AMELIORATION

SOME INVESTIGATIONS ON SPRINKLERS

by

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(Received February 8, 1972)

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1. Introduction

Sprinklers are the most important item in irrigation equipment. The quality of irrigation is determined by hydraulic and operational characteristics of the sprinkler. Sprinklers are expected to spray irrigation water at a proper intensity and with an adequate drop size, uniformly distributed over the area to be irrigated. Sprinklers have to transform pressure energy into kinetic (jet) energy with a good efficiency i.e. at the lowest loss possible.

Sprinklers have to meet many demands, such as being cheap, simple, long-lasting, safe in operation, etc. Also, they should fulfil all the requirements established by agriculture and hydraulics, such as the adequateness of their radius of action, drop size, uniform distribution of the artificial rain, etc.

Some of the above requirements are *contradicting each other*. The various factors are interacting and by changing one of them, some others may change too, and perhaps in the unwanted sense. If e.g. one endeavours to obtain a longer sprinkling radius, this involves the application of nozzles with a greater diameter, and the jet leaving the nozzle is compact. This, however, results in a larger drop size, detrimental to crops and soil as well. If there is no sufficient atomization, little water will be sprayed over areas nearer the nozzles and areas where more sprinklers are overlapping, there will be excess water and unnecessary erosion. If, on the other hand, jets are well atomized, drops are fine-sized, then the radius of action will decrease, involving a higher rate of evaporation loss and more wind effects.

During the development history of sprinklers, emphasis was laid alternately upon these points and hence, there are many sprinklers of very different types and construction in operation.

In Hungary, sprinklers discharging 1—2 lit/sec at an intensity of 7.5 to 10 mm/hr are preferred, laid out mostly in a quadratic grid of 24×24 m. With regard to prevailing operation methods, the specific demand can be put as about 0.6 sprinkler per hectare. In long-range plans, sprinkler irrigation of 800,000 ha is foreseen, necessitating about 500,000 sprinklers. Assuming a life span of 5 years, 100,000 sprinklers will have to be replaced every year.

The necessity of carrying investigations into the design and operation of sprinklers is thus well justified by the above figures. The final goal is the *home manufacturing of large series of sprinklers* meeting agricultural and hydraulic requirements as well.

Certain problems concerning sprinklers have been investigated over many years by the *Department of Water Resources* but research work became intensified since 1969 when our own sprinkler-testing station was put into operation. A review will be given below on research made by the station, spotlighting some items of our ramified field of research.

2. Research made at the sprinkler-testing station of the Department

The station is suited for research in connection with the calibration, qualification and development of sprinklers. At the sprinkler, any pressure head up to $H = 50$ m can be applied. Rain is intercepted by gauging vessels of 1000 cm^2 surface, situated radially at distances of 0.5 to 1.0 m. Measurements are made in night-time and windless weather.

The testing procedure developed by DOBOS includes the following items: complex hydraulic testing of the sprinkler body and the jet pipes, testing of the sprinkler body and the jet pipes, testing of the nozzles, testing of the whole sprinkler, testing of the intermittent revolution speed of the sprinkler, investigation of the relationship between number of impacts and revolution time, testing of the buffer element, plotting of characteristic curves.

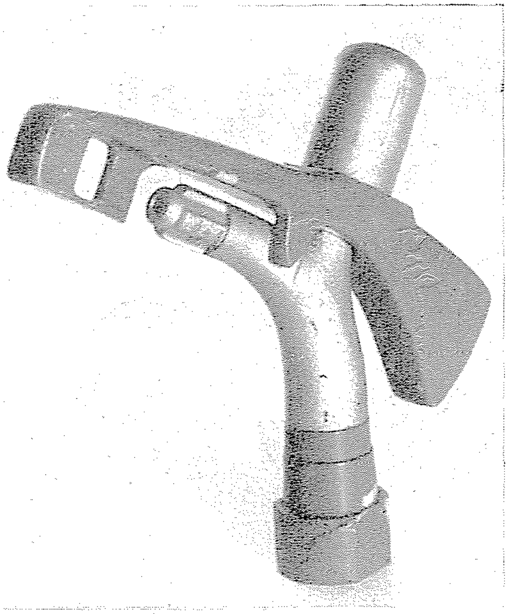


Fig. 1. Smallest sprinkler prototype

Research work done so far included among others: nozzle design (taper angle, nozzle edge), determination of the right proportion of diameter for the main and auxiliary nozzle of double-nozzled sprinklers, the effect of flow rectifiers in the jet pipe, the effect of shape and weight of the swinger upon the number of impacts, the time of revolution and rain characteristics; various ways of atomizing jets, observations on jet hydraulics. Investigations were carried out upon the relationship between number of swinger impacts and time of revolution at variously strained springs, and upon the effect of revolution time on spraying distance and radial rain distribution.

Based upon research made by others and by our own staff (A. DOBOS), the new family of Hungarian sprinklers, consisting of four members, has been developed and the prototypes of three members manufactured (KISS). Fig. 1 shows the prototype of the smallest sprinkler designed for private and public gardens and play-grounds, having sprinkler diameters of 4 and 5 mm and a spraying intensity of 3 to 6 mm/hr.

