Determination and adjustment of the irrigation uniformity coefficient: a case study in a forest nursery in Durango, Mexico

Díaz-Blanco, Gerardo G.[1]; **Salcido-Ruiz, Silvia**[1*]; **Prieto-Ruíz, José A.**[1]; **Santana-Aispuro, Enrique**[1]; **Chávez-Simental, Jorge A.**[2]; **Madrid-Aispuro, Rosa E.**[3]

[1] Universidad Juárez del Estado de Durango, Facultad de Ciencias Forestales y Ambientales. Calle Río Papaloapan y Blvd. Durango s/n, Colonia Valle del Sur. Durango, México. C. P. 34120.
[2] Universidad Juárez del Estado de Durango, Instituto de Silvicultura e Industria de la Madera. Blvd. Guadiana núm. 501, Cd. Universitaria. C.P. 34120. Durango, Dgo. México.
[3] Colegio de Postgraduados, Posgrado en Ciencias Forestales. Carretera México-Texcoco Km. 36.5, Montecillo, Texcoco, Estado de México, México. C. P. 56264.
* Correspondence: silesad@gmail.com

ABSTRACT

Objective: To determine the Irrigation Uniformity Coefficient (CUR) in the "Praxedis Guerrero" forest nursery, managed by the Secretariat of Natural Resources and Environment of the Government of the State of Durango, and, based on the results, propose system adjustments to enhance irrigation efficiency.

Methodology: To evaluate the CUR across the six production structures, the procedure outlined in the Mexican standard NMX-AA-170-SCFI-2016 was followed. In each of the four greenhouses and two shade houses, one sector comprising one of the four quadrants within each structure was randomly selected. A grid was drawn within each selected sector, and a total of 60 collection containers were placed at each intersection point. The irrigation system was operated for 30 minutes, after which the volume of water collected in each container was measured. The CUR formula was applied accordingly. The structure with the lowest coefficient underwent corrective interventions, including emitter homogenization, cleaning of filters and pipes, followed by a re-evaluation to assess the impact of the adjustments.

Results: The average CUR values across the production structures exhibited statistically significant differences ($p \leq 0.05$), ranging from a minimum of 50.9% to a maximum of 86.0%. In the greenhouse with the lowest CUR, system adjustments led to an improvement of 17.0%; however, this value still fell short of the minimum 80% threshold established by the reference standard. Moreover, the distribution grid of the 60 containers revealed unequal water distribution among plants within the same sector.

Conclusions: The irrigation systems in and among the six production structures lacked uniformity. Only structure IN2 achieved an acceptable CUR. The corrective actions implemented had a direct and positive impact on the uniformity coefficient, which was reflected in a more even spatial distribution of irrigation water.

Keywords: protected agriculture, microspray system, water efficiency, plant quality.

Citation: Díaz-Blanco, G. G., Salcido-Ruiz, S., Prieto-Ruíz, J. A., Santana-Aispuro, E., Chávez-Simental, J. A., Madrid-Aispuro, R. E. (2025). Determination and adjustment of the irrigation uniformity coefficient: a case study in a forest nursery in Durango, Mexico. *Agro Productividad*. https://doi.org/10.32854/ptdnsr22

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: June 17, 2025.
Accepted: October 28, 2025.
Published on-line: December XX, 2025.

Agro Productividad, 18(11). November. 2025. pp: 47-55.

INTRODUCTION

Mexico has 154 forest nurseries dedicated to producing seedlings for reforestation programs. During the 2018-2019 cycle, a total of 81 million seedlings were produced, 89% of which were cultivated under technified systems (CONAFOR, 2020). The

