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Water Distribution Uniformity for Turf Using a Simulation System Program

Shahenda Y El-Basha*, Khaled F Elbagoury, Osama M Bedair
Agric Engineering Dept, Fac of Agric, Ain Shams Univ, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt

*Corresponding author: Shahenda.elbasha@gmail.com

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Abstract: The study examines factors affecting sprinkler irrigation system distribution uniformity, including sprinkler type, operating pressure and computer software design. The pressures used were 1.5, 2.1, and 2.5 bar for spray nozzles 4A and 17A, and 1.7, 2, 2.5, and 3 bar for rotor nozzles 1 and 3. The results showed a strong correlation, with (R^2) values of 0.996 and 0.973, between SIDUL-Program (Sprinkler Irrigation Distribution Uniformity for Landscape–Program) and Excel program with respect to coefficient of uniformity (CU) and distribution uniformity (DU) respectively, suggesting a strong correlation between the two programs. The HEDIA program validated the SIDUL–Program, revealing a 0.42% difference in CU values between the two programs for rotor nozzle 3, indicating also a strong correlation (R^2 = 0.953) between the two programs. The results showed that DU for spray 4A at a pressure of 2.1 bar was 7.4%, higher than DU at a pressure of 1.5 bar; the CU for spray 17A was 11.9% higher, as supported by manufacturer specifications. The study concluded that calculating CU and DU using the SIDUL–Program is critical for assessing sprinkler performance in irrigation systems since it considers factors such as soil type, irrigation 1methods and location; in addition to being easy to use and accurate compared to other programs.

1 Introduction

Irrigation is the world's largest use of water, accounting for 70% of total water usage (Steduto 2018). Sprinkler irrigation mimics rainfall by delivering water to plants through small droplets using sprayers. This method leads to saving over 50.0% of irrigating water compared to surface irrigation and is easily implementable in agricultural fields (Mattar et al 2022).

The actual field locations receiving a specific quantity of water are identified using overlap maps of sprinklers. Additionally, maps displaying the depth distribution of water usage are created by interpolating data from catch cans (Rezayati et al 2023). Understanding water distribution patterns is crucial for assessing uniformity and improving performance in irrigation systems. Distribution Uniformity (DU) and Coefficient of Uniformity (CU) are commonly used evaluation parameters for irrigation quality. DU and CU focus on assessing water distribution uniformity and comprehensive uniformity respectively (Xue et al 2023). The effectiveness of irrigation projects and their financial return is significantly impacted by CU, which serves as a reliable indicator of water loss and is a crucial design parameter for irrigation systems (Maroufpoor et al 2019).

Choosing the right irrigation system is essential for minimizing water loss, reducing operating costs and maintaining high grass quality (Bedair 2018). In particular, the uniformity of sprinkler systems depends on climatic factors, particularly wind speed and direction, in addition to mechanical features such as flow rate, operating pressure, overlap and spray nozzle diameter, etc., while CU is commonly utilized to evaluate uniformity estimation (Faria et al 2016).

DU of several irrigation techniques is influenced by specific elements unique to each type of irrigation (Andrade et al 2015). DU, the measured ability of an irrigation system to apply the same amount of water throughout the irrigated area, is used to estimate distribution efficiency (Mohamed et al 2019).

Spray heads are used for small areas requiring overhead irrigation, while fixed spray heads are preferred for irregular landscapes and small regions (Wang et al 2022). Water is statically sprayed and distributed over the entire arc of coverage (1/4, 1/2, full variable arc, etc.) using fixed spray heads. Fixed spray heads can be placed in "pop-up" heads or fixed risers that rise once water is turned on. The rotor sprinkler relies on gear-driven technology, rotary motion and its body (Rain Bird 2022).

The objectives of this work are to develop computer software for calculating DU and CU for grass and to study the technical factors (sprinkler type and operating pressure) affecting the distribution uniformity of sprinkler irrigation systems for lawns.

2 Materials and Methods

2.1 Experiment for SIDUL model and treatments

An experiment was conducted in the Fifth Settlement City, Cairo, Egypt, located at the following coordinates: 30°02`18.7"N, 31°30`01.4"E. The water supply was provided by domestic sources. The irrigation network consists of a pump with a discharge of 3 m^3/h and an operating pressure of 4 bar, along with other components of the main control unit. Both the main and sub-main lines were made of PVC pipes with a diameter of 32 mm, and a pressure-regulating valve was utilized. Four different types of sprinkler nozzles commonly used in the Cairo region were employed: sprayer 4A and 17A, as well as rotor 1 and 3, at varying spacing and pressure levels as depicted in **Figs 1 and 2**. There was no wind speed during the experiment. **Table 1** illustrates the hydraulic performance of the spray and rotor head sprinklers, including parameters such as pressure, throw radius, flow rate and precipitation rate.

Two types of spray nozzles (spray 4A and 17A) and rotor nozzles (rotor nozzles 1 and 3) were used. Different operating pressures (1.5, 2.1 and 2.5 bar) were applied for the spray nozzles, and (1.7, 2, 2.5, and 3 bar) for the rotor nozzles.

2.2 Data collection methods

Catch cans are commonly used in agricultural and landscaping contexts to measure the distribution and uniformity of irrigation water application. The data collected using catch cans helps adjust irrigation systems to ensure optimal water distribution across the target area. Before data collection, catch cans need to be strategically placed throughout the irrigated area, as shown in **Fig 3**. After the irrigation event, the catch cans are collected and the water collected in each can is measured. Catch cans provide a practical and effective method for collecting data on water distribution in irrigated areas, allowing for informed decision-making to improve irrigation efficiency.

2.3 SIDUL program structure and user interface

The SIDUL–Program (Sprinkler Irrigation Distribution Uniformity for Landscape–Program) was tested using four different sprinkler nozzles and various operating pressures. The program was developed using Microsoft Visual Basic 2015 and was designed to facilitate easy use for both novice and expert users. The main inputs, data processing and outputs of the SIDUL-Program are illustrated in the flowchart depicted in **Fig 4**.

The program's structure considers factors (soil type, irrigation methods & location) utilizing formulas to analyze these parameters. When developing a sprinkler irrigation distribution uniformity program for a landscape, significant emphasis was placed on the same factors mentioned above. These parameters were examined in relation to various rules and variables using specific formulas.

