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APPLICATION RATES AND UNIFORMITY OF APPLICATION FROM MECHANICAL-MOVE SPRINKLER SYSTEMS[1]

Claude H. Pair
Agricultural Engineer
Snake River Conservation Research Center
Kimberly, Idaho

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

Uniform water distribution by sprinkler systems is essential to optimize crop yield and quality; allow minimum sprinkler system capacity; conserve pumping power, and make more efficient use of the available irrigation water supplies. It is very important where the system is used to apply fertilizers and pesticides in irrigation water. To obtain uniform water distribution in the soil with sprinkler systems, the application rate should be equal to or less than the intake rate and surface storage capacity of the soil so that there is no runoff or water movement on the soil surface.

Factors Influencing Water Distribution

Water distribution and permissible application rates by these various systems can be affected by soil, topography, system design, climate, crop and management. The soil type, depth, profile and compaction conditions determine the intake rate which limits the application rate of a given sprinkler system if runoff is to be prevented.

Variations in topography can cause changes in pressure at the sprinklers along the lateral in addition to the pressure loss caused by pipe friction. On steeper slopes, there is also less surface water storage capacity available if the application rate exceeds the soil intake rate. Movement of water on the surface soil can reduce the uniformity of water retained by the soil.

The system design parameters which affect distribution include the type of sprinkler head, nozzle size and 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 stationary systems, uniformity of movement of continuously moving laterals, and pressure variations in all systems. Individual sprinkler distribution tests have been made where many of these parameters have been varied to give the system designer the information needed to predict the water distribution under the field conditions where the system is used.

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The two climatic factors that affect both application rate and distribution are windspeed and direction. These factors have less effect on the distribution pattern of continuously moving laterals than on stationary laterals.

Higher application rates can be used on a given soil type with crops having a continuous ground cover, such as alfalfa and grass, than with crops having partial ground cover. Some crops interfere with the water distribution in installations, like undertree sprinkling in orchards, citrus groves, and shrubbery.

Management factors concern the manner in which a sprinkler system is operated, which can affect both the seasonal water distribution and crop production. Irrigations may be planned to minimize under or over-irrigating parts of the field. Irrigation planning also includes the proper time to start irrigation as well as the operating time for each lateral set in a stationary system so that each subarea receives the same depth of water.

The timing of an irrigation also can affect the overall water distribution pattern. Many stationary systems are operated at different times of the day on successive irrigations, such as irrigating once during the day when windspeeds are high, and irrigating the next time at night when windspeeds are low. Many continuously moving center-pivot systems operate on an 18-, 36-, or 60-hour rotation so that each subarea is irrigated alternately under the high wind conditions during the day and the low wind conditions at night, thus improving the overall seasonal water distribution pattern where more than one irrigation per season is applied.

Evaluation of Systems

The application rate and uniformity with which sprinklers distribute water over the field was measured by setting catch cans on a regularly space pattern over the area irrigated, measuring the depth of water caught and the time of application at each can for one irrigation. The average rate of water application for each point in the pattern is calculated by dividing the depth of water caught by the time of application.

Various coefficients have been developed to describe the uniformity of water application by a sprinkler system. The coefficient most generally used is the Christiansen coefficient of uniformity (Cu) (1) which is calculated from the following equation:

$$Cu = 100 \quad 1.0 \quad \left(\frac{|\Sigma x|}{mn} \right)$$

where x is the deviation of the individual point measurement from the mean value m of all point measurements, and n is the number of point measurements. A coefficient of uniformity of 100 means an equal depth of water has been applied over the area. Most designers consider a Cu of 80 or better to be acceptable.

A method for determining the coefficient of uniformity for center-pivot systems was developed by Heermann and Hein (3). A radial row of catch cans spaced at regular intervals along the length of the lateral is used to catch the water during one pass of the lateral. The depth measured in each can is assumed to be representative of a circular ring with a subarea having a width equal to the can spacing and an average diameter equal to the distance from the pivot point to the catch can. The equation for calculating the coefficient of uniformity Cu is:

$$Cu = 100 \left| 1.0 - \frac{|Vs - \overline{V}s|}{V} \right|$$

where V_s is the volume of water applied to each subarea and is assumed to be equal to the measured depth (d) time the subarea represented by this depth measurement; $\overline{V}_s$ is the average volume for a subarea and is the product of $\overline{D}$, the average depth over the total area irrigated by the center-pivot and the subarea as; V is the total water volume applied to the total area irrigated by the center-pivot.