operation of these nurseries requires both an adequate quantity and quality of water to meet the physiological needs of the seedlings, as water constitutes between 80% and 90% of plant biomass and plays a vital role in photosynthesis, nutrient uptake, and other metabolic processes (Aguilera-Rodríguez *et al.*, 2023). The primary function of an irrigation system is to distribute water uniformly over a given production surface to ensure optimal plant physiological performance (González et al., 2009). Irrigation is also a common medium for fertilization (fertigation), directly influencing the two most critical activities for healthy seedling growth in nurseries: irrigation and fertilization (Dumroese *et al.*, 2012). Moreover, irrigation helps regulate substrate temperature, leach excess salts, and mitigate adverse effects from low temperatures (Gutiérrez *et al.*, 2016). Pressurized irrigation systems are commonly used in forest nurseries; however, such systems often exhibit inefficiencies, with water losses ranging from 49% to 72% of the total applied volume (Dumroese *et al.*, 2006). For an irrigation system to be efficient, water must be distributed homogeneously across the production area. To assess this efficiency, numerical indices known as the Coefficient of Uniformity of Irrigation (CUR) are used. These coefficients, expressed as percentages, serve as reference indicators of irrigation performance (Bedoya & Ángeles, 2016). According to the Mexican Standard for the Operation of Forest Nurseries (NMX-AA-170-SCFI-2016), an acceptable CUR must be ≥80% (Secretaría de Economía, 2016). However, when evaluating micro-sprinkler irrigation systems in production plots, the acceptable threshold increases to ≥90% (Tun *et al.*, 2011). In both cases, these reference values indicate uniform water distribution, ensuring that plants have sufficient water for physiological processes and minimizing water losses due to uneven application. Before the start of each production cycle, it is recommended to evaluate the CUR as a diagnostic tool to determine the condition of the irrigation system and to identify potential maintenance needs. Such preventive actions can significantly improve water distribution uniformity and help avoid excess or deficit moisture in the production area (Aguilera-Rodríguez *et al.*, 2023). Based on the above, the aim of this study was to determine the Coefficient of Uniformity of Irrigation (CUR) in a forest nursery and, based on the results, implement adjustments to improve the efficiency of the irrigation system. The working hypothesis was that maintenance interventions on the irrigation system would have a direct and positive impact on increasing the CUR.

MATERIALS AND METHODS

Study area

The study was conducted at the "Praxedis Guerrero" forest nursery, operated by the Secretariat of Natural Resources and Environment of the Government of the State of Durango. The nursery is located southeast of the city of Durango, Dgo., at coordinates 23° 56' 58.3" N and 104° 34' 07.4" W, at an elevation of 1,890 meters above sea level. The nursery has a production capacity of six million seedlings, primarily of *Pinus engelmannii* Carr., *P. greggii* Engelm., *P. cembroides* Zucc., and *Agave durangensis* Gentry. It comprises six production structures: two 50% shade net houses (MS1 and MS2), each measuring 75 m in length by 39 m in width; and four multi-tunnel greenhouses (IN1, IN2, IN3, and IN4).

The first two greenhouses measure 45 m in width by 80 m in length, while the remaining two measure 35 m in width by 105 m in length.

The irrigation system employed is a fixed and suspended microsprinkler system. Water is supplied from a main storage tank with a capacity of 330 m^3, which feeds into secondary and tertiary tanks with capacities of 22 m^3 and 5 m^3, respectively. From the tertiary tank, water is pumped using a 3.5 HP hydraulic pump through a 7.6 cm diameter main pipeline that distributes water to the six production structures. Each structure is irrigated independently, with a flow rate of 200 L/min. The greenhouses and shade net houses are subdivided into four sectors, each averaging 10 irrigation lines. The distance between emitters varies depending on the structure (Table 1). Each emitter is equipped with an anti-drip valve and consists of a rotor, arc, and nozzle.

Determination of the Coefficient of Uniformity of Irrigation (CUR)

To evaluate the CUR, one sector from each production structure was randomly selected, following the methodology established in the Mexican standard NMX-AA-170-SCFI-2016 (Secretaría de Economía, 2016). Within each selected sector, a grid layout was drawn, forming 50 quadrants (six vertical and ten horizontal lines). At each intersection point of the grid corresponding to the vertex of each quadrant a 220 mL collection container was placed, for a total of 60 collectors.

The irrigation system was then operated for 30 minutes to ensure a measurable volume of water in each container. The collected volume in each vessel was measured using a graduated cylinder (Figure 1), and this operation was repeated three times to obtain an average value per container.

