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EVALUATION OF SPRINKLER IRRIGATION SYSTEM FOR LANDSCAPE APPLICATIONS

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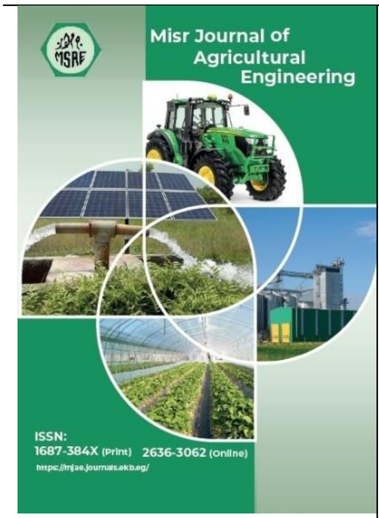

Keywords:
Sprinkler irrigation;
Sprinkler nozzle;
Hydraulic performance;
Irrigation uniformity.

ABSTRACT

Efficient irrigation practices are essential for sustainable agricultural and landscape management. Improving the hydraulic performance and water distribution uniformity of pressurized irrigation systems is therefore a priority. This study aimed to evaluate the hydraulic performance and uniformity of different sprinkler nozzle types under varying operating pressures for landscape irrigation applications. Field experiments were conducted to assess three sprinkler nozzle types, namely Pro Spray, Uni Spray, and HE-VAN, operating at pressures of 1.5, 2.1, and 3.0 bar. System performance was evaluated using Christiansen's uniformity coefficient (CU) and distribution uniformity (DU), in addition to analyzing the radial distribution of applied water along the wetted radius. The results indicated that both nozzle type and operating pressure significantly affected CU and DU values ($p \leq 0.05$). Increasing operating pressure from 1.5 to 2.1 bar significantly improved irrigation uniformity for all nozzle types. Conversely, increasing pressure further to 3.0 bar did not result in additional improvement and, in some cases, reduced uniformity. The HE-VAN nozzle achieved the highest CU and DU values across pressure levels, demonstrating superior hydraulic performance. Radial distribution analysis showed that the HE-VAN nozzle provided a more consistent water application across the wetted radius compared with Pro Spray and Uni Spray nozzles. Overall, the study highlights the importance of selecting appropriate nozzle type and operating pressure to enhance irrigation uniformity and efficiency. The combination of the HE-VAN nozzle operating at 2.1 bar is recommended for landscape irrigation systems under similar environmental conditions.

INTRODUCTION

Freshwater resources are a natural blessing and a fundamental requirement for sustaining life. Water is a vital input for all economic sectors and plays a central role in social and economic development. However, many regions of the world are classified as arid or semi-arid due to an imbalance between low rainfall and high evapotranspiration. As a result, water availability is limited, and pressure on freshwater resources continues to increase (Mishra and Tushaus, 2022). The growing demand for water in agriculture, industry, and urban areas has become a serious global concern. It has been reported that more than 80 countries, representing about 40% of the world's population, currently suffer from water shortages. Predictions indicate that nearly half of the global population could experience severe water scarcity by 2050 (Savari et al., 2025).

Egypt faces severe water scarcity due to its arid climate, limited rainfall, and rapidly growing population. The country relies heavily on the Nile River as its primary freshwater source. The current available water resources in Egypt are estimated at about 66 billion cubic meters (BCM) per year. These resources include approximately 55.5 BCM/year from the Nile River, 1.6 BCM/year from effective rainfall over the northern Mediterranean coast and Sinai, 2.4 BCM/year from non-renewable deep groundwater in the Western Desert and Sinai, and 6.5 BCM/year from shallow groundwater. In contrast, the total annual water demand from all sectors is estimated at about 79.5 BCM/year (Christoforidou et al., 2023; Maharjan et al., 2025). This creates a water deficit of nearly 13.5 BCM/year, which is partially offset by the reuse of agricultural drainage water, either officially or unofficially. Rapid population growth is one of the most critical challenges hindering sustainable development in Egypt. Urban expansion and landscape construction are increasing, which leads to higher water demand. This situation highlights the need for economic and efficient use of available water resources, particularly in landscape irrigation (Ramzi and El-Nahry, 2015).

