SPRINKLER UNIFORMITY AND ITS EFFECT ON PRODUCTION[1/]

By

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About a million acres of land in Nebraska are being irrigated by all types of sprinkler systems. Uniform water distribution by these systems is important to optimize crop yield and quality, allow minimum sprinkler system capacity and power requirements, and make more efficient use of the available irrigation water supplies. Even distribution of water over the soil surface is important to irrigated agriculture, but more important is uniform distribution of the water in the soil to optimize production where water is the limiting production factor.

When I first started to work with agricultural sprinkler irrigation systems, there was only one type — handmove. The cost and lack of labor for moving the handmove sprinkler laterals one, two or more times each day during the irrigation season resulted in the development, marketing, and use of many types of mechanical move systems.

Today's farmer has a choice of nine major types of sprinkler systems and many versions of each type. The nine types are: handmove, tow line, giant sprinkler, side roll, side move with and without trailer lines, solid set, center pivot self-propelled, straight lateral self-propelled, and traveller. The first six major types of sprinkler systems are set systems — the sprinkler or sprinklers apply water while in a fixed position in the field. The last three types are moving systems — the sprinkler or sprinklers apply water while continuously moving across the field.

The water distribution to the soil or crop by these various systems is affected by system design, climate, and management.

The system design factors include the sprinkler head, nozzle size, nozzle angle, number of nozzles, sprinkler head rotation speed, pressure at the nozzle, spacing of sprinklers along the lateral, spacing of laterals on the main pipeline in set systems, uniformity of lateral movement in continuously moving laterals, and pressure variations in all systems. Enough individual sprinkler distribution tests have been made where these factors have been varied to give a system designer the information needed to predict the water distribution that can be obtained under the field conditions where the system is used.

The climatic factors affecting distribution are windspeed and direction. These factors have less effect on the distribution pattern of continuously moving lateral systems than on set systems.

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Management factors are concerned with how you operate your sprinkler system and how they affect water distribution, as well as production from the field. Do you plan your irrigation to minimize under- or overwatering parts of the field? This planning includes the proper time to start irrigation, as well as the duration of operation of the laterals in a set system so that each area gets the same amount of water from each sprinkler lateral set. I've seen some operations where the morning lateral set was operated 10 hours and the evening lateral set operated 12 hours. With this unbalanced operation, crop growth was uneven across the field because the shorter set was subjected to higher daytime winds and evaporation and did not apply the needed water to the crop. The longer set applied too much water, which probably leached some of the soluble plant food from that area.

Also, the timing of the irrigation can affect the overall water distribution pattern. Many continuously moving sprinkler systems operate on a 36-hour rotation, so that an area is irrigated alternately under the high wind conditions of daytime and the no or very low wind conditions of nighttime, thus improving the overall water distribution pattern.

The uniformity with which sprinklers distribute water over the field is measured by setting catch cans on a regularly spaced pattern over the area and measuring the depth of water caught in each can for one irrigation. Various formulas have been developed to describe the uniformity indicated by these measurements. The formula most generally used is the Christiansen coefficient of uniformity (Cu) (1), which is calculated by the following equation:

$$Cu = 100\left(1.0 - \frac{|\Sigma x|}{mn}\right) \qquad [1]$$

where x is the deviation of the individual observations from the mean value, m, and n is the number of observations. A uniformity coefficient of 100 means uniform distribution of water over the area. Most designers consider a uniformity coefficient of 80 or better to be acceptable.

A method for determining the uniformity coefficient for center-pivot systems was developed by Heerman and Hein (4). A radial row of catch cans set at regularly spaced intervals along the length of the lateral is used to catch the water from one irrigation. The depth measured in each can is assumed to be representative of a circular subarea having a width equal to the can spacing and a subarea diameter equal to the distance from the pivot point to the can location. The equation for calculating Cu is:

$$Cu = 100\left|1.0 - \frac{\Sigma\left|Vs - \overline{V}s\right|}{V}\right| \qquad [2]$$

where Vs is the volume of water applied to each subarea and is assumed to be equal to the measured depth (d) times the subarea (As) represented by a point measurement. $\overline{V}s$ is the average volume for a subarea and is the product of the average depth, $\overline{D}$, for all lateral measurements by the subarea (As), and V is the total volume applied to the total area irrigated by the center-pivot system.

Not many system water distribution uniformities have been measured under field conditions, but a few have been reported in the literature for handmove, side roll, side move, center-pivot, and straight moving laterals.

Table 1 shows the uniformity coefficient evaluated at Kimberly, Idaho (5) for each irrigation and for accumulated irrigations of a barley crop using a handmove sprinkler lateral having a 5/32-inch nozzle and a 40- × 60-foot sprinkler spacing.

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-foot sprinkler spacing.

