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Evaluation of watering uniformity in operating conditions for center pivot irrigation systems

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Abstract. The objective of the paper is to verify the watering uniformity in operating conditions for center pivot irrigation systems, used by more farmers in Romania. Evaluation of uniformity was done by the Christiansen method and Heerman and Hein method.
Keywords: Sprinkler irrigation, center pivot irrigation systems, uniformity of watering.

1.INTRODUCTON

Uniformity of watering is an important indicator of irrigation, because the allocation of water on the land, determines at the utmost extent the quality of sprinkler, the watering efficiency in the field, the uniformity and increase of agricultural production.

When irrigation plant is used for applying fertilizer and pesticides, achieving a good uniformity is becoming more important.

Plant manufacturer of this study, Valley Valmont Irrigation Company, mentions in the project specification the fact that, the system design data is based on theoretical calculations and that, during operation they may vary slightly, depending on some factors that cannot be defined precisely (friction losses, slip coefficient of wheels, standard tolerances, irregularities of the field, coefficient of evaporation). It is therefore recommended that owners and operators of irrigation plants to check this flag periodically.

2. MATERIALS AND METHODS

The experiment presented was performed under the SPP Fântânele block, of irrigation land Fântânele-Sagu. The analysed perimeter is located in Plain Vinga on the left bank of Mures, between Tisa Noua and Fântânele, near the county road DJ 682C, and limited on the south by the channel of the feed pipe CAd II.

Soil type of the studied area belongs to the chernozem (black earth).

Studied irrigation system type is a fixed pivot from Valley Valmont Industries company, has a length of 400 m and consists of 8 openings.

Main technical-functional characteristics of plant are given in Table 1.

Necessary time and the rule of watering on a full and continuous rotation of surface irrigation, according to setting regulator percentages are given in Table 2.

Table 1. Technical and functional characteristics of fixed pivotal Valley installation type [4]

Nr. crt.	Specification	[U.M.]/pieces
Geometrical characteristics		
1.	Irrigated area in a position	50,27 ha
2.	Coverage ratio	78,54 %
Structural characteristics		
3.	Plant length	400 m
4.	Type sections 6-5/8 inch, 180’	8
5.	Maximum elevation of the field	3 m
6.	Distance between sprinklers	288 cm
7.	Sprinkler irrigation diameter	13 m
8.	Package type sprinkler	Valley LEN 0,4 bar
9.	Minimum height above ground	2,86 m
Requirements and hydraulic characteristics		
10.	Necessary pressure at the downstream end of the installation	0,69 bar
11.	Necessary pressure of the system	2,19 bar
12.	Duty water (specific flow)	0,4 l/s/ha
13.	Flow of the system	60 l/s

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14.	Minimum watering norm	9,24 mm/rot.
15.	Daily watering norm	3,46 mm/day
16.	Monthly watering norm	103,68 mm/month
17.	Instant watering norm	82,79 mm/h
18.	Minimum time for a rotation	21,39 hours
19.	Maximum speed of plant	112,95 m/h

Table 2. Watering norm and the time of a rotation depending on setting regulator of fixed pivotal Valley installation type [4]

Regulator setting [%]	Time on a rotation [hour/rot.]	Watering rule on a rotation [mm/rot.]
9	174,01	60,62
20	78,31	27,28
30	52,20	18,18
40	39,15	13,64
50	31,32	10,91
60	26,10	9,09
70	22,37	7,79
80	19,58	6,82
90	17,40	6,06
100	15,56	5,46

Irrigation pipe is equipped with 149 sprinklers and a cannon sprinkler head to water in the area of a circle .

Measurements were made in July 2009, in low to moderate wind conditions, at a maximum air temperature of 35 ° C [1].

Data collection required the use of the following materials: pluviometric pots with a collection surfaces of 104 cm^2, a graduated cylinder of 1000 cm^3, stopwatch, tape measure. To minimize evaporation of water from collecting pots we measured, with a graduated cylinder, those volumes, as soon after the cease of rain sprinklers (figure 1).

a) b)

Fig. 1 Aspects during the measurements:
a) the volume of water collected is measured, b) plant in operation

During measurements, the engine was set in a proportion of 60%, which means, according to Table 2, the theoretical watering norm is 9.09 mm/ rotation.

