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APPLICATION FOR EVALUATION OF THE UNIFORMITY OF SYSTEMS OF PRESSURIZED IRRIGATION

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Keywords:
Agriculture 4.0
Christiansen uniformity coefficient
Distribution uniformity coefficient
Pressurized irrigation
Statistical uniformity coefficient

ABSTRACT

The evaluation and monitoring of the performance of irrigation systems are crucial in maintaining water efficiency and conservation of water and energy resources. Therefore, the objective of this study was to develop and validate an application for the coefficient of uniformity coordinators of pressurized irrigation systems. So, the UniIrrig® application was developed, using the integrated development environment Android Studio10 version 4.0.1, in JAVA language, with applicability in devices with the Android operating system. For quantitative verification, the same input values in the UniIrrig® application were also inserted in Microsoft® Excel 2010, in all uniformity conductors used in the application. For the qualitative analysis, together with the experience of the user, 68 students of the Agronomy course at the Federal University of Ceará (UFC) participated in tests in order to evaluate the perception of usability, design, usefulness, and general satisfaction of the tool. To validate the application in the field, a uniformity test was carried out on a center pivot in the municipality of Cascavel, Ceará state, with the aid of collectors (Kit Fabrimar) to deliver the applied depth and the consequent result of the distribution uniformity coefficient (DUC), of Hart (HDC) and weighted mean depth analysis. These values were compared to the results obtained in Microsoft® Excel 2010. The dynamic analysis of the data evolved in “r”= 1, thus providing perfect adaptation between the results obtained by the application and by Microsoft® Excel, finding an error equal to zero. In the qualitative assessment, 84.1% consider the application a good tool for coefficient determination. It is concluded that the UniIrrig® application, designed for the Android operating system, can be used to quantify the assessed irrigation uniformity coefficients.

Palavra-chave:
Agricultura 4.0
Coeficiente de uniformidade de Christiansen
Coeficiente de uniformidade de distribuição
Coeficiente de uniformidade estatístico
Irrigação pressurizada

APLICATIVO PARA AVALIAÇÃO DA UNIFORMIDADE DE SISTEMAS PRESSURIZADOS DE IRRIGAÇÃO

RESUMO

A avaliação e monitoramento do desempenho dos sistemas de irrigação é determinante na manutenção da eficiência hídrica e conservação dos recursos hídricos e energéticos. Sendo assim, o objetivo deste estudo foi desenvolver e validar um aplicativo para a determinação de coeficientes de uniformidades de sistemas pressurizados de irrigação. Para isso, foi desenvolvido o aplicativo UniIrrig®, utilizando o ambiente de desenvolvimento integrado Android Studio10 versão 4.0.1, em linguagem JAVA, com aplicabilidade em aparelhos portando sistema operacional Android. Para verificação quantitativa, os mesmos valores de entrada inseridos no aplicativo UniIrrig® também foram inseridos ao Microsoft® Excel 2010, em todos os coeficientes de uniformidade empregados no aplicativo. Para a análise qualitativa, com experiência no usuário, 68 discentes do curso de agronomia da Universidade Federal do Ceará (UFC), participaram de testes a fim de avaliarem a percepção de usabilidade, design, utilidade e satisfação geral da ferramenta. Para validação do aplicativo em campo foi realizado um teste de uniformidade em um pivô centerno município de Cascavel-CE, com auxílio de coletores (Kit Fabrimar) para obtenção da lâmina aplicada e conseguinte resultado do coeficiente de uniformidade de distribuição (DUC), de Hart (HUC) e análise da lâmina média ponderada. Estes foram comparados aos resultados obtidos no Microsoft® Excel 2010. A análise de correlação dos dados resultou em “r”= 1, conferindo, portanto, perfeita correlação entre os resultados obtidos pelo aplicativo e pelo Microsoft® Excel , constatando erro igual à zero. Na avaliação qualitativa, 84,1% consideram o aplicativo uma boa ferramenta para determinação dos coeficientes. Conclui-se que, o aplicativo UniIrrig®, idealizado para o sistema operacional Android, pode ser utilizado para a determinação dos coeficientes de uniformidade de irrigação estudado.

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INTRODUCTION

Modern irrigated agriculture includes a large collection of technologies capable of raising productivity to a sustainable standard which, despite demanding high investment related to the installation, management, and monitoring of the system, has been the main strategy for coping with drought, especially in the semi-arid region. According to Jobbágy (2021), to achieve stability and high crop yields, the irrigator needs to achieve high system quality, through the correct application intensity and irrigation uniformity.

Furthermore, an efficient water application depth depends not only on a good hydraulic dimensioning project but also on a periodic evaluation of the flow rate and uniformity of water application (COELHO *et al*., 2013; CAMPÊLO *et al*., 2014). The quality of work in the irrigation system is generally evaluated based on the value of the irrigation uniformity coefficient (TOPAK *et al*., 2005), the most common being Christiansen's uniformity coefficient (CHRISTIANSEN, 1942), the Statistical (WILCOX & SWAILES, 1947), Distribution (CRIDDLE, 1956) and, Heermann and Hein (BRALTS, 1986), the most adopted in the evaluation of center pivot irrigation systems.

For the calculation of these coefficients, field tests are carried out beforehand to obtain water volumes through a network of collectors or rain gauges on the surface to be investigated (BARBERENA *et al*., 2022). Using these calculated results, it becomes possible to evaluate the current uniformity of the irrigation system based on the classifications defined in the literature and, to establish a decision-making process, to increase the efficiency of water application of the irrigation system.

