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# UNIFORMIDADE DA IRRIGAÇÃO POR ASPERSÃO EM FUNÇÃO DA ALTURA DO DOSSEL DA CANA-DE-AÇÚCAR

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## 1 RESUMO

O objetivo do presente trabalho foi avaliar a uniformidade de aplicação e a distribuição do conteúdo de água em um solo cultivado com plantas soca da cana-de-açúcar aos 100 e 330 dias após o corte, irrigadas por aspersão convencional sob diferentes espaçamentos de aspersores. Para tal, no Município de Carpina-PE, em condições de campo, em uma área de 44 x 44 m, subdividida em duas áreas iguais com plantas de 0,70 e 2,80 m de altura do dossel, respectivamente, instalou-se, no centro da área, um aspersor a 1,7 m do solo e monitorou-se a lâmina precipitada e a umidade do solo em 144 pontos distribuídos em malha simétrica de 4 x 4 m. De posse dos resultados experimentais foram realizadas simulações de onze combinações de espaçamentos entre aspersores por meio de modelagem numérica e comparou-se os resultados mediante estatística descritiva. Na área sob cana com dossel de 2,8 m ocorreu maior armazenamento de água no solo em relação a cana com dossel de 0,7 m, e as simulações realizadas permitiram estabelecer uma correlação entre a lâmina necessária e o espaçamento entre aspersores, sendo recomendado espaçamento de 12x18 m para ambas alturas de plantas.

**Palavras-chave**: *Saccharum spp*., irrigação pressurizada, eficiência de irrigação.

**SILVA, M.M.; SANTOS JÚNIOR, J. A.; MELO FILHO, M.S.; SILVA, E. F. F.; SANTOS, J. B.**
**UNIFORMITY OF SPRINKLER IRRIGATION IN FUNCTION OF CANOPY HEIGHT OF SUGARCANE**

## 2 ABSTRACT

The objective of the present work was to evaluate the uniformity of application and distribution of the water content in a soil cultivated with soca plants of sugarcane, with 100 and 330 days after the cut, irrigated by conventional sprinkling under different spacings of sprinklers. For such, in the municipality of Carpina-PE, under field conditions, in an area of 44 x 44 m, subdivided into two equal areas with plants of 0.70 and 2.80 m canopy height, respectively; it was installed in the center of the area, a sprinkler at 1.7 m from the ground and the precipitated blade and the soil moisture were monitored in 144 points distributed in 4 x 4 m symmetrical

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mesh. With the experimental results, eleven combinations of sprinkler spacings were conducted using numerical modeling and the results were compared through descriptive statistics. It was verified that in the area cultivated with sugarcane presenting a canopy of 2.8 m, there was a greater water storage in the soil in relation to the sugarcane area with a canopy of 0.7 m, and the simulations performed allowed to establish a correlation between the necessary water blade and the spacing between sprinklers, and spacing of 12x18 m is recommended for both plant heights.

**Keywords**: *Saccharum spp*., pressurized irrigation, irrigation efficiency.

## 3 INTRODUCTION

The advent of irrigation practices allowed humanity to transition from a nomadic and extractive lifestyle to settled societies, which were initially located along the banks of large rivers (CARVALHO et al., 2014). Floodwaters seasonally fertilize their banks by depositing suspended organic matter, thus favoring significant harvests. However, with demographic growth and the proportional increase in food demand in successive periods of history, the emergence of rustic irrigation methods, such as the dikes and canals of ancient Egypt, made it possible to address the seasonality of floods and increase production rates (RIBEIRO; CÂMARA, 2015).

Despite the development of modern irrigation systems in the 20th century, with the expansion of irrigated areas and the consequent increase in water demand, the design of the systems used began to consider not only the availability of water to plants but also the uniformity and efficiency of water application (ARAQUAM; CAMPECHE, 2012; MARTINS et al., 2011a). In this sense, Christiansen (1942), studying the uniformity of water distribution for sprinklers as a function of the effects of pressure, spacing, rotation, and wind speed on water distribution, proposed a parameter indicating the uniformity of water application, called the Christiansen uniformity coefficient (CUC). Another indicator parameter, the coefficient of distribution uniformity (CUD), was recommended by the Soil Conservation Service (1968), whose calculation methodology considers the average of the 25% lowest precipitation values in relation to the total average.

The parameters indicating uniformity and application efficiency express the quality of irrigation and are fundamental in the planning and operation of these systems; thus, for high-yield crops with a shallow root system, sprinkler irrigation must present a CUD above 80% and a CUC above 88% (MERRIAN; KELLER, 1978).

In this sense, the use of numerical models that allow the simulation of different scenarios enables the estimation of irrigation efficiency in a wide range of field situations, including crops with different canopy heights, and, consequently, the anticipation of future problems, optimizing irrigation efficiency in the field. Highlighting the relevance of this demand, Martins et al. (2011b), in studies on the behavior of conventional sprinkler irrigation systems in southern Espírito Santo, reported low uniformity efficiency in 60% of the projects evaluated.