The objective of this study was to determine the uniformity of watering for the plant with fixed pivot, in different types of pluviometric pots location.

Watering uniformity can be experimentally determined in the laboratory and in field, in a work scheme. Frequently used method for determining watering uniformity in the field is Christiansen method [2], which established the following mathematical relationship for the uniformity coefficient :

$$C_u = 100\left[1 - \frac{\sum|a|}{m \cdot n}\right] \quad (\%) \qquad (1)$$

where:

m - average volume of water collected in rain gauges, located on the irrigation surface of a sprinkler, at different distances from it (cm^3);

n - number of rain gauges (pluviometers) ;

V_i- partial volume of water measured in each rain gauge (cm^3);

|a| - sum of partial deviations, positive and negative, compared to the average volume (cm^3).

$$|a| = V_i - m \; ; \; m = \frac{\sum V_i}{n} \qquad (2)$$

Christiansen uniformity coefficient values interpretation is as follows:

$C_u < 65$ % - inadequate uniformity;
$C_u = 65 - 75$ % - stable uniformity;
$C_u = 75 - 85$ % - average uniformity;
$C_u > 85$ % - good uniformity.

Specific method for pivotal installation type is that of Heermann and Hein uniformity coefficient (1968), being the method recommended by the American Society of Agricultural and Biological Engineers (ANSI / ASAE S436. 1) for calibration and for determining watering uniformity of these plants. Under this method, Heermann and Hein uniformity coefficient is calculated as follows [3].

$$C_{uHH} = 100\left[1 - \frac{\sum d_i \left|h_i - \bar{h}\right|}{\sum h_i \cdot d_i}\right] \quad (\%) \qquad (3)$$

where :

h_i – height of collected water in "i" rain gauge, positioned at a distance d_i from the center point (cm);

$$h_i = \frac{V_i}{S} \quad (cm) \qquad (4)$$

V_i - volume of collected water in "i" rain gauge; (cm^3);

S – surface of rain gauge (cm^2);

$\bar{h}$ - average height of water obtained by the relationship:

$$\bar{h} = \frac{\sum h_i \cdot d_i}{\sum d_i} \quad (cm) \qquad (5)$$

The estimation of irrigation uniformity :

$C_{uHH} < 80$ % insufficient uniformity;
$C_{uHH} = 80–85$ % satisfactory uniformity;
$C_{uHH} = 85-90$ % good uniformity;
$C_{uHH} > 90$ % excellent uniformity.

3. RESULTS AND DISCUTION

First, to determine radial watering uniformity (along the plant), we placed 18 collecting pots on the radial direction, starting with the second section, respectively from a distance of 50 m and going from 20 to 20 m, to the last section, after the scheme of Figure 2.

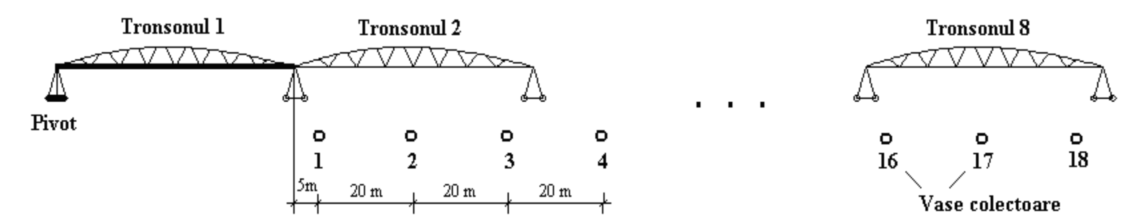

Fig. 2 Scheme for determining the radial uniformity of watering

Using volumes of water collected in pluviometric pots to a full shift of watering plant and 1-5 relations we determined Christiansen uniformity coefficient, respectively Heermann and Hein uniformity coefficient on plant length, the calculations are presented in Tables 3 and 4.