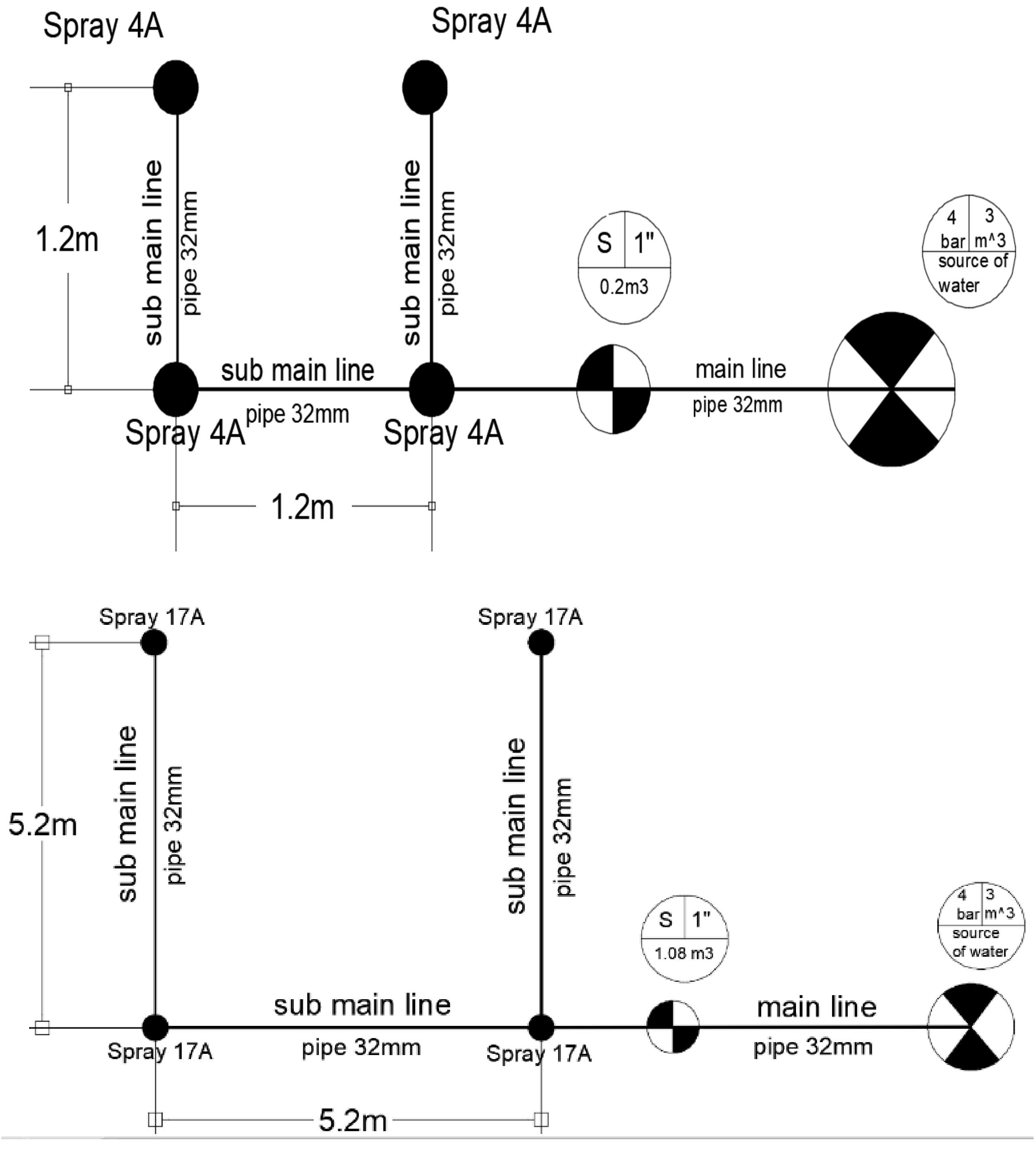

Fig 1. The layout of the irrigation system network for spray 4A and 17A

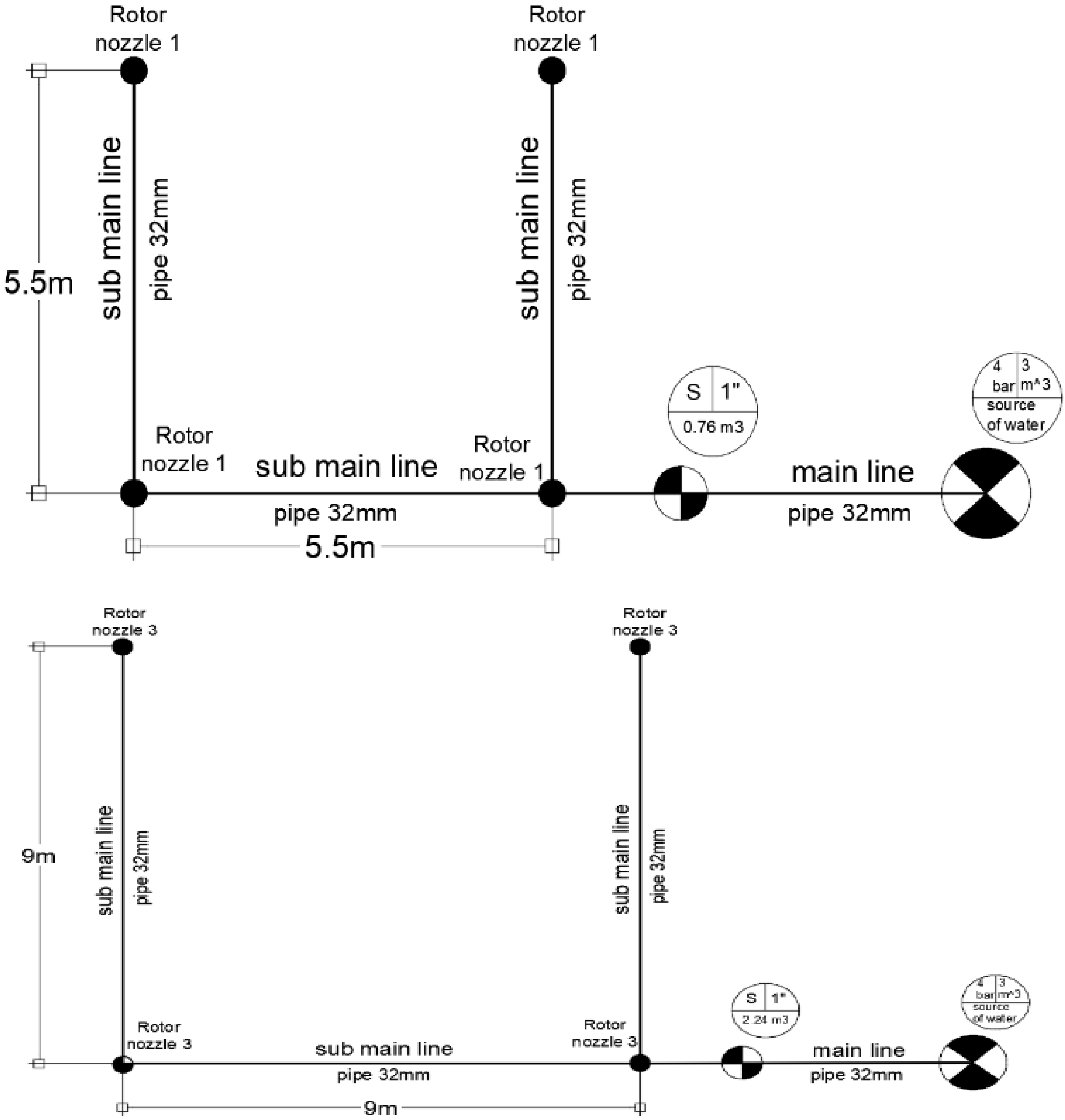

Fig 2. The layout of the irrigation system network for rotor nozzle 1 and 3

Table 1. Hydraulic performance for spray and rotor head sprinklers

Sprinkler head	Nozzle	Pressure (bar)	Radius (m)	Flow at 90 ° (m^3/hr)	Precipitation Rate (mm/hr)
Spray	4A	1.5	1	0.05	89
		2.1	1.2	0.05	84
		2.5	1.3	0.05	79
	17A	1.5	4.9	0.23	38
		2.1	5.2	0.27	39
		2.5	5.2	0.3	39
Rotor	1	1.7	5.2	0.18	13
		2	5.5	0.19	13
		2.5	5.5	0.21	14
		3	5.8	0.23	14
	3	1.7	8.1	0.51	13
		2	9.1	0.56	13
		2.5	9.1	0.64	15
		3	9.4	0.77	16

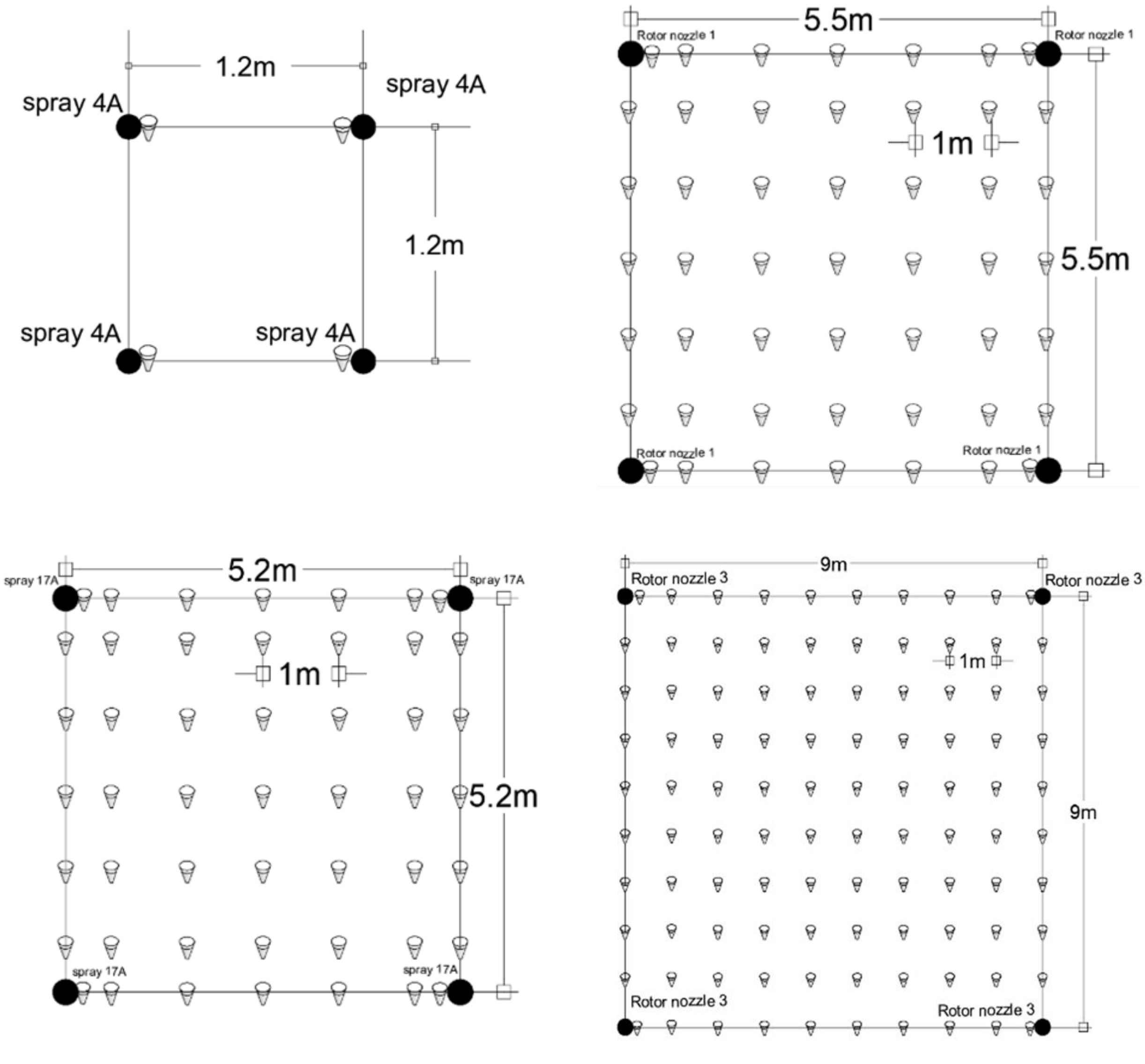

Fig 3. Catch can placement

2.4 Description of SIDUL-program

The input data for the program includes location, soil, and irrigation data. The input screen features buttons for starting and exiting the program, as well as menu strips for selecting location, irrigation, and soil options, along with additional details about the software's developers. The location screen displays the district name, field area (m^2), and available irrigation time (hours per day). The irrigation screen includes options for sprinkler types (spray 4A, spray 17A, rotor nozzle 1 and rotor nozzle 3), pressure and spacing, as shown in **Fig 5**. The soil screen shows the soil slope and texture. The output screen presents the district name, location, area, flow rate, radius, precipitation rate, CU and DU.

2.5 Verification and validation of SIDUL-Program

The verification and validation process involves ensuring the accuracy and reliability of the SIDUL-Program. As a stage in the verification process, the results of the SIDUL-Program are compared to those of a spreadsheet that was created individually. Spreadsheet verification primarily focuses on ensuring that the input data is correctly processed to generate accurate output from the SIDUL-Program. This involves checking formulas, functions and calculations within the spreadsheet.