3. Uniformity of rainfall distribution

One of the most important requirements established for sprinklers is the possibly high uniformity of rain distribution, viewing the fact that although sprinklers do cover circular areas, they are laid out in quadratic, rectangular or triangular grids.

Areal distribution of rain is mainly influenced by the following factors:

a) the shape of the so-called $i-R$ curves showing the relationship between rain intensity i in mm/hr and the radial distance R from the sprinkler in metres;

b) the sprinkler layout pattern, including distance between sprinklers;

c) wind effects.

In cases where $i-R$ curves have an unfavourable shape or the pattern and distance of sprinklers have been selected inadequately, or where there is a wind effect, the areal distribution of irrigation water may show marked non-uniformities. Thus, after irrigation, dry spots may appear as well as puddles, resulting in a non-uniform growth of crops. A uniform rain distribution is also required by irrigation for frost prevention, the sprinkling of sewage, dung water, fertilizers, weed killers and pesticides.

Detailed investigations were made in order to find out the shape of $i-R$ curves yielding the most uniform rain distribution in windless weather by using quadratic, rectangular or triangular grid patterns with varying degree of overlapping. Thus e.g. Fig. 2 shows an $i-R$ curve that proved very favourable for quadratic grids.

The $i-R$ curve and the grid pattern being known, the isohyetal map of artificial rain can be constructed graphically. Very many such maps have been plotted by us. The whole process, including the calculation of final characteristics, has been computerized by IJJAS.

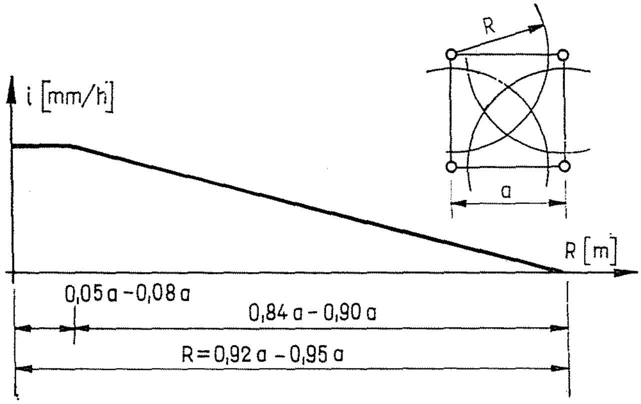


Fig. 2. Characteristic curve of uniform rain intensity for quadratic grids

4. Characterization of areal rainfall distribution

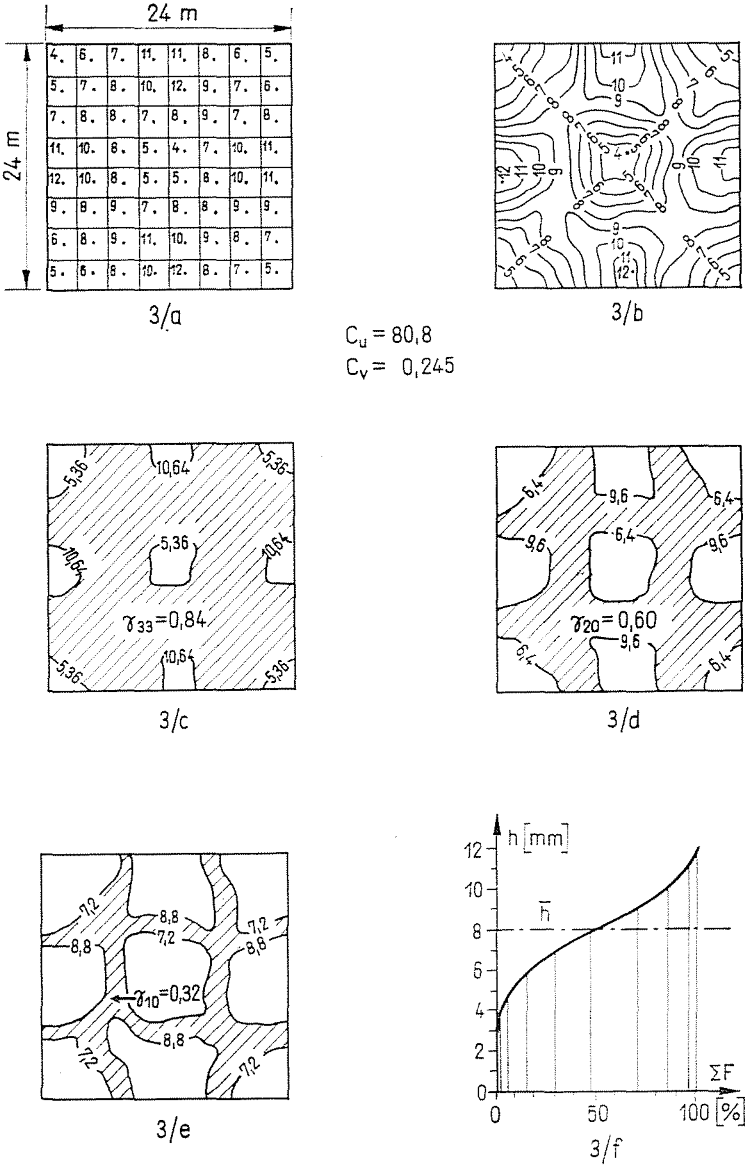
Various indices have already been proposed by several authors to characterize the degree of uniformity of rainfall distribution, to be calculated by aid of gauging vessels laid out in a quadratic grid. These indices express certain ratios to the average rain gauging.

