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Field evaluation of centre pivot sprinkler irrigation system in the North-East of Iran

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Abstract

A field evaluation of the technical performance of centre pivot sprinkler irrigation system was carried out during the maize crop growing season and when operating with different working speeds: S_1 – 40%, S_2 – 60% and S_3 – 80%. For this goal, four uniformity measurements are to be considered in the evaluation; coefficient of uniformity (*CU*), distribution uniformity (*DU*), potential efficiency of low quarter application (*PELQ*) and actual efficiency of low quarter application (*AELQ*). The first step of evaluation of the sprinkler irrigation system is to compare the measured uniformity values with the standard values, $DU \geq 75\%$, $CU \geq 85\%$, *AELQ* and $PELQ \geq 90\%$. Effect of variation of speed produced *CU* values of 80.3, 82.7 and 86% for S_1, S_2, and S_3 speed, respectively. Furthermore, *DU* standard value was obtained at S_3 speed of 82%. Moreover, *AELQ* and *PELQ* were below the acceptable standard level of 90% for all speeds. Non-uniform water application leads to over or under irrigation in various parts of the field which can result in wasted water and energy. Therefore, regular evaluation of the irrigation equipments is needed to efficiently and effectively manage irrigation.

Key words: *centre pivot system, distribution uniformity, irrigation, uniformity coefficients*

INTRODUCTION

Agriculture is central of food security and economic growth in developing countries. However, food production requires substantial amounts of water. Therefore, irrigation water should be adequately applied to crops to avoid water waste. Hence, the efficiency of water use in agriculture needs to increase in a sustainable manner [NORELDIN *et al.* 2015]. Also, agriculture water demand is one of the serious pressures on water sector in Iran, since 80-85% of total available water is consumed in agriculture and coupled with poor irrigation management. Water scarcity is a problem facing Iran these days. Centre pivot (CP) sprinkler irrigation systems are invented about 67 years ago to enhance agricultural production and crop water productivity. A centre pivot consist a lateral circulating around a fixed pivot point. The lateral is supported above the field by a series of A-frame towers, each tower having two driven wheels at the base. The lateral line is rotated slowly around a pivot point at the centre of the field by electric motors at each tower. Water is discharged under pressure from sprayers or sprinklers mounted on the laterals as is sweeps across the field or suspended by flexible hose over the crops. Evaluation of a system means to assess the system performance for parameters such as irrigation efficiencies, water distribution coefficient and water adequacy at the field site.

Precision agriculture technologies make it possible for farmers to adjust production inputs site-specifically to address the spatial variability in the field. Currently two primary control methods are used to realize variable rate irrigation (*VRI*), speed control and duty cycle control. The speed control method varies travel speed of the centre pivot to accomplish the desired application depth, while the duty cycle control changes the duty cycle of individual sprinklers or groups of sprinklers. Knowledge of the accuracy and uniformity of an irrigation system are essential for the success of precision irrigation management [LARUE, EVANS 2012]. Evaluation of a system performance is obligatory at each field repeated for two or three times per year to find weather it works well. Although, many investigations about systems evaluation have been done so far over the world, but due to variety of climates, soil types, types of plants and characteristics of systems, the results of investigation cannot be generalized to other part of the world [AL-GHOBARI 2010].

Some works have been reported on the evaluation of center pivot sprinkler irrigation system performance. A research was conducted to evaluate the performance of centre pivot sprinkler irrigation system and its effect on sugarcane yield at Ubombo Sugar estate in the South-East of Swaziland. Performance indicators showed that centre pivots were performing relatively well as uniformity coefficients (*CU* – coefficient of uniformity and *DU* – distribution uniformity) for the systems were within acceptable standards above the base values of 85% for *CU* and 75% for *DU* [MSIBI *et al.* 2014]. Assessment of different portable sprinkler irrigation systems in Nigeria is reported at the rate of 86% and 87% values for water distribution uniformity coefficient and water application efficiency, respectively [AHANEKU 2010]. A comparison was done for different sprinkler irrigation systems with surface irrigation system in Utah State. The results revealed that application efficiencies (*Ea*) were obtained by 70% for sprinkler and 50% for surface irrigation system [HILL 2002]. Evaluation of center pivot sprinkler irrigation system was done using low quarter distribution uniformity (*DU*) and water efficiency evaluation factors in the South Africa. The results showed that the *DU* values of 81.4, 60.9, 72.7, 67.4 and 56.9 percent and the values of 83.6, 73.5, 67.7 and 78.9 percent for centre pivot, rain gun, micro-irrigation, conventional and floppy sprinkler systems, respectively [ASCOUGH, KIKER 2002]. Also, an evaluation was done on uniformity of water distribution (*CU*) of a commercial variable rate centre pivot irrigation system. So, a constant water application rate (100%) was applied in each zone, and in the other, variable application rates (0%, 30%, 50%, 70%, and 100%) were assigned to different zones. Results showed a *CU* of 86.5% for the constant application rate test. In the variable rate test, average *CU* over the application rates of 30%, 50%, 70%, and 100% was 84.3% with the highest *CU* of 89.2% in the 100% application rate [SUI, FISHER 2015].