Table 3 Calculation of Heermann and Hein uniformity coefficient on plant length

Nr. crt.	Distance from the pivot (m)	Volume of collected water in rain gauge V_i (cm^3)	Average volume m (cm^3)	V_i - m (cm^3)	$\sum\|a\|$ (cm^3)	C_u (%)
1.	55	100	93	+7	256	85 Average uniformity
2.	75	110		+17		
3.	95	100		+7		
4.	115	70		-23		
5.	135	90		-3		
6.	155	80		-13		
7.	175	105		+12		
8.	195	90		-3		
9.	215	90		-3		
10.	235	100		+7		
11.	255	90		-3		
12.	275	85		-8		
13.	295	100		+7		
14.	315	160		+67		
15.	335	100		+7		
16.	355	50		-43		
17.	375	90		-3		
18.	395	70		-23		

Table 4 Calculation of Heermann and Hein uniformity coefficient on plant length

Nr. crt.	Distance from the pivot (m)	Volume of collected water in rain gauge V_i (cm^3)	The height of water collected in rain gauge hi (cm)	h_i d_i (cm^2)	The average height of water $\overline{h}$ (cm)	$h_i - \overline{h}$ (cm)	$d_i\left\|h_i - \overline{h}\right\|$ (cm^2)	C_{uHH} (%)
1.	55	100	0,96	5.280	0,88	+0,08	440	86 Good uniformity
2.	75	110	1,05	7.875		+0,17	1.275	
3.	95	100	0,96	9.120		+0,08	760	
4.	115	70	0,67	7.705		-0,21	2.415	
5.	135	90	0,86	11.310		-0,02	270	
6.	155	80	0,77	11.935		-0,11	1.705	
7.	175	105	1,01	17.675		+0,13	2.275	
8.	195	90	0,86	16.770		-0,02	390	
9.	215	90	0,86	18.490		-0,02	430	
10.	235	100	0,96	22.560		+0,12	2.820	
11.	255	90	0,86	21.930		-0,02	510	
12.	275	85	0,81	22.275		-0,07	1.925	
13.	295	100	0,96	28.320		+0,08	2.360	
14.	315	160	1,54	48.510		+0,66	20.790	
15.	335	100	0,96	32.160		+0,08	2.680	
16.	355	50	0,48	17.040		-0,04	1.420	
17.	375	90	0,86	32.250		-0,02	750	
18.	395	70	0,67	26.465		-0,21	8.295	
Σ	4.050	-	-	357.970		-	51.510	

We represented the heights of collected water in rain gauges at a full shift and average values (8. 88 mm) in Figure 3 and, compared with theoretical rule of watering on a rotation (9,09 mm), corresponding to percentage regulator setting of 60% (Table 2), resulted that the average and the most watering hight values are very closed to the theoretical rule.

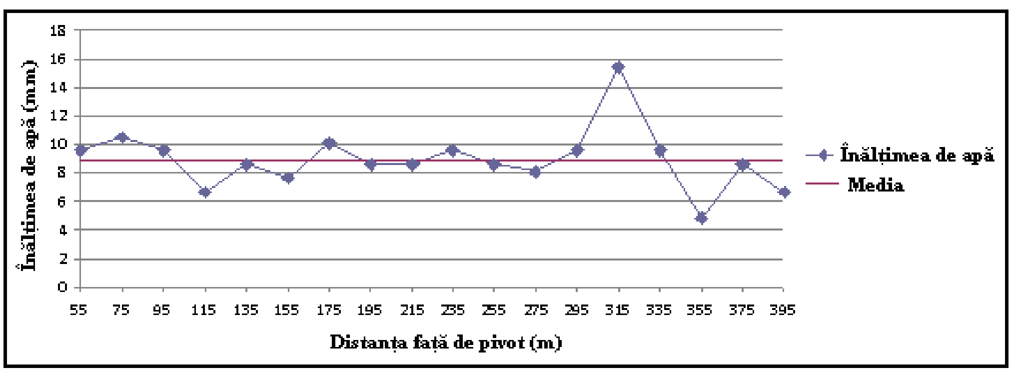

Fig. 3 Pluviometrical distribution on plant lenght

In another determination of watering uniformity, on the section of 250-300 m, we placed on radial direction, from 3 to 3 meters, 16 rain gauges of 62 cm^2 surface according to the scheme in Figure 4.