Irrigation number	Area between sprinklers, 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
6	82	83	56	50	80	84	87	86	86	85	69
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
1-6	88	89	87	86	88	90	90	91	91	92	89

The water distributions for the first, third, and fourth irrigations were all below the 80 or better level that most designers strive to obtain, but multiple irrigations gave uniformity that was equal to or better than that required by acceptable design standards.

Table 2 shows the uniformity coefficients obtained for five systems for individual irrigations.

Table 2. Individual system coefficients of uniformity, Kimberly, Idaho.

Sprinkler system	Average windspeed during test, mph	Speed of lateral travel	Christiansen's coefficient of uniformity
Side roll	13.0	—	71
	13.0	—	76
	1.9	—	86
	1.9	—	89
Sequencing solid set	6.0	—	75
	5.5	—	75
	4.3	—	78

(Table 2 - continued)

Self-propelled center-pivot	7.1	1 rev./48-hr.	81
	5.0	1 rev./48-hr.	86
Straight lateral self-propelled	6.0	11.1 ft./hr.	89
	3.2	8.3 ft./hr.	89
	2.9	12.8 ft./hr.	90
Side move with three sprinklers on each trailer line	2.8	—	84
	3.9	—	86
	4.1	—	87
	2.9	—	88

The uniformity coefficients for three types of irrigation systems operating at the same time, with the same nozzle sizes, nozzle pressures, and climatic conditions show that the self-propelled straight moving lateral gave a better distribution pattern, Table 3.

Table 3. Coefficients of uniformity and maximum application rates for three irrigation systems operated under the same conditions, Kimberly, Idaho.

Sprinkler system	Average windspeed during test, mph	Christiansen's coefficient of uniformity
Handmove, 40' × 50'	4.9	79
	5.2	92
Straight lateral self-propelled	4.9	90
	5.2	95
Side move with three trailer lines	4.9	77
	5.2	89

Table 4 shows the alfalfa yield obtained for four coefficients of uniformity under sprinklers on a deep, well-drained soil at Davis, California (2).

Table 4. Effect of uniformity coefficient on alfalfa yield, Davis, California, 1962.

Coefficient of uniformity	87.2	86.8	63.0	16.0
Hay yield, tons/acre	8.04	8.12	8.12	7.54

The uniformity results reported in Tables 1, 2, and 3 were from systems that applied the water to the soil at a rate at which it could be absorbed at the point of application. Since the plant responds to the distribution of the water replaced in the root zone depth of the soil, the uniformity with which a sprinkler system applies water to the soil may or may not result in optimum production. If the application rate exceeds the soil infiltration rate and the land topography is irregular, some water is going to move to areas other than where it was applied, so that water distribution in the soil may be highly non-uniform. This has happened on some Idaho center-pivot operations, even though the water distribution uniformity under a 1285-foot lateral on a silt loam soil was 89. The soil moisture percentage by weight for typical high and low areas after an irrigation are shown in Table 5.

Table 5. Soil moisture content by weight*

Soil depth	Low areas	High areas
inches	%	%
0-6	16.4	5.6
6-12	15.8	7.4
12-18	16.4	10.4
18-24	17.0	14.7

* Data courtesy Dr. Robert A. Kohl

When potatoes were grown under this sprinkler system, the yield and quality were much better on the low soil areas than on the high areas. The same was true for bean yield; the high soil areas had 4 bean pods per plant at harvest, whereas the low soil areas had 14 to 16 bean pods per plant.

Yield of potatoes under two standard quarter-section length center-pivot sprinkler systems was measured between the outside two towers, between the middle two towers, and between the inside two towers on soils where there could be no water movement on the soil surface. The water distribution uniformity and yields are shown in Table 6.

Table 6. Potato yields under two center-pivot systems.

Coefficient of	Yield in tons per acre		
uniformity	Outside	Middle	Inside
81	22.32	21.78	24.09
74	30.51	25.55	22.37

In conclusion, from the very limited data available, the uniformity with which sprinklers apply water over an area may have a large or a minor effect on crop yield. The uniformity with which water is applied to a shallow-rooted crop on soils of low water-holding capacity would affect the crop yield. On deep soils with a high water-holding capacity and a deep-rooted crop, crop yields would vary less, providing that the water is applied at a rate that permits its infiltration at the point of application. Also, water applied by the sprinklers is redistributed in all soils, so the soil water distribution coefficient of uniformity may be better than the water application coefficient of uniformity of the sprinkler system (3).

Multiple irrigations showed better water distribution than single irrigations. Continuously moving lateral sprinkler systems gave better water application uniformity to the soil than the set systems under windy conditions.

Yield variations can result from the improper amount of water being applied or the poor timing of a single irrigation, or both. Poor system maintenance also has caused poor water distribution uniformity and poor yields.

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