Although effective, the application of this methodology has been an impasse, especially when one wants to investigate large areas, given the difficulty of calculations to obtain the coefficients. As a result, given that technological advances make the optimization of irrigation feasible, the use of facilitating tools for mobile devices, such as software for computers and smartphones, are indispensable strategies, particularly because, according to Lopes *et al.* (2019), in the management of the user's time, it dispenses manual calculations in evaluations of irrigation systems.

Borges Junior *et al*. (2008) points out that this complexity is mainly due to the number of variables in the processes involved in the soil-plant-water-atmosphere system. Furthermore, access to the internet in rural areas is still an obstacle for irrigating producers, with the use of software assigned for offline applications being a decisive strategy for the expansion of technology in the countryside. In this sense, the objective of this work was to develop and validate an application for the determination of uniformity coefficients of pressurized irrigation systems.

MATERIALS AND METHODS

Description of the Application

The application developed named UniIrrig® (*Uniformity Irrigation*) aims to help the user in the calculation of uniformity coefficients of pressurized irrigation systems, specifically conventional sprinkler systems, center pivots, micro-sprinkler, and dripping. Currently, the application is available on the digital platform Google Play Store, for devices with Android operating system residing at the following address: <https://play.google.com/store/apps/details?id=com.Getai.cuccalcteste > under registration at the National Institute of Industrial Property (INPI) n° BR512021003107-5, where the Federal University of Ceará is the main co-holder of the application.

Initially, exploratory research related to the theme was carried out, verifying the originality of the developed application. The interpretation of the Christiansen Uniformity Coefficient (CUC), Distribution Uniformity Coefficient (DUC), and Statistical Uniformity Coefficient (SUC) results was based on the proposition of Mantovani (2009), and for the Heermann and Hein Uniformity Coefficient (HUC), the classification of Bralts (1986) was adopted (Table 1). The results are displayed in different highlights, indicating "good to excellent" uniformity in green color, in yellow color, when "fair" uniformity, and in red color for "poor" uniformity

To evaluate the irrigation uniformity in the sprinkler and localized irrigation systems, the CUC (Christiansen, 1942), and the DUC (Criddle, 1956) were adopted in the development of the application, which considers the average of 25% of the lowest precipitation values and also the SUC (Wilcox &

Swailes, 1947) (Table 2).

For the center pivot system, the Heermann and Hein uniformity coefficient (HUC) (Bralts, 1986) was adopted. This coefficient consists of the absolute mean deviation in relation to the weighted mean, and the modified distribution uniformity coefficient (DUC), where for this, the weighted average of the data is used (Table 3).

In the center pivot system, it is possible to evaluate uniformity by installing one or two radial lines with the aid of collecting containers. The test methodology using two radial lines with collectors follows the norms of ABNT NBR ISO 11545 of 2016, adopted in the programming logic (Figure 1). The application also assists in measuring evaporation, as directed by the aforementioned standard.

Number 1 indicates the distance from the

Table 1. Classification of CUC, DUC, SUC, and HUC results

Classification	CUC (%)	DUC (%)	SUC (%)	HUC (%)
	-------------Mantovani *et al*.----------			Bralts
Excellent	> 90	> 84	90 – 100	> 90
Good	80 – 90	68 - 84	80 – 90	80 – 90
Fair	70 – 80	52 – 68	70 – 80	70 – 80
bad	70-60	36-52	60 – 70	70 – 60
unacceptable	< 60	< 36	< 60	

Source: Mantovani *et al.* (2009); Bralts (1986)

Table 2. Uniformity coefficient equations for localized and conventional sprinkler irrigation systems

Equation – Coefficient of Uniformity		
$CUC = 100 \cdot \left|1 - \frac{\sum_{i=1}^{a} Q_i - Q}{n\,Q}\right|$	$CUE = 100\left(1 - \frac{S}{X}\right)$	$CUD = 100 \cdot \frac{Q_{25}}{Qmed}$

Qi= with the lowest flows, (L h^{-1}); Qmed= Arithmetic mean; Q_{25}: Weighted average of 25% of the total number of drippers with the lowest flows (L h^{-1}); S= Standard deviation of data of precipitation (mm); $\underline{X}$= Average precipitation (mm); Q= average flow rates collected from all drippers (L h^{-1}); n= number of issuers analyzed

Table 3. Uniformity coefficient equations for the center pivot irrigation system

Equations – Coefficient of Uniformity	
$CUH = 100\left[\frac{\sum_{i=1}^{n} \lvert V_i - \bar{V}_w \rvert S_i}{\sum_{i=1}^{n} (V_i S_i)}\right]$	$CUD = 100 \cdot \frac{Q_{25}}{Qmed}$

X= Average of the flows collected in the drippers in the subarea, (L h^{-1}); n: Number of collectors used in the test; i: I-th collector; Vi: Volume collected in the I-th collector; Si: Distance from the I_{th} collector to the pivot axis; Weighted average volume; Q_{25}: Weighted average of 25% of the total number of drippers with the lowest flows (L h^{-1}); Qmean= Weighted mean of collected volumes (L h^{-1})