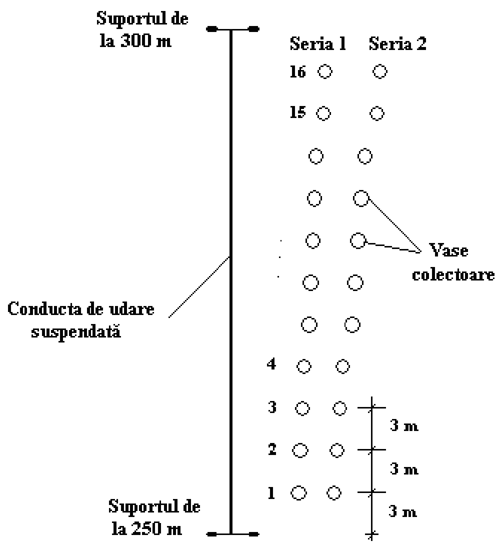

Fig. 4 Work scheme for determining water uniformity on the section of 250-300 m

We conducted two series of measurements, measuring volumes of collected water during a full shift. Registered values and all data processing was done by the two methods, achieving for watering coefficients values between 79-82%, suggesting an average uniformity of watering. For example, pluviometrical distribution for series I of measurements was the one in Figure 5.

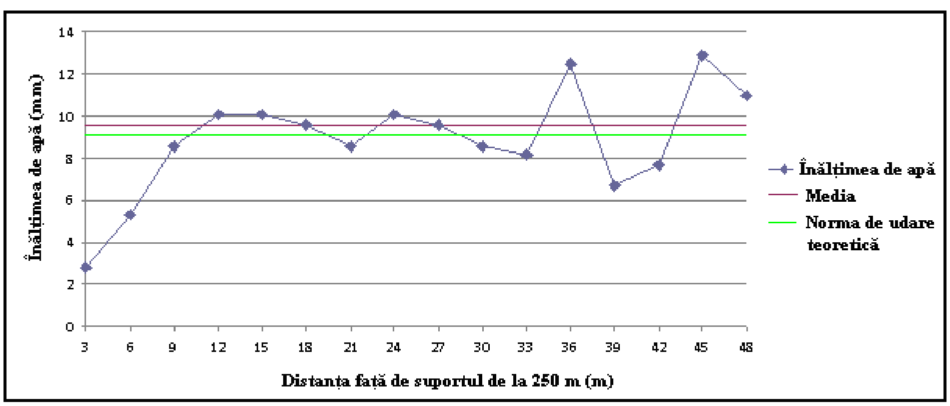

Fig. 5. Pluviometrical distribution on section of 250-300 m series I

We found that, excluding some extreme values, the values recorded for height water layer are close to the theoretical rule of watering, especially in case of series I measurements, with a better uniformity of watering, compared to series II.

4. CONCLUTIONS

Pluviomerical study led to the following conclusions:

- installations with a central pivot are modern plants, with a high level of mechanization and automation, which secure a good watering uniformity;
- in operating conditions, the fixed pivotal

installation Valley type analysed, it was obtained an average/satisfactory distribution of watering, with values of the coefficients of watering between 79-90%;

- height of water layer achieved by spray irrigation is, generally, closed to the theoretical value; watering non-uniformity devices may have several causes: malfunctioning sprinklers, pressure failure to higher areas of land, intensity and wind direction, changes brought to installation compared to the initial project, etc.

- in practice, to obtain a layer of water as evenly and as close to the theoretical normal value of watering, sprinklers should be properly set on the pipe, checking their correct functioning, remedy defects, checking operating pressure and filters, etc.

- not to cause a pond on land area is required to link technical and functional characteristics of plants with soil factors;

- in Romania using these installations is limited by some factors such as : equipment costs, low land parcels, etc., as a result, the study of plants with central pivot in operating conditions is at the start.

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