The CUR was calculated using the following formula:

$$CUR = 100\left[1 - \left(B / A\right)\right]$$

Where: CUR=Irrigation uniformity coefficient; A=the sum of the individual volumes collected in each container; B=the sum of the absolute differences of the individual volumes of each container, with respect to the average volume collected in all containers.

The CUR was determined for each production structure and along the vertical lines of the container grid. In the structure with the lowest CUR, corrective measures were

Table 1. Emitter distribution by production structure.

Structure	Distance range between emitters	Issuers per line	Issuers by sector
MS1	0.70 a 3.20 m	17 a 19	182
MS2	1.10 a 2.30 m	18 a 20	189
IN1	0.50 a 3.90 m	17 a 19	166
IN2	1.00 a 2.90 m	17 a 19	165
IN3	1.00 a 2.00 m	24 a 26	201
IN4	0.30 a 2.40 m	25 a 26	208

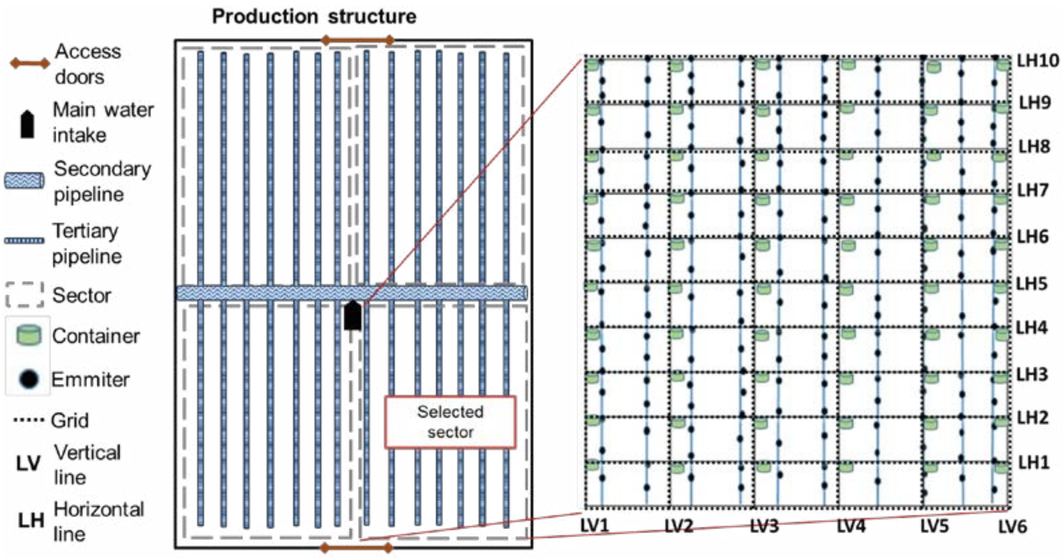

Figure 1. Schematic layout of collection container distribution within each selected sector per production structure. Where LV=vertical line and LH=horizontal line.

implemented in the irrigation system: emitter homogenization, filter cleaning, and pipeline flushing. Following these adjustments, a second CUR evaluation was performed to assess the impact of the interventions on irrigation uniformity.

The data obtained provided insights into the water distribution within the evaluated sectors. Three collection volume categories were established based on the amount of water retrieved per container: low (0-40 mL), medium (41-80 mL), and high (81-120 mL).

Statistical analysis

A completely randomized design was used for the determination of the CUR. Prior to data analysis, percentage values were transformed using the arcsine function (McDonald, 2014). Analysis of variance (ANOVA) was conducted using the PROC GLM procedure in SAS 9.2®. When significant differences were detected, Tukey's multiple comparison test was applied ($p \leq 0.05$). In all cases, assumptions of data normality and homogeneity of variances were verified using the Shapiro-Wilk and Levene's tests, respectively (Statistical Analysis System [SAS] Institute, 2009).

RESULTS AND DISCUSSION

The average CUR among the different types of production structures showed statistically significant differences ($p<0.0001$), with values ranging from 50.9% to 86.0%. The highest Coefficient of Uniformity of Irrigation was recorded in structure IN2, while the lowest was observed in IN4. Theremaining structures fell into an intermediate statistical group (Figure 2).