Agriculture is the largest water-consuming sector, accounting for more than 70% of total global freshwater withdrawals. Despite this high consumption, irrigation water contributes to approximately 40% of global food production and supports nearly 20% of the world's cultivated land. This highlights the importance of irrigation in ensuring food security, while also emphasizing the need to use water resources more efficiently (Abdelfattah and Mostafa, 2024). Water scarcity is one of the main challenges facing irrigated agriculture worldwide. In many countries, water shortages threaten agricultural productivity and long-term sustainability. Therefore, improving water use efficiency has become a top priority for the agricultural sector. This can be achieved through the adoption of improved irrigation techniques that aim to deliver water efficiently, increase crop productivity, and reduce water losses and operational costs (Farag et al., 2026; Marston et al., 2020).

Sprinkler irrigation systems are widely used around the world as an effective method for rationalizing irrigation water use. These systems are considered suitable for a wide range of crops, soil types, and topographic conditions. Compared with traditional surface irrigation methods, sprinkler systems can provide better control over water application and reduce deep percolation and runoff losses (Chauhdary et al., 2023). In Egypt, sprinkler irrigation is increasingly used as a practical solution to overcome water scarcity, particularly in agricultural and landscape applications. The selection of an appropriate sprinkler is critical to achieving optimal application rates and uniform water distribution. Distribution uniformity is a key indicator of sprinkler irrigation performance. Sprinkler systems are generally classified as excellent or acceptable when distribution uniformity reaches approximately 85%. High distribution uniformity ensures that water is applied evenly across the irrigated area, which helps reduce water waste, improve crop growth, and lower operational costs (Elhussiny et al., 2023).

Several factors influence water distribution uniformity in sprinkler irrigation systems. Sprinkler discharge mainly depends on operating pressure and nozzle diameter. Previous studies reported that the highest irrigation uniformity and the lowest coefficient of variation are achieved under 100% overlapping conditions (Xue et al., 2023). In addition, the layout of sprinklers plays an important role. It has been found that square layouts provide higher application efficiency and better distribution uniformity compared to rectangular or triangular layouts (Benami, 2019; Coles et al., 2023).

Other important factors affecting sprinkler performance include sprinkler type, nozzle characteristics, flow rate, riser height, lateral spacing, and environmental conditions such as wind speed and direction. Several studies confirmed that wind significantly reduces distribution uniformity by causing uneven water distribution and increasing evaporation losses (Aminpour et al., 2023; Sanchez et al., 2011) . It has been reported that Christiansen's uniformity coefficient decreases as wind speed increases, and that rectangular layouts are more sensitive to wind effects than square layouts. Proper system design and management are therefore essential to achieve high application uniformity (Aminpour et al., 2023; Xue et al., 2023).

In practice, sprinkler selection is often influenced by cost considerations. However, focusing solely on price can lead to increased water losses and reduced system efficiency. Three main categories of factors were identified to affect sprinkler irrigation losses: design factors, management factors, and climatic factors. Design factors include sprinkler type, spacing, nozzle characteristics, operating pressure, and lateral length. Management factors mainly involve irrigation scheduling and system maintenance. Climatic factors, particularly wind speed and direction, strongly influence application efficiency (Hussain et al., 2025; Xue et al., 2023).

Given Egypt's arid climate, limited rainfall, and increasing population, improving irrigation performance has become essential for sustainable agricultural and landscape development. Therefore, the aim of this study is to evaluate and improve the hydraulic performance and water distribution uniformity of sprinkler irrigation systems under local environmental and operational conditions, contributing to more efficient water use and improved water resource sustainability.