In the specific case of sugarcane, the agricultural crop with the largest irrigated area in Brazil (AGÊNCIA NACIONAL DE ÁGUAS, 2012), whose harvest management can affect areas with plants with different canopy heights, few studies have addressed irrigation management (VIEIRA, et al., 2012; CAMPOS et al., 2014) and the water distribution efficiency on the soil surface and profile and its correlation with different canopy heights and sprinkler spacings. Despite the relevance of this crop to the country's economy, it is used in the preparation of sugar, ethanol, and alcoholic beverages; studies that understand these nuances in its irrigation management routine still need to be further conducted (MARIN et al., 2013).

In this sense, the objective of the present work was, on the basis of the simulation of CUD and CUC for eleven spacings between sprinklers, to estimate the efficiency of water distribution on the surface and in the soil profile in sugarcane cultivation with two canopy heights.

## 4 MATERIALS AND METHODS

The experiment was carried out under field conditions between October and November 2014 in a sugarcane field located at the Carpina Sugarcane Experimental Station (EECAC), Advanced Research Unit of the Federal Rural University of Pernambuco (UFRPE), Carpina-PE, located at 7° 51' 13" south latitude and 35° 14' 10" west longitude and an average altitude of 184 m.

The experimental area used (1,936 m2) measured 44 × 44 m and was subdivided into two subareas of equal dimensions, one cultivated with sugarcane at 100 m and the other at 330 days after cutting (DAC), with heights of 0.70 and 2.80 m, respectively. On the dividing line of the areas, a lateral line of the irrigation system was placed, over which a sprinkler with a riser pipe 1.70 m high in relation to the soil surface and a nominal diameter of 1/2" was installed.

The sugarcane cultivar used was RB 92579, which has an erect growth habit and, in the adult phase, stalks with an average diameter of 30 mm and broad leaves (CAMPOS et al., 2014; HOLANDA et al., 2014).

A Plona KS 1500 mini-cannon sprinkler was used, with two conical nozzles of 12.0 and 5.0 mm, whose rotation mechanism occurs by impact of the oscillating arm and has a wetted diameter of 24 m. The operating pressure adjustment for the collection mesh used was defined in previous tests with the aid of a Bourdon-type pressure gauge with pitot adaptation so that, under an operating pressure of 20.0 mca, the sprinkler used applied an average flow rate of 9.87 $m^3h^{-1}$. The irrigation events lasted one hour and were carried out between six and seven hours, resulting in four irrigation events used in the experiment.

The environmental conditions were monitored during the tests to assess potential climate influences on the experimental analyses. To this end, the wind speed was monitored every fifteen minutes via a portable thermoanemometer installed 2 m above the ground surface and 2 m from the edge of the area. During the experimental analyses, the average wind speed was 0.25 $ms^{-1}$, and the average temperature was 29.4 °C. Water loss through evaporation was minimal, likely due to the timing of the tests.

The soil of the experimental area was classified as Distrocohesive Yellow Argisol (EMBRAPA, 1997), and prior to the start of the experimental activities, undisturbed samples were collected, according to the methodology of Santos et al. (2005), from the 0--20 cm layer, with the aim of characterizing the physical parameters of the soil (Table 1), which was carried out according to the methodology of Embrapa (1997).