Overall, centre pivot sprinkler irrigation systems are often the preferred type of sprinkler irrigation system by producers due to their relatively high water application uniformity and degree of automation which can substantially reduce labour costs compared to other types of sprinkler irrigation systems. The operational characteristics of commercial centre pivot sprinklers are well documented but few studies have been conducted to evaluate the effects that operating characteristics of a particular sprinkler (working speed and application rate) have on infiltration, system reliability, and water satisfaction and distribution for specific soil types. The objectives for this study were: a) evaluate the coefficient of uniformity, distribution uniformity and potential application efficiency under field conditions providing necessary information for more effective water management; b) to evaluate performance of configurations of centre pivot operating conditions (speed: 40%, 60%, 80%) that can achieved to the best uniformity efficiencies (*DU* and *CU*).

MATERIALS AND METHODS

EXPERIMENTAL SITE

Jovein plain area of 42 830 hectares is located between 57°25′19″ E longitude and 36°42′22″ N latitude at an average elevation of 1100 m a.m.s.l. This plain

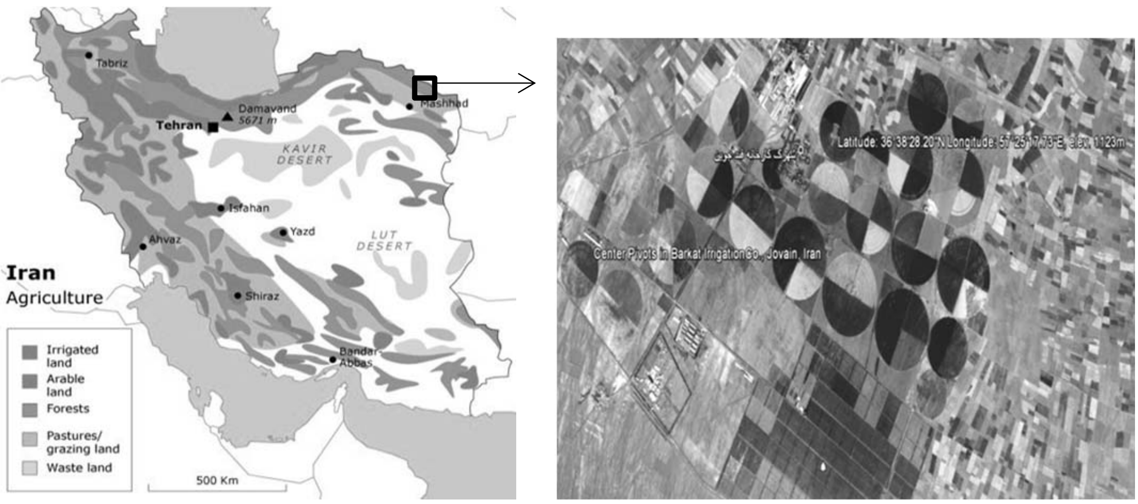

Fig. 1. Location of the centre pivot irrigation systems; source: Google Earth

is located 75 km from the city of Sabzevar, Iran. The total number of 106 center pivot irrigating about 6000 hectares of the part of Jovain plain (Fig. 1). The climate in this area is hot and dry which amount of annual precipitation is about 219 mm. The historical weather data indicated that the average temperature in the hottest and coldest months of the year is 38 and –3°C. The averages of meteorological data of cropping period are presented in Table 1. The soil physical properties of the field experiment is presented in Table 2.

Table 1. The average of meteorological data during the experiment

Month	Temperature, °C		Wind speed $m \cdot s^{-1}$	Rainfall mm	*RH* %
	min	max			
June	26.9	34.4	1.81	0	55.3
July	25.05	35.9	1.62	0	51.3
August	24.6	36.7	1.72	0	63.6
September	24.0	30.8	1.51	15	58.8
December	23.7	29.6	1.60	0	69.8

Explanation: *RH* = relative humidity.
Source: own elaboration based on Sabzevar synoptic weather station data.