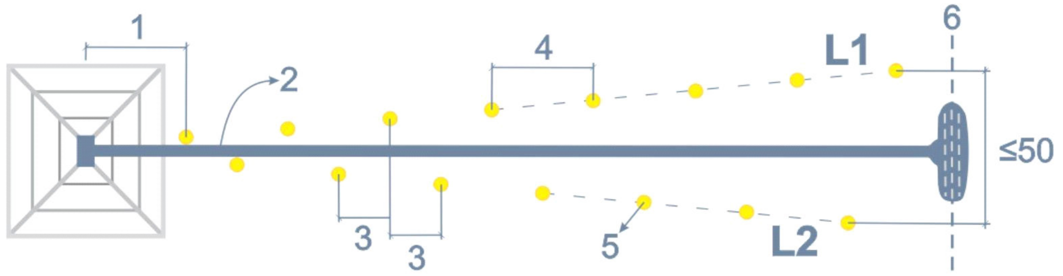

Image: Author. Adapted from ABNT NBR ISO 11545: 2016

Figure 1. Arrangement of collectors in the center pivot irrigation system to determine the irrigation uniformity, in the double-row methodology

pivot axis to the first collector; number 2, the side of the center pivot; number 3 refers to the decentralization between collectors of the two lines; number 4 concerns the spacing between collectors; number 5 is the i^{th} collector of the j^{th} line and 6 is the wheel track. L1 and L2, row 1 and row 2, respectively.

Operation flowchart

The UniIrrig® Application was developed using the Integrated Development Environment (IDE) Android Studio10 version 4.0.1, in JAVA language, with applicability in smartphones that run the Android operating system. The language of the application follows the norms of the Brazilian Portuguese language.

The flowchart of the data stream's working logic (Figure 2) illustrates the general model of operations for the UniIrrig® application. As a starting point, the different irrigation systems available for calculating the coefficients are presented. Then, segue the insertion of the evaluated system information for later introduction in the generated matrix, of the respective volumes collected by the collectors. After the calculation, the application displays the results of the coefficients, later generating a report containing the inserted slides, results, and information from the test site, so it is possible to save it in the device's memory in PDF and XLS.

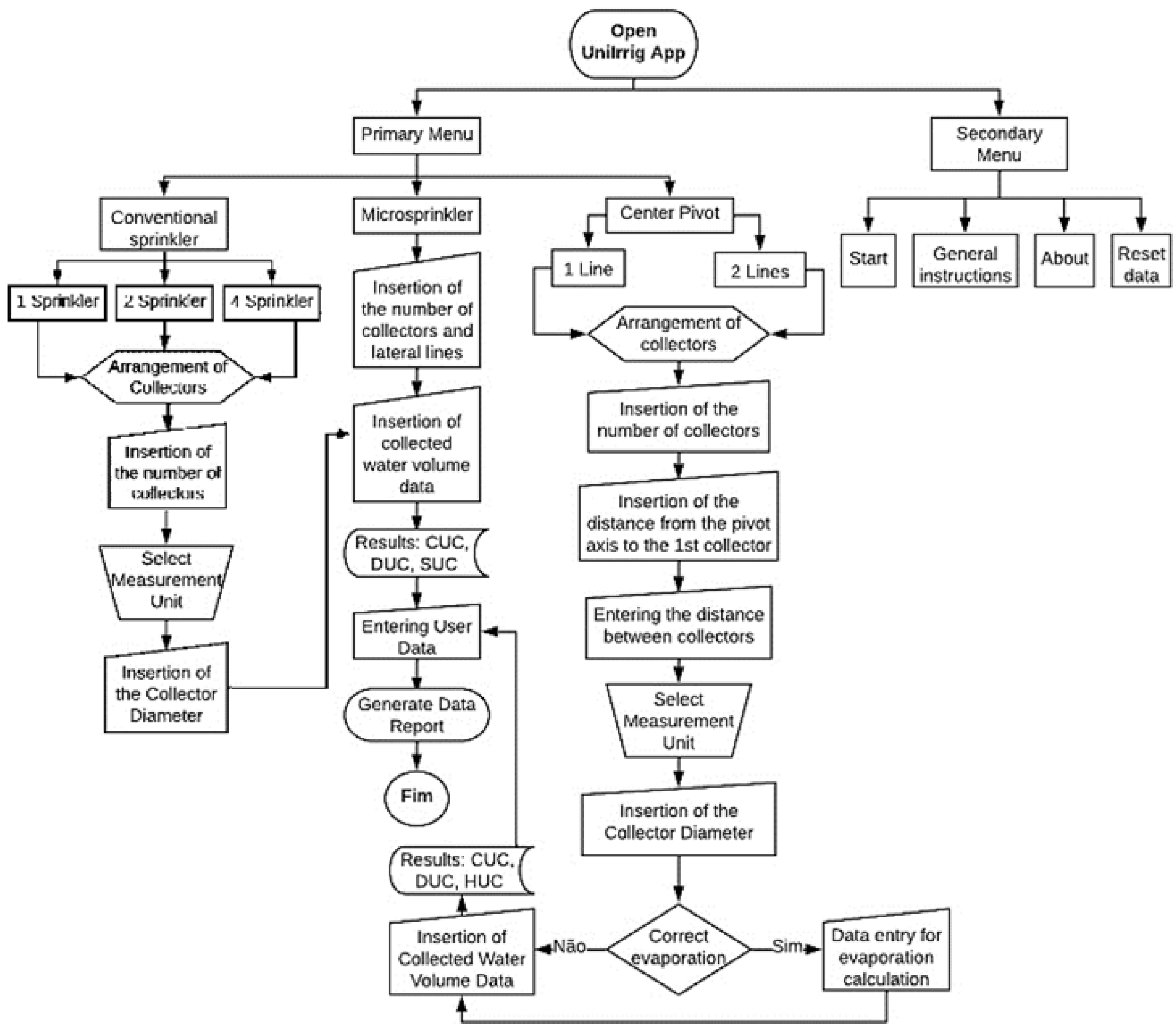

Image: Author (2022)

Figure 2. General flowchart of UniIrrig® application operation

Quantitative validation

To check the application of the calculations, the same input values inserted in the UniIrrig® application were also inserted into Microsoft® Excel 2010, to obtain the uniformity coefficients. The water depth data assigned to the tests for the conventional sprinkler system and the localized method were obtained by drawing lots in Microsoft® Excel, in order to attest to the validation of the results obtained by the application and its safety for field test results.