**Table 1.** Physical characteristics of the soil in the experimental area. Carpina-PE, 2014.

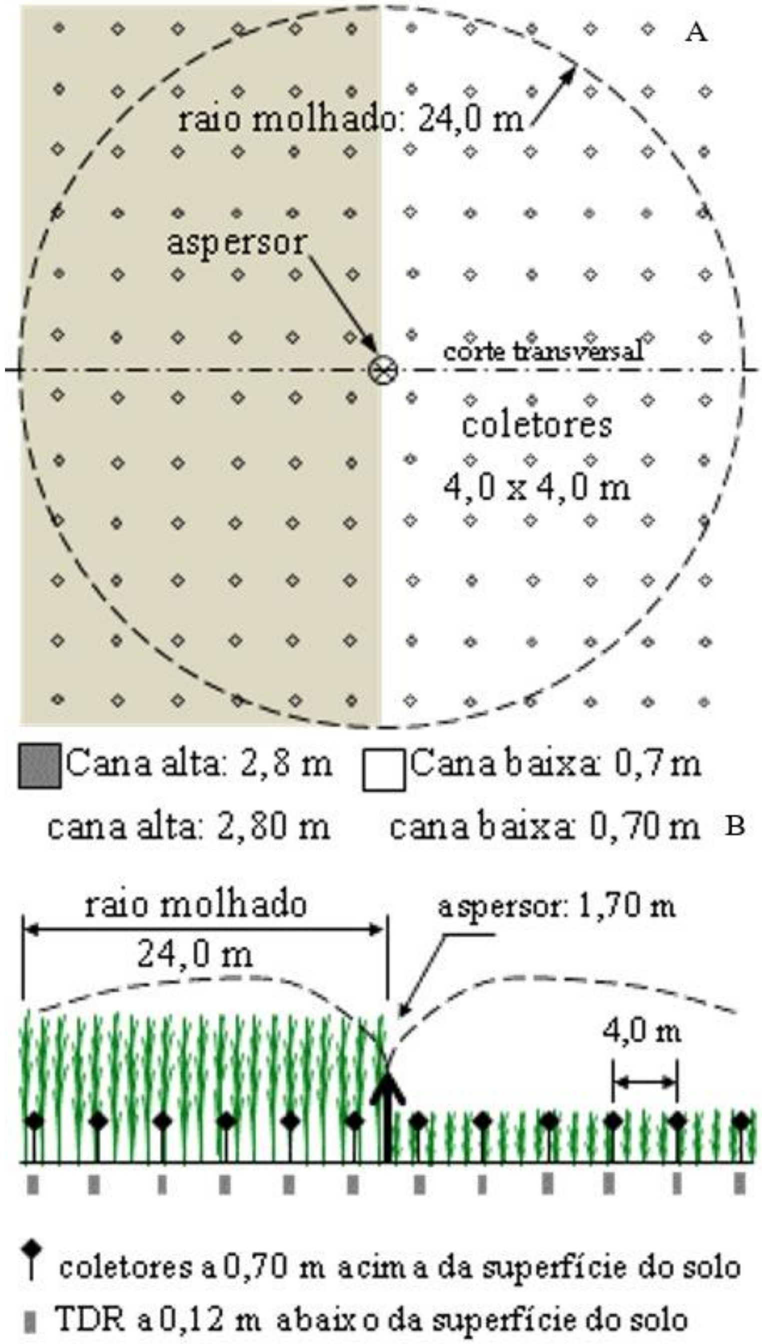
| Layer of soil | Height of sugarcane | Ds | Texture | | | Humidity | |
|---|---|---|---|---|---|---|---|
| | | | Sand | Silt | Clay | CC | PMP |
| (m) | (m) | g cm$^{-3}$ | g kg$^{-1}$ | g kg$^{-1}$ | g kg$^{-1}$ | m$^3$ m$^{-3}$ | m$^3$ m$^{-3}$ |
| 0.0 - 0.2 | 0.70 | 1, 60 | 761.16 | 73.26 | 165.58 | 0.10 | 0.05 |
| 0.0 - 0.2 | 2.80 | 1.48 | 727.28 | 84.66 | 188.06 | 0.12 | 0.06 |

Ds - soil density; CC - field capacity; PMP - permanent wilting point.

With respect to the variables analyzed, the precipitated layer was monitored with the aid of 144 collectors distributed symmetrically in a 4 × 4 m grid throughout the area; these collectors were installed at a height of 0.7 m relative to the soil surface and had a water collection section of 0.00785 $^{m2}$. At the end of each test, the collected volume was measured and cataloged.

Soil moisture was also monitored in the 0 to 0.12 m layer with a TDR (time domain reflector). For this purpose, at the 144 points located below the collectors, soil moisture was measured at 0, 4, and 8 hours in relation to the start of the irrigation event. The TDR calibration was performed with a fit of R $^2$ = 0.8699 and the following equation: $\theta_{SOIL} = 1.5279.\ \theta_{TDR} + 3.1133$, where $\theta_{SOIL}$ is the soil moisture in % volume and $\theta_{TDR}$ is the moisture obtained by the probe in % volume. A schematic of the precipitation and soil moisture collection points is shown in Figure 1.

**Figure 1.** (A) Top view of the grid of points used to collect precipitation depth and soil moisture. (B) Cross-sectional view of the tall and short sugarcane areas and the precipitation and soil moisture monitoring points.