Table 2. Physical properties of the soil of the field experiment

Soil depth cm	Texture	Content, %			*Bd* $g \cdot cm^{-3}$	θ_{FC} %	θ_{PWP} %	*Ks* $cm \cdot d^{-1}$
		sand	silt	clay				
0–20	sandy loam	54.4	21	24.6	1.45	22.8	10.7	26.7
20–40	sandy loam	53.5	18	28.5	1.43	26.1	11.8	25.6
40–60	loam	46	23	31	1.39	28.9	13.3	17.5
60–80	loam	37	25	38	1.35	30.5	13.7	18.3

Explanations: *Bd* = bulk density, θ_{FC} = gravimetric soil moisture at field capacity, θ_{PWP} = gravimetric permanent wilting point, *Ks* = saturated hydraulic conductivity.
Source: own study.

EQUIPMENT DESCRIPTION

Under the standard, catch cans were spaced 3 m apart in two rows extending from the pivot centre straight out to the circle edge. When the pivot is started, no water should be entering the cans until the unit is at full pressure and speed. The centre pivot sprinkler installed in the experimental area was consisting of 6 towers, with 54 m between towers and 3 m between cans within each tower, to give a total of 108 cans. The diameter of each can was 10 cm with a height of 15 cm. Each can represent an irrigated area as part of the field, so the volume caught by each can was the depth of water times the represented area. Cans were placed across the way of the lateral. The characteristics of centre pivot are shown in the Table 3.

Table 3. The characteristics of center pivot sprinkler irrigation system

Length of spans m	Number of span	Discharge of system $dm^3 \cdot s^{-1}$	Total number of sprayers	Pressure bar	Distance between sprayers m	Discharge of sprayers $dm^3 \cdot s^{-1}$	System length m	Type of sprayers
54	6	43.5	108	2	3	0.4	324	Nelson R3000

Source: own elaboration.

The locations of cans were level and far enough ahead of the lateral to ensure that no water enters the cans. When the centre pivot (lateral) is passed over all of the cans, the volumes of water in each can was measured and recorded for further process.

INDICATORS OF IRRIGATION UNIFORMITY EVALUATION

Uniformity coefficient (*CU*)

This coefficient takes into account the amount of variation in test can readings both above and below the average value of all can readings. A *CU* value of 100% would represent a perfectly uniform or even application of water. The industry standard suggests that *CU* be greater than 85%. Modified Hermann and Hein formula will be used equation (1) to calculate the coefficient of uniformity (*CU*) as follows:

$$CU = \left[1 - \frac{\sum_{i=1}^{n} (D_i - D_t)}{\sum_{i=1}^{n} (D_i \cdot S_i)} \right] 100 \tag{1}$$

where: n = number of collectors used in the evaluation; i = number assigned to identify a particular can (i = 1 to $i = n$); D_i = depth of water measured in the i^{th} can; S_i = distance of the i^{th} can from the pivot point; D_t = weight average of the depth of the water collected, equation (2).

$$D_t = \frac{\sum_{i=1}^{n} (D_i \cdot S_i)}{\sum_{i=1}^{n} S_i} \tag{2}$$

Distribution uniformity (*DU*)

Distribution uniformity is a measure of the uniformity of water application by sprinkler system using a catch can test. This coefficient takes into account the average of the lowest 25% of readings obtained from test cans and compares this value to the average of all readings. *DU* is an indicator of the magnitude of the distribution problems. A *DU* of 85% or greater is considered excellent, 80% is considered very good, 75% is considered good, 70% is considered fair, and 65% or less is considered poor and unacceptable [KELLER, BLIESNER 2000]. It is generally accepted that sprinkler systems should have a minimum *DU* of 75%. In order to determine whether the system is operating at acceptable efficiency, *DU* (of low quarter) will be calculated using equation (3).

$$DU = \frac{D_{lq}}{D_a}100 \tag{3}$$

where: DU = low quarter distribution uniformity, %; D_{lq} = average weight of low 1/4 depth catch; D_a = average weight of all depth catch.

Low quarter actual water application efficiency (*AELQ*)

AELQ achieved in the field indicates how well a system is being used. When the average low quarter depth of irrigation water infiltrated exceeds the soil moisture deficit (*SMD*), which is the storage capacity of the root zone, *AELQ* can be expressed as equation (4):

$$AELQ = \frac{SMD}{D_a}100 \tag{4}$$

where: D_a = mean water depth applied by nozzles.