Results

Water distribution and application rates were measured at Kimberly, Idaho under field conditions for five types of mechanical-move sprinkler systems. Some of these results have been previously reported (4) and are shown in Tables 1 and 2.

The application rates for center-pivot systems vary from the pivot to the outer end of the lateral with the maximum rates occurring near the far end of the lateral from the pivot, and depend upon the arrangement, types, and sizes of sprinklers along the lateral. Figure 1 shows typical wetted areas for three types of sprinkler arrangements in use today. The lateral with variable size sprinklers has small sprinklers near the pivot and progressively larger sprinklers and spacings toward the outer end of the lateral. This lateral usually has 35 to 40 sprinklers in a quarter-mile system. The lateral with all one size sprinklers from the pivot to the outer end has progressively decreasing sprinkler spacings and increasing nozzle sizes from the pivot to the outer end. This lateral usually has from 80 to 100 sprinklers in a quarter-mile system. The lateral with spray jets has fixed spray-type nozzles with the water discharge capacity increasing from the pivot toward the outer end of the lateral.

Application rates 1200 feet from the pivot were measured using tipping bucket raingages and recorders for the three types of center-pivots. Typical application rates are shown in Figures 2, 3, and 4. The peak rates were highest for the spray jet systems and lowest for the variable size sprinkler systems.

Multiple irrigations will usually improve the overall uniformity of distribution over a field. A stationary system was monitored during four irrigations. Coefficients of uniformity between sprinklers for the length of the lateral for the individual irrigations are shown in Table 3. The cumulative water depths obtained at each irrigation location were determined, and the uniformity calculated for 2, 3, and 4 irrigations. The results are shown in Table 3. The maximum application rate measured in each area is shown in Table 4.

Discussion

All systems tested gave acceptable to good water distribution patterns except the sequencing solid set system and two of the center-pivot systems. The poor distribution from the sequencing solid set system was due to sprinklers being spaced too far apart for the winds in the area, risers not tall enough to eliminate interference with the sprinklers by the crop, and insufficient support for the riser which permitted vibration of the sprinkler head. The center-pivot systems having lower distribution coefficients were due to poor design in one case where a filter was not used to remove trash from the water which plugged spreader nozzles and the nozzles on the second system were not arranged properly.

Conclusions

The trend in sprinkler systems is toward more mechanization because of irrigation labor shortages at critical irrigation times. Mechanized systems give equal or better water distribution than handmove systems when properly designed and operated. Also,

Table 1. Coefficients of uniformity, maximum average application rates, and windspeeds observed for various systems.

Type system	Christiansen's coefficient of uniformity	Maximum pattern application rate in/hr	Average windspeed during test mph
Side roll	71	0.38	13.0
	76	0.32	13.0
	86	0.19	1.9
	89	0.18	1.9
Sidemove with trail lines having 3 sprinkler per line	84	0.31	2.8
	86	0.37	3.9
	87	0.42	4.1
	88	0.38	2.9
Sequencing solid set	75	0.22	6.0
	75	0.22	5.5
	78	0.24	4.3
Self-propelled straight lateral	89	0.17	6.0
	89	0.18	3.2
	90	0.16	2.9
Self-propelled gun traveler (5, 6)	81.8	0.48	----
	87.7	----	16.0
	92.0	----	14.0
	89.9	----	5.0
	86.4	----	Calm
	88.8	----	7.0
	89.5	----	12.0
	89.0	----	3.0
	93.8	----	4.0

Table 4. Maximum rate of water application measured in each plot for each irrigation.

Irrigation	Area Number										
Number	1	2	3	4	5	6	7	8	9	10	11
	in/hr										
1	0.24	0.19	0.19	0.20	0.27	0.25	0.17	0.17	0.21	0.20	0.20
2	0.20	0.22	0.20	0.24	0.34	0.20	0.18	0.18	0.21	0.21	0.19
3	0.17	0.15	0.21	0.17	0.15	0.25	0.16	0.23	0.15	0.17	0.24
4	0.18	0.16	0.20	0.22	0.22	0.27	0.26	0.13	0.14	0.18	0.19

water applied to the soil surface by any system is redistributed in all soils, so the soil water distribution coefficient of uniformity may be better, or worse when runoff occurs, than the water application coefficient of uniformity of any sprinkler system (2).