In the shade net structures, the average CUR calculated along the vertical lines of the container grid showed statistically significant differences ($p \leq 0.05$), with differences between extreme values of 19.4% in MS1 and 18.3% in MS2. The lowest CUR values in both structures were recorded at the lateral lines (lines 1 and 6) (Table 2).

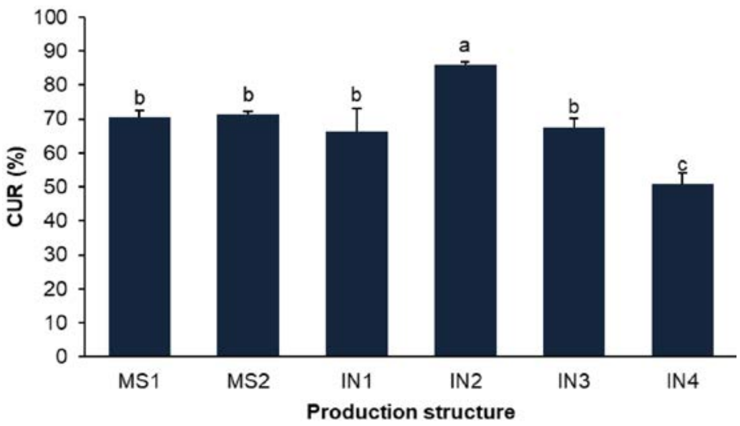

Figure 2. Coefficient of Uniformity of Irrigation by production structure. Means with different letters are statistically different (Tukey, p≤0.05).

Table 2. CUR by vertical line (LV) of collection containers in shade mesh.

LINE	MS1 (%)	MS2 (%)
LV1	60.2±1.8 c	63.1±1.5 d
LV2	79.6±0.7 a	68.6±0.9 c
LV3	75.0±0.8 ab	75.4±0.7 b
LV4	68.2±3.4 bc	81.4±0.4 a
LV5	72.9±2.1 ab	74.9±1.3 b
LV6	67.0±3.6 bc	64.5±0.9 cd
p value	0.0013	<0.0001

Means with different letters in the same column are statistically different (Tukey, p≤0.05).

In the greenhouse structures, the average CUR per vertical line of collection containers also revealed statistically significant differences in IN2, IN3, and IN4. The difference between the highest and lowest values was 33.7% in IN1, 8.7% in IN2, 24.2% in IN3, and 53.0% in IN4. In all four greenhouses, the lowest CUR values were recorded along vertical line 6 (LV6) (Table 3).

Table 3. CUR by vertical line (LV) of collection containers in greenhouses.

LINE	IN1 (%)	IN2 (%)	IN3 (%)	IN4 (%)
LV1	70.8±1.2 a	86.5±0.9 ab	66.2±1.0 a	45.6±3.2 b
LV2	70.7±3.2 a	86.6±1.3 ab	73.6±1.5 a	63.2±4.5 a
LV3	69.7±7.5 a	87.8±0.2 ab	75.2±2.0 a	65.5±2.0 a
LV4	72.0±10.2 a	89.7±1.1 a	73.3±2.7 a	53.4±5.8 ab
LV5	74.5±5.8 a	84.2±1.6 bc	67.1±1.1 a	65.5±2.0 a
LV6	40.8±11.6 a	81.0±0.4 c	51.0±6.4 b	12.5±0.9 c
p value	0.0648	0.0014	0.0012	<0.0001

Means with different letters in the same column are statistically different (Tukey, p≤0.05).

Irrigation water distribution

The grid formed by the 60 collection containers in each production structure revealed uneven access to irrigation water among plants within the same sector (Figure 3). Among the shade net structures, MS1 recorded the highest average volume of water collected, with each container capturing an average of 41.1 mL. In the case of the greenhouses, IN3 registered the highest average per container at 34.6 mL, while the lowest value was observed in IN1, with just 19.7 mL approximately 50% less than the other structures.