MATERIALS AND METHODS

The field trials were conducted at the Easttown compound, New Cairo, Egypt (30°00'59.3" N, 31°30'50.4" E) during the period from July to October 2025. The soil of experimental area is classified as sand and the experimental site is characterized by an arid climate. Mean monthly precipitation was below 5 mm, with air temperatures ranging from a minimum of 9°C to a maximum of 40°C. Mean wind speed at the experimental site ranges from 10 to 25 km h^{-1}.

The irrigation system for the site is served by three electric centrifugal pumps. Each pump has a discharge capacity of 60 m^3/h, a maximum operating pressure of 0.6 MPa, and an operational efficiency of 95%. The main pipes are made of UPVC PN 16 with a diameter of 160 mm. The submain pipes are also made of UPVC PN 16 with diameters ranging from 110 mm to 75 mm. The lateral lines consist of UPVC PN 10 pipes with diameters ranging from 63 mm to 32 mm, connected to the right and left sides of the branch pipes to supply water to the associated sprinklers. The area control unit includes electric solenoid valves connected to manual valves, pressure gauges, a mesh filter, and a control panel. A Hunter control valve and a Hunter SC1 control panel are also included, along with a traditional system. Three commercially available spray nozzles were selected for hydraulic performance evaluation: the Hunter Pro-Spray Adjustable (PS-15A), the Rain Bird Uni-Spray (15 Series VAN), and the Rain Bird 15 Series HE-VAN.

The experiments were conducted under three operating pressures: 1.5, 2.1, and 3.0 bar, with a constant operating duration of 15 minutes for each test. The operating pressure at each treatment was regulated using control valves installed on the main line. Pressure was continuously monitored at the sprinkler inlet using pressure gauges, and fine adjustments were achieved by opening or closing the valves prior to each experimental run to maintain the target pressure throughout the irrigation events. Four sprinklers of each type were arranged in a square layout with dimensions of 4.80 × 4.80 m between sprinklers. Catch cans were placed at a spacing of 0.6 m (center-to-center), with each can having a diameter of 10 cm, figure 1.

Catch cans were placed in a regular grid within the sprinkler coverage area, with a spacing of 0.5 m between adjacent cans, to ensure accurate representation of water distribution in the field. After the predetermined operating time (15 minutes), the volume of water collected in each can was measured using a graduated cylinder. All readings were carefully recorded for subsequent calculations. For each of the three sprinkler types, three replicates were conducted at each of the three operating pressures to ensure the reliability of the results and to allow for statistical analysis. The collected data were analyzed to calculate the precipitation rate (PR), Christiansen Uniformity Coefficient (CU), and Distribution Uniformity (DU) using the standard equations commonly applied in the evaluation of sprinkler irrigation system performance (Evans et al., 2007; Schneider, 2000).

The evaluation of the sprinkler irrigation system was carried out using some hydraulic and performance parameters. These parameters include precipitation rate, distribution uniformity, and Christiansen's uniformity coefficient. The precipitation rate (PR) was calculated as the ratio of the sprinkler discharge to the wetted area and expressed in millimeters per hour (mm h^{-1}), according to the following equation:

$$PR = \frac{Q \times 1000}{A} \ldots\ldots (1)$$

where Q is the sprinkler flow rate (m^3 h^{-1}), and A is the area wetted by the sprinkler, calculated as the product of sprinkler spacing (S) and lateral spacing (L).

Distribution uniformity (DU) was used to evaluate the uniformity of water application over the irrigated area. DU was calculated as the ratio of the average depth collected in the lowest quarter of catch cans to the average depth collected in all catch cans, as expressed by equation (2):

$$DU = \frac{D_{lq}}{D} \ldots\ldots (2)$$

where DU is the distribution uniformity (%), D_{lq} is the average water depth of the lowest quarter of catch can measurements (mm), and D is the average water depth of all catch can measurements (mm).