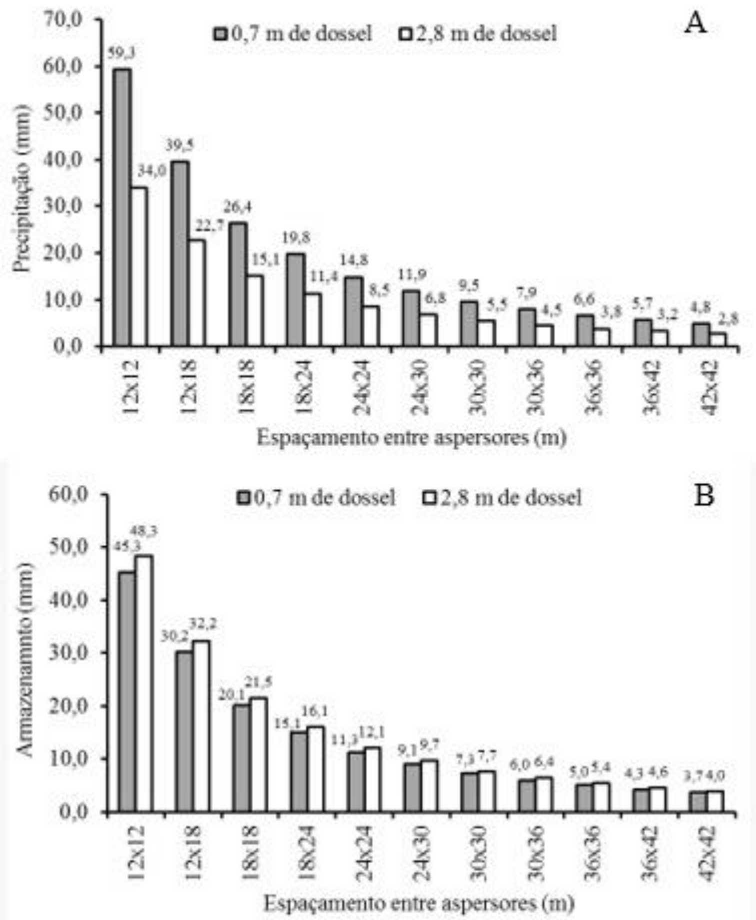



Using the collected data, simulations were performed for eleven spacings between sprinklers (12x12 m; 12x18 m; 18x18 m; 18x24 m; 24x24 m; 24x30 m; 30x30 m; 30x36 m; 36x36 m; 36x42 m; 42x42 m) through numerical modeling with the aid of software, and for these scenarios, the Christiansen uniformity coefficient (CUC) and distribution coefficient (CUD) were determined for the precipitated depth and for the soil moisture in the 0--0.12 m layer. The results were subjected to descriptive statistics and classified according to Bernardo, Soares and Mantovani (2011).

## 5 RESULTS AND DISCUSSION

The behavior of the collected precipitation in the scenarios under sugarcane with a 0.7 and/or 2.8 m canopy showed a decreasing trend with increasing spacing. However, regardless of the spacing between sprinklers, the precipitation collected under a 0.7 m canopy was, on average, 42.66% greater than the depth collected in sugarcane with a 2.8 m canopy (Figure 2A). Notably, the adopted elevation for the collectors was equal to the height of the sugarcane with a 0.7 m canopy; thus, the precipitation fell directly on them. From another perspective, in the sugarcane with a 2.8 m canopy, whose height was one meter above the collector elevation, the effect of leaf interception on the collected precipitation was evident, regardless of the adopted sprinkler spacing.

**Figure 2.** Averages of (A) precipitated and (B) stored water depths. The results of eleven simulations of sprinkler spacing as a function of sugarcane canopy height. Carpina-PE, 2014.




In contrast to what was observed in the collected precipitation, the stored water depth in the 0–0.12 m interval of the soil profile (Figure 2B) was greater in the area under sugarcane with a 2.8 m canopy height in all the simulated sprinkler spacings. That is, especially in sugarcane with a 2.8 m canopy, the stored water depth was always greater than the collected precipitation depth, probably due to the redistribution of water in the soil profile. In fact, Zocoler et al. (2013), studying the variation between the applied and stored irrigation water depths, suggested that the uniformity of the stored water depth does not depend on the uniformity of the collected water depth, a situation that can be attributed to the redistribution of water in the soil profile.