Some of the methods (e.g. the one most generally known, the uniformity factor C_u by CHRISTIANSEN) are using all observation data, and are based on the differences between actual and average values; others use the square of these differences (e.g. STEFANELLI, STRONG, WILCOX-SWALES), and there are methods where the index is calculated from a selected part of the observation data.

These methods have the common feature of characterizing the degree of uniformity of rainfall by means of a *single number*, obtained through the statistic processing of rain gauge data. Such index numbers are, however, but of an informative value yielding some basis to compare various sprinklers, but utterly insufficient to characterize the quality of irrigation, or that of the sprinklers.

Rainfall distribution can best be visualized by means of an isohyetal map. This map enables the calculation of the *area factor* γ, the usefully irrigated percentage of the whole area. By usefully irrigated area the area is meant where the difference between actual and average rainfall does not exceed a given percentage in either the plus or minus sense (in the tested case 33, 20 or 10%). The simultaneous display of several area factors (like γ_{33}, γ_{20}, γ_{10}) yields incomparably more information on rain distribution than a single number does.

A still better picture of rain distribution can be obtained by a method developed by the author. Based upon the isohyetal map, areas lying between adjacent isohyetal lines should be determined. These areas, expressed as percentage of the whole area are marked on the abscissa, whilst ordinates represent rainfall in mms. On the diagram thus plotted, the average rain gauging $\bar{h}$ should be drawn too.



4.	6.	7.	11.	11.	8.	6.	5.
5.	7.	8.	10.	12.	9.	7.	6.
7.	8.	8.	7.	8.	9.	7.	8.
11.	10.	8.	5.	4.	7.	10.	11.
12.	10.	8.	5.	5.	8.	10.	11.
9.	8.	9.	7.	8.	8.	9.	9.
6.	8.	9.	11.	10.	9.	8.	7.
5.	6.	8.	10.	12.	8.	7.	5.

Fig. 3. a) Rain gaugings of 64 gauges over a square grid area of 24 by 24 m. b) Isohyetal map. c) γ_{33}. d) γ_{20}. e) γ_{10}. f) Proposed curve of rain distribution

Figs 3a to f and the table below present a numerical example, indicating also the uniformity coefficient C_u of Christiansen and the variability coefficient C_v used by Stefanelli, Strong and others. There is no doubt that either the isohyetal map (Fig. 3b), or the diagrams showing usefully irrigated areas (Figs 3c, d, e) and above all, the curve of rain distribution (Fig. 3f) are much more informative than a single number like factors C_u or C_v.

Table 1

Rainfall h [mm]	Area F		h · % [mm]
	%	Σ F %	
4	0.5	0.5	2.0
4–5	5.6	6.1	25.2
5–6	10.2	16.3	56.2
6–7	14.7	31.0	95.7
7–8	17.6	48.6	132.0
8–9	22.3	70.9	189.5
9–10	14.1	85.0	134.0
10–11	10.2	95.2	107.2
11–12	4.8	100.0	55.2
			Σ = 797.0

$\bar{h} = 797/100 = 7.97$ mm

Summary

A review is given of requirements for sprinklers, of the sprinkler-testing station of the Department of Water Resources and its recent activity. Attention is paid to the importance of areal rainfall uniformity. Instead of the index numbers used so far, the application of a characteristic curve of rainfall distribution is recommended, followed by an illustrative example.

References

1. Christiansen, J. E.: Irrigation by sprinkling. Bulletin No. 670. University of California.
2. Stefanelli, G.: Funzionalità e distribuzione della pioggia negli apparecchi irrigatori e norme di prove. Verona, 1954.
3. Strong, W.: Christiansen's coefficient of uniformity. Pearson's variability coefficient and standard deviation. Sprinkler Irrigation Association, Washington. 1955.
4. Dobos, A.: Design of sprinkler laterals. (In Hungarian). Hidrológiai Közlöny (Budapest) **2** (1963).
5. Beale, J. G.—Howell, D. T.: Relationships among sprinkler uniformity measures. Journal of the Irrigation and Drainage Division of ASCE. IR 1. March 1966.
6. Lipták, F.: Rainfall distribution of sprinkler irrigation. (In Hungarian). Hidrológiai Közlöny (Budapest) **9** (1968).
7. Lipták, F.: Characterization of areal distribution of sprinkler rain. (In Hungarian). Hidrológiai Közlöny (Budapest) **6** (1970).
8. Lipták, F.: Evaluation of rainfall distribution in sprinkler irrigation. (In Hungarian). Hidrológiai Közlöny (Budapest) **8—9** (1971).

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