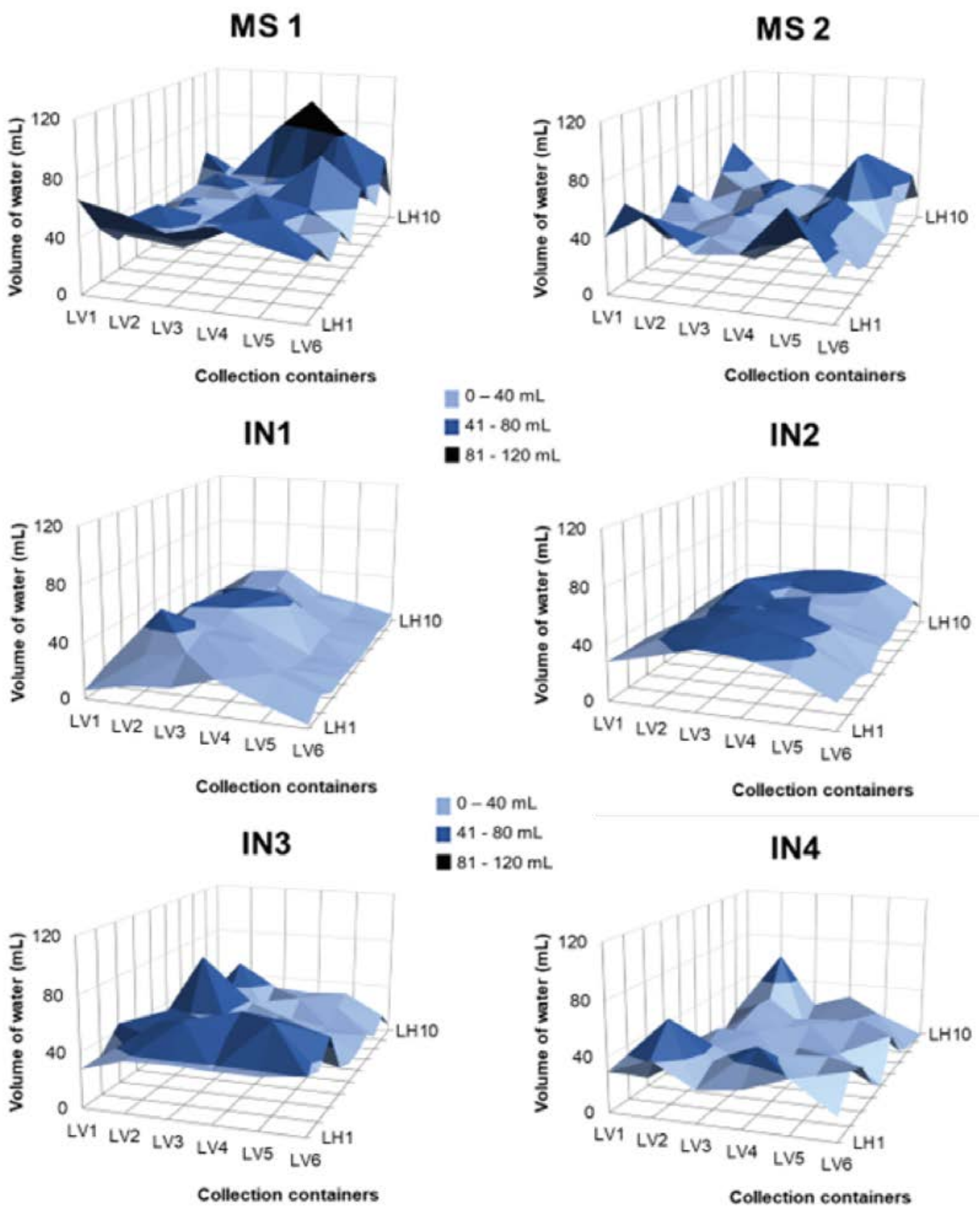

Figure 3. Spatial distribution of collected water based on three volume ranges. Where: LV=vertical line, LH=horizontal line.

