

## Efficiency and uniformity of a subsurface drip irrigation system in sugarcane crops

José Wibison Ferreira dos Santos<sup>1</sup>, Lígia Sampaio Reis<sup>1</sup>, Mirandy Dos Santos Dias<sup>2</sup>, Rilbson Henrique Silva dos Santos<sup>3</sup>, Francisco de Assis da Silva<sup>2</sup>, João Paulo de Oliveira Santos<sup>4</sup>

<sup>1</sup> Universidade Federal de Alagoas, Unidade Acadêmica de Rio Largo, Rio Largo, Alagoas, Brasil. E-mail: wibissonf@gmail.com, lavenere\_reis@hotmail.com

<sup>2</sup> Universidade Federal de Campina Grande, Unidade Acadêmica de Campina Grande, Campina Grande, Paraíba, Brasil. E-mail: mirandysd@gmail.com, agrofdsilva@gmail.com

<sup>3</sup> Universidade Federal Rural de Pernambuco, Unidade Acadêmica de Garanhuns, Garanhuns, Pernambuco, Brasil. E-mail: rilbsonagro@gmail.com

<sup>4</sup> Universidade Federal da Paraíba, Campus Areia, Areia, Paraíba, Brasil. E-mail: jpos@agronomo.eng.br

Received: 07/01/2022; Accepted: 11/03/22

### ABSTRACT

Agricultural productivity in irrigated areas depends on several factors, including the design and maintenance of irrigation systems. Excessive or insufficient applications of water affect plant growth and development, hence agricultural productivity. For this reason, the evaluation of the irrigation system is essential to avoid water loss during application. This study aimed to evaluate the efficiency and uniformity of a subsurface drip irrigation system in sugarcane crops in an area of the company Usina Coruripe, Alagoas, Brazil. For data collection, the flow rates were obtained in four points along the lateral line, in the first dripper, in the drippers located at 1/3 and 2/3 of the lateral line length, and in the last dripper of each operational unit of the irrigation project. In each row, four emitters were evaluated, totalizing 16 emitters, using a chronometer, collectors, and a measuring cylinder for data collection. In these emitters, the volume of water was collected for 3 minutes, with three repetitions. Christiansen's uniformity coefficient, distribution uniformity coefficient, statistical uniformity coefficient, Hart's uniformity coefficient, and application efficiency were estimated. The irrigation system was considered excellent for distribution uniformity. The application efficiency was classified as acceptable, with an average value of 88.9%. However, despite the application efficiency being classified as acceptable, periodic evaluations of the system are recommended.

**Keywords:** *Saccharum officinarum* L., Irrigation management, Localized irrigation.

## Eficiência e uniformidade de um sistema de irrigação por gotejamento subterrâneo na cultura da cana-de-açúcar

### RESUMO

A produtividade agrícola em áreas irrigadas depende de uma série de fatores, dentre eles, o dimensionamento e manutenção dos sistemas de irrigação. Aplicações excessivas ou insuficientes de água afeta o crescimento e desenvolvimento das plantas, consequentemente, a produtividade agrícola. Nesse sentido, a avaliação do sistema de irrigação é essencial para evitar perdas de água durante a aplicação. Este trabalho teve como objetivo avaliar a eficiência e uniformidade de um sistema de irrigação por gotejamento subterrâneo na cultura da cana-de-açúcar em uma área da Usina Coruripe, Alagoas. Para a coleta dos dados em campo, foram obtidas as vazões em quatro pontos ao longo da linha lateral, no primeiro gotejador, nos gotejadores situados a 1/3 e a 2/3 do comprimento da linha lateral e no último gotejador de cada unidade operacional do projeto de irrigação. Nesses emissores, foram coletados o volume de água durante 3 minutos, com três repetições. Após coleta dos dados, estimaram-se os coeficientes de uniformidade de Christiansen, coeficiente de uniformidade de distribuição, coeficiente de uniformidade estatístico, coeficiente de uniformidade de Hart e eficiência de aplicação. O sistema de irrigação foi considerado excelente, em relação à uniformidade de distribuição. A eficiência de aplicação do sistema de irrigação foi classificado em aceitável, com valores médios de 88,9%, porém, apesar da eficiência de aplicação ser classificada como aceitável, recomenda-se avaliações periódicas do sistema.