Thus, 50 repetitions were performed in both software in the 16 executable combinations in the application (2x2, 2x4, 2x6, 2x8, 4x2, 4x4, 4x6, 4x8, 6x2, 6x4, 6x6, 6x8, 8x2, 8x4, 8x6, 8x8), where they refer to the number of rows versus the number of columns in the conventional sprinkler system for one sprinkler, two sprinklers, and four sprinklers, totaling 800 data for each uniformity coefficient (CUC, DUC, and SUC) in the different numbers of sprinklers available in the application.

The volumes of water collected at the end of each test are inserted by the user into the data matrix of the UniIrrig® application and converted into precipitation intensity values (mm h^{-1}). In the data overlay process, only square and rectangular arrangements were considered. In the application, it is possible to apply three types of arrangement: One sprinkler and four quadrants, two sprinklers, and two quadrants, and four sprinklers and one quadrant (Figure 3A, 3B, and 3C, respectively).

In the localized method, the validation of the results was also verified through 50 replications in the 16 combinations executable in the application (2x2, 2x4, 2x6, 2x8, 4x2, 4x4, 4x6, 4x8, 6x2, 6x4, 6x6, 6x8, 8x2, 8x4, 8x6, 8x8), which refer to the number of emitters per sideline versus the number of sidelines, totaling 800 data for CUC, DUC, and SUC. For the center pivot, 50 replications were also performed in the test methodologies for one and two lines of water collectors.

The CUC, DUC, SUC, and HUC results determined by the UniIrrig® application were compared with those obtained by Microsoft® Excel, through correlation analysis to obtain the coefficients of the equation (Y = a + bX), which configures in a descriptive analysis of the degree of dependence of two variables, ranging from -1 a +1.

System Evaluation through center pivot

For field testing, an evaluation of a center pivot system was carried out at the Vitória farm in the city of Cascavel, Ceará state, using a system composed of three spans and a cantilever, totaling 183.77 m of the total length of the equipment, corresponding to 156.95 m to the last tower and 26.82 m from the cantilevered span. The useful irrigated area (360°) is 10.61 ha, with an average spacing between emitters of 3.0 m. The centimeter adjusted at a speed of 50% was adopted.

The evaluation of the irrigation system was based on the standards of ABNT NBR ISO 11545 (2016). To determine the water depths in each collector, the methodology of two radial lines (A and B) with an angle of 3° was used, containing 58 collectors in row A and 59 collectors in row B, arranged along the radius of the pivot, from the center tower to the cantilevered span (Figure 4). The distance from the axle to the first collector in row A is 15m and 13.5m in row B.

The system operating pressure at the beginning of the pivot was maintained at 24.05 mca, with a total manometric head of 49.63 mca. For the characterization of uniformity, the ABNT NBR ISO 11545 (2016) standard project was used as a basis. The evaluated center pivot has a total of 68 emitters, 1.1 m high, divided into spans as shown in Table 3.

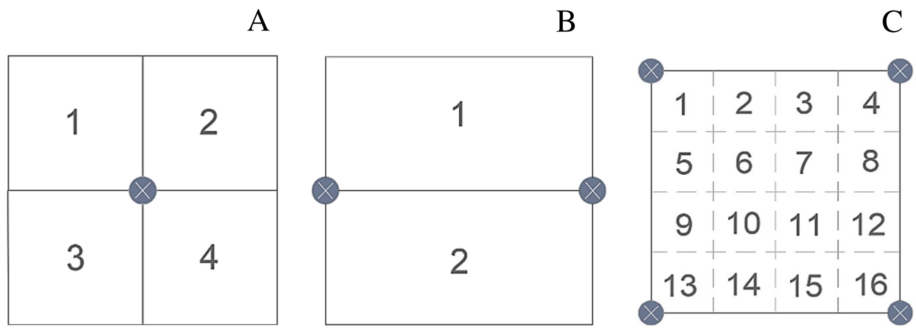

Image: Author (2022)