The validation also involves regression testing, which ensures that changes or updates to the program do not adversely affect its existing functionality. The validation process of the SIDUL-Program is completed by comparing its outputs with those of another program known as the HEDIA program. The HEDIA computer model was created to simulate the shape and overlap space of sprinkler patterns; statistical analysis was used to describe the performance indicators of the overlap pattern.

2.6 The formulas used in the program

The formulas used in the SIDUL-Program include those for calculating the coefficient of uniformity (CU) and the Distribution Uniformity of the Lower Quarter (DULQ).

2.6.1 The coefficient of uniformity (CU)

CU was proposed by **Christiansen (1942)**:

$$CU = (1-(\frac{\Sigma(x-\bar{x})}{\bar{x}/n})*100 \text{ …… (1)}$$

Where $\Sigma(x-\bar{x})$ represents the absolute sum of deviations of values from the arithmetic mean (ml), n represents the catch cans number and $\overline{X}$ represents the average volume of application overall catch cans measurements (ml).

2.6.2 Distribution uniformity of the Lower Quarter (DULQ)

DULQ was calculated by **El-Zakaziky (2012)**:

$$DULQ = 100 \times (\frac{VLQ}{VaVg}) \text{ …… (2)}$$

Where V_{avg} represents the total average (ml) and VLQ represents the average low quarter (ml).

3 Results and Discussion

3.1 SIDUL-Program verification

The verification process involved comparing the results of the SIDUL program with those of an individual spreadsheet. The outputs of the SIDUL-Program, as shown in **Fig 6**, are compared with the values of the Excel program, as depicted in **Fig 7**, for rotor nozzle 3. From **Fig 8**, when comparing DU and CU results of the SIDUL-Program and the Excel program, differences of 0.24% and 1.18%, respectively, were found for rotor nozzle 1, and 0.3% and 0.3%, respectively, for rotor nozzle 3. Similarly, differences of 0.3% and 0.5%, respectively, were found for spray 4A, and 0.3% and 0.5%, respectively, for spray 17A.

Fig 9 presents the CU calculated by the program compared to those calculated by the Excel program. Results indicate a strong correlation ($R^2 = 0.996$) between SIDUL-Program and Excel program CU data. The calculation of DU using SIDUL-Program compared to that of the Excel program is shown in **Fig 10**. Data indicate a high correlation ($R^2 = 0.973$) between DU calculated by SIDUL-Program and that of the Excel program. The results showed a high correlation between the two programs. The same finding was reported by Alashram (2021).

3.2 SIDUL-Program validation

The HEDIA program was used to validate the SIDUL-Program results. Comparing the values of the SIDUL-Program (**Fig 6)** and the those of HEDIA program (**Fig 11)** for rotor nozzle 3, a difference of 0.42% was found regarding CU, as shown in **Fig 12**.