**Palavras-chave:** *Saccharum officinarum* L., Manejo de irrigação, Irrigação localizada.

## 1. Introduction

Sugarcane (*Saccharum officinarum* L.) is an agricultural commodity that has seen the highest growth in recent years. Besides the economic potential, due to its use in the production of ethanol and sugar, this crop has great social importance in generating employment and income throughout the production chain (Pessoa et al., 2021). Brazil is the largest producer and leader in exports (Cordeiro Júnior et al., 2019).

The state of Alagoas is the largest producer of sugarcane in the Northeast of Brazil, but despite its high technological level in the sugar and ethanol industry, the irregular distribution of rainfall affects the production of sugarcane crops (Silva et al., 2015). According to Doorenbos and Kassam (1979), the water requirement of sugarcane varies between 1500 and 2500 mm during the cycle. The daily consumption of water varies between 2 and 6 mm/day in the main producing regions and may differ between the varieties and the phenological phase of the crop (Bernardo, 2006).

The adequate supply of water during the crop cycle, in addition to favoring plant growth and development, increases productivity and total recoverable sugar (ATR) (Farias et al., 2009). Moura et al. (2014) state that irrigated sugarcane may have better industrial quality, with higher values in technological parameters such as °Brix, which may favor earlier maturation.

In view of the great demand for water during the sugarcane cultivation cycle, more efficient irrigation systems in the use of water, such as drip irrigation, are essential. Drip irrigation enables the application of the water depth in the root zone region, with small intensities and high frequency, maintaining soil moisture at field capacity (Silva et al., 2015; Bernardo et al., 2019).

However, the distribution of water by localized irrigation is influenced by the pressure change along the pipes caused by the clogging of emitters and the wear of accessories, which affect the water supply and the efficiency of application (Dantas Neto et al., 2013). For irrigation to be efficient, the system must have high uniformity of water application, because it affects the efficiency of water use and, as a consequence, the quantity and quality of the final product (Dantas Neto et al., 2013; Araújo Neto et al., 2015).

Taking into account the importance of the knowledge on this technological contribution to sugarcane culture by evaluating the performance of irrigation systems, this study aimed to evaluate the efficiency and uniformity of a subsurface drip irrigation system in the sugarcane crop in an area of the company Usina Coruripe, Alagoas, Brazil.

## 2. Material and Methods

The study was carried out in an area of 31.95 hectares, belonging to Usina Coruripe, located in the eastern mesoregion of the state of Alagoas, under geographic coordinates 9° 59' 52" S, 36° 17' 55" W. According to Silva and Barbosa (2021), the climate is tropical rainy with dry summers. The rainy season starts in autumn, beginning in February and ending in October. The average annual rainfall is 1,634.2 mm, and the average temperature is 24.4 °C.

The irrigation system evaluated was the underground drip type (self-compensating) in a sugarcane crop, variety RB92 579, with row spacing of 1.30 x 0.50 meters. The drip tapes (16 mm in diameter) were distributed at 30 cm of soil depth, 200 m long, and emitters were spaced every 50 cm in the sugarcane planting lines. According to the manufacturer's specifications, the emitters under a pressure of 1.0 kgf cm<sup>-2</sup> provide a nominal flow rate of 1.0 L h<sup>-1</sup>.

For data collection, the evaluation method proposed by Keller and Karmeli (1975) was used, which recommended obtaining flow rate at four points along the lateral line, that is, in the first dripper, in the drippers situated at 1/3 and 2/3 of the length of the lateral line (200 m), and in the last dripper of each operational unit, totaling 16 evaluated emitters, using a chronometer, collectors, and a cylinder. In these selected emitters, the volume of water was collected for 3 minutes, with three repetitions.

The data were plotted in an Excel spreadsheet. With the results obtained, the interpretation of the values of CUC, CUD, CUE, and Ea was based on the methodology presented by Mantovani (2001) (Table 1), in which irrigation performance is considered using indices; therefore, it was not necessary to apply statistical analysis to these data.