Figure 3. Layout arrangement of sprinklers and their respective overlaps

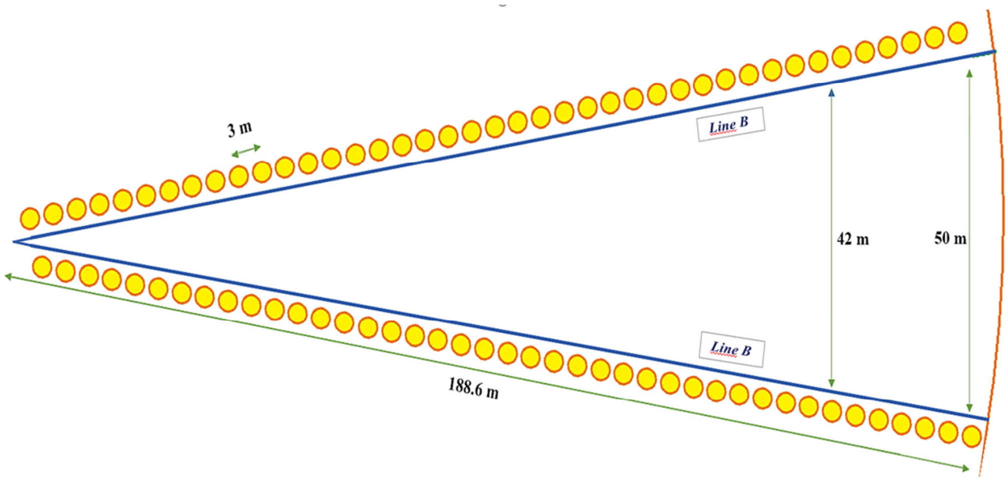

Image: Marcio Régis (2022)

Figure 4. Design of the irrigated water depth collection area (kit Fabrimar)

Table 3. Technical information on the center pivot equipment

	Pivot Point	Segment 1	Segment 2	Segment 3	Cantilever	
Length (m)	0 - 13.5	40.4	54.6	54.6	28	m
No. of Emitters	0	10	24	21	13	emitters
Space between emitters	4.2	4.04	2.28	2.6	2.15	m

The water collection for the uniformity test was carried out for 64 min. In this interval, the wind speed (m/s), pressure (mca), and flow (m^3/h) were measured every 15 minutes. To evaluate the uniformity in the system, the DUC and HUC were calculated using the UniIrrig® application.

Qualitative assessment

A qualitative assessment was proposed for users of the latest version of the application. For this, 68 undergraduate students in Agronomy, attending the disciplines of Pressurized Irrigation and Irrigation and Drainage at the Federal University of Ceará, simulated a uniformity test, assigning data from irrigation depths to obtain the coefficients.

The indication was to evaluate, through an electronic questionnaire, the usability of the program under the following aspects: ease of use, loading time, adequacy to screen resolution, frequency of use, and relevance of data. For Nielsen (1993), an interface with satisfactory usability equips five attributes: efficiency, ease of use, error prevention, ease of learning, and subjective satisfaction.

RESULTS AND DISCUSSION

Conventional sprinkler irrigation

After starting the application, the main menu is displayed (Figure 5A), allowing the user to indicate which irrigation system was used in the uniformity evaluation. Selecting "Sprinkler", the possible numbers of sprinklers to be used for calculation (1, 2, or 4) will be displayed. Then, the user defines the number of rows, number of columns, measurement unit (cm^3 or mm), collector diameter (cm), and operating pressure (mca) (Figure 5B). Based on these definitions, a matrix is generated to insert the values of the volume of water collected in the collectors (Figure 5C).

Dripping and micro sprinkler irrigation

In the initial menu, after selecting "Localized Irrigation", the user is directed to the variables insertion screen (Figure 6A), consisting of the number of emitters per lateral line, number of lateral rows, flow unit (cm^3/min. or L/h) and pressure at the end of the row (mca). Next, the values for the volume of water collected by the emitters are introduced for each lateral line (Figure 6B).

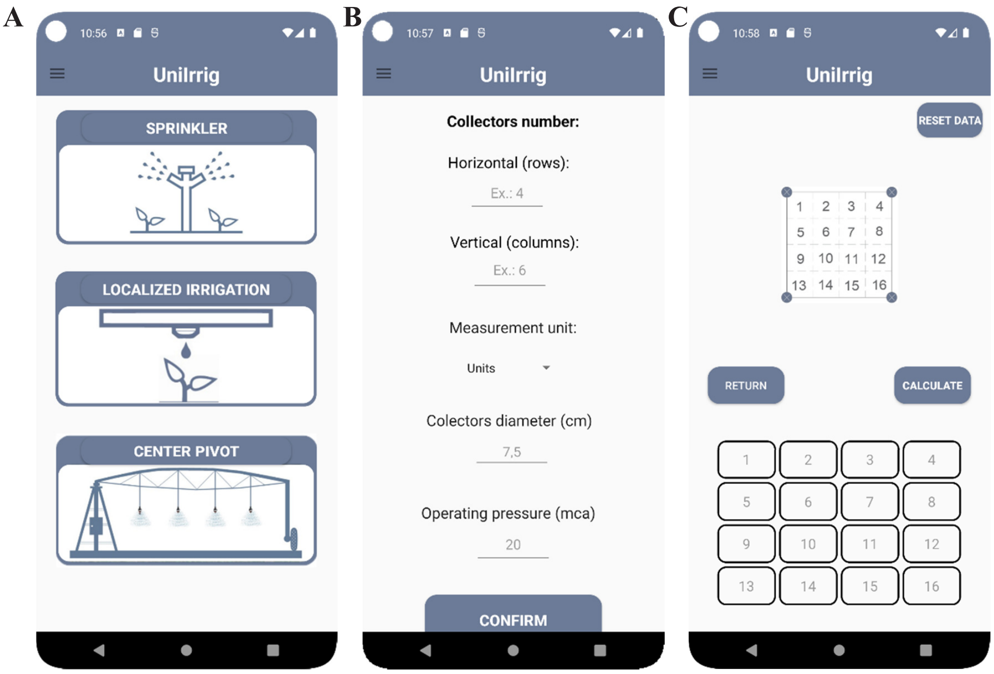

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Figure 5. UniIrrig® application guides: (A) Main menu, (B) Information on the evaluated system for building the data insertion matrix, (C) Introduction of collection values for the example of four sprinklers