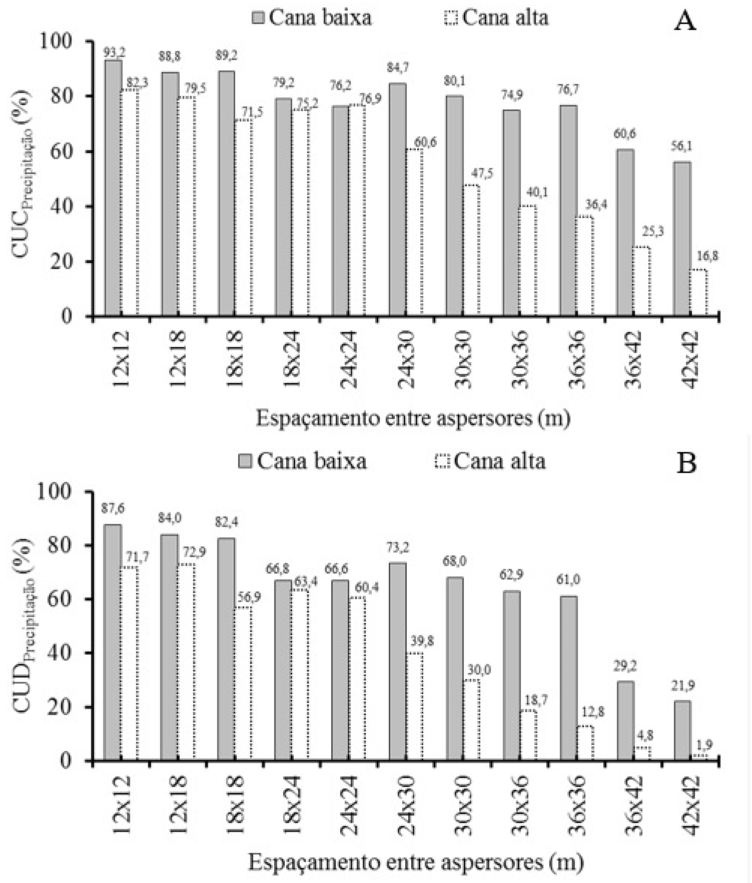
However, on average, under 12x12 m spacing, the water depth stored under sugarcane with a 2.8 m canopy was 4.82% greater than that stored under a 0.7 m canopy. In the same comparison, considering a 42x42 m spacing, the values reached 6.38%. In this case, the leaf mass that intercepted rainfall favored the conduction of water through the stem to the soil, optimizing storage and obviously enabling greater water and soil conservation rates.

However, it is worth emphasizing the results from the specific perspective of the different simulated spacings, which demonstrate a marked reduction in the precipitated and stored water depth with increasing spacing. In this case, although increasing the spacing between sprinklers indicates a reduction in the cost per millimeter applied, future work should correlate the required and/or economical water depth with the appropriate spacing and then assess the final cost per millimeter applied on the basis of the increased production resulting from the use of the irrigation system.

Regarding the quality of the uniformity of the collected precipitation or the stored sheet in the proposed scenarios, as a rule, all classifications, in the two calculation methodologies used, were carried out according to Bernardo, Soares and Mantovani (2011).

An analysis of rainfall collected from sugarcane with a 0.7 m canopy revealed a reduction of up to 39.8% in the Christiansen uniformity coefficient (CUC) and up to 75% in the distribution uniformity coefficient (CUD) for the eleven simulated sprinkler spacings when comparing the number of sprinklers spaced 12x12 m compared with those spaced 42x42 m. The Christiansen uniformity coefficient (CUC) was classified as excellent for 12x12 m spacing, good for 12x18 and 18x18 m spacing, reasonable for 18x24 and 24x24 m spacing, and insufficient for the other simulated spacings (Figure 3A). The distribution uniformity coefficient (CUD) was excellent for the 12x18 and 18x18 m spacings; under spacings of 18x18 and 24x30 m, they were classified as good; when spacings of 18x24, 24x24, 30x30, 30x36 and 36x36 m were simulated, they were classified as reasonable; and the other spacings produced uniformity classified as insufficient (Figure 3B).

**Figure 3.** (A) Christiansen uniformity coefficient (CUC) and (B) distribution uniformity coefficient (CUD) for the precipitated blade in eleven simulations of spacing as a function of sugarcane cutting height. Carpina-PE, 2014.