Based on the results, greenhouse IN4 identified as having the lowest CUR was selected for system improvements. After homogenizing emitter types and cleaning both filters and pipelines, the CUR was re-evaluated. The results indicated a 17% increase in the CUR. At the vertical line level, improvements were observed in most lines, except for line 3, where no differences were detected. Line 6 showed the most substantial improvement, with an increase of 58% (Figures 4 and 5).

Despite the statistically significant improvement ($p \leq 0.05$), the CUR did not reach the minimum threshold of 80% required by the standard. On average, the post-adjustment CUR was 68%.

The scarcity of technical studies evaluating CUR limits the ability to compare results; however, Pereira *et al.* (2010) state that optimal irrigation system performance is closely tied to the quality of hydraulic design, as well as proper operation and maintenance, which directly influence water use efficiency. Regarding system design, Cun *et al.* (2009) determined that CUR can be negatively affected by improper emitter installation. In the present study, the heterogeneity in emitter spacing and irrigation line layout within the production structures may have contributed to the fact that only IN2 surpassed the

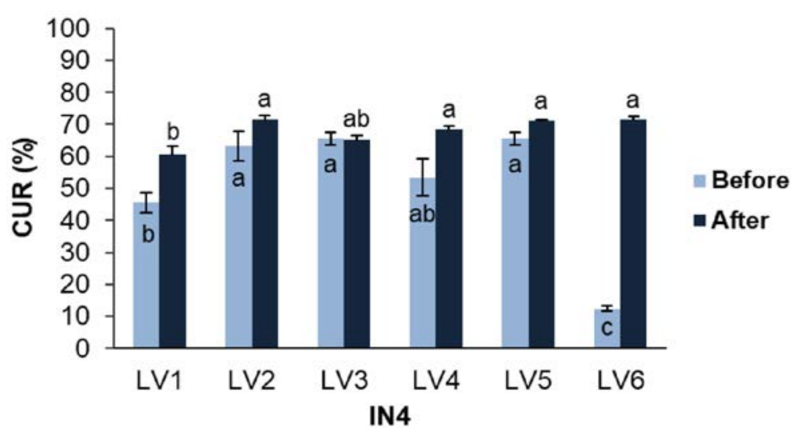

Figure 4. Response of IN4 irrigation system improvements to the CUR. Means with different letters are statistically different (Tukey, $p \leq 0.05$).

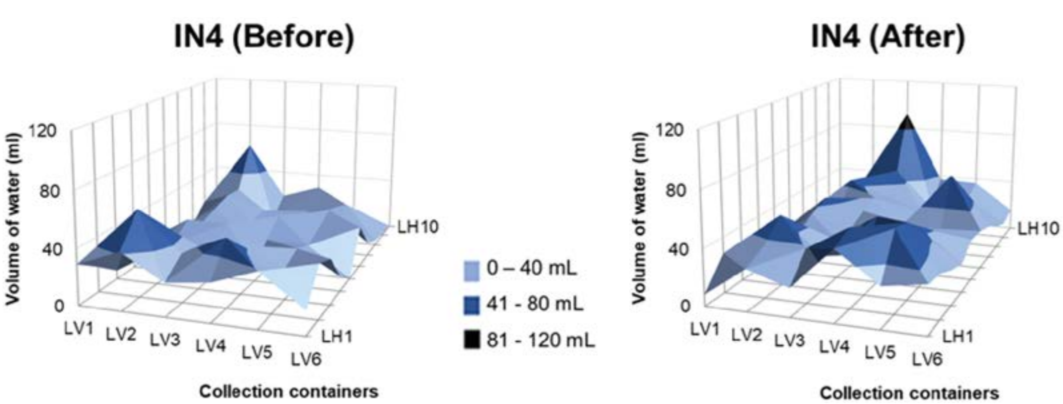

Figure 5. Effect of irrigation system improvements in IN4 on the spatial distribution of collected water.