The average low quarter depth of infiltrated and stored water in the crop root zone is the mean value of the lowest quarter depth (1/4) of the measured values. Irrigated area means the area receiving water; for most systems this is the entire field. However, where a limited area is being wetted, the term refers only to that part of the area receiving water. Implicit in *AELQ* is a measure of uniformity, but it does not indicate adequacy of the irrigation. It merely shows that, for any value greater than zero, all the area is receiving water. Low values for *AELQ* indicate problems in management and/or use of the system [MERRIAM, KELLER 1978].

Low quarter potential water application efficiency (*PELQ*)

The *PELQ* indicates a measure of system performance attainable under reasonably good management when the desired irrigation is being applied. The *PELQ* is the precise value of *AELQ* when the low quarter depth of water infiltrated is just sufficient to satisfy the *SMD* (soil moisture deficit) when *SMD* = *MAD* (management allowed depletion) in all parts of the field. Low *PELQ* usually is associated with inefficient system design, but may be intentional for economic reasons. The difference between *PELQ* and *AELQ* is a measure of management problems, whereas low values for *AELQ* merely indicate the possible existence of such problems.

$$PELQ = \frac{A}{B}100 \tag{5}$$

where: A = average low quarter depth infiltrated when equal to *MAD*; B = average depth of water applied when *MAD* just satisfied.

The *PELQ* should be determined in order to evaluate how effectively the system can utilize the water supply and what the total losses may be. Then the total amount of water require to irrigate the field fully can be estimated. The *PELQ* is always a little lower than *DU* a sprinkle irrigation systems because the average water applied (which is the denominator for *PELQ*) is larger than the average water caught which is the denominator for *DU*. The numerator for both *PELQ* and *DU* is the average low quarter depth of catch. The difference between the average water applied and the water caught or received is an approximation of losses due to evaporation and drift plus loss of water due to some of the area's being ungauged are some evaporation from the gauge cans. It is therefore a measure of the best management can do and should be thought of as the potential of the system within the limit that the test represents the whole field [MERRIAM, KELLER 1978].

$$PELQ = \frac{SMD}{D_n}100 \tag{6}$$

where: SMD = soil moisture deficit, mm

$$SMD = (\theta_{FC} - \theta_i)D_{rz} \tag{7}$$

where: θ_{FC} = volumetric soil moisture content at field capacity, %; θ_i = volumetric soil moisture content before irrigation, %; D_{rz} = effective root zone depth, mm.

RESULTS AND DISCUSSION

EFFECTS OF OPERATING DIFFERENT SPEED ON *DU*

Effects of operating speed (40%, 60%, and 80%) on distribution uniformity (*DU*) are presented in Table 4. Classes of DU acc. to Merriam and Keller are as follows $DU \geq 85$ – excellent, $75 \leq DU < 85$ – very good, $70 \leq DU < 75$ – good, $65 < DU < 70$ – fair, $DU \leq 65$ – poor. The average distribution uniformity is good for 40% and very good for 60 and 80% speeds. Furthermore, results of mean *DU* values are in the range of 73.9 to 82%.

Table 4. Variation of distribution uniformity (*DU*) with different operating speed and scale of evaluation

Replication	Calculated *DU*, %		
	speed set		
	40%	60%	80%
1	72.4	75.6	81.7
2	78.5	77.2	84.3
3	70.8	74.5	79.8
Mean	73.9	75.8	82
Evaluation	good	very good	very good

Source: own study.

Table 5. Variation of coefficient uniformity (*CU*) with different operating speed and scale of evaluation

Replication	Calculated *CU*, %		
	speed set		
	40%	60%	80%
1	78.1	82.7	83.2
2	83.6	84.6	90.1
3	79.2	80.8	84.7
Mean	80.3	82.7	86
Evaluation	fair	fair	good

Source: own study.

Moreover, the results indicated that the distribution uniformity increased as center pivot speed increased. Also, Figure 2 shows that the average value of *DU* in the speed of S_1 for all spans were 73.9%. Also, *DU* values for S_2 and S_3 in this research did meet the acceptable standard for all spans ($DU \geq 75\%$). The results of this study are similar to those verified by several authors in the literature. Distribution uniformity of centre pivot irrigation system should be at least 75% [SAVVA, FRENKEN 2002]. MSIBI *et al.* [2014] revealed that uniformity coefficient (*DU*) for the center pivot irrigation systems were within acceptable standards above the base values of 75% for *DU*.