The Christiansen Uniformity Coefficient (CU) was used to evaluate sprinkler irrigation uniformity. CU is one of the most widely accepted indices for assessing uniformity in agricultural sprinkler systems and is calculated using the following equation:

$$CU = 100 \times \left(1 - \frac{\sum_{i=1}^{n} | X_i - \bar{X} |}{n \times \bar{X}}\right) \ldots\ldots (3)$$

where CU is the Christiansen uniformity coefficient (%), X_i is the individual water depth collected in each catch can (mm), $\bar{X}$ is the average water depth collected over all catch cans (mm), and n is the total number of catch cans.

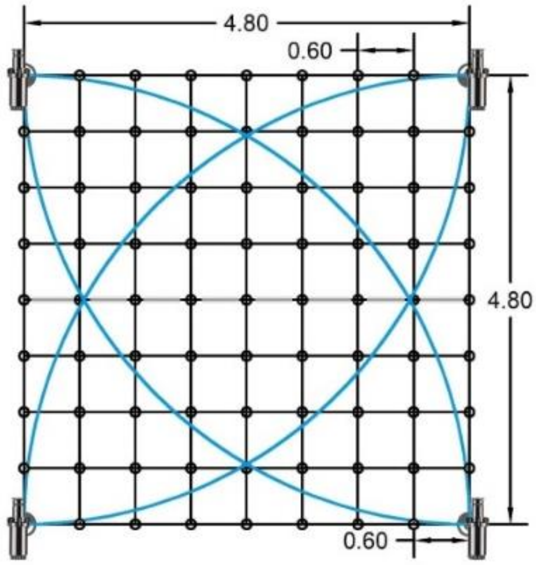

Fig. (1): Layout of the experimental setup showing the arrangement of sprinklers (at the corners) and catch cans (in the interspaces).

RESULTS AND DISCUSSION

The results presented in Table (1) indicate that both nozzle type and operating pressure significantly affected the uniformity coefficient (CU) and distribution uniformity (DU). Across all nozzle types, increasing the operating pressure from 1.5 to 2.1 bar significantly improved CU and DU values ($p \leq 0.05$). However, increasing the operating pressure to 3 bar did not lead to additional improvement. Instead, it caused a slight reduction in uniformity.

At 2.1 bar operating pressure, the HE van nozzle achieved the highest CU value (83.57%), followed by Uni Spray (81.07 %) and Pro spray (80.50 %). A similar trend was observed for distribution uniformity, where the maximum DU values were also recorded at 2.1 bar, with HE van showing the highest DU (72.82 %). These results confirm that moderate pressure provides optimal hydraulic conditions for achieving stable spray patterns and sufficient overlap, as reported by (Hussain et al., 2025; Qureshi et al., 2023).

At the lower pressure (1.5 bar), reduced CU and DU values were observed for all nozzle types. This can be attributed to insufficient pressure energy, which compromises water droplet trajectory and distribution, leading to incomplete coverage. At low operating pressure, the energy available to project water droplets is insufficient, resulting in poor droplet breakup, shorter throw distances, and uneven spatial distribution. This leads to incomplete overlap between adjacent sprinklers and reduced uniformity. Similar findings were reported by (Sanchez et al., 2011; Xue et al., 2023), who showed that inadequate operating pressure significantly reduces sprinkler uniformity due to unstable spray patterns and non-uniform water application.

Conversely, operating at higher pressure (3 bar) resulted in decreased DU values, likely due to excessive droplet breakup, wind drift, and evaporation losses. Similar observations were reported by (Al-Ghobari et al., 2018; Chen et al., 2024), who indicated that excessive pressure negatively affects sprinkler irrigation performance and water distribution uniformity. Higher pressures produce finer droplets that are more susceptible to wind drift and evaporation losses, particularly under open-field conditions. These effects distort the intended spray pattern and reduce effective water deposition within the target area. Several studies have confirmed that excessively high pressure negatively affects sprinkler irrigation performance by increasing drift losses and reducing distribution uniformity (Elhussiny et al., 2023; Li et al., 2019). Therefore, although higher pressure increases discharge energy, it does not necessarily improve uniformity and may instead degrade system performance.