Multiple irrigations give higher coefficients of uniformity and result in better water distribution. This can be important where more than one fertilizer, insecticide, and weedicide application is being applied through the sprinkler system.

Table 2. Water distribution data for center-pivot sprinkler systems.

System No.	Average depth of application	Average application rate	Peak rate	Wind velocity	Christiansen's coefficient of uniformity
	in	in/hr	in/hr	mph	Cu
1	0.76	0.62	0.83	10.0	80.1
2	0.52	0.59	1.09	5.2	70.6
3	0.89	0.62	----	--	80.2
4	0.47	0.88	----	3.6	85.9
5	0.63	0.38	----	8.2	80.2
6	0.49	1.20	2.55	2.9	80.6
7	0.43	0.56	----	---	88.6
8	0.31	3.33	----	2.0	76.0

Table 3. Christiansen's coefficient of uniformity for each plot along a lateral for individual and combined irrigations.

Irrigation	Area Number										
Number	1	2	3	4	5	6	7	8	9	10	11
1	81	85	87	85	81	85	87	87	84	82	82
2	83	87	89	88	78	89	88	90	86	85	84
3	80	76	78	75	76	71	76	75	77	76	76
4	82	78	81	85	81	78	73	83	59	79	74
1-2	85	90	91	90	82	86	91	91	88	85	84
1-2-3	87	88	87	88	81	85	88	86	89	85	86
1-2-3-4	88	88	87	88	82	84	88	86	84	86	86