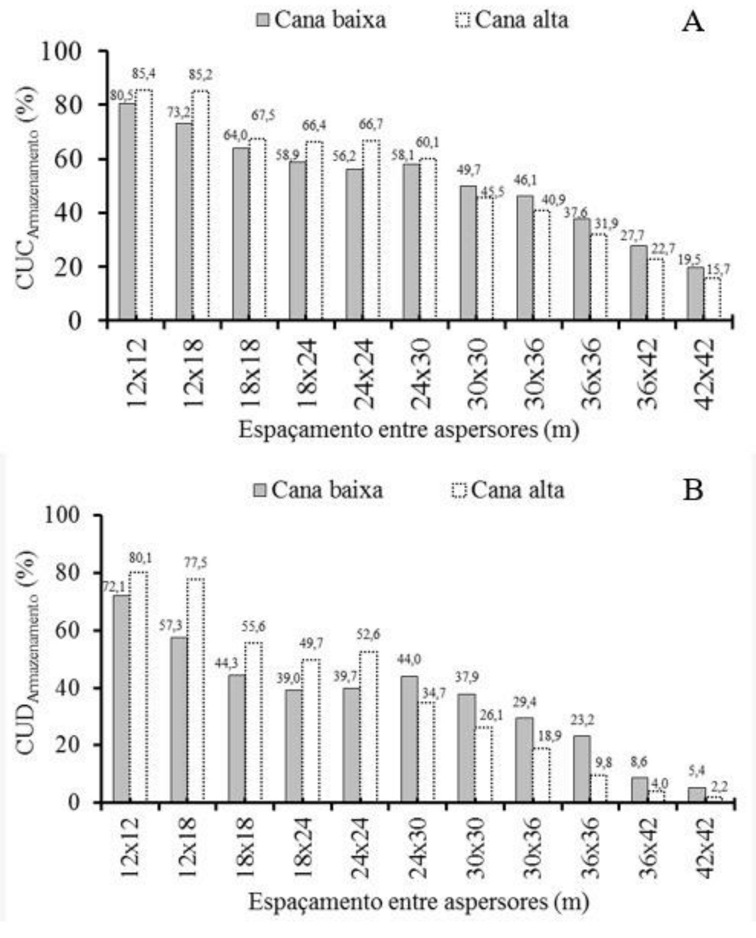



An analysis of the collected precipitation in sugarcane with a 2.8 m canopy revealed a reduction of 79.58% and 97.35% in the application uniformity CUC and CUD, respectively, with increasing spacing between sprinklers. With respect to CUC (Figure 3A), a spacing of 12x12 m, the uniformity was classified as good; spacings of 12x18, 18x18, 18x24, and 24x24 m provided reasonable uniformity; a spacing of 24x30 m resulted in poor uniformity; and the other spacings provided undesirable uniformity. With respect to the CUD (Figure 3B), the 12x12 and 12x18 m spacings provided good uniformity, the 18x18, 18x24 and 24x24 m spacings resulted in reasonable uniformity, the 24x30 m spacing uniformity was classified as poor, and the other spacings uniformity was undesirable. For Cunha et al. (2008), low uniformity indices, such as those verified in larger spacings, can cause irregular plant growth, as well as other problems related to soil degradation.

In a general evaluation of the results, comparing the percentage values of precipitation uniformity between sugarcane with canopies of 0.7 and 2.8 m, differences were found for the CUC, in the order of 10.9, 9.3, 9.7, 4.0, -0.7, 24.1, 32.6, 34.8, 40.3, 35.3 and 39.3% for spacings of 12x12, 12x18, 18x18, 18x24, 24x24, 24x30, 30x30, 30x36, 36x36, 36x42 and 42x42 m. In relation to the CUD, the differences were in the order of 15.9, 11.1, 25.5, 3.4, 6.2, 33.4, 38.0, 44.2, 48.2, 24.4 and 20% in relation to the aforementioned spacings, respectively. The CUC and CUD results verified in the present work were consistent with the trends verified in research carried out by Drumond et al. (2006), in which the Christiansen uniformity coefficient (CUC) was always greater than the distribution uniformity coefficient (CUD).

With respect to the CUC (Figure 4A), good uniformity was observed for the 12x12 m spacing, which was reasonable for the 12x18 m spacing, poor for the 18x18 m spacing and undesirable for the other simulated spacings; thus, the reduction in the CUC with increasing spacing from 12x12 to 42x42 m was 81.61%. In relation to the CUD (Figure 4B), this variation was 92.51%, and the classification (Bernardo; Soares; Mantovani, 2011) was good for the 12x12 m spacing, reasonable for the 12x18 m spacing, and poor for the 18x18, 18x24, 24x24, 24x30 and 30x30 m spacings; the other spacings presented undesirable uniformity.

**Figure 4.** (A) Christiansen uniformity coefficient (CUC) and (B) distribution uniformity coefficient (CUD) for storage in eleven spacing simulations as a function of sugarcane cutting height. Carpina-PE, 2014.