**Table 1.** Classification of Christiansen's uniformity coefficient, distribution uniformity coefficient, statistical uniformity coefficient, and application efficiency for a drip system

Classification	CUC	CUD	CUE	CUT	CV	Classification	EA
Excellent	90 - 100	≥ 90	> 90	90 - 100	< 5	Ideal	≥ 95
Good	80 - 90	80 - 90	80 - 90	80 - 90	5 - 7		
Reasonable	70 - 80	70 - 80	70 - 80	70 - 80	7 - 11	Acceptable	80 - 95
Bad	60 - 70	< 70	< 70	60 - 70	11 - 15		
Unacceptable	< 60	-	-	-	> 15	Unacceptable	< 80

Source: Mantovani (2001); Merriam and Keller (1978); Bernardo et al. (2019); Borssoi et al. (2012). CUC – Christiansen's uniformity coefficient; CUD – distribution uniformity coefficient; CUE – statistical uniformity coefficient; Ea – application efficiency; CV – coefficient of variation.

With the volume of water collected from the emitters selected for the test, the Christiansen's uniformity coefficient (CUC) (Mantovani, 2001), the distribution uniformity coefficient (CUD) (Keller and Karmeli, 1975), the statistical uniformity coefficient (CUE) (Wilcox and Swales, 1947), Hart's uniformity coefficient (CUH) (Hart, 1961), the application efficiency (Ea) (Keller and Karmeli, 1975), and the coefficient of variation (CV) were calculated according to Equations 1 to 6, respectively.

$$\text{CUC (\%)} = 100 \left\{ 1 - \frac{\sum_{i=1}^n |X_i - X_{\text{avg}}|}{n \cdot X_{\text{avg}}} \right\} \quad (1)$$

where:

$X_i$  - collected flow rate in each dripper ( $\text{L h}^{-1}$ );

$X_{\text{avg}}$  - the average of flow rates collected from all drippers ( $\text{L h}^{-1}$ );

$n$  - number of drippers analyzed.

$$\text{CUE (\%)} = 100 \left( 1 - \frac{\text{Sd}}{X_{\text{avg}}} \right) \quad (2)$$

where:

Sd - standard deviation of the data;

$X_{\text{méd}}$  - the average of flow rates collected from drippers in the subarea ( $\text{L h}^{-1}$ ).

$$\text{CUD (\%)} = 100 \left( \frac{X_{25}}{X_{\text{méd}}} \right) \quad (3)$$

where:

$X_{25}$  - the average of the lowest observed flow rates ( $\text{L h}^{-1}$ );

$X_{\text{avg}}$  - the average of the flow rates collected from drippers in the subarea ( $\text{L h}^{-1}$ ).

To determine Ea, the value of 90% was used, where the desirable coefficient of transmissivity (Ks) is around 85 to 90% (Vermeiren and Jobling, 1997).

$$\text{Ea (\%)} = \text{Ks} \times \text{CUD} \quad (4)$$

where:

Ks - coefficient of transmissivity;

CUD - distribution uniformity coefficient.

$$\text{CUH (\%)} = \left[ 1 - \sqrt{\frac{2}{\pi}} \times \frac{\text{Sd}}{q_{\text{avg}}} \right] \times 100 \quad (5)$$

where:

Sd - standard deviation of the data;

$Q_{\text{avg}}$  - the average of the flow rates collected from drippers in the subarea ( $\text{L h}^{-1}$ ).

$$\text{CV (\%)} = \left( \frac{\text{Sd}}{q_{\text{avg}}} \right) \times 100 \quad (6)$$

where:

Sd - standard deviation of the data;

$Q_{\text{avg}}$  - the average of the flow rates collected from drippers in the subarea ( $\text{L h}^{-1}$ ).

### 3. Results and Discussion

Table 2 shows the flow data as a function of the tests performed in the drip irrigation system in the sugarcane crop. The emitters showed a flow rate close to that recommended by the manufacturer, which is  $1.0 \text{ L h}^{-1}$ . Thus, based on the average flow rates obtained in the test, the irrigation system in the study area is meeting the flow rate established by the manufacturer.

The flows of the emitters directly influence the efficiency of the irrigation system and the incorrect operation causes variations that change the irrigation depth useful for crop development. For sugarcane, there is a strong positive correlation between the optimal soil moisture regimes and the growth rates of this crop, which is essential for its good economic performance (Surendran et al., 2016).

Table 3 shows that the values of CUC, CUD, CUH, CUE, and Ea are 96.96, 98.74, 99.09, 98.8, and 88.9%, respectively. According to the criteria for the classification of the hydraulic performance of emitters, all the values found in the evaluation were classified as excellent, except Ea, which was classified as acceptable for drip irrigation systems.

