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Evaluation of a Novel Sprinkler Irrigation System (Darbasti) and Its Comparison with Common Sprinkler Irrigation Systems: Investigating the Impact on Alfalfa Water Productivity

Abstract: - With the objective of enhancing the performance of sprinkler irrigation systems, a novel sprinkler irrigation system, the Darbasti irrigation system, was conceived and implemented. The current study evaluates and compares the effectiveness of movable sprinkler solid-set, center-pivot, and Darbasti irrigation systems in alfalfa cultivation in Saveh, situated in the central plain of Iran. Key performance metrics, including distribution uniformity (DU), coefficient of uniformity (CU), application efficiency of the low quarter (AELQ), and water productivity (WP), were determined for each irrigation system in 2018 and 2019 following the third, fourth, and fifth harvests. The results indicate that the average CU of the Darbasti irrigation system in the first and second years was 82.39% and 84.75%, respectively. The DU for Darbasti, center-pivot, and solid-set sprinkler irrigation systems in the first and second years was 75.38% and 77.66%, 74.56% and 75.99%, and 30.16% and 33.26%, respectively. This indicates excellent performance for Darbasti and center-pivot irrigation systems, but poor performance for the solid-set sprinkler irrigation system. Furthermore, the AELQ index showed no significant difference in the first and second years for Darbasti and center-pivot irrigation systems, while a sharp decrease in this index in the solid-set sprinkler irrigation system revealed a significant difference compared to the other two systems. According to the results, water productivity for Alfalfa in Darbasti, solid-set sprinkler and center-pivot irrigation systems in the first and second years was 2.28 kg/m3 and 2.43 kg/m3, 1.08 kg/m3 and 1.15 kg/m3, and 2.27 kg/m3 and 2.3 kg/m^3, respectively.

Keywords: solid-set sprinkler irrigation, center-pivot, DU, CU

I. INTRODUCTION

The escalating global population has created an unprecedented demand for food and agricultural products (Masoudi et al. 2018). Alfalfa stands as one of these crucial agricultural products, with its demand intensifying alongside population growth (Montazar and Sadeghi 2008). Meanwhile, countries like Iran have been grappling with dwindling water resources due to recurrent droughts and shifting climate patterns (Haghverdi et al. 2016). Hence, the quest to enhance irrigation efficiency and water productivity for this valuable crop becomes imperative. Over recent decades, various irrigation systems have evolved to optimize water distribution in fields while minimizing losses. Among these methods, various sprinkler irrigation systems have been employed for densely planted crops like Alfalfa (Isla and Aragüés 2009; Urrego-Pereira et al. 2013; Cavero et al. 2016; Li and Su 2017; Wang et al. 2020; Li et al. 2021).

While sprinkler irrigation systems offer numerous advantages, they are not without limitations. For instance, researchers have scrutinized the center-pivot irrigation system and uncovered drawbacks such as heightened soil erosion in the end spans due to increased flow per unit area (Lehrsch et al. 2005), limited suitability for small and irregularly shaped fields (dos Santos Almeida et al. 2023), the potential formation of soil surface cracks from water droplet impact, etc. (Laker and Nortjé 2019). On the other hand, traveling guns pose their own challenges, including high working pressures (400 to 1000 kPa), low application efficiency, poor distribution uniformity,

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elevated operational costs, large droplet sizes (with the potential to harm soil structure and crops), as well as increased risk of rainfall, runoff, and erosion (Rolim and Teixeira 2016).

Further exploration also reveals other issues, such as wind drift and evaporation losses, low distribution uniformity, and more, that can affect sprinkler irrigation systems differently depending on system type and climatic conditions (Yacoubi et al. 2012; Marey et al. 2018; Li et al. 2021; Sarwar et al. 2021; García Bandala et al. 2022).

These limitations necessitate the upgrading of existing sprinkler irrigation systems or the construction and development of new sprinkler irrigation systems to enhance the performance of sprinkler irrigation systems (Sarwar et al. 2021). In addition to the change in the nature of irrigation systems, the correct selection of the type of irrigation system according to the climatic conditions and the type of crop is also of particular importance, because the incorrect selection of the irrigation system can lead to an increase in irrigation losses, a decrease in the quality of agricultural products, etc. Therefore, it is necessary to choose the most appropriate irrigation system according to the type of crop, climatic conditions, shape and size of the field.

To identify the optimal irrigation system for a given crop, it is essential to initially evaluate the efficiency and performance of the system under similar conditions (Wu et al. 2024). As such, irrigation system efficiency is often assessed through indicators such as distribution uniformity (DU), coefficient of uniformity (CU), application efficiency of water use in the lower quartile (AELQ), and potential efficiency of water use in the lower quartile (PELQ) (Merriam and Keller 1978). Numerous studies have investigated these indicators across various irrigation systems and conditions (Merriam and Keller 1978; Maroufpoor et al. 2010; Farg et al. 2017; Abedinpour 2017; Ngasoh et al. 2018; Saretta et al. 2018; Kazemi and Izadpanah 2019; Jobbágy et al. 2021; Hashim et al. 2021; GÜLTEKİN et al. 2022; Xue et al. 2023). These findings highlight the significance of these indicators but also underscore their inability to fully reflect the impact of an irrigation system on crop yield. Consequently, it is crucial to consider water productivity (WP) alongside these indicators. This has spurred numerous studies focused on determining the water productivity of alfalfa under sprinkler irrigation across varying conditions. A review of these studies reveals that alfalfa productivity under full irrigation and sprinkler irrigation ranges from 0.86 to 2.51 kg/m^3 on average (Grimes et al. 1992; Montazar and Sadeghi 2008; Mobtaker et al. 2011; Salvador et al. 2011; Naroua et al. 2014; Li et al. 2016, 2023; Li and Su 2017; Ebrahimian and Gholami 2019; Djaman et al. 2020). This wide range underscores the need for further investigations to enhance irrigation efficiency.

In order to enhance the performance of sprinkler irrigation systems in dense crops such as alfalfa, and to address challenges related to water distribution uniformity and irregular field shapes, a novel irrigation system named the "Darbasti Irrigation System" was developed and implemented. This system was specifically designed to improve irrigation in alfalfa fields. To evaluate its effectiveness, the performance of the Darbasti Irrigation System was compared with that of other commonly used sprinkler irrigation systems, including center-pivot and solid-set sprinkler systems with movable sprinklers, which are frequently employed in alfalfa irrigation. The evaluation of these irrigation systems was conducted using CU, DU, and AELQ indexes to assess their efficiency. Additionally, the water productivity (WP) of alfalfa in each system was compared and analyzed. The results of this comparative analysis provide valuable insights into the performance of the Darbasti Irrigation System and its potential benefits for alfalfa cultivation.