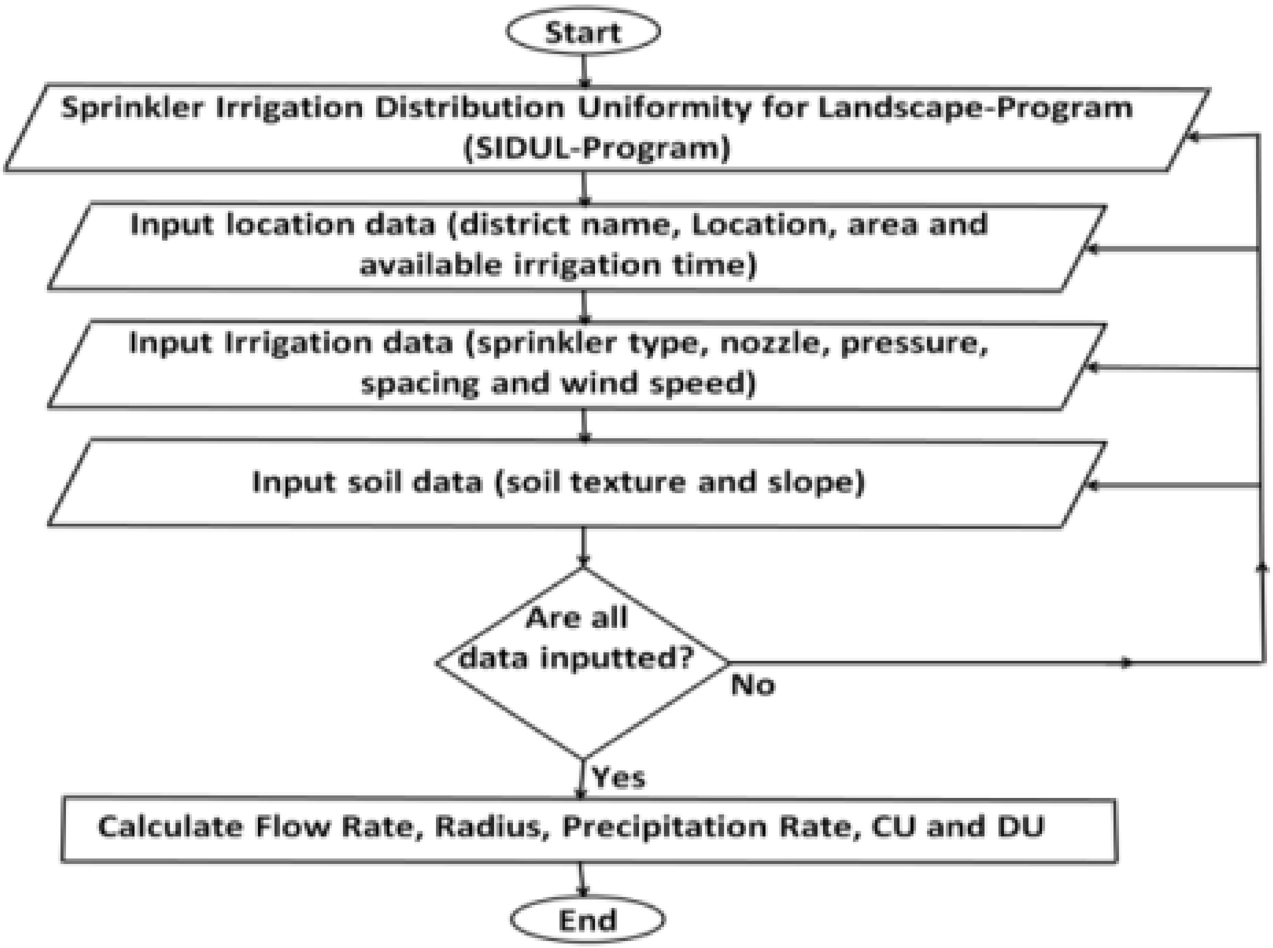

Fig 4. Flow chart for operating the SIDUL-Program

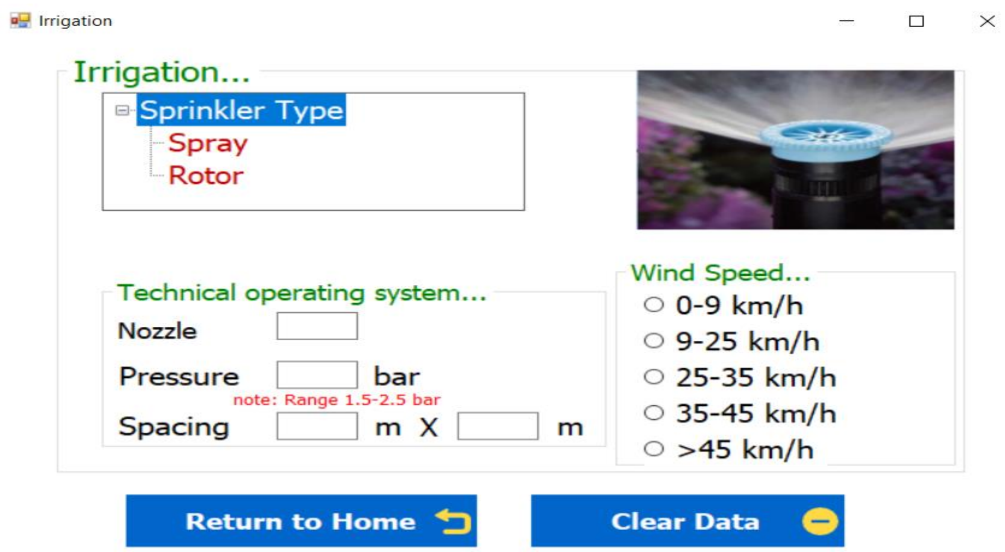

Fig 5. Irrigation screen for the SIDUL-Program

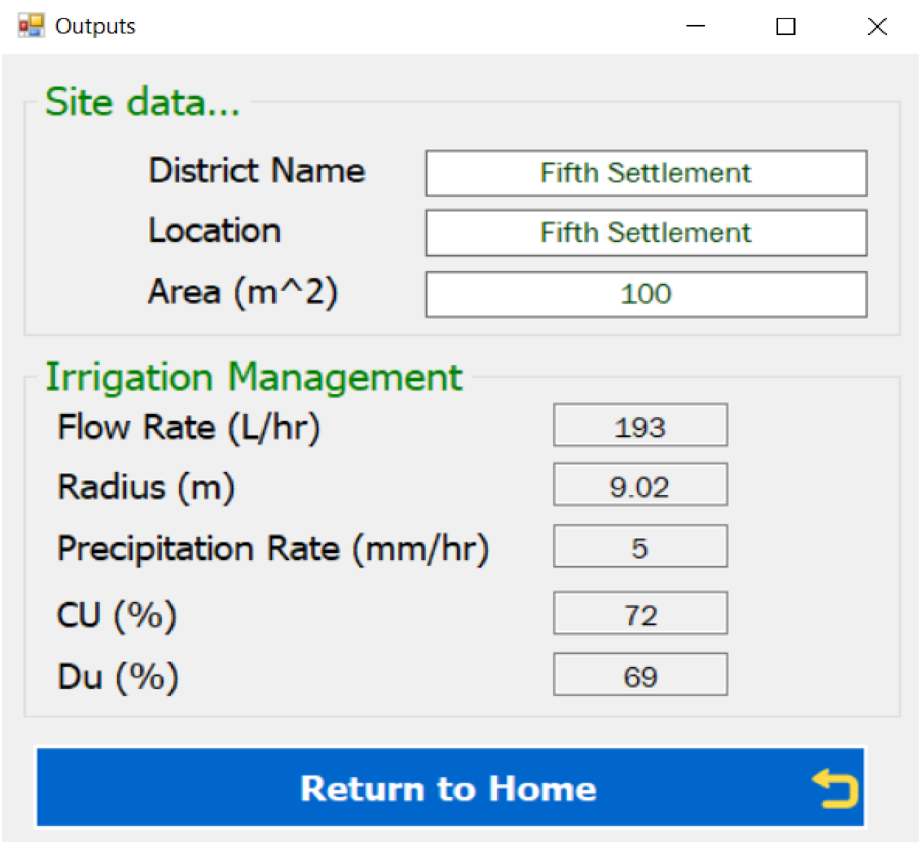

Fig 6. Outputs screen of SIDUL-Program for rotor nozzle 3

(Rotor sprinkler - Nozzle 3 - Pressure 2bar @ No wind)				
	Catch Cans Volumes (mm/hr)			
	19	28	25	22
	27	13	10	16
	26	14	14	18
	25	11	10	23
	26	12	11	25
	25	15	13	16
	16	18	11	11
	15	16	18	14
	19	11	10	22
	24	9	10	28
	23	17	15	15
	26	16	29	16
Total Catch Can Volume	853			
Average Volume	18			
Total Low Quarter	159			
Average Low Quarter	12			
CU	71.8			
DU	68.8			