minimum acceptable CUR of ≥80% established by NMX-AA-170-SCFI-2016 required to ensure uniform plant development across production areas (Secretaría de Economía, 2016). In terms of irrigation system operation, Pizarro (1990) emphasized that uniformity can be compromised by emitter malfunctions. In this evaluation, issues identified included emitter wear or clogging caused by organic matter and calcium carbonate buildup in the irrigation water. Additionally, an uneven distribution of irrigation lines was observed, with some cases involving microsprinklers of varying discharge rates. These factors resulted in non-uniform water application across production beds, with over-saturation in some areas and insufficient water in others (Figure 3). Oliveira *et al.* (2009) reported that blockages in emitter lines are often due to the interaction of mucilage-forming bacteria and suspended solids. As a preventive strategy, Dehghanisanij *et al.* (2005) recommended regular inspection, filtration, system flushing, and, when necessary, chemical treatment. These recommendations align with the 17% CUR improvement observed in IN4 following the corrective measures. A consistent trend of lower CUR values along lateral vertical lines was noted across all production structures, indicating an edge effect. Franquet (2019) observed that the highest water saturation occurs in the overlap zones of central emitters, whereas peripheral areas receive less water, limiting uniform plant growth. This issue is compounded during fertigation, where non-uniform irrigation leads to uneven nutrient distribution, resulting in growth disparities. Thus, the CUR is a critical indicator of hydraulic system efficiency for the two most essential nursery tasks: irrigation and fertilization. Strategic planning of the irrigation system from water extraction to emitter distribution is essential. Operating a system with a CUR below 80% requires longer irrigation times, increasing water and energy consumption and potentially necessitating additional labor to manually irrigate under-watered areas. This leads to inefficient use of natural resources and higher production costs in forest nurseries. As noted by Tun *et al.* (2011), irrigation system technification alone does not guarantee efficient water use without proper management; continuous monitoring and maintenance are indispensable. Moreover, achieving a CUR ≥80% in a fixed microsprinkler system does not necessarily ensure that plants receive this level of uniformity. According to Aldrete *et al.* (2023), such systems may lose 25-30% of irrigation water and agrochemicals due to runoff into walkways and the outer areas of production structures. Implementing more efficient water management systems, such as subirrigation, could offer a viable alternative for nursery production. In this closed-cycle system, water is applied from below and moves upward through the substrate by capillary action (Wan *et al.*, 2019). Supporting this, Thebaldi *et al.* (2016) evaluated both microsprinkler and subirrigation systems in a forest nursery and found lower efficiency in microsprinkler systems due to poor maintenance, which resulted in zones of water deficit and over-saturation patterns also observed in this study. Consequently, subirrigation is considered a promising irrigation method for forest nursery production.

CONCLUSIONS

In the "Praxedis Guerrero" forest nursery, irrigation systems were found to lack uniformity both within and between the six production structures. Only IN2 met the minimum Coefficient of Uniformity of Irrigation (CUR) of ≥80% as specified by the

Mexican standard NMX-AA-170-SCFI-2016. The corrective actions implemented homogenization of emitters and maintenance procedures including filter and pipeline cleaning had a direct and positive impact on the CUR, resulting in improved spatial distribution of irrigation water.

REFERENCES

Aguilera-Rodríguez, M., Aldrete, A., Sánchez-Velázquez, J. R., & Prieto-Ruíz J.A. (2023). Instalaciones e insumos para la producción. En: A. Aldrete, J. R. Sánchez-Velázquez, M. Aguilera-Rodríguez, D. Cibrián-Tovar & S. E. García-Díaz (Eds.). Manual de buenas prácticas para el manejo de la salud de planta en viveros forestales (pp. 41-90). Estado de México, México: Universidad Autónoma Chapingo.

Aldrete, A., Sánchez V., J. R., Aguilera R., M., Cibrián T., D., & García D., S. E. (Eds.). (2023). Manual de buenas prácticas para el manejo de la salud de planta en viveros forestales. Estado de México, México: Universidad Autónoma Chapingo.

Bedoya, M., & Ángeles, V. (2016). Estrategias para estimar el coeficiente de uniformidad en laterales de riego. *Ingeniería y Región, 16*(2), 65-71. https://doi.org/10.25054/22161325.1300

CONAFOR (Comisión Nacional Forestal). (2020). Estado que guarda el sector forestal en México. Consultado el 7 de marzo, 2025, desde http://www.conafor.gob.mx:8080/documentos/ver.aspx?articulo=7825&grupo=1.