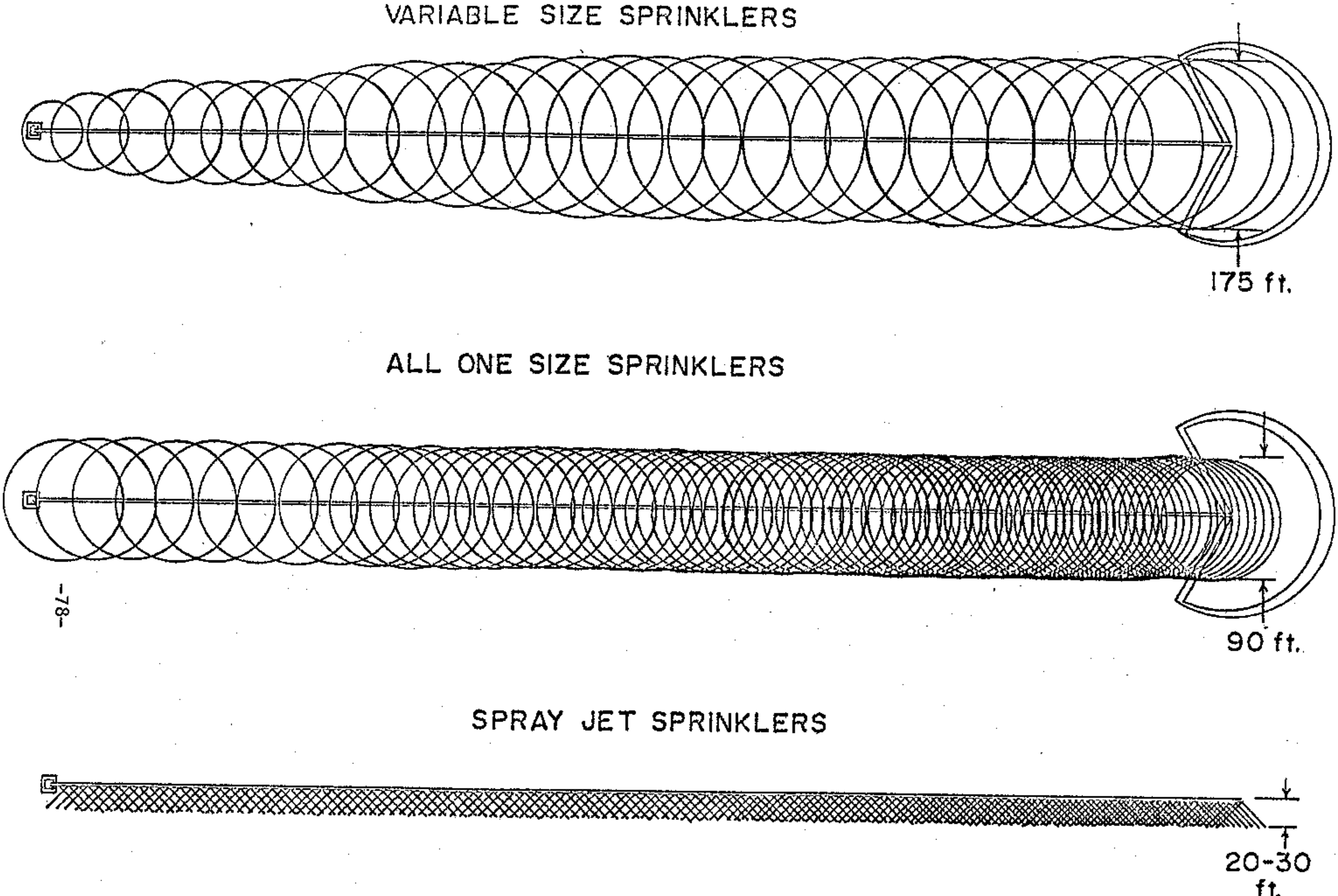

Fig. I Wetted pattern for various sprinkler arrangements along center pivot laterals.