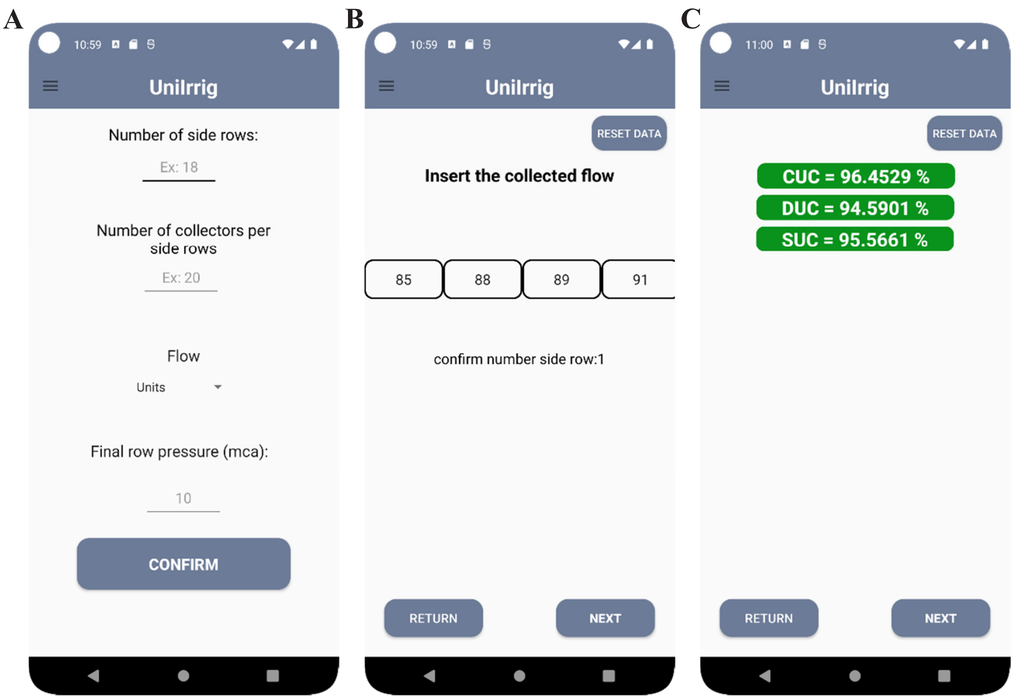

Image: Author (2022). Christiansen Uniformity Coefficient (CUC), Distribution Uniformity Coefficient (DUC), and Statistical Uniformity Coefficient (SUC)

Figure 6. UniIrrig® application guides: (A) Information from the evaluated system to build the data insertion matrix, (B) Introduction of collection values for four sprinklers, (C) Result of CUC, DUC, and SUC

Once the “Calculate” button is pressed for both “Sprinkling” and “Localized Irrigation”, the result of the Christiansen Uniformity Coefficient, Distribution Uniformity Coefficient, Statistical Uniformity Coefficient, and the collected average depth (CUC, DUC, SUC, and Lmc, respectively) (Figure 6) are immediately displayed. showing enhancement in the green color, which shows an “excellent rating”, according to the classification by Mantovani *et al*. (2009).

In addition, the main user and property information is required through a form, to be stored in the report. It can be stored in the device’s memory in PDF format, as well as the inserted volume data, in XLS.

Center pivot irrigation

In the initial menu, after selecting the system through “CenterPivot”, the user is directed to the variables insertion screen (Figure 7A), consisting of the number of collectors, distance from the pivot axis to the first collector, and distance between collectors. Then, the volume values collected by the pluviometers are introduced (Figure 7B). When the “Calculate” button is pressed, the result of the DUC, HUC, and the graph of the collected slide is displayed as a function of the weighted average depth (Figure 7C), following the analogous classification by Mantovani *et al*. (2009) for the DUC and Bralts classification (1986) for the HUC.

UniIrrig® application validation

In validating the UniIrrig® application through the theoretical knowledge proposed by Bernardo et al. (2006), it can be seen that the measurement of the UniIrrig® application with the Microsoft® Excel software attested to an error equal to zero, showing that the algorithm works well in the measurement of irrigation uniformity coefficients.

In the descriptive analysis of the degree of dependence, the data correlation analysis between the software used in this work resulted in r = 1,