II. MATERIALS AND METHODS

Characteristics of the Experimental Region

The current study was conducted from 2018 to 2019 in a 115-hectare field located in Saveh, situated in the central plain of Iran, with a longitude of 50 degrees, 20 minutes East, and a latitude of 35 degrees, 3 minutes North. Three distinct irrigation systems, namely center-pivot, movable sprinkler solid-set, and the innovative Darbasti system, were utilized, each partially covering specific areas within the field, irrigating alfalfa over 21.7, 0.7, and 0.8 hectares, respectively (refer to Fig. 1 for visualization). The soil properties of the field at various depths are detailed in Table 1. The average annual temperature in this region is 18.1 degrees Celsius, accompanied by an average wind speed of 1.2 meters per second at a height of two meters above the ground, and an average relative humidity of 37%. Further monthly meteorological data is provided in Table 2. The annual average rainfall in this area totals 196 mm, typically concentrated between October and March. This underscores the imperative need for irrigation to satisfy the water requirements of Alfalfa.

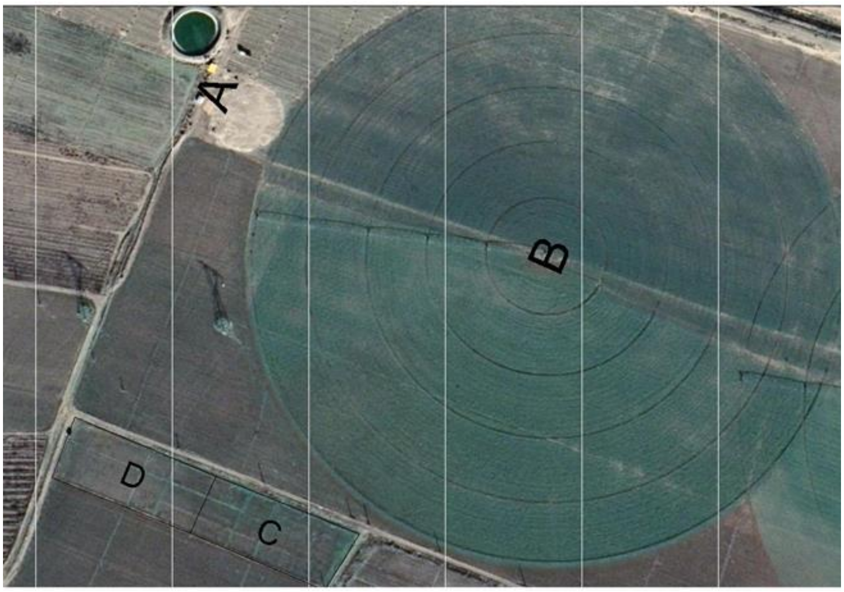

Fig. 1 The location of irrigation systems: A. Meteorological station; B. Center-pivot irrigation system; C. Darbasti irrigation; D. Solid-set sprinkler irrigation

Table 1 Soil properties of the experimental field

Depth (c*m*)	Soil texture	EC_e (*dS/m*)	pH	FC (*%*)	PWP (*%*)	**Bulk density (*g/cm³*)**
0-30	Clay loam	10.29	7.8	21.5	10.3	**1.35**
30-60	Clay loam	13.91	7.8	21.5	10.3	**1.34**
60-90	Clay loam	6.99	8.1	21.5	10.3	**1.37**

Table 2. Meteorological information of the experimental field

	April	May	June	July	August	September	October	November	December	January	February	March	Annual
T_{avg} (C°)	17.5	22.9	27.5	31.4	30.7	26	19.8	11.6	6.3	4.4	7	11.9	18.1
P (mm)	28.5	13.1	1.5	1.3	0.5	0.6	8.6	29.5	28.8	30	22.3	31.1	19.6
RH (%)	36	28	24	25	24	26	33	45	57	56	47	38	37
W (m/s)	1.1	0.9	0.7	0.9	1.2	1.4	1.5	1.5	1.4	1.4	1.2	1.1	1.2

Data collection and experimental design

Field evaluations were conducted on soil with young alfalfa crop (Medicago sativa) in its early stages of growth. All measurements were conducted early in the morning under standard field conditions, with the utmost haste to minimize evaporation from the collectors.

To determine the key indicators under scrutiny, catch-cans with a diameter of 15 cm and a height of 17 cm were employed. Data were collected for each of the irrigation systems after the third, fourth, and fifth harvests, with each measurement being replicated three times. Subsequently, the efficiency indicators of the irrigation systems (CU, DU, AELQ, and WP) were calculated for each replication. The variations in these indicators across different systems were compared separately for each year using one-way analysis of variance (One-way ANOVA) and the LSD pairwise comparison test. In the following sections, the design of each irrigation system and the arrangement pattern of the catch cans are presented in detail.

Darbasti Irrigation System

This irrigation system comprises a set of columns, lateral irrigation pipes made of Lowden polyethylene, cables, MP Rotator Hunter sprinklers, and various related connections. It operates through hydraulic water pressure, effectively simulating artificial rainfall across a large area (see Figure 2). The columns' height ranges from five to seven meters, and the spacing between them varies between 9 and 70 meters, depending on the field's size, allowing most agricultural equipment to function effectively. In this irrigation system, the operating pressure for the sprinklers falls between 20 to 25 meters. Given the close proximity of the sprinklers to each other, approximately 100 to 150 sprinklers operate simultaneously within a one-hectare area, which increases the overlapping of sprinklers and as a result more appropriate distribution of water in different parts of the field. Moreover, the large number of sprinklers has created a microclimate that increases the relative humidity and decreases the temperature and prevents the increase in evaporation losses due to the increase in height above the ground. Furthermore, due to the large area of irrigation, in each irrigation shift, a smaller part of the water is removed from the irrigation area, which leads to less wind losses than is thought. Depending on the flow rate of the sprinklers used at the desired pressure, water consumption per hectare typically ranges from 20 to 30 liters per second, contingent on the number of sprinklers employed.

The flexibility of column placement and the ability to adjust their spacing make this irrigation system suitable for fields of various shapes and sizes. Furthermore, the system's fixed nature results in minimal depreciation. Additionally, the deliberate avoidance of hydraulic, electronic, and electromechanical components simplifies operation, making it accessible to non-specialist operators and reducing both operating and maintenance costs.