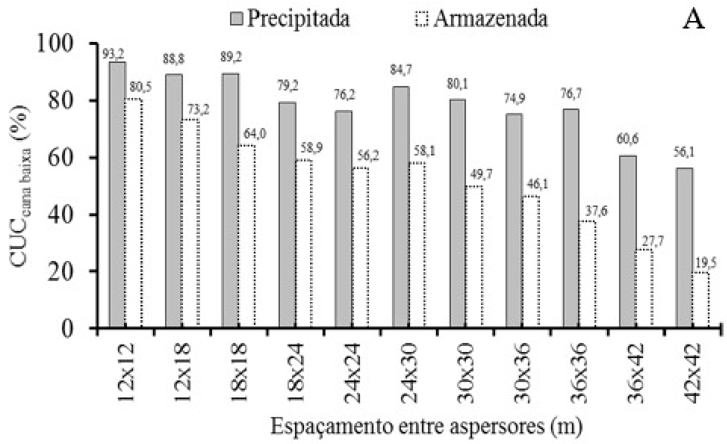


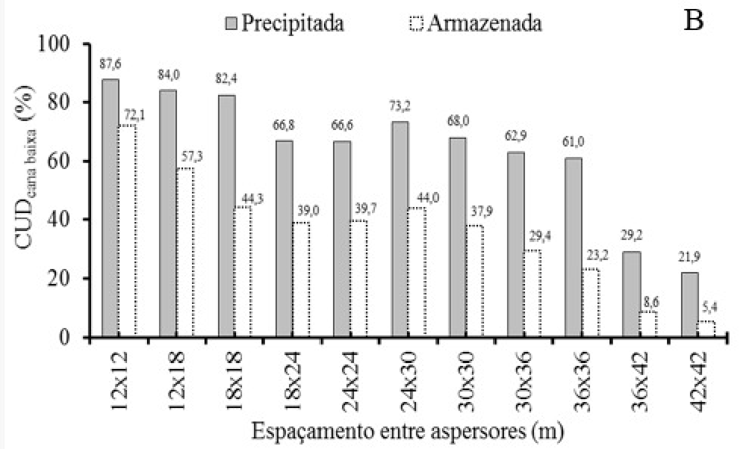

In relation to sugarcane with a 2.8 m canopy and the uniformity of the stored blade, specifically in relation to the CUC (Figure 4A), the uniformity was classified as good at spacings of 12x12 and 12x18 m; bad at spacings of 18x18, 18x24, 24x24 and 24x30 m; and undesirable at the other spacings, with a loss in uniformity being verified when the results verified at spacings of 12x12 and 42x42 m of up to 81.63%. With respect to the stored blade and its CUD (Figure 4B), for the sugarcane with a 2.8 m canopy, good uniformity was observed under spacings of 12x12 and 12x18 m, reasonable and poor under spacings of 18x18 and 18x24 m, respectively, and under the other spacings, the uniformity was undesirable.

Comparing the results of storage uniformity between sugarcane with canopies of 0.7 and 2.8 m, when the CUC was used as a reference, there was a difference between the uniformity percentages verified at spacings of 12x12, 12x18, 18x18, 18x24, 24x24, 24x30, 30x30, 30x36, 36x36, 36x42 and 42x42 m, in the order of -4.9, -12.0, -3.3, -7.6, -10.5, -2.0, 4.2, 5.2, 5.7, 5.0 and 3.8%, respectively. Regarding the CUD, the differences were -8.0, -20.2, -11.3, -10.7, -12.9, 9.3, 11.8, 10.5, 13.4, 4.6 and 3.2% for the aforementioned spacings, respectively. In general, when the uniformity coefficients are compared, the CUD is more sensitive to variations in water distribution because it considers only the measurement of the lowest quartile of the total data. In work carried out with sprinkler irrigation at spacings of 6x6, 6x12, 12x12, 12x18, 18x18, 18x24, 24x24, 24x30 and 30x30 m, Tuta et al. (2013) reported results similar to those reported in this work.

When comparing the uniformity of the precipitated water depth and the stored water depth in sugarcane with a 0.7 m canopy, it was found, on the basis of the CUC, that as the spacing between sprinklers increased, the difference between the precipitated and stored water depths tended to increase (Figure 5A). In this sense, at a 12x12 m spacing, the difference in uniformity between the precipitated and stored water depths was 13.62%, and at a 42x42 m spacing, it was 65.24%. That is, with increasing spacing between sprinklers, other components of the water balance, such as leaf interception, began to decisively influence the reduction in the uniformity of the stored water depth in relation to the precipitated water depth.

**Figure 5.** Results for eleven simulations of spacing as a function of sugarcane cutting height, considering the precipitated and stored blades. Carpina-PE, 2014. (A) Christiansen uniformity coefficient (CUC) and (B) distribution uniformity coefficient for low sugarcane.



