
Side move with	77	0.34	4.9
three trailer lines	89	0.34	5.2

the water distribution from the sprinkler system.

Conclusions

Multiple irrigations by handmove portable sprinkler laterals gave acceptable seasonal water distribution as measured by the Christiansen coefficient of uniformity, even though some individual irrigations yielded poor water distributions. If water distribution on the first irrigation of a crop is a critical factor in better crop production, better results might be obtained by applying half the water in one irrigation and half in a second irrigation if windy conditions prevail.

Straight lateral, self-propelled sprinkler systems gave better water distribution for individual irrigations than handmove or carriage with trailer line systems when all factors were the same.

Poor water distribution can result from water movement on the soil surface due to the sprinkler system applying water faster than the soil can absorb it. This may be caused by poor system design, high wind speeds, or machinery compaction of soil in parts of the irrigated area.

TABLE 6. WATER DISTRIBUTION AND APPLICATION RATE FROM A SIDE ROLL SPRINKLER SYSTER OPERATED AT 40 PSI NOZZLE PRESSURE

Nozzle size, in.	Christiansen's coefficient of uniformity, 40 × 50 ft	Maximum average application rate in. per hr	Average wind-speed, mi per hr	Percentage of area average application rate exceeded infiltration rate of soil*
5/32	76	0.32	13.0	40
5/32	89	0.18	1.9	0
11/64	71	0.38	13.0	50
11/64	86	0.19	1.9	0

* Measured sprinkler design infiltration rate of soil was 0.19 in. per hr.

TABLE 7. CHANGES MEASURED IN SPRINKLER-DESIGN INFILTRATION RATES IN A POTATO FIELD

	Maximum sprinkler design infiltration rate, in. per hr					
	Wheel furrow		Middle furrow		Furrow ridge	
Date, 1965	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
June 10*	0.41	0.44	0.49	0.47	0.49	0.47
July 15	0.35	0.31	0.46	0.44	....	....
July 27†	0.25	0.24	0.38	0.37	....	....

* Measured after first irrigation.
† Measured after fourth irrigation.

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