This irrigation system was implemented in a section of the studied field measuring 120 by 50 meters. The columns were positioned five meters above ground level, with a 50-meter spacing widthwise and a 10-meter spacing lengthwise. Within each lateral section (each lateral measuring 50 meters in length), the first sprinkler (Hunter MP 3000 360) was installed at a distance of 4 meters from the start, followed by other sprinklers spaced 8 meters apart from each other. The final sprinkler (Hunter MP2000-180) was situated 6 meters away from the preceding one and attached to the column (refer to Figure 3). For this field, an 8*10 pattern for sprinkler installation was chosen based on the soil texture and alfalfa's water requirements. The pressure (inflow pressure at 2.5 bar) and the initial water inflow into this irrigation system were measured using a pressure gauge and a flow meter, respectively.

To assess the efficiency of this irrigation system, catch-cans were positioned in a square pattern, with a spacing of 2.5 meters between each can beneath the irrigation system (as depicted in Fig. 3). The depth of water reaching the ground was measured in a rectangular area measuring 30 by 125 meters, with data collected in three replications.

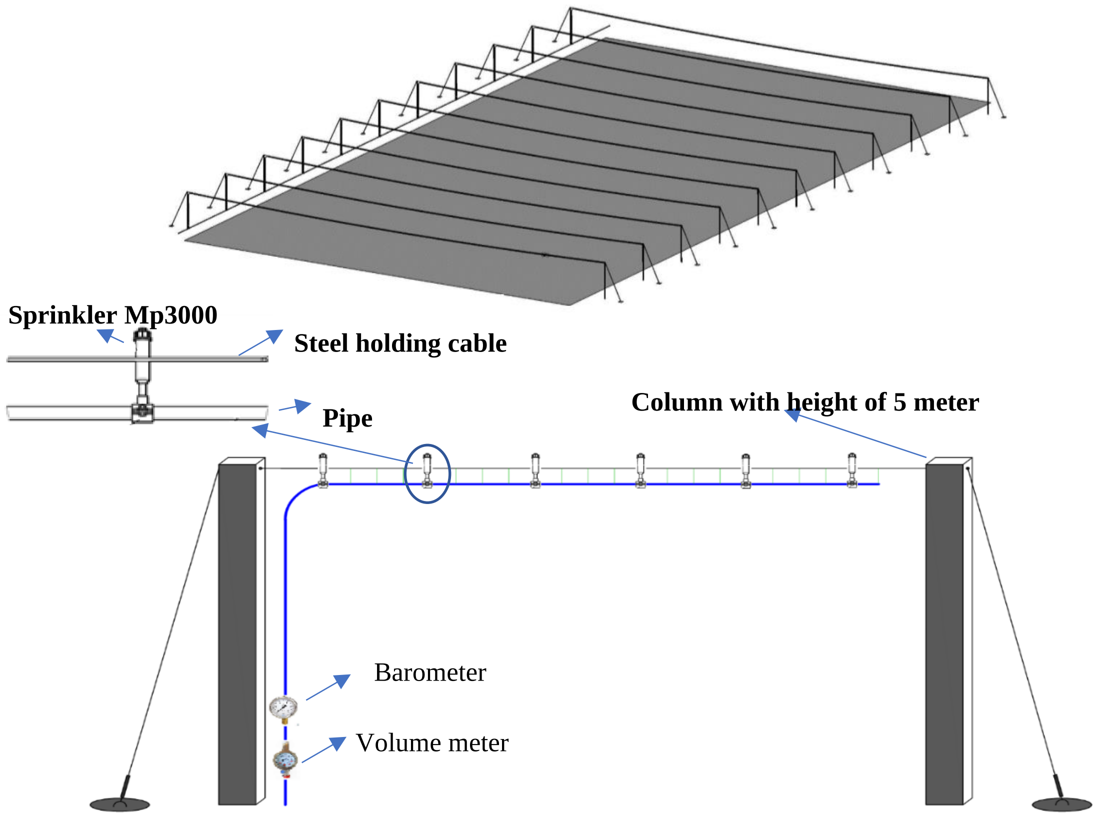

Fig. 2 Darbasti irrigation picture, map and plan

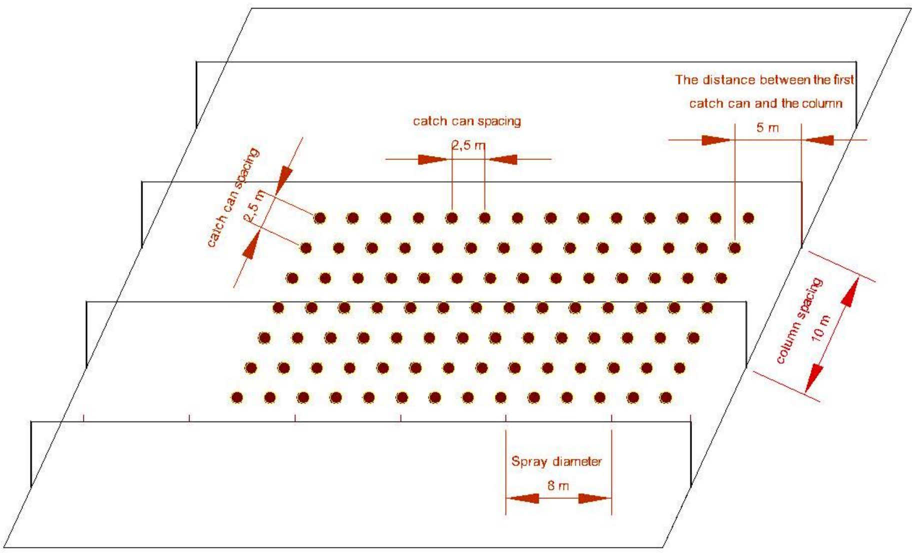

Fig. 3 Placement of catch-cans in Darbasti irrigation

2.2.2. Center Pivot irrigation system

In another part of the field, a center pivot irrigation system with 5 openings was designed and installed in accordance with the principles and guidelines of the hydraulic standard, which irrigated 21.7 hectares. In this system, 90 R3000 Nelson sprinklers (sprinklers were positioned at a distance of 3 meters from each other) with variable nozzle diameters and a working pressure of 1.5 bar were used (all sprinklers had a pressure regulator). In order to evaluate the efficiency of this irrigation system, catch-cans were placed at a distance of 2.5 meters from each other along the radius of the device and in two sectors (two sectors with a distance of 30 degrees) and the depth of water reaching the ground was measured in three replications (Fig. 4).