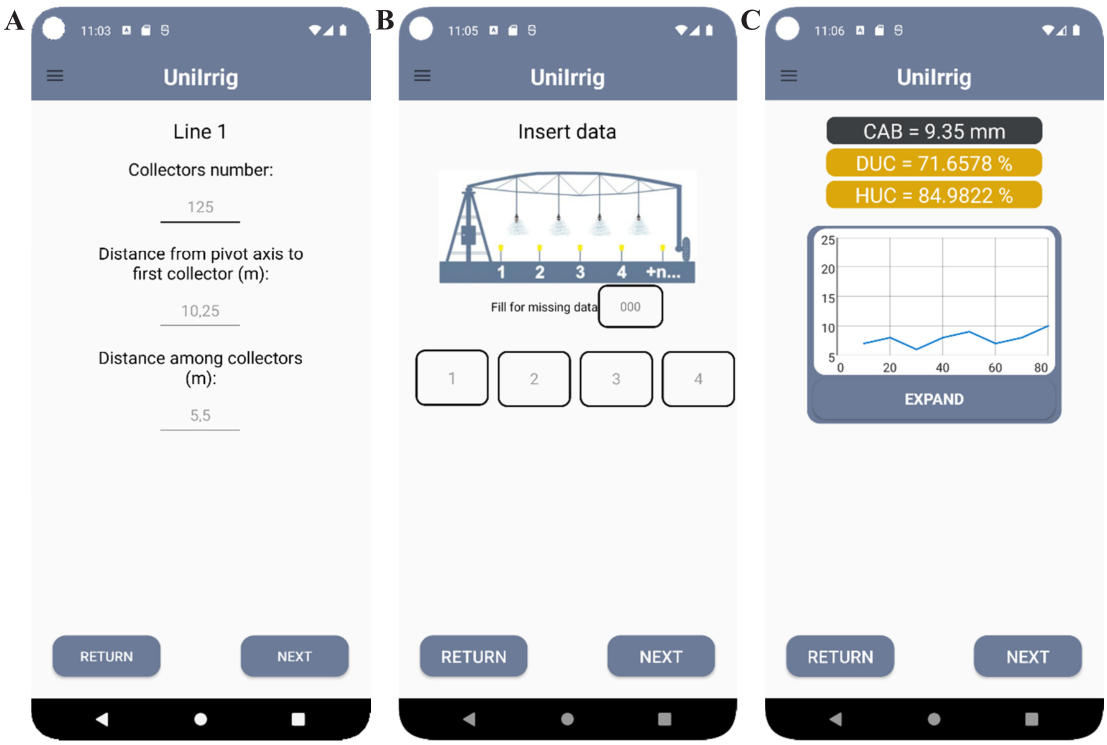

Image: Author (2022). CAB= calculated average blade, Distribution Uniformity Coefficient (DUC), Heermann and Hein Uniformity Coefficient (HUC)

Figure 7. UniIrrig® application guides: (A) Information on the evaluated system to construct the data insertion matrix, (B) Introduction of collected water volume values, (C) Result of DUC, HUC, and graph. For the graph elaboration, (Figure 7C), the MPAndroidChart library, made available by Philipp Jahoda, under the Apache 2.0 license, was used

which means, according to Guimarães (2017), a perfect correlation between the two variables (Microsoft Excel and UniIrrig® application), showing that they did adequately describe the same results.

Also, it should be observed that, according to Santos *et al*. (2013) and Rodrigues *et al*. (2013), the joint analysis of the water application uniformity coefficients is essential in assessing the applied distribution variability and, consequently, the performance of any irrigation system.

Qualitative assessment

After the usability test, 71% of the participants indicated that they were satisfied with the application's performance, 62.3% indicated that the tool was easy to be used, 75.4% believed that the application had the potential for field activities, 59.4% consider the application interface pleasant, 87% indicated that the application performs the results rapidly and conveniently, 73.9% consider the organization of information on the application screen to be clear and intuitive, 84.1% consider the application a good tool for determination of uniformity coefficients and 89.9% would recommend the application.

Of the 69 interviewees, 95.7% did not find any faults during the operation of this tool. The remaining 4.3% presented their criticisms and suggestions at the end of the form, which is currently being implemented to improve the tool and update it in the Google Play Store. According to Nielsen (1993), with only five users, it is already possible to detect about 80% of the usability problems of an application.

Evaluation of a system through center pivot

The analysis of the results (Figure 8A) shows that the DUC, according to Mantovani *et al*. (2009), indicated good uniformity of the evaluated system, presenting 75.61% (< 84% and ≥ 68%). on the other hand, the HUC, classified according to Bralts (1986), exhibits good uniformity, with results < 90% and ≥ 80%. Knowing that the standard deviation is used for the calculation of the HUC, in the condition in which the application layer demonstrates non-uniformity, the higher the standard deviation will be and the lower the HUC value will be.

Table 4 shows the data referring to the travel time of the central pivot, wind speed, operating pressure, system flow, and information about the test operation.

The wind speed during the test showed a mean of 2.74 m/s, which did not interfere with the coefficient values. Heermann & Hein (1968), when observing the effect of wind on the uniformity of water distribution in a center pivot system, inferred that this was not significantly affected by the wind as the uniformity remained greater than 80%. Authors such as Solomon (1979), Kincaid (1996), and Dechmi (2003), state that wind speed is one of the main factors that influence the uniformity of irrigation systems. According to Bernardo et al. (2019), other factors such as air temperature and fractionation of the water jet increase water loss through evaporation and drift caused by wind.