Fig 7. Personally designed spreadsheet for rotor nozzle 3

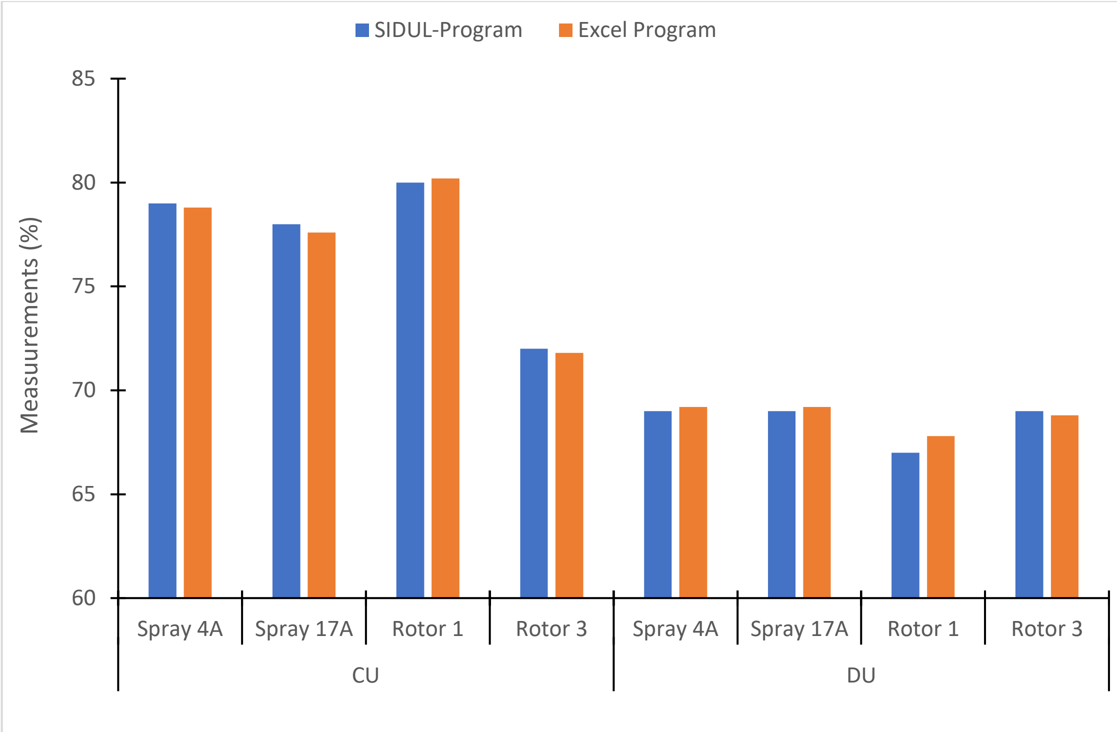

Fig 8. A comparison of CU and DU between SIDUL-Program and spreadsheet

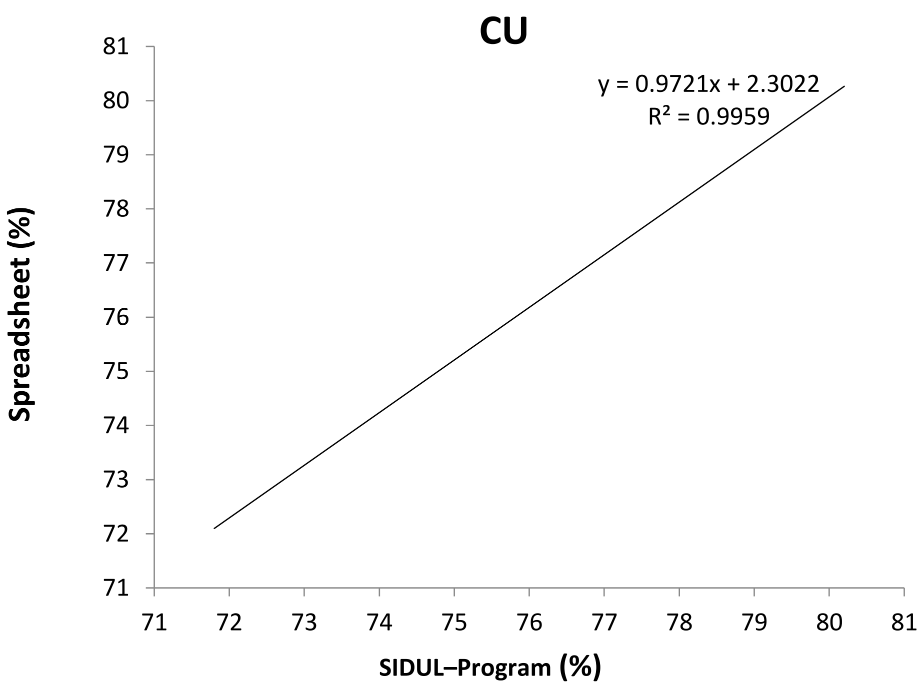

Fig 9. Correlation analysis of CU using SIDUL–Program against the spreadsheet

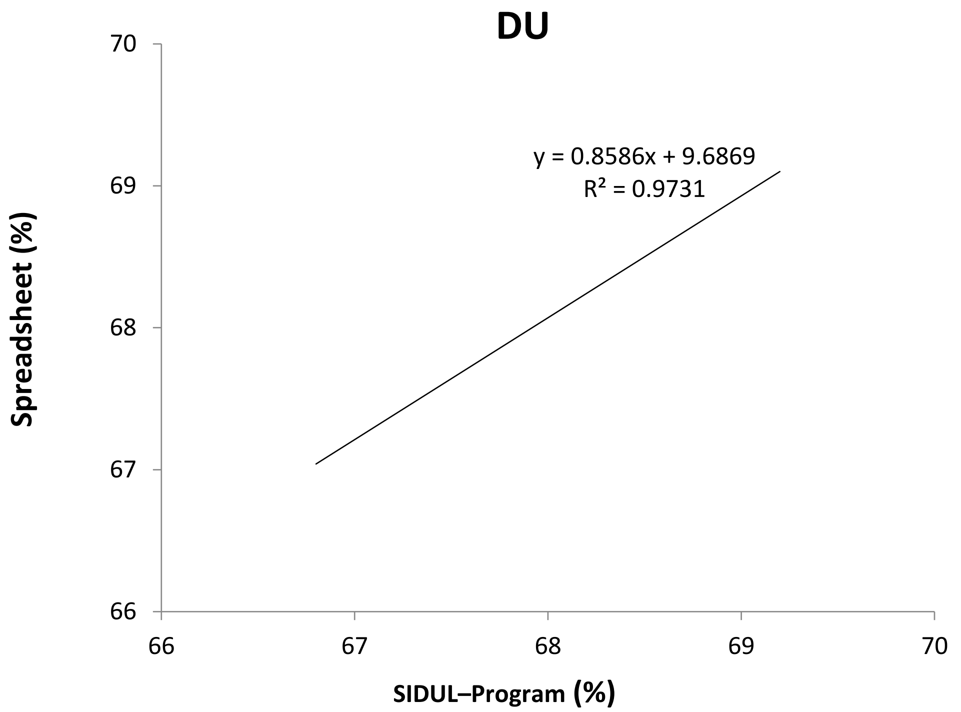

Fig 10. Correlation analysis of DU using SIDUL–Program against spreadsheet

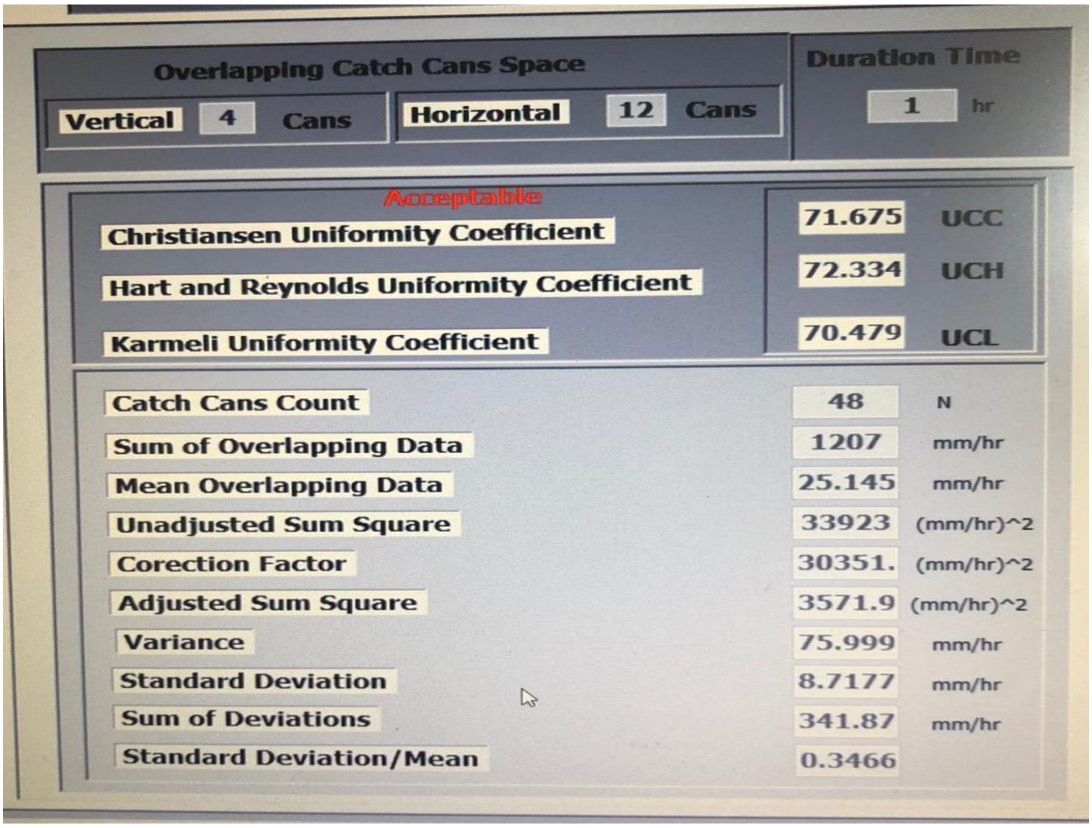

Fig 11. Outputs generated by using the HEDIA program for rotor nozzle 3

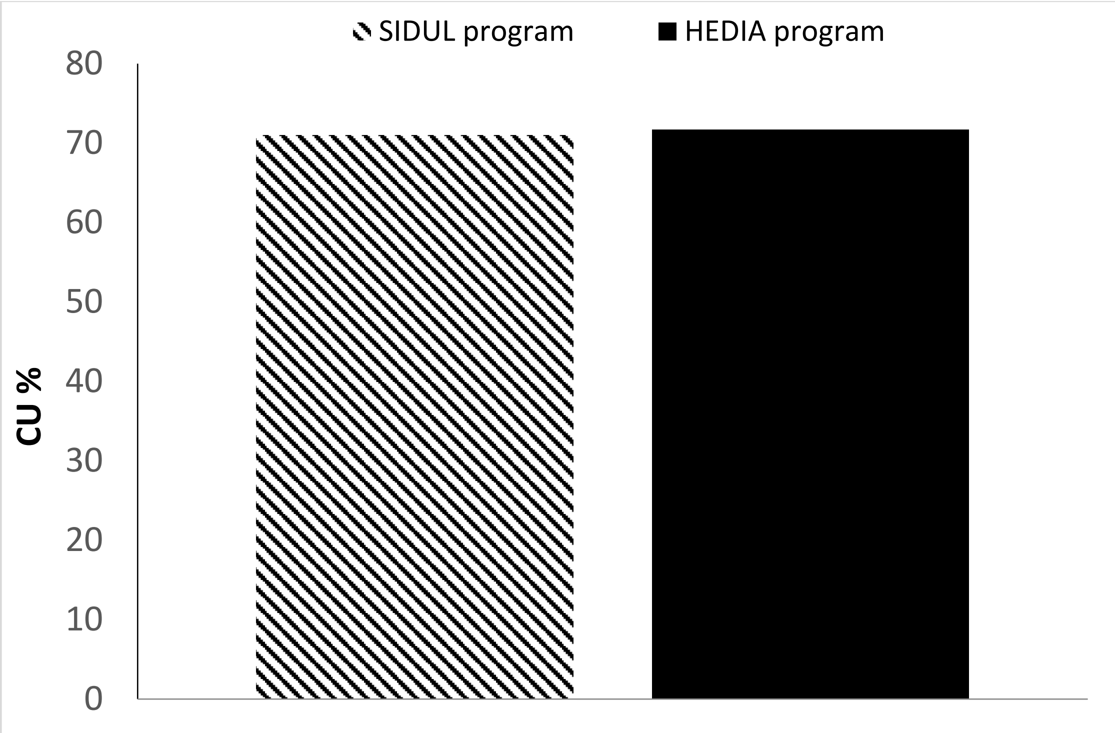

Fig 12. A comparison between SIDUL-Program and the HEDIA program regarding CU for rotor nozzle 3

Fig 9 shows the CU calculated by SIDUL-Program compared to those calculated by the HEDIA program; a strong correlation ($R^2 = 0.953$) was obtained indicating a strong correlation between the two programs and the validation of SIDUL-Program results.

3.3 Experimental results obtained from SIDUL-Program

Fig 14 shows that the DU for spray 4A at a pressure of 2.1 bar is 7.4% higher than DU at a pressure of 1.5 bar. Similarly, CU for spray 4A at a pressure of 2.1 bar is 2.6% higher compared to CU at a pressure of 1.5 bar. However, DU for spray 17A at a pressure of 2.1 bar is 11.9% higher than DU at a pressure of 1.5 bar, and CU for spray 17A at a pressure of 2.1 bar is 8% higher compared to the CU at a pressure of 1.5 bar.

The DU for rotor nozzles 1 and 3 at a pressure of 2.1 bar is higher by 5.9% and 9%, respectively, compared to DU at a pressure of 1.7 bar. Similarly, CU for rotor nozzles 1 and 3 at a pressure of 2.1 bar is higher by 5.1% and 5.7%, respectively, compared to CU at a pressure of 1.7 bar. These findings are supported by manufacturer specifications and the weather conditions at the site, and they align with the results obtained by Mehanna et al (2021).