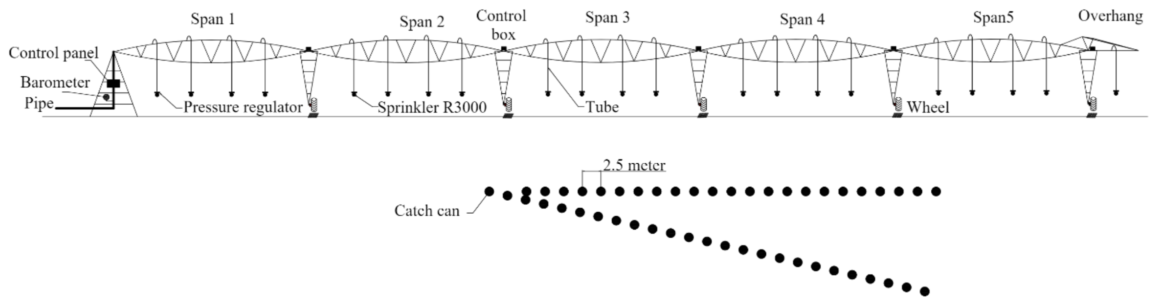

Fig. 4 Location of catch-cans in center-pivot irrigation (no scale)

Solid-Set Sprinkler Irrigation System

This irrigation system which is in accordance with the principles and guidelines of the hydraulic standards, was installed in a field spanning 5202 square meters (104*51 meters), designated for alfalfa irrigation using six Comet 163 sprinklers operating in two shifts. These sprinklers were mounted on two lateral pipes, each 102 meters in length and spaced 17 meters apart. Within each lateral, three sprinklers were evenly positioned, maintaining a 17-meter separation between them. The operating pressure of each lateral inflow, measured using a pressure gauge, was recorded at 3.5 bar. As part of this irrigation system, catch-cans were strategically placed at 2.5-meter intervals from one another, forming a square pattern between the two laterals (see Fig. 5). Measurements were conducted in three replications.

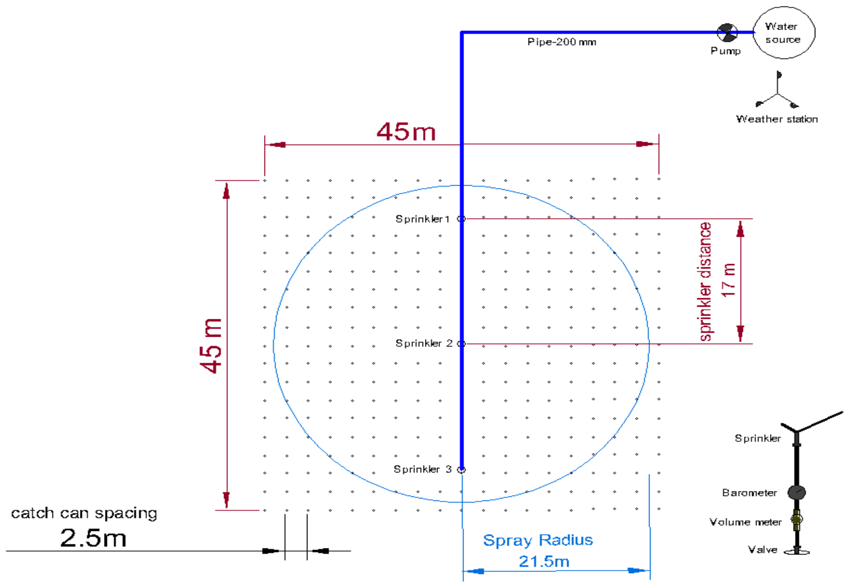

Fig. 5 The location of sprinklers and catch cans in solid-set sprinkler irrigation system

Parameters for irrigation performance measurement

Performance evaluation is an integral part of irrigation systems (Ngasoh et al. 2018) and researchers have always attempted to improve the performance of these systems (Hashim et al. 2021). In this respect, a range of indices are scrutinized, and the present study focused on key indices, namely CU, DU, AELQ, and WP.

Distribution Uniformity (DU)

Water distribution uniformity was defined as the ratio of the mean depth caught in the fourth of the field receiving the least amount to the mean depth caught over the entire area, as per (Keller and Bliesner 2001). This index, denoted by DU, is calculated using the following equation:

$$DU = \frac{\bar{x}_{Low\ quarter}}{\bar{X}} \times 100 \quad \text{(Eq. 1)}$$

where DU is the distribution uniformity (%), $\bar{x}_{Low\ quarter}$ is the average of the lowest quarter of the depths collected in the catch-cans (mm), and $\bar{X}$ is the average of the total water depth collected in the catch cans.

Keller and Bliesner (2001) rated the efficiency of the system with Du > 85, 75 < DU < 85, 70 < DU < 75, 65 < DU < 70, and DU < 65 percent as excellent, very good, good, fairly good (fair), and weak, respectively.

Coefficient of Uniformity (CU)

Christiansen coefficient of uniformity was primarily used to determine the uniformity of sprinkler irrigation systems (Christiansen 1942). This coefficient is now used as a well-known method for evaluating water uniformity in the mentioned systems (Maroufpoor et al. 2010). This index, represented by CU, is measured by the following equation:

$$CU = 100 \times (1 - \frac{\sum_{i=1}^{n} |x_i - \bar{x}|}{\sum_{i=1}^{n} x_i}) \quad \text{(Eq. 2)}$$

where CU is Christiansen coefficient of uniformity (%), x_i is the depth of water collected in each of the catch cans (mm), and $\bar{x}$ is the average depth of water collected in all catch cans.

Keller and Bliesner (2001) introduced the efficiency of a sprinkler irrigation system with a uniformity coefficient of more than 84% as excellent, between 75% and 84% as appropriate, and less than 75% as weak.

Application Efficiency of the Low Quarter (AELQ)

The AELQ index, which shows how to exploit an irrigation system, is determined using the following equation (Merriam and Keller 1978):

$$AELQ = \frac{D_q}{D_r} \times 100 \quad \text{(Eq. 3)}$$

where AELQ is the application efficiency of the low quarter (%), Dq is the average of the lowest quarter of the measured depths (mm), and Dr is the average depth of water removed from the sprinkler (mm).

Water Productivity (WP)

Water productivity (WP) is calculated using various formulas in accordance with the given objectives (Wang et al. 2010; Carracelas et al. 2019; Wakchaure et al. 2020; Zhang et al. 2021). In the current research, water productivity was calculated using the following equation:

$$WP = \frac{D_m}{I} \quad \text{(Eq. 4)}$$

where WP is water productivity ($kg.m^{-3}$), D_m is the weight of dry alfalfa (moisture 13%), and I is the volume of irrigation water.