The results further revealed that nozzle type significantly affected system performance ($p \leq 0.05$) with the HE-VAN nozzle demonstrating superior performance indicators. This may be attributed to its improved flow regulation and more uniform spray characteristics compared with Pro spray and Uni Spray nozzles. The HE-VAN nozzle is designed with advanced internal geometry that enables better control of water discharge and droplet distribution. This results in a more consistent radial application pattern and improved overlap between adjacent sprinklers. Moreover, its flow-regulating design contributes to greater spray stability across different operating pressure levels, thereby reducing variability in applied water depth and enhancing overall distribution uniformity. This agrees with the findings of (Hua et al., 2022; Kheir et al., 2020), who emphasized that nozzle geometry and hydraulic characteristics are critical factors affecting sprinkler irrigation uniformity.

Overall, the results demonstrated that appropriate selection of nozzle type combined with optimal operating pressure is essential for improving irrigation uniformity and efficiency. The combination of the HE van nozzle operating at 2.1 bar provided the most favorable CU and DU values, suggesting enhanced water distribution and uniformity.

Table 1: Effect of nozzle type and operating pressure on Christiansen's Uniformity Coefficient (CU) and Distribution Uniformity (DU)

Nozzle Type	**CU (%)**			**DU (%)**		
	1.5 bar	**2.1 bar**	**3.0 bar**	**1.5 bar**	**2.1 bar**	**3.0 bar**
Pro Spray	76.99^{b}	80.50^{a}	78.68^{a}	64.21^{d}	71.96^{c}	66.15^{d}
HE-VAN	78.74^{b}	83.57^{a}	78.79^{b}	67.81^{d}	72.82^{c}	68.81^{d}
Uni Spray	77.95^{b}	81.07^{a}	78.46^{b}	64.77^{d}	72.73^{c}	67.15^{d}
LSD (0.05)	1.82			1.89		

Means followed by different letters within the same parameter indicate significant differences at $P \leq 0.05$.

Figures (2,3, and 4) present the radial distribution of applied water, expressed as precipitation rate (mm h^{-1}), for the Uni Spray, HE-VAN, and Pro Spray nozzles at increasing wetted radius from the sprinkler. The variation in application depth with distance from the sprinkler reflects the hydraulic distribution pattern of each nozzle type. For the Uni Spray nozzle, the applied water depth increased progressively from the inner radius (11.73 mm h^{-1} at 60 cm) toward the mid-radius zone, reaching a maximum value of 48.45 mm h^{-1} at 360 cm. Beyond this distance, the applied depth declined toward the outer edge of the wetted radius, decreasing to 31.62 mm h^{-1} at 480 cm. This distribution indicates that the Uni Spray nozzle delivers a greater proportion of water to the middle portion of the wetted radius, with lower application at both the inner and outer zones.