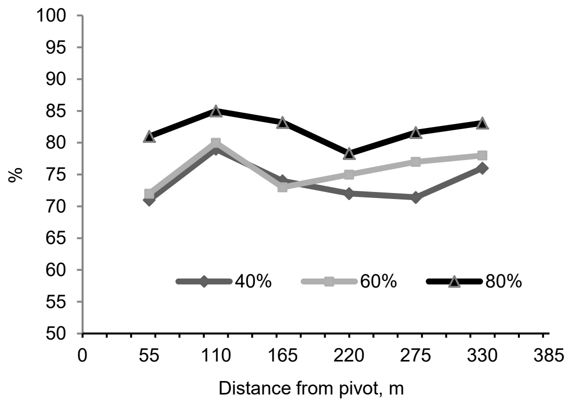

Fig. 2. Distribution uniformity (*DU*) for all evaluation tests; source: own study

EFFECTS OF OPERATING DIFFERENT SPEED ON *CU*

Table 5 shows the effect of different operating speeds on coefficient uniformity (*CU*). Classes of *CU* are as follows: $CU \geq 90$ – excellent, $85 \leq CU < 90$ – good, $80 \leq CU < 85$ – fair, $CU < 80$ – poor. The average *CU* is good for all operation speeds set. Also, results of mean *CU* values were in the range of 80.3 to 86 %. *CU* values for S_1 and S_2 were 80.3% and 82.7% respectively which did not meet the acceptable standard value ($CU \geq 85\%$). Moreover, the *CU* value for S_3 was achieved by 86% with the above standard value of 85.0%. HASSAN [2015] reported that the *CU* values for 50%, 75% and 100% of speeds were 79.1, 82.9 and 90.7 respectively, which indicate a range typical to that found in this study. Also, results of performance evaluation of centre pivots were showed that uniformity coefficient (*CU*) for the systems were within acceptable standards above the base values of 85% for *CU* [MSIBI *et al.* 2014].

Also, results from a study showed that the low value of uniformity coefficients obtained under different system speeds can also be attributed to clogging of nozzles caused by sedimentation, trashes and/or nozzles being worn out [EVANS, SNEED 1996]. Figure 3 shows that *CU* in the speeds of 40% and 60 % for all spans were more than 75%, and were close together.

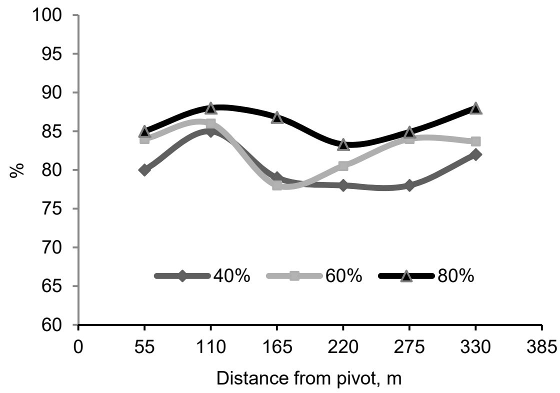

Fig. 3. Uniformity coefficient (*CU*) for all evaluation tests; source: own study

PELQ AND *AELQ* RESULTS

The recommended *AELQ* were only met by span number 2, 5 and 6 at the rate of 84, 81 and 88% for S_1 speed (Fig. 4). Also, this parameter for S_2 was 80 and 83 percent for spans number 5 and 6, respectively. Moreover, *AELQ* for maximum speed (S_3) achieved by 84, 84 and 90% for spans number 2, 5 and 6, respectively (Fig. 4).

Also the maximum value for *PELQ* was matched by span no. 6 with 83% in all speeds. The performance evaluation of centre pivot under all the operating speeds did not meet the recommended performance standards which states that spray nozzle sprinkler centre pivot *PELQ* and *AELQ* should be at least 90%.