In this research, since the texture and structure of the soil as well as the amount of fertilization were the same in all three irrigation methods, it was possible to compare the yield of alfalfa in different irrigation systems during the third, fourth and fifth harvests. Each of these harvest rounds comprised four irrigation shifts, with the total volume of irrigation water measured using a flow meter. In addition, the efficiency of alfalfa water productivity was calculated.

III. RESULT AND DISCUSSION

Coefficient of Uniformity (CU)

Table 3 presents the performance indicator values of sprinkler irrigation systems in various iterations over the two years of the study. The results indicated that the average coefficient of uniformity (CU) for the Darbasti irrigation system in the first and second years was 82.39% and 84.75%, respectively, with an overall average of 83.57%. This system demonstrated the highest uniformity compared to the other two irrigation systems. The center-pivot irrigation system also performed well, with average CU values of 81.35% and 81.87% in the first and second years, respectively. CU values for Gun, center-pivot, and linear irrigation systems have been reported in the range of 60% to 92% in various studies (Menezes et al. 2015; Jobbágy and Krištof 2018; Jobbágy et al. 2019, 2021; Al-ghobari and Dewidar 2021).

The one-way analysis of variance results for both years indicated a significant difference in CU values among the three irrigation systems at the 1% level (Table 4). Further examination through the LSD test revealed that while there was no statistically significant difference in CU between the center-pivot and Darbasti irrigation systems, there was a significant difference between the solid-set sprinkler irrigation system and the other two systems at the 1% level (Table 5).

Comparing the CU values in the studied irrigation systems in this research with those presented by Keller and Bliesner (2001) revealed that both Darbasti and center-pivot irrigation systems performed well. In contrast, the solid-set sprinkler irrigation system exhibited weaker performance. Figures 6 and 7 illustrate the water distribution patterns in the solid-set and Darbasti irrigation systems in different replications. A closer examination of these patterns shows that in the Darbasti irrigation system, water distribution uniformity, and consequently the coefficient of uniformity, are higher compared to the solid-set irrigation system.

The better coefficient of uniformity in the Darbasti and center-pivot irrigation systems compared to the other systems may be attributed to several factors. Firstly, the sprinklers used in the Darbasti and center-pivot systems, as indicated in the manufacturer's catalog, produce a more uniform spray at the appropriate pressure compared to Commet sprinklers, owing to their relatively low spray radius. Secondly, the distance between the sprinklers in the former two systems was relatively short compared to the solid-set sprinkler irrigation system (with distances of 3, 7, and 17 meters in center-pivot, Darbasti, and solid-set systems, respectively). This resulted in a more consistent water depth reaching the surface, leading to enhanced uniformity in water distribution. Keller and Bliesner (2001) and (Kara et al. 2008) have also noted that increasing the spacing between sprinklers reduces the amount of water collected in the end catch cans, thus lowering the coefficient of uniformity. Thirdly, the overlap in the Darbasti and center-pivot systems (involving more sprinklers per hectare) is greater compared to other systems, contributing to the higher coefficient of uniformity. As overlap increases, the depth of water collected in the end catch cans may rise due to receiving less water due to its distance from the sprinkler or the influence of evaporation and wind drift (Ortíz et al. 2010). Despite the expectation that evaporation and wind drift loss would increase in the Darbasti irrigation system (Tarjuelo et al. 2000; Ortíz et al. 2010; Mengistu Debela 2017), where the sprinkler is farther from the surface, high overlap, superior sprinkler quality, the creation of a microclimate with higher relative humidity and lower temperature (due to the simultaneous use of more than 100 sprinklers per hectare), among other factors, may have contributed to an adequate coefficient of uniformity in this irrigation system.

Table 3. Indices of DU, CU, ALEQ in Darbasti, solid-set and center-pivot irrigation systems

Year	replication	Darbasti			Solid-set sprinkler			Center-pivot		
		CU	DU	AELQ	CU	DU	AELQ	CU	DU	AELQ
First	1	81.94	76.15	71.01	61.48	27.38	26.36	81.36	74.57	70.14
	2	81.31	74.30	66.36	63.00	31.22	26.44	81.29	74.42	69.95
	3	83.93	75.71	71.28	62.25	31.87	24.32	81.41	74.69	68.00
	Mean	82.39	75.38	69.55	62.24	30.16	25.71	81.35	74.56	69.36
	Eval.	Acceptable	Very good		Poor	Poor		Acceptable	Good	
Second	1	84.85	77.77	72.27	63.63	34.07	26.36	82.16	76.36	70.14
	2	85.01	78.12	71.10	61.90	33.70	26.44	82.12	76.31	69.95
	3	84.39	77.10	70.29	62.57	31.99	24.32	81.35	75.29	68.00
	Mean	84.75	77.66	71.22	62.70	33.26	25.71	81.87	75.99	69.36
	Eval.	Excellent	Very good		Poor	Poor		Acceptable	Very good	

Table 4. The ANOVA for comparing the average indices of CU, DU, AELQ, and WP in different irrigation methods

Index	Year	Source change	Sum of squares	degree of freedom	Mean square	The F statistic	Level of significance
CU	First	Inter-treatment	1003.120	4	250.78	190.416	0.00**
		Intra-treatment	13.170	10	1.317		
		Total	1016.290	14			
	Second	Inter-treatment	1020.51	4	13.255	251.56	0.00**
		Intra-treatment	10.14	10	1.014		
		Total	1030.66	14			
DU	First	Inter-treatment	4768.235	4	1192.059	348.798	0.00**
		Intra-treatment	34.176	10	3.418		
		Total	4802.411	14			
	Second	Inter-treatment	5444.07	4	1361.01	319.20	0.00**
		Intra-treatment	42.63	10	4.26		
		Total	5486.70	14			
AELQ	First	Inter-treatment	4604.26	4	1151.06	285.12	0.00**
		Intra-treatment	40.37	10	4.037		
		Total	4644.63	14			
	Second	Inter-treatment	5100.62	4	1275.15	72.03	0.00**
		Intra-treatment	177.02	10	17.70		
		Total	5277.64	14			
WP	First	Inter-treatment	3.33	4	0.832	507.58	0.00**
		Intra-treatment	0.016	10	0.002		
		Total	3.34	14			
	Second	Inter-treatment	3.46	4	0.867	228.96	0.00**
		Intra-treatment	0.038	10	0.004		
		Total	3.50	14			

Significant at the 0.01 level **

Table 5. The LSD test for comparing the CU, DU, AELQ and WP indices in the studied irrigation systems