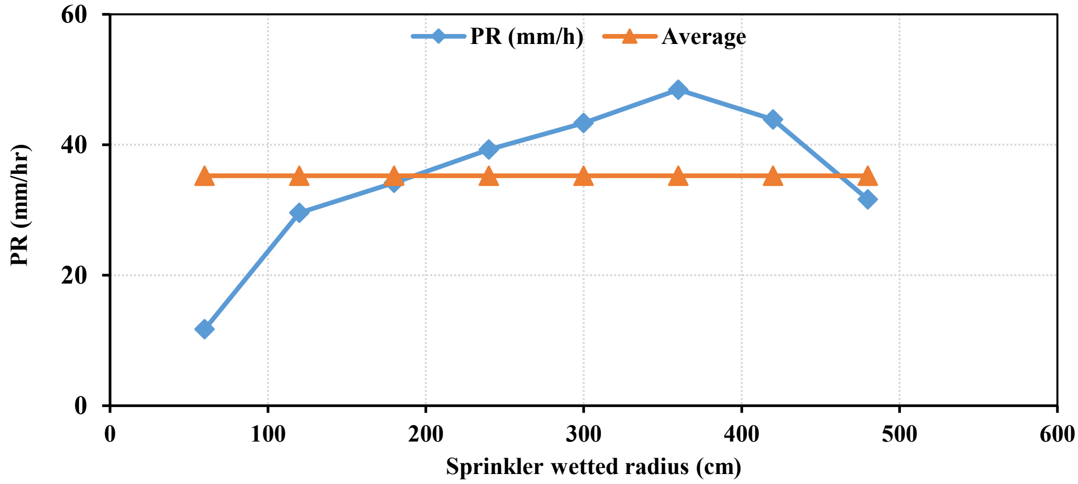

Fig. (2): Precipitation Rate (PR) as a Function of Radial Distance under the Uni-Spray Nozzle Type.

The Pro Spray nozzle exhibited a less uniform radial distribution. The PR values increased from 19.89 mm h^{-1} at the inner radius to a maximum of 47.94 mm h^{-1} at 360 cm. These values decreased sharply to 24.99 mm h^{-1} at the outer radius. The wider fluctuations in PR across the wetted radius indicate a less consistent radial distribution compared with the HE-VAN nozzle. The HE-VAN nozzle exhibited a more uniform radial distribution pattern. The PR increased from 23.97 mm h^{-1} at 60 cm to a peak value of 45.39 mm h^{-1} at 360 cm, then declined gradually toward the outer radius. Compared to the Uni Spray, it showed a reduced differential between the minimum and maximum values of PR, indicating a more balanced radial profile with less pronounced water concentration in a single zone.

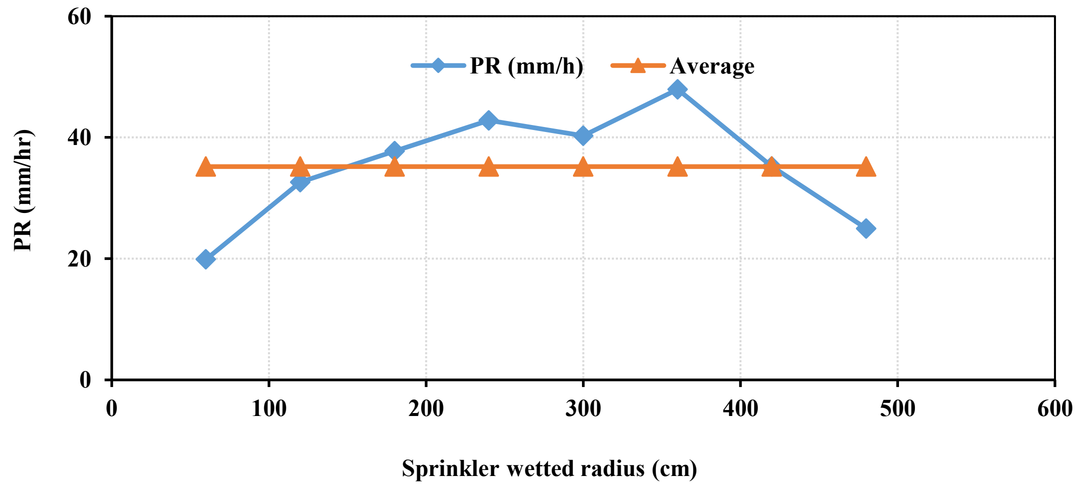

Fig. (3): Precipitation Rate (PR) as a Function of Radial Distance under the PRO Spray Nozzle Type.

These results indicated that all nozzles reached their maximum application depth at approximately 360 cm from the sprinkler. This suggests similar throw characteristics under the tested operating conditions. However, the degree of variation in application depth across the wetted radius differed among nozzle types. The HE-VAN nozzle produced the most uniform water application with increasing distance. Conversely, the Uni Spray and Pro Spray nozzles were characterized by high PR at the mid-radius and a sharper declines at the edges.