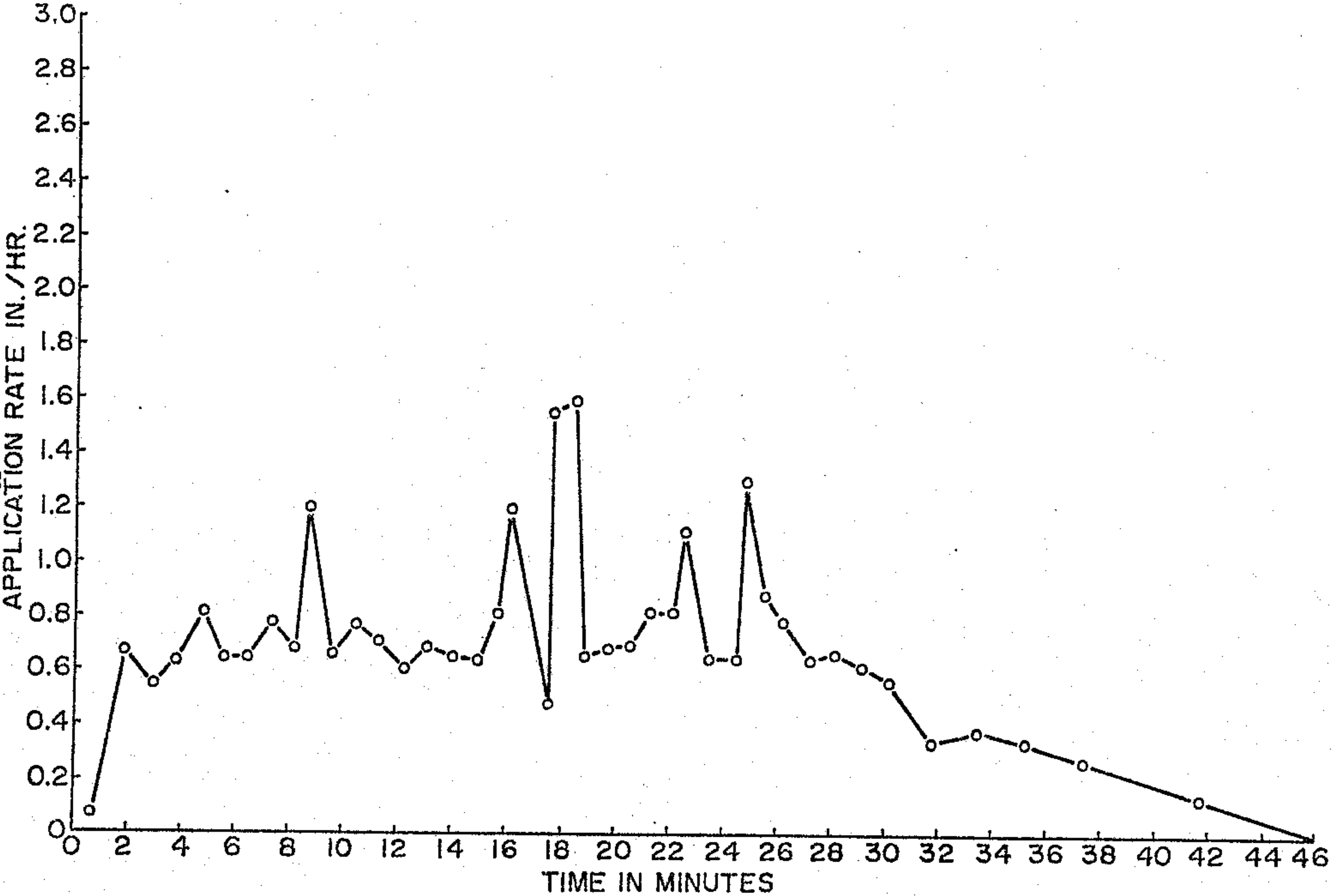

Fig. 2 Application rate pattern for variable size sprinklers on lateral.

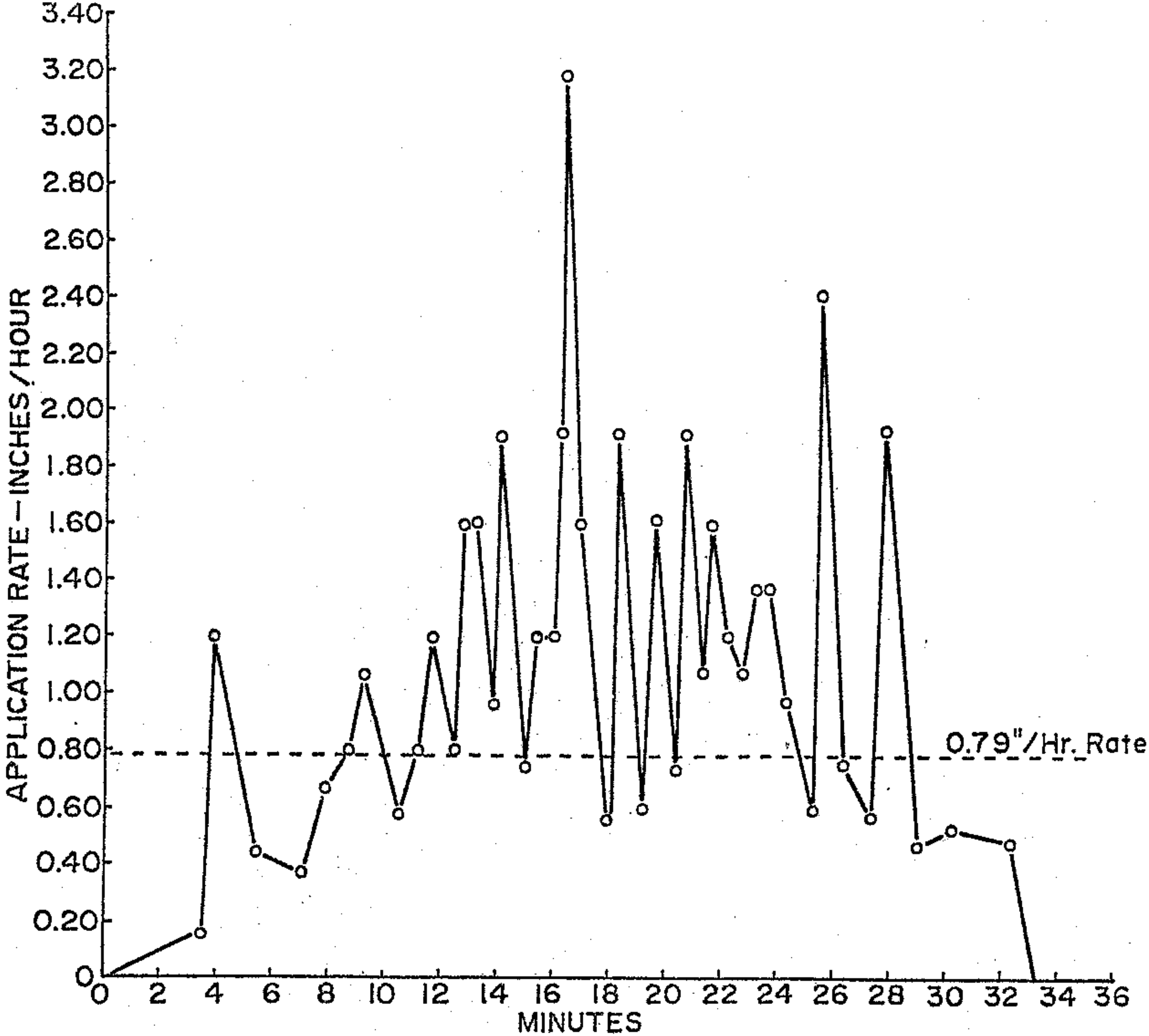

Fig. 3 Application rate pattern for all one size sprinklers on lateral.