Table 3 also shows an excellent CV (1.15%). According to Borssoi et al. (2012), the smaller the CV, the lower the dispersion when compared to the average rate and, consequently, the better the uniform distribution of water, resulting in less spatial variability between depths. CUC, as described in Table 3, showed a result of 96.9%, indicating that the performance of the drip irrigation system was classified as excellent. The recommended value for this type of irrigation system should be greater than 90% (Mantovani, 2001).

The result obtained for CUD (98.7%) demonstrates excellent performance of the system regarding uniformity, showing that the system was hydraulically well-sized, without the risk of compromising the growth and development of plants. According to Nascimento et al. (2017), the uniformity of water distribution is a measure frequently used as an indicator of the problems of irrigation distribution, and a low CUD indicates excessive loss of water by deep percolation, which increases nutrient loss and decreases crop yield. In addition, inadequate uniformity of water application causes excess of water in part of the crop area and deficiency in another, decreasing the availability of water to the crop, favoring a non-uniform development of cultivated plants, and increasing the cost of production (higher water and electricity consumption) Santos et al., 2015; Nascimento et al., 2017).

**Table 2.** Values of water volume collected at emitters for 3 minutes, obtained from field tests performed for evaluation of a drip irrigation system in a sugarcane crop

Line transmitter	Drifting sideline			
	1st row	2nd row	3rd row	4th row
	q (L h <sup>-1</sup> )	q (L h <sup>-1</sup> )	q (L h <sup>-1</sup> )	q (L h <sup>-1</sup> )
1st dripper	0.985	0.998	0.994	1.006
Dripper 2/3	1.002	0.999	1.007	1.001
Dripper 1/3	0.987	1.000	0.990	1.001
Last dripper	1.002	0.992	1.004	1.006
Average	0.994	0.997	0.998	1.003
Manufacturer's recommended flow rate	1.0 L h <sup>-1</sup>			

**Table 3.** Values of Christiansen's uniformity coefficient, distribution uniformity coefficient, statistical uniformity coefficient, and application efficiency of a drip irrigation system in a sugarcane crop

Irrigation system	CUC	CUD	CUH	CUE	Ea	CV
	------(%)-----					
	96.96	98.74	99.09	98.85	88.97	1.15
Classification	Excellent	Excellent	Excellent	Excellent	Acceptable	Excellent

CUC – Christiansen uniformity coefficient; CUD – distribution uniformity coefficient; CUH – Hart's uniformity coefficient; CUE – statistical uniformity coefficient; Ea – application efficiency; and CV – coefficient of variation.

In Table 3, HUC was higher than CUC. According to Hart (1961), the HCU should follow the same trend as the CUC, indicating a normal distribution of the water depths. In this work, the HCU followed the same trend as the CUC, being found to be excellent. CUC is an index that uses the mean absolute deviation to express the dispersion of slopes (Rezende et al., 2002).

In this study, we found a water Ea of 88.9% (Table 3). This means that 88.9% of all water applied remain useful to plants and 11.1% are lost. However, although this efficiency (Ea = 88.9%) is lower than the ideal for drip irrigation (90 to 95%), this Ea value is classified as acceptable for the drip irrigation system, mainly because of the high installation costs of the system and the impossibility of properly checking the operation of all drippers (Bernardo et al., 2019). Studies have already shown that, for sugarcane, the water required to produce one kilo of biomass through irrigation by surface drip or subsurface drip is lower than conventional irrigation (Ranomahera et al., 2020).

To reach high values of efficiency, it is essential that, during the operation, the losses are minimal. Rodrigues et al. (2013) emphasize that the analysis of uniformity coefficients is essential to evaluate the performance of any irrigation system. Thus, for irrigation to be efficient, it is necessary that the system have high water application uniformity. This parameter is essential in any irrigation method because it affects the efficiency of water use and, as a consequence, the quantity and quality of the final product (Dantas Neto et al., 2013; Araújo Neto et al., 2015).

In many situations, the causes of inefficiency of an irrigation system can be influenced by pressure changes

along the pipes, clogging of emitters, and the wear and tear of accessories and old irrigation systems, affecting water supply and application efficiency (Frigo et al., 2006; Dantas Neto et al., 2013).