The observed differences in PR along the wetted radius among the tested nozzles can be attributed to variations in nozzle design, internal flow regulation, and droplet formation mechanisms. Fixed-spray nozzles such as Uni Spray and Pro Spray produce a non-uniform radial distribution, where a higher proportion of water is discharged at intermediate distances from the sprinkler. Similar radial distribution patterns have been reported by (Eid et al., 2019; Hua et al., 2022), who reported that conventional spray nozzles resulted in lower water application near the sprinkler and at the outer edge of the wetted area.

In contrast, the improved radial consistency observed for the HE-VAN nozzle can be explained by its variable arc and pressure-compensating flow characteristics, which allow better control of water distribution across the wetted radius. The internal design of HE-VAN nozzles promotes a more even breakup of the water stream and reduces excessive discharge concentration at specific distances. Previous studies have shown that nozzles with flow-regulating or variable arc features may produce more uniform radial distribution patterns and improve uniformity compared with conventional fixed spray nozzles (Gaber et al., 2024). This design helps maintain more consistent application depths across the wetted area, even under minor pressure fluctuations.

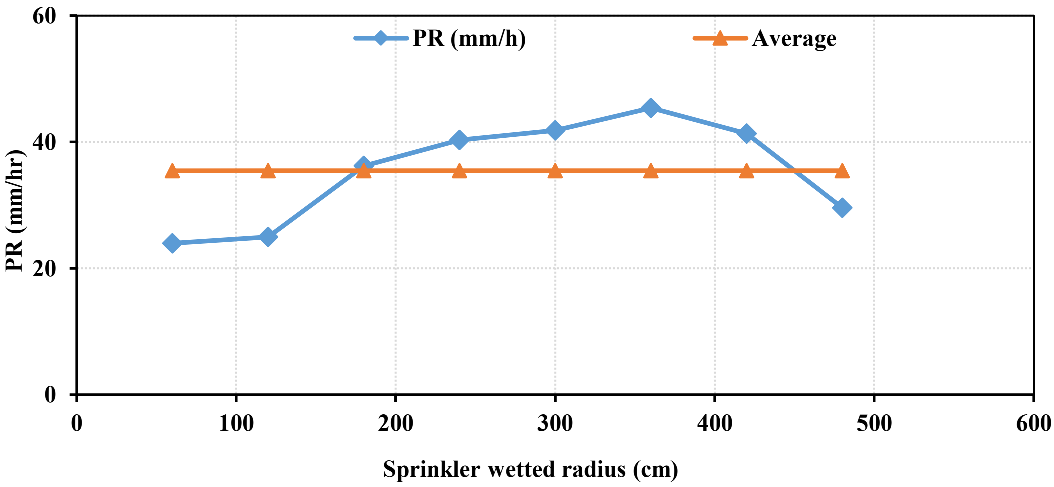

Fig. (4): Precipitation Rate (PR) as a Function of Radial Distance under the HE-Van Nozzle Type.

Radial distribution characteristics of a spray nozzle have direct implications for irrigation uniformity. High PR at the mid-radius region and the inadequate coverage near the sprinkler and at the outer edges creates a non-uniform application pattern. In such scenarios, excessive irrigation in some areas risks runoff and deep percolation, whereas under-irrigation in others induces plant water stress (Hua et al., 2022; Hussain et al., 2025). The more uniform radial distribution observed for the HE-VAN nozzle supports its higher uniformity performance compared with the Uni Spray and Pro Spray nozzles.