Cun González, R., Puig Estrada, O., & Morales Gómez, C. (2009). Comportamiento del coeficiente de uniformidad del riego por microaspersión en condiciones de organopónicos y huerto intensivo. *Revista Ciencias Técnicas Agropecuarias, 18*(3), 35-39.

Dehghanisanij, H., Yamamoto, T., Ould Ahmad, B., Fujiyama, H., & Miyamoto, K. (2005). The effect of chlorine on emitter clogging induced by algae and protozoa and the performance of drip irrigation. *Transactions of the ASAE, 48*(2), 519-527. https://doi.org/10.13031/2013.18326

Dumroese, R. K., Buamscha, M. G., Contardi, L. T., Enricci, J. A., Escobar, R., Gonda, H. E., Jacobs, D. F., Landis, T. D., Luna, T., Mexal, J. G., & Wilkinson, K. M. (2012). Producción de plantas en viveros forestales. Buenos Aires, Argentina: Consejo Federal de Inversiones.

Dumroese, R. K., Pinto, J. R., Jacobs, D. F., Davis, A. S., & Horiuchi, B. (2006). Subirrigation reduces water use, nitrogen loss, and moss growth in a container nursery. *Native Plants Journal, 7*(3), 253-261.

Franquet, J. M. (2019). Dimensionamiento y distribución de las condiciones hidráulicas (Una contribución de la ingeniería matemática). España: UNED-Centro Asociado a Tortosa.

González, C., Puig, R., Morales, O., & Gómez, C. (2009). Comportamiento del coeficiente de uniformidad del riego por microaspersión en condiciones de organopónicos y huerto intensivo. *Revista Ciencias Técnicas Agropecuarias, 18*(3), 35-39.

Gutiérrez, J. V., Olvera, M., Rodríguez, D. A., Aldrete, A., Cibrián, D., Rodríguez, C., & Castro, S. (2016). Diagnóstico de la calidad del agua en los viveros forestales de México. *Nova Scientia, 8*(16),123-139.

Oliveira, R., Alves, A., Zapata, O. L., Rodrígues, J. A., Aparecida, M., & Oliveira, R. (2009). Eficiencia del tratamiento químico en la prevención del taponamiento de goteros aplicando agua residual sanitaria tratada. *Dyna, 76*(160), 149-157.

Pereira, L. S., Valero, J. A. J., Picornell, M. R., & Tarjuelo, J. M. (2010). El riego y sus tecnologías. Albacete: CREA-UCLM.

Pizarro Cabello, F. (1990). Riegos localizados de alta frecuencia (RLAF) goteo, microaspersión, exudación. Madrid, España: Mundiprensa.

Secretaría de Economía. (2016). Norma Mexicana NMX-AA-170-SCFI-2016: Certificación de operación de viveros forestales. Diario Oficial de la Federación. México, D. F.: SEGOB.

SAS Institute. (2009). Statistical Analysis System SAS/STAT User's Guide. version 9.2. Cary, NC, USA: SAS Institute Inc.

Thebaldi, M. S., Lima, L. A., da Silva, A. C., Colares, M. D. F. B., & Lima, P. L. T. (2016). Irrigation efficiency on native forest seedlings grown in recipient tubes. *Ciência Florestal, 26*(2), 401-410. https://doi.org/10.5902/1980509822741

Tun Dzul, J. C., Ramírez Jaramillo, G., Sánchez Cohen, I., Lomas Barrié, C. T. & Cano-González A. J. (2011). Diagnóstico y evaluación de sistemas de riego en el distrito 048 Ticul, Yucatán. *Revista Mexicana de Ciencias Agrícolas*, 1: 5-18.

Wan, F., Ross-Davis, A. L., Shi, W., Weston, C., Song, X., Chang, X., Davis, A. S., Liu, Y., & Teng, F. (2019). Subirrigation effects on larch seedling growth, root morphology, and media chemistry. *Forest, 10*(1):38. https://doi.org/10.3390/f10010038