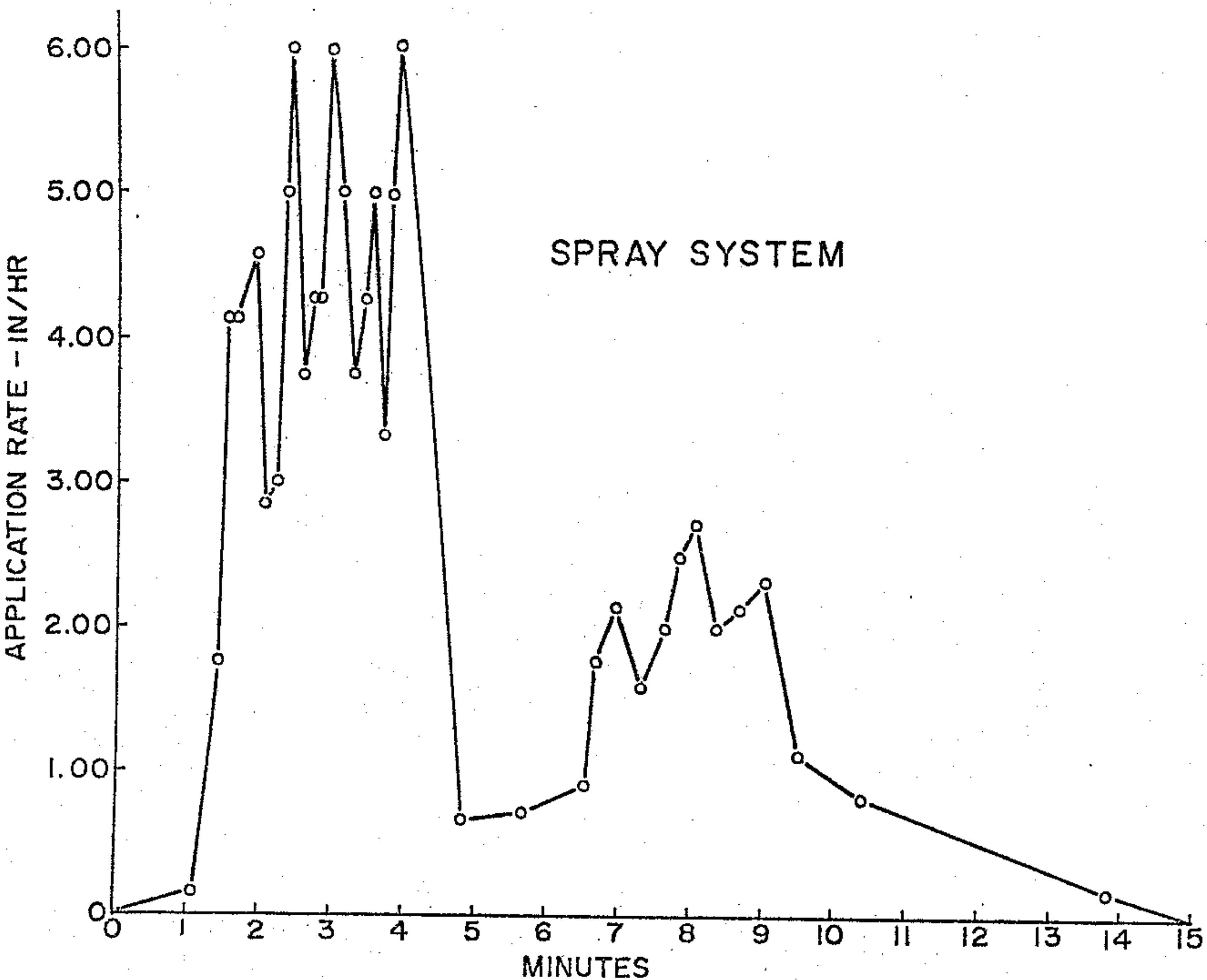

Fig. 4 Application rate pattern for spray jet sprinklers on lateral.

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