As a results, the SIDUL-Program can provide, for farmers and stakeholders, accurate prediction of water distribution patterns for achieving uniform water application across the irrigated area by optimizing system layouts, nozzle configurations and operating parameters.

The study may have several potential limitations that could affect the generalizability and robustness of its findings. The study may have focused on only four nozzle types and pressure ranges (1.5-2.5 bar), which might not fully represent the diversity of sprinkler systems used in different landscape settings. This could limit the applicability of the findings to other nozzle types and pressures. Wind conditions play a significant role in water distribution from sprinkler systems, as wind can cause drifting and affect the uniformity of water application. The study's lack of consideration for wind conditions could limit the accuracy of its results. Acknowledging these limitations is essential for interpreting the study's findings accurately and for guiding future research efforts to address these gaps and improve the understanding of sprinkler performance in various contexts.

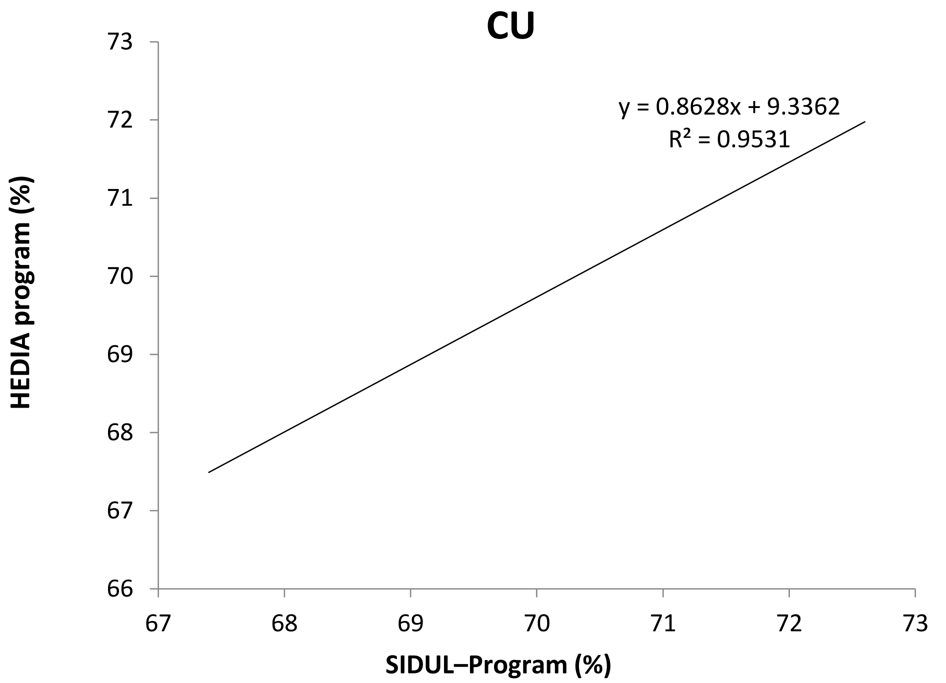

Fig 13. Correlation analysis of CU using SIDUL–Program against the HEDIA program

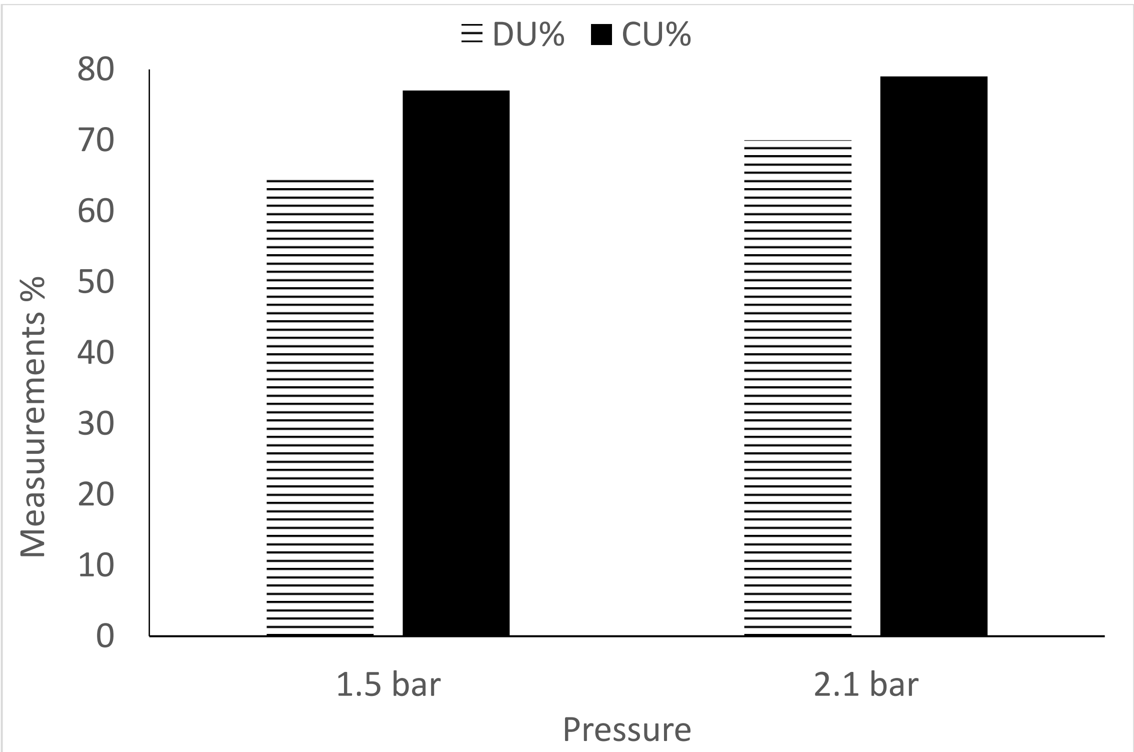

Fig 14. DU and CU for spray 4A

4 Conclusions

The SIDUL-Program utilizes input data such as location, soil and irrigation to calculate parameters including flow rate, radius, precipitation rate, CU and DU. This correlation was verified by comparing the SIDUL-Program data with those of the Excel program. Data were also validated by using the HEDIA program. The results showed a strong correlation between the SIDUL-Program and Excel program results. Additionally, there was a strong correlation between the SIDUL-Program and HEDIA program data. According to these comparisons, we can conclude that computer programs can accurately calculate the uniformity of sprinkler irrigation distribution for landscaping, indicating their potential for precise field case calculations.

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