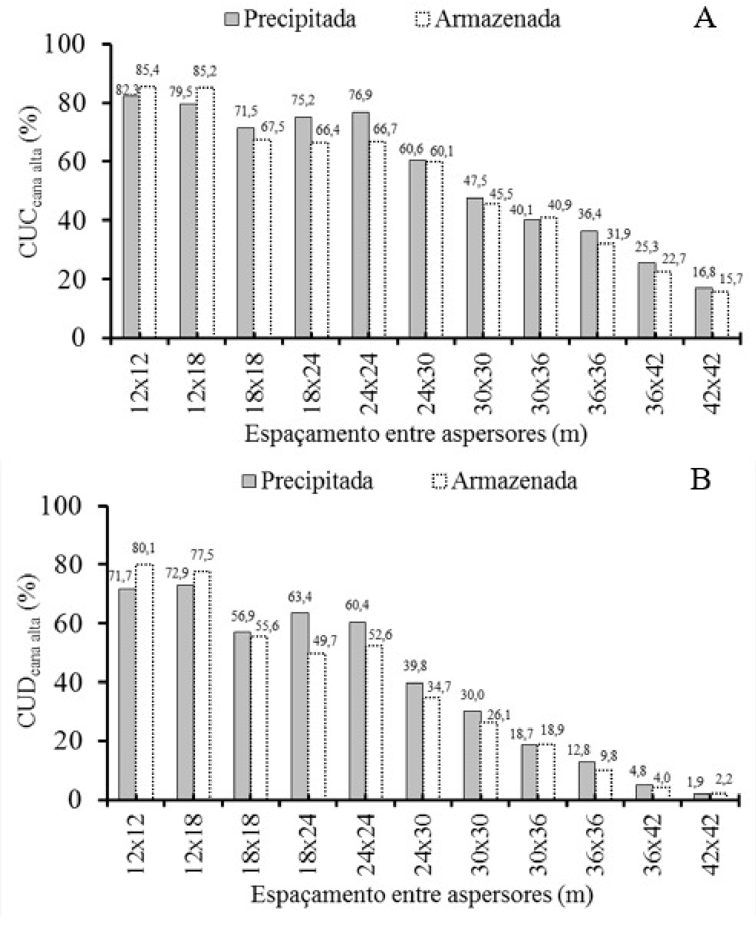




Nevertheless, in relation to the difference between the uniformity of the precipitated and stored water depths in sugarcane with a 0.7 m canopy, when the CUD was used as a reference (Figure 5B), the difference in uniformity between the precipitated and stored water depths was greater than that in the previous analysis (CUC), with a difference of 17.69% under spacings of 12x12 m and 75.34% under spacings of 42x42 m. These results allow us to infer that the uniformity behavior, when the CUD was adopted, was more sensitive to the positive variation in the spacing between sprinklers in relation to the behavior observed when the CUC was used.

In another analysis, the reduction in distribution uniformity, considering the precipitated and stored water depths, showed an increasing trend regardless of the calculation methodology. Therefore, despite the obvious increase in costs with sprinkler densification, given the plant's water needs, the cost per stored millimeter may increase with increased spacing in the sugarcane scenario with a 0.7 m canopy. In another analysis, when the sprinkler height was varied between 1.0 and 1.5 m, Tamagi et al. (2016) reported greater uniformity when a taller sprinkler was adopted, and Paulino et al. (2009) reported that reduced uniformity values increase production costs due to greater water and energy consumption, greater nutrient loss, and water deficit in a significant proportion of the irrigated area.

In the sugarcane scenario with a 2.8 m canopy, from the perspective of CUC (Figure 6A), the difference between the precipitated and stored water depths changed with the variation in the spacing between sprinklers without presenting a specific behavioral trend, with a greater difference being observed between the precipitated and stored water depths (13.26%) under a spacing of 24 × 24 m. Notably, with increasing spacing between sprinklers, the CUC of the precipitated and stored water depths tended to decrease in absolute value. When the CUD was adopted (Figure 6B), still in sugarcane with a 2.8 m canopy, greater sensitivity of uniformity was observed with increasing spacing between sprinklers, with differences between the precipitated and stored layers of up to 97.25% when comparing data under spacings of 12x12 and 42x42 m, that is, a value 16.08% greater than that in the same comparison using the CUC.

**Figure 6.** Results for eleven simulations of spacing as a function of sugarcane cutting height, considering the precipitated and stored blades. Carpina-PE, 2014. (A) Christiansen uniformity coefficient (CUC) and (B) distribution uniformity coefficient for tall sugarcane.




In general, regardless of the methodology adopted to calculate uniformity, the difference between the precipitated and stored water depths was smaller in sugarcane with a 2.8 m canopy than in sugarcane with a 0.7 m canopy. Among other plausible aspects, the difference in the leaf area index (LAI) in the proposed scenarios emphasizes the role of the interception of part of the water mass carried out by sugarcane leaves and the microclimate resulting from plant density. These factors, under the effect of gravity, promote the movement of water to the soil and favor its storage and conservation. For the area under sugarcane with a 0.7 m canopy, other conditions, such as greater direct sunlight on the soil, greater wind flow, direct evapotranspiration, and other deductive factors of the water balance, imply greater water losses and increase the differences in uniformity above and below the soil surface.

## 6 CONCLUSIONS

Compared with sugarcane with a 0.7 m canopy, sugarcane with a 2.8 m canopy provides greater water storage in the soil and better distribution uniformity, regardless of the spacing between sprinklers. However, with an increase in spacing in the range of 12x12 to 42x42 m, an average reduction in storage of up to 91.89% and in uniformity of up to 97.25% was observed.

Compared with the Christiansen uniformity coefficient, the distribution uniformity coefficient is more sensitive to increased spacing between sprinklers, although both indicate a reduction in uniformity with increased spacing between sprinklers, regardless of the height of the sugarcane canopy.

The simulations carried out allowed establishing a correlation between the required blade and the respective adequate spacing between sprinklers; therefore, under the conditions presented, it is recommended that the spacing between sprinklers be 12x18 m.

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