#### 4. Conclusions

Regarding the uniformity and efficiency of water application, the subsurface drip irrigation system evaluated was classified as excellent, although the application efficiency was classified as acceptable. For that reason, periodic evaluations of the system are recommended

#### Authors' Contribution

José Wibison Ferreira dos Santos contributed to the execution of the experiment, data collection, analysis and interpretation of results, writing of the manuscript and final correction of the manuscript. Lígia Sampaio Reis contributed to analysis and interpretation of results, writing of the manuscript and final correction of the manuscript. Mirandy dos Santos Dias contributed to analysis and interpretation of results, writing of the manuscript and final correction of the manuscript.

Rilbson Henrique Silva dos Santos contributed to the writing of the manuscript. Francisco de Assis da Silva contributed to analysis and interpretation of results, writing of the manuscript and final correction of the manuscript. João Paulo de Oliveira Santos contributed to the data analysis and final correction of the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

## Bibliographic References

- Araújo Neto, R.A., Sarmento, P.L., Ferreira Júnior, R.A., Silva, M.B.P., Rocha, A.E.Q., Teodoro, I., 2015. Desempenho de um sistema de irrigação por gotejamento em cana-de-açúcar. *Revista Ciência Agrícola*, 13(1), 13-20. DOI: <https://doi.org/10.28998/rca.v13i1.1318>
- Bernardo, S. 2006. Manejo da irrigação na cana-de-açúcar. *Alcoolbrás*, 106(1), 72-80.
- Bernardo, S., Mantovani, E.C., Silva, D.D., Soares, A.A., 2019. Manual de Irrigação. 9. ed. UFV, Viçosa. 545p.
- Borssoi, A.L., Vilas Boas, M.A., Reisdörfer, M., Hernández, R.H., Follador, F.A., 2012. Water application uniformity and fertigation in a dripping irrigation set. *Engenharia Agrícola*, 32(4), 718-726. DOI: <https://doi.org/10.1590/S0100-69162012000400011>
- Cordeiro Júnior, J.J.F., Guiselini, C., Pandorfi, H., Moraes, A.S., Menezes, D., Almeida Neto, L.A. 2019. Sprouting of pre-sprouted sugarcane seedlings and micrometeorological variables under photo-selective nets. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 23(8), 625-629. DOI: <https://doi.org/10.1590/1807-1929/agriambi.v23n8p625-629>
- Dantas Neto, J., Azevedo, C.A., Silva, L., Silva, P., Santos, C., 2013. Desempenho de sistema de irrigação por gotejamento em áreas de pequenos produtores do semiárido paraibano. *Enciclopédia Biosfera*, 9(16), 679-688.
- Doorenbos, J., Kassam, A.H., 1979. Yield Response to Water. *FAO Irrigation and Drainage Paper* n. 33. FAO.
- Farias, C.H.D.A., Fernandes, P.D., Gheyi, H.R., Dantas Neto, J. 2009. Qualidade industrial de cana-de-açúcar sob irrigação e adubação com zinco, em Tabuleiro Costeiro Paraibano. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 3(4), 419-428. DOI: <https://doi.org/10.1590/S1415-43662009000400008>
- Friego, E.P., Sampaio, S.C., Freitas, P.L., Nóbrega, L.H., Santos, R.F., Mallmann, L.S., 2006. Desempenho do sistema de gotejamento e de filtros utilizando água residuária da suinocultura. *Irriga*, 11(3), 305-318. DOI: <https://doi.org/10.15809/irriga.2006v11n3p305-318>
- Hart, W.E., 1961. Overhead irrigation pattern parameters. *Transactions of the ASAE*, 42(7), 354-355.
- Keller, J., Karmeli, D., 1975. Trickle irrigation design. *Rain Bird Sprinkler Manufacturing Corporation*, Glendora, 133p.