Graph 1 shows the distribution profile of the

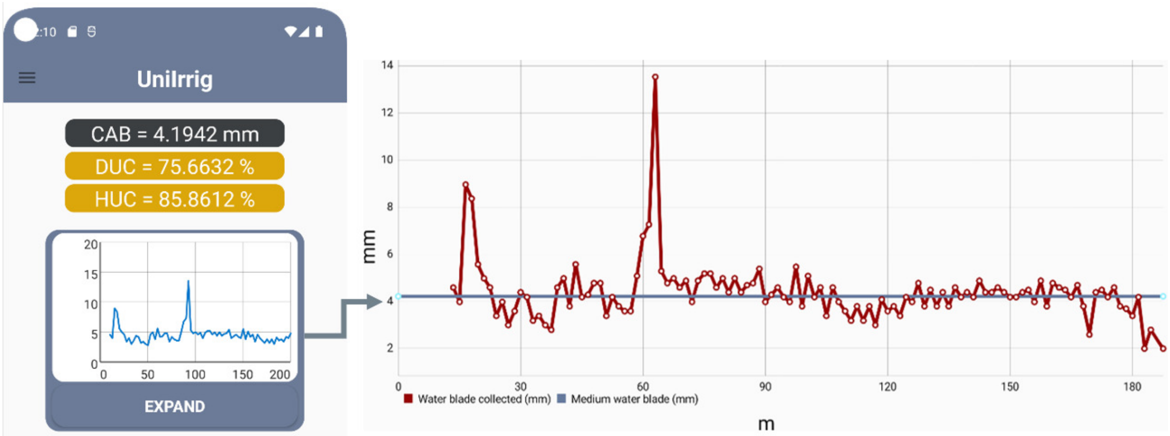

Image: Author (2022). CAB= calculated average blade, DUC= distribution uniformity coefficient, HUC= Heermann and Hein Uniformity Coefficient

Figure 8. Result of the center pivot evaluation using the UniIrrig® application and magnification of the system uniformity graph.

Table 4. Uniformity test information on center pivot irrigation system

Time	Pressure (mca)	Flow (m^3/h)	Process
10:40	10	66.09	Start - Passage of the side through A row
10:55	10	66.45	
11:10	10	64.43	
11:25	10	65.60	
11:40	10	64.10	
11:44			Final - Passage of the side through B row
11:53			Start of the collection A row
11:57			Start of collection start B row

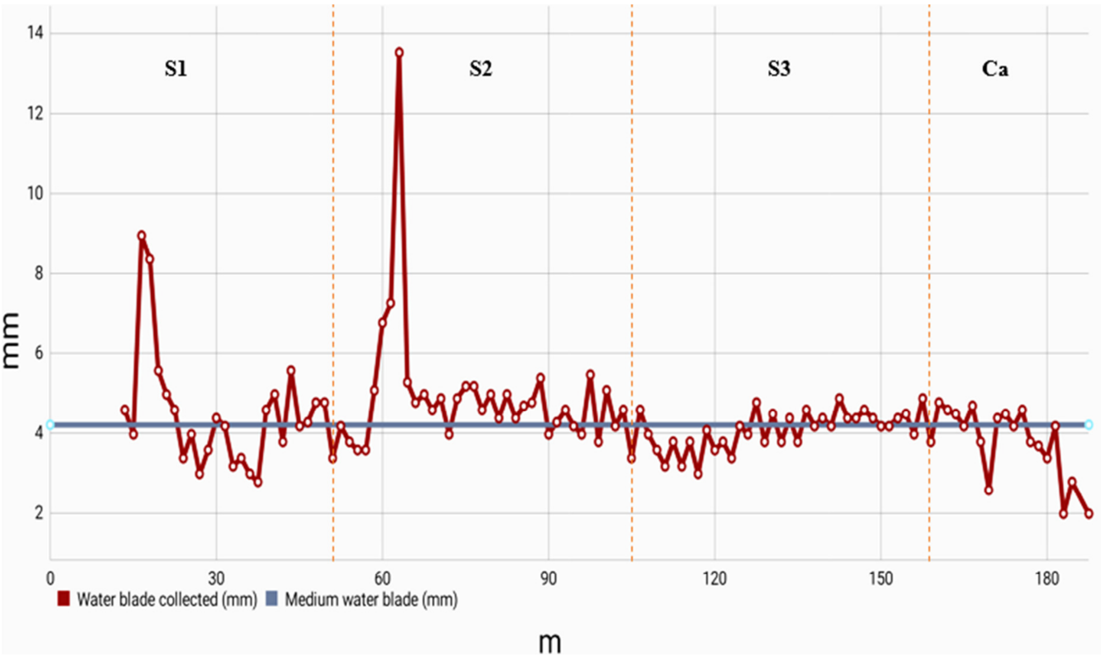

Image: Author (2022). S1: segment 1 of the center pivot, S2: segment 2, S3: segment 3, Ca: cantilever

Graphi 1. Profile of the collected depth as a function of the weighted mean depth

water depth applied along the radius of the center pivot, considering the depth collected as a function of the calculated weighted average depth (4.12 mm). In general, irregularity in the application uniformity and distribution of water along the center pivot is observed in some strips (Graph 1).

By analyzing the distance from the pivot axis to the best uniformity results of the applied depth, it can be seen that from 66m of distance, equivalent to half of segment 2 (S2), a smaller variation of the blades is found. However, it is denoted that segment 3 (S3) presents greater uniformity of the depths. Thus, the observation of the non-uniformity of the system shown in the graph and the calculation of the coefficients executed in the UniIrrig® application, the system presents itself with good uniformity according to Mantovani *et al*. (2009) and Bralts (1986).

CONCLUSIONS

- The UniIrrig® application, developed for the Android operating system, can be used to determine uniformity coefficients for the evaluation of localized irrigation, conventional sprinkler, and center pivot irrigation systems.

AUTHORSHIP CONTRIBUTION STATEMENT

SILVA, D.A.: Data curation, Methodology, Project administration, Writing – original draft, Writing

– review & editing; **MARIANO, A.B.R.:** Data curation, Methodology, Project administration, Software, Validation; **SILVA, D.R.:** Methodology, Project administration, Software, Validation, Visualization; **SOUSA, A.B.O.:** Formal Analysis, Methodology, Project administration, Supervision, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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