Index	Treatment 1	Treatment 2	First year		Second year	
			Average difference	Level of significance	Average difference	Level of significance
CU	Darbasti	Solid-set sprinkler	21.15	0.000**	20.71	0.00**
		Center pivot	2.04	0.055	1.60	0.080
	Solid-set sprinkler	Darbasti	-21.15	0.000**	-20.71	0.00**
		Center pivot	-19.11	0.000**	-19.11	0.00**
	Center pivot	Darbasti	-2.04	0.055	-1.60	0.080
		Solid-set sprinkler	19.11	0.000**	19.11	0.00**
DU	Darbasti	Solid-set sprinkler	45.23	0.00**	52.79	0.00**
		Center pivot	0.823	0.596	8.33	0.001**

	Solid-set sprinkler	Darbasti	-45.23	0.00**	-52.79	0.00**
		Center pivot	-44.40	0.00**	-44.46	0.00**
	Center pivot	Darbasti	-0.823	0.596	-8.33	0.001**
		Solid-set sprinkler	44.40	0.00**	44.46	0.00**
AELQ	Darbasti	Solid-set sprinkler	43.84	0.00**	44.97	0.00**
		Center pivot	0.1866	0.912	2.69	0.451
	Solid-set sprinkler	Darbasti	-43.84	0.00**	-44.97	0.00**
		Center pivot	-43.65	0.00**	-42.27	0.00**
	Center pivot	Darbasti	-0.1866	0.912	-2.69	0.451
		Solid-set sprinkler	43.65	0.00**	42.27	0.00**
WP	Darbasti	Solid-set sprinkler	1.20	0.00**	1.28	0.00**
		Center pivot	0.0066	0.844	1.3	0.027*
	Solid-set sprinkler	Darbasti	-1.20	0.00**	-1.28	0.00**
		Center pivot	-1.19	0.00**	-1.15	0.00**
	Center pivot	Darbasti	-0.0066	0.844	-0.13	0.027*
		Solid-set sprinkler	1.19	0.00**	1.15	0.00**

****Significant at the 0.01 level**
***Significant at the 0.05 level**

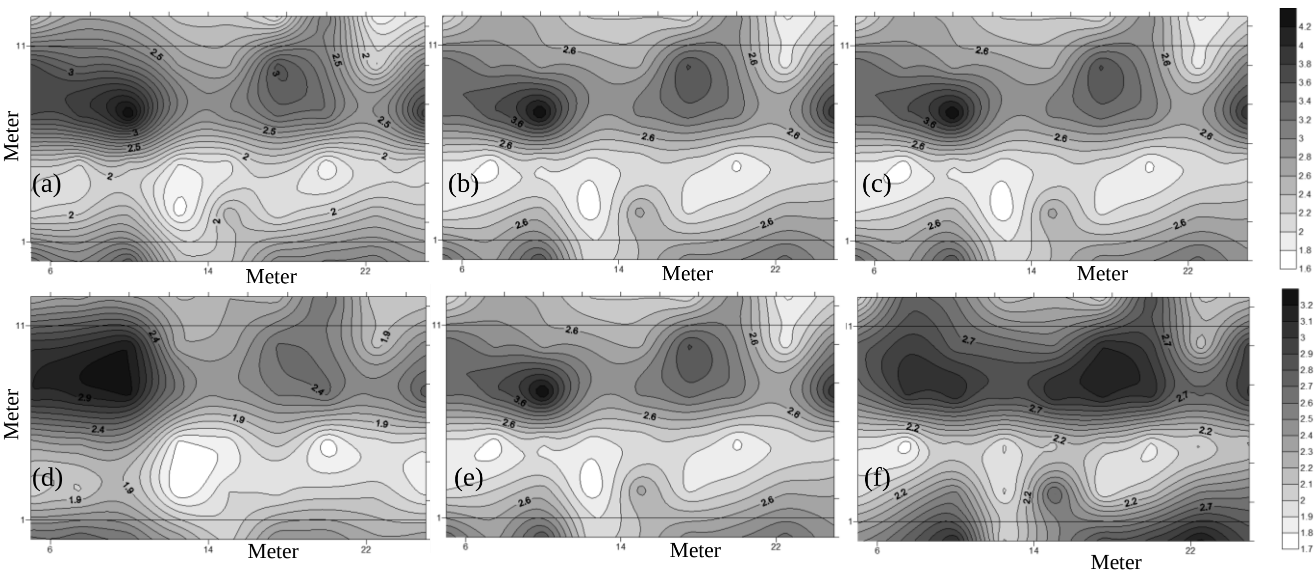

Fig. 6 Water distribution pattern in Darbasti irrigation (a. First year, first replication, b. First year, second replication, c. First year, third replication, d. second year, first replication, e. second year, second replication, and f. second year, third replication)