- Mantovani, E.C., 2001. Avaliação: Programa de Avaliação da Irrigação por Aspersão e Localizada. UFV, Viçosa.
- Merriam, J.L., Keller, J., 1978. Farm irrigation system evaluation: a guide for management. *Utah State University*, Logan.
- Moura, L.C., Silva, N.F., Cunha, F.N., Bastos, F.J.C., Célia, J.A., Teixeira, M.B., 2014. Índice de maturação da cana-de-açúcar fertirrigadas sobre diferentes lâminas. *Revista Brasileira de Agricultura Irrigada*, 8(1), 64-76. DOI: <https://doi.org/10.7127/rbai.v8n100199>
- Nascimento, V.F., Feitosa, E.O., Soares, J.I., 2017. Uniformidade de distribuição de um sistema de irrigação por aspersão via pivô central. *Journal of Neotropical Agriculture*, 4(4), 65-69. DOI: <https://doi.org/10.32404/rean.v4i4.1643>
- Pessoa, G.G.F.A., Alves, A.K.S., Dantas, É.A., Almeida, L.J.M., Silva, J.A., Araújo, J.R.E.S., Silva, D.A.M., Santos, J.P.O., 2021. Dinâmica temporal da produção de cana-de-açúcar em um município do Brejo Paraibano, Brasil (1995–2019). *Scientific Electronic Archives*, 14(11), 18-24. DOI: <https://doi.org/10.36560/141120211451>
- Ranomahera, M.R.R., Puspitasari, A.R., Putra, R.P, Gustomo, D., Winarsih, S., 2020. Agronomic Performance and Economic Benefits of Sugarcane (*Saccharum officinarum* L.) Under Drip Irrigation for Sandy and Clay Soils in East Java, Indonesia. *Jurnal Tanah dan Iklim*, 44(2), 141-153. DOI: <http://dx.doi.org/10.21082/jti.v44n2.2020.141-153>
- Rezende, R., Gonçalves, A.C.A., Freitas, P.S.L., Frizzone, J.A., Tormena, C.A., Bertonha, A., 2002. Influência da aplicação de água na uniformidade da umidade no perfil do solo. *Acta Scientiarum Agronomy*, 24(1), 1553-1559. DOI: <https://doi.org/10.4025/actasciagron.v24i0.2419>
- Rodrigues, R.R., Cola, M.P.A., Nazário, A.A., Azevedo, J.M.G., Reis, E.F., 2013. Eficiência e uniformidade de um sistema de irrigação por gotejamento na cultura do cafeeiro. *Ambiência*, 9(2), 323-334.
- Santos, M.A.L., Santos, D.P., Silva, D.S., Silva, M.S., Cavalcante, P.H.S., 2015. Avaliação da uniformidade de distribuição de um sistema de irrigação por gotejamento em inhame (*Dioscorea cayennensis* L.). *Revista Ciência Agrícola*, 13(1), 7-12. DOI: <https://doi.org/10.28998/rca.v13i1.1272>
- Silva, S., Dantas Neto, J., Teodoro, I., Souza, J.L.D., Lyra, G.B., Santos, M.A., 2015. Demanda hídrica da cana-de-açúcar irrigada por gotejamento nos tabuleiros costeiros de Alagoas. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 19(9), 849-856. DOI: <http://dx.doi.org/10.1590/1807-1929/agriambi.v19n9p849-856>
- Silva, W.T.S., Barbosa, H.A., 2021. Avaliação da precipitação na produtividade agrícola da cana-de-açúcar: estudo de caso usina Coruripe para as safras de 2000/2005. *Revista Brasileira de Geografia Física*, 13(3), 1352-1366. DOI: <https://doi.org/10.26848/rbgf.v14.3.p1352-1366>
- Surendran, U., Jayakumar, M., Marimuthu, S., 2016. Low cost drip irrigation: Impact on sugarcane yield, water and energy saving in semiarid tropical agro ecosystem in India. *Science of the Total Environment*, 573(1), 1430-1440. DOI: <https://doi.org.ez15.periodicos.capes.gov.br/10.1016/j.scitotenv.2016.07.144>
- Vermeiren, L., Jobling, G.A., 1997. Irrigação Localizada. Tradução de Ghey, H.R., Damasceno, F.A.V., Silva Júnior, L.G.A., Medeiros, J.F. UFPB, Campina Grande. 184 p. (Estudos FAO: Irrigação e Drenagem, 36)
- Wilcox, J.C., Swales, G.E., 1947. Uniformity of water distribution by some under tree orchard sprinklers. *Scientific Agriculture*, 27(11), 565-583. DOI: <https://doi.org/10.4141/sa-1947-0067>