CONCLUSION

Irrigation management is critical in arid and semi-arid regions, where efficient water use is crucial for sustainable development. This study evaluated the hydraulic performance and water distribution uniformity of sprinkler irrigation under different nozzle types and operating pressures. The results demonstrated that both nozzle type and operating pressure significantly influenced irrigation uniformity. Increasing pressure from 1.5 to 2.1 bar significantly improved CU and DU values for all nozzle types, indicating more uniform spray patterns and improved water overlapping. However, further increasing pressure to 3.0 bar did not enhance uniformity and, in some cases, resulted in reduced performance due to increased spray instability and losses. Among the tested nozzle types, the HE-VAN nozzle consistently exhibited superior hydraulic performance and uniformity across all pressure levels. Based on the findings, it is recommended that sprinkler irrigation systems in similar climatic conditions operate at operating pressure of 2.1 bar. The study also recommends the use of HE-VAN nozzles to enhance application uniformity, reduce water losses, and improve overall irrigation efficiency.

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تقييم نظام الري بالرش لأغراض ري المسطحات الخضراء

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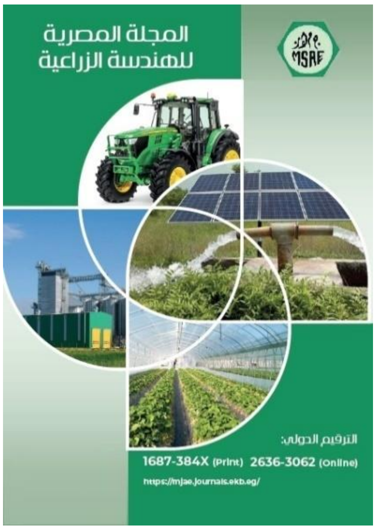

الكلمات المفتاحية:
الري بالرش؛ فوهة الرشاش؛ الأداء الهيدروليكي؛ انتظامية الري.

الملخص العربي

تعد تحسين ممارسات الري ضرورة لتحقيق الإدارة المستدامة لقطاع الزراعة. ومن هذا المنطلق فإن تحسين الأداء الهيدروليكي وانتظامية توزيع المياه في نظم الري بالضغط أولوية قصوى. هدفت هذه الدراسة إلى تقييم الأداء الهيدروليكي وانتظام التوزيع المائي لعدة أنواع من فوهات الري بالرش تحت ضغوط تشغيل مختلفة لاستخدامها في ري المسطحات الخضراء. أجريت تجارب حقلية لتقييم ثلاثة أنواع من فوهات الري بالرش، وهي Pro Spray :و Uni Sprayو HE-VAN، عند ضغوط تشغيل: ١,٥ و ٢,١ و ٣,٠ بار. وتم تقييم أداء النظام باستخدام معامل انتظام كريستيانسن (CU) وانتظام التوزيع(DU) ، بالإضافة إلى معدل ترسيب المياه المضافة على طول نصف قطر دائرة الابتلال للرشاش. وأظهرت النتائج أن نوع فونية الرشاش وضغط التشغيل كان لهما تأثير معنوي على قيم CUو DU (عند مستوى معنوية $p \leq 0.05$). وقد أدى رفع ضغط التشغيل من ١,٥ إلى ٢,١ بار إلى تحسن معنوي في انتظامية الري لجميع أنواع الفوهات، في حين لم يؤدي رفع الضغط إلى ٣,٠ بار إلى مزيد من التحسن، بل تسبب في بعض الحالات في انخفاض انتظامية توزيع المياه. وقد حققت فوهات HE-VAN أعلى قيم لكل من CU و DU تحت جميع مستويات الضغط، مما يدل على تفوقها في الأداء الهيدروليكي. كما أظهر تحليل معدل ترسيب المياه أن فوهات HE-VAN قد أعطت توزيعًا مائيًا أكثر تجانسًا على طول نصف قطر البلل مقارنة بفوهات Pro Sprayو Uni Spray. تؤكد نتائج هذه الدراسة أهمية الاختيار المناسب لنوع فوهة الرشاش وكذلك ضغط التشغيل لتحسين انتظام الري وكفاءة استخدام المياه. ويوصى باستخدام فوهات HE-VAN عند ضغط تشغيل ٢,١ بار في نظم ري المسطحات الخضراء.