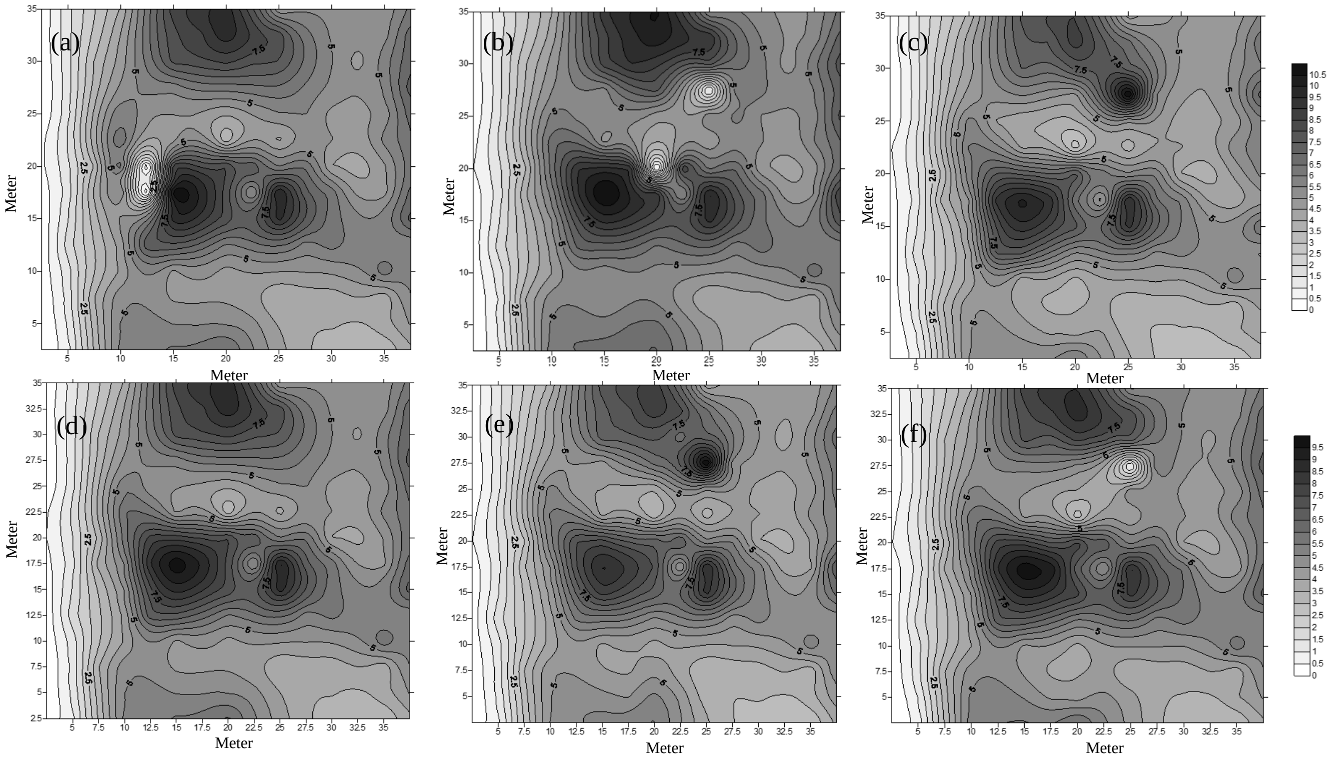

Fig. 7 Water distribution pattern in solid-set sprinkler irrigation (a. First year, first replication, b. First year, second replication, c. first year, third replication, d. second year, first replication, e. second year, second replication, and f. second year, third replication)

Distribution Uniformity (DU)

The data collected revealed that the distribution uniformity (DU) of water in the Darbasti, center-pivot, and solid-set sprinkler irrigation systems in the first and second year was estimated to be 38.75 and 66.77, 56.74 and 99.75, and 16.30 and 26.33, respectively. According to Keller and Bliesner (2001), the average efficiency of this index over two years for the Darbasti, center-pivot, and solid-set sprinkler irrigation systems was classified as very good, good, and weak, respectively (Table 3). Pitts et al. (1996) conducted a study on the performance of 159 sprinkler irrigation systems and estimated the average distribution uniformity (DU) at 65%. Ascough and Kiker (2002) reported the value of this index to be 81.4% on average in the center-pivot irrigation system and 56.9% in the semi-permanent sprinkler irrigation system. Al-ghobari and Dewidar (2021) determined the average of this index in center-pivot irrigation systems to be between 60 and 80 percent.

The investigation into the causes of changes in average distribution uniformity across various fields and conditions revealed that several factors could be attributed to these changes. These factors include insufficient overlap, the use of worn-out sprinklers, the utilization of nozzles with differing and inappropriate diameters, variations in irrigation system pressure (both high and low), all of which could potentially contribute to a decrease in distribution uniformity (Hashim et al., 2021; Pitts et al., 1996).

In this study, the center-pivot and Darbasti irrigation systems demonstrate proper distribution uniformity, indicating the correct design and relatively suitable performance of these systems in water distribution. However, the solid-set sprinkler irrigation system exhibits significantly lower distribution uniformity. In this regard, the influence of the distance between the sprinklers and the reduced overlap between them is notable. Consequently, as the distance from the sprinkler increases, the amount of water reaching the ground surface (collected in catch cans) decreases due to the sprinkler's bell-shaped spraying pattern, leading to a decline in distribution uniformity (Keller and Bliesner, 2001). When the operating pressure of the sprinkler (two-nozzle sprinklers) is optimal, it is expected that a larger proportion of water will reach the ground surface near the sprinkler, with this value decreasing as the distance from the sprinkler increases. Additionally, the effect of the spraying height of the

Commet sprinkler (according to the catalog, with a pressure of 4 bar, the spraying height is 4 meters) should not be overlooked. As the spraying height increases, there is increased wind loss, evaporation, and subsequently, a decrease in distribution uniformity.

The results of statistical tests using one-way analysis of variance in the first and second years indicated a significant difference at the 1% level in the DU index between different irrigation systems (Table 4). Further, the results of the LSD test showed that in the first year, no significant difference was observed in the coefficient of uniformity between the Darbasti and center-pivot irrigation systems. However, in the second year, all sprinkler irrigation systems exhibited a significant difference at the 1% level from each other (Table 5).

AELQ

The average application efficiency of the lower quartile in the first and second years was 69.36% for the center-pivot irrigation system, and 69.55% and 71.22% for the first and second years in the Darbasti irrigation system, respectively. This index had significantly lower values in the solid-set irrigation system, as with other indices. The results of one-way analysis of variance and LSD tests indicated that there was no significant difference in this index between the first and second years in the Darbasti and center-pivot irrigation systems, while, as expected, the solid-set irrigation system showed a significant difference from the other two systems (Tables 4 and 5). According to the optimal range of this index, which is between 65 and 88% (Merriam and Keller 1978), both Darbasti and center-pivot irrigation systems demonstrated favorable performance. Lower values of this index are typically attributed to management issues within the irrigation system (Mengistu Debela 2017; Hashim et al. 2021). In conclusion, the solid-set irrigation system employed in this field exhibits management issues in addition to inherent defects. Therefore, efforts should be directed towards improving this index by addressing management concerns. The most effective approach to narrow this gap involves adjusting the sprinkler set time based on the sprinkler outflow rate and Alfalfa water demand.

Water Productivity (WP)

Yield, the amount of water consumption, and water productivity of alfalfa in different irrigation systems are presented in Table 6. According to the table, the average yield of alfalfa in the Darbasti irrigation system in the first and second years was 3394 and 3621 kg per hectare, respectively. These values were 3651 and 3698 kg/ha in the center-pivot irrigation system and 2246 and 2398 kg/ha in the solid-set irrigation system, respectively. The results of statistical tests indicated that alfalfa yield in the first year differed significantly among all three irrigation systems, but in the second year, this difference was not significant in the Darbasti and center-pivot irrigation systems. The average amount of water consumed in the Darbasti, center-pivot, and solid-set sprinkler irrigation systems was 1487, 1605.7, and 2080.8 m^3 per hectare, respectively. As specified, alfalfa irrigated with the Darbasti and solid-set sprinkler irrigation systems consumed 7.4% and 29.6% more water compared to the center-pivot irrigation system, respectively. However, despite the increased water consumption in the solid-set sprinkler irrigation system, alfalfa yield was much lower than in the other two irrigation systems. It was expected that alfalfa yield would increase with the additional irrigation water (Testa et al. 2011; Lamm et al. 2012; Ismail and Almarshadi 2013; Li and Su 2017). Still, in this irrigation system, the low coefficient of uniformity and distribution uniformity resulted in non-uniform and insufficient water availability for the plants, consequently leading to a decrease in yield.