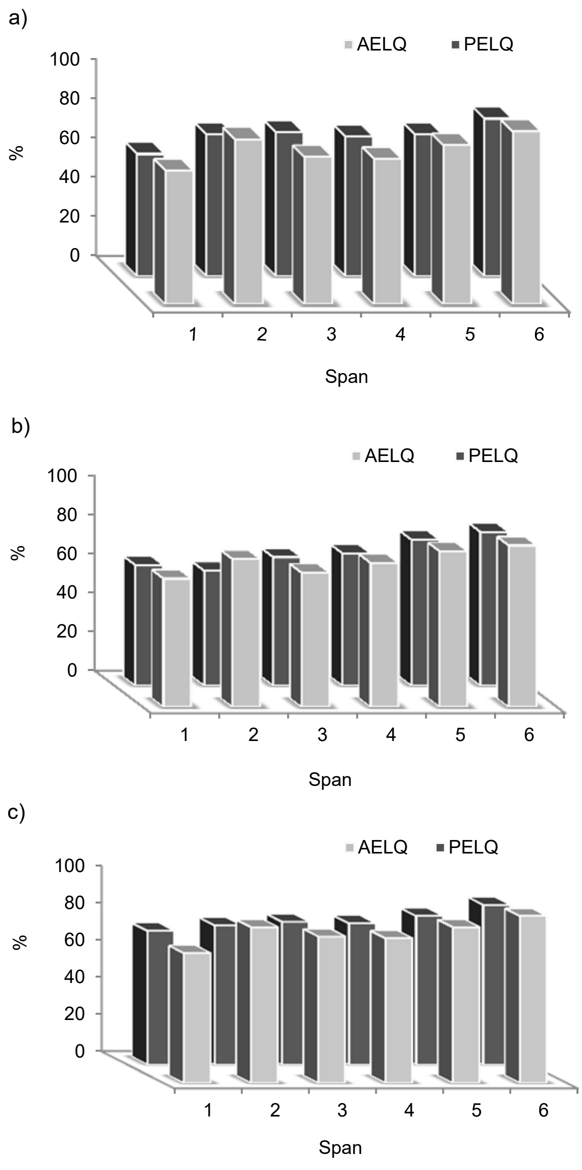

Fig. 4. Low water application efficiency (*AELQ*) and potential water application efficiency (*PELQ*) of the system under different speeds: a) 40%, b) 60%, c) 80%; source: own study

CONCLUSIONS

The advantage of centre pivot irrigation system is to operate under different speeds with acceptable water distribution uniformities. The higher water distribution uniformities percentage obtained as speed increased. Also, effects of variation of speed obtained *CU* values of 80.3, 82.7 and 86% for 40, 60, and 80% speed, respectively. The *CU* standard value ($CU \geq 85\%$) was achieved in S_3. Furthermore, for *DU* the results obtained indicate standard levels ($DU \geq 75\%$) for S_2 and S_3 speed, while a higher value of 82% is obtained with the maximum operating speed (S_3). This clarified that the *DU* and *CU* increased as speed increased as general treat. Also, Application efficiencies (*AELQ* and *PELQ*) were below the standard value of 90%. Water leakage from the system is affecting the performance of the sprayers and the distribution of the water pressure at the sprayer's outlets. Finally, it is crucial to regularly maintain a system and perform a type of uniformity test to assure appropriate applications.

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Meysam ABEDINPOUR

Polowa ocena systemu deszczowania w północno-wschodnim Iranie

STRESZCZENIE

Polową ocenę sprawności technicznej systemu deszczowania przeprowadzono w sezonie wegetacyjnym kukurydzy, kiedy system pracował z różną prędkością roboczą: S_1 – 40%, S_2 – 60% i S_3 – 80%. W ocenie uwzględniono cztery miary jednorodności: współczynnik jednorodności (*CU*), jednorodność dystrybucji (*DU*), potencjalną wydajność dolnej ćwiartki aplikacji (*PELQ*) i rzeczywistą wydajność dolnej ćwiartki aplikacji (*AELQ*). Pierwszym etapem oceny systemu zraszania było porównanie zmierzonych wartości jednorodności z wartościami standardowymi: $DU \geq 75\%$, $CU \geq 85\%$, *AELQ* i $PELQ \geq 90\%$. Wpływ różnych prędkości wyraził się różnymi wartościami *CU*, wynoszącymi odpowiednio 80,3, 82,7 i 86,0%, gdy prędkość była równa S_1, S_2, i S_3. Ponadto standardową wartość *DU* uzyskano, gdy prędkość S_3 wynosiła 82%. Wartości *AELQ* i *PELQ* były poniżej dopuszczalnego standardu 90% dla wszystkich prędkości. Nierównomierne rozprowadzanie wody prowadzi do nadmiernego bądź niedostatecznego nawodnienia w różnych częściach pola, co skutkuje zmarnowaniem wody i energii. Z tego powodu niezbędna jest regularna kontrola urządzeń irygacyjnych dla wydajnego i efektywnego zarządzania nawodnieniami.

Słowa kluczowe: *nawodnienia, równomierność dystrybucji, system deszczowania, współczynniki równomierności*