Table 6. water consumption, yield, and productivity of alfalfa in different irrigation systems

Replication	Parameter amount	Darbasti		Solid-set sprinkler		Center pivot	
		First year	Second year	First year	Second year	First year	Second year
First replication (third harvest)	Water consumption (m3)	1491.1	1484.9	2143.2	2143.2	1606.9	1606.9
	Yield (kg)	3450	3560	2343	2386	3773	3614
	Water productivity (kg/m3)	2.31	2.40	1.09	1.11	2.35	2.25

Second replication (fourth harvest)	Water consumption (m3)	1484.9	1497.3	2080.8	2080.8	1610.5	1610.5
	Yield (kg)	3376	3747	2275	2597	3627	3776
	Water productivity (kg/m3)	2.27	2.50	1.09	1.25	2.25	2.34
Third replication (fifth harvest)	Water consumption (m3)	1484.9	1478.7	2018.4	2018.4	1599.7	1599.7
	Yield (kg)	3556	3555	2119	2210	3552	3703
	Water productivity (kg/m3)	2.26	2.40	1.05	1.10	2.22	2.32

The water productivity of alfalfa in the Darbasti, center-pivot, and solid-set irrigation systems in the first and second years was 2.28, 2.43, and 2.27, 2.3, and 1.08, 1.15 kg/m3 respectively (Fig. 8). Analysis of alfalfa water productivity in different irrigation systems showed that the average water productivity in the Darbasti irrigation system was slightly higher compared to the other two systems for both years. However, statistical tests revealed no significant difference at the 1% level between the water productivity values in the Darbasti and center-pivot irrigation systems (Table 4). This suggests that the Darbasti irrigation system achieves comparable water productivity despite lower water consumption than the center-pivot irrigation system. In other words, Darbasti irrigation system has been observed to save 7.4% water consumption and create the same water productivity as center-pivot irrigation system.

In contrast, the solid-set sprinkler irrigation system exhibited higher water consumption, lower yield, and consequently, lower water productivity, indicating inadequacy in design for this field. Statistical analysis also showed a significant difference in alfalfa water productivity values between the solid-set system and the other two systems (Table 5). The low water productivity of alfalfa in the solid-set system may be attributed to the low coefficients of uniformity and distribution uniformity. Decreased uniformity and distribution can lead to reduced alfalfa performance despite increased water consumption. Montazer and Sadeghi (2008) highlighted the direct relationship between sprinkler water distribution patterns, distribution uniformity, and alfalfa water productivity, emphasizing that a reduction in these factors can diminish water productivity.

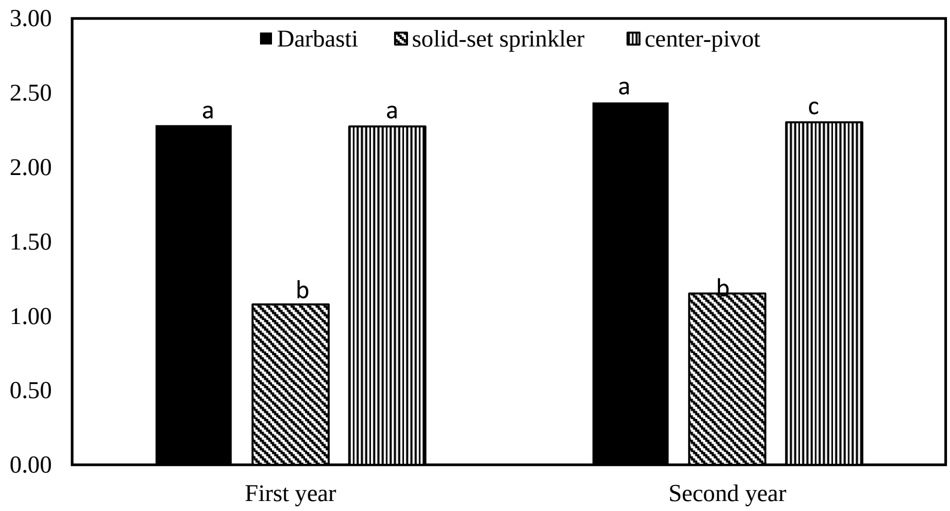

Fig 8. The average values of alfalfa water productivity in Drabasti, solid-set sprinkler, and center-pivot irrigation systems in the first and second years (different letters in each year indicate the presence of significant differences between irrigation systems)

IV. CONCLUSION

In the pursuit of enhancing the performance of sprinkler irrigation systems in dense crops like alfalfa and addressing irrigation challenges in irregularly shaped and sized fields, a new irrigation system called the Darbasti Irrigation System was designed and implemented. Its performance was evaluated alongside other common sprinkler irrigation systems (Center-pivot and solid-set sprinkler irrigation system) in alfalfa irrigation. The assessment of performance indices revealed that the Darbasti irrigation system provided a more uniform water distribution in the field compared to the other two irrigation systems.

The water consumption in the Darbasti irrigation system was lower compared to the other two systems due to the uniformity of water distribution. While the center-pivot irrigation system yielded more due to higher water consumption, the water productivity index indicated that the Darbasti irrigation system, with a WP of 2.35 kg/m3, outperformed the other two systems in alfalfa yield. The solid-set sprinkler irrigation system with movable sprinklers showed consistently poor performance across all indicators, implying significant limitations in its use.

The Darbasti irrigation system demonstrates superior distribution uniformity and increased water consumption efficiency compared to the other two systems. Its adaptability to fields of varying dimensions and shapes sets it apart from the center-pivot system. Moreover, being a fully fixed system without electronic or electromechanical components, the Darbasti system offers ease of operation in comparison to the other two irrigation systems, making it a more favorable choice for agricultural applications.

It is important to acknowledge that the indicators examined in this study do not definitively establish the superiority of the Darbasti irrigation system over the center-pivot irrigation system. Therefore, further research is essential to compare these systems in terms of energy consumption, implementation and operating costs, suitability for fields with irregular shapes and slopes, and more. Additionally, it is recommended to assess the Darbasti irrigation system under various climatic conditions, soil textures, structures, and with different sprinkler placement patterns.

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