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Research note

Prototipo de vivero forestal con fertirriego por subirrigación

A prototype for a forest nursery with fertigation by sub-irrigation

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Abstract

Research in forest nurseries has focused on producing quality stock with efficient irrigation and fertigation systems and substrate alternatives to reduce environmental impacts. The objectives of the present research were to design a sub-irrigation system prototype to produce 600 seedlings of three species at nursery and to quantify the amount of water and fertilizer used. The prototype was compared to a hand watering system. Morphological traits were evaluated at the end of the production stage. To create the prototype, four 0.30×0.30×3.0 m trenches were dug inside the nursery. The amount of water used in the hand fertigation system exceeded the subirrigation system by 219 %. With overhead hand fertigation, 8 960 l of water were used, while in sub-irrigation, only 2 808 l were utilized. However, the amount of soluble fertilizer used in overhead hand fertigation was 4 779.4 g, whereas in sub-irrigation, the total amount was 5 347.6 g. With overhead-hand fertigation, the nutrient solution dripped off the containers and leached through the soil. In sub-irrigation however, the nutrient solution was reused to fertigate a fruit tree orchard.

Key words: Water, fertilizers, plant, overhead-hand fertigation, system, nutrient solution.

Resumen

La investigación en el ámbito de viveros forestales se ha enfocado en la producción de planta de calidad con sistemas de riego y fertirriego eficientes y sustratos alternativos que se han implementado para mitigar impactos ambientales. El presente estudio tuvo por objetivos diseñar un prototipo de sistema de fertirriego por subirrigación para la producción de 600 plantas de tres especies forestales en vivero, y cuantificar la cantidad de agua y fertilizante soluble utilizado durante la producción. Este método se comparó con fertirriego mediante regadera. Al final del periodo de producción se evaluó la morfología de la planta obtenida. Para la construcción del prototipo, se excavaron cuatro zanjas en el suelo del vivero de dimensiones 0.30×0.30×3.0 m. Se estimó la cantidad de agua y fertilizante utilizado en ambos sistemas. En el fertirriego con regadera, se utilizaron 8 960 L de agua, 219 % mayor que en subirrigación, en el cual se requirieron 2 808 L. Empero, la cantidad de fertilizante soluble usado en regadera fue de 4 779.4 g, mientras que en el sistema alterno se emplearon 5 347.6 g. El desperdicio de la solución nutritiva con el uso de regadera fue directamente al suelo y en el prototipo de sistema, se recuperó y reutilizó para fertirriego de árboles frutales.

Palabras clave: Agua, fertilizante, planta, regadera, sistema, solución nutritiva.

Introduction

In technified forest nurseries, the most frequently used irrigation is by sprinkling, however, water is not distributed evenly and a large proportion is wasted, resulting in nutrient losses, especially nitrogen and phosphorus (Gent *et al.*, 2012).

The problem of water waste becomes worse when it is limited, since the production of forest plants demands a large amount of it and as well as other resources (DeVincentis *et al*., 2015). Under these circumstances, a possible solution is the use of closed irrigation systems such as sub-irrigation (Wan *et al.*, 2019).

Thus, the objectives of the present work consisted in designing a prototype of a sub-irrigation fertigation system for the production of forest plants and quantifying the amount of water and fertilizer used during the production cycle, which was compared with a manual system using a watering can. In addition, the morphology of the plant obtained in both systems was evaluated.

The experiment was established in the *Palo Bendito ejido* in *Huayacocotla*, state of *Veracruz*, Mexico (20°30'33" North and 98°30'14" West). Climate is temperate sub-humid with rains in summer and frequent fogs; the average annual temperature is 14° C and the average annual rainfall is 1 315 mm (García, 2004).

The prototype was implemented inside a rustic greenhouse; the minimum temperature inside the greenhouse was 4° C and the maximum 32° C.

The performance of the system was assessed through the production of *Fraxinus uhdei* (Wenz.) Lingelsh., *Pinus patula* Schltdl. & Cham. and *Pinus pseudostrobus* Lindl. The plants were produced in 310 mL capacity tubes with two substrate mixtures. The fertigation plants irrigated with a watering can received a mixture of slow-release fertilizer, Osmocote 14-14-14 and Multicote 18-06-12, with a 0.6, 0.21 and 0.45 g of N, P and K, formulation in doses of 3 and 1 g L^{-1}, respectively.

The experimental design was completely randomized with a 2^2 factorial arrangement in which the fertigation system factor (watering can vs sub-irrigation) and the mixture of substrates (60:30:10 peat:perlite:vermiculite, Vol.:Vol. vs 60:30:10 raw pine sawdust:perlite:vermiculite, Vol.:Vol.).

The model used was the following:

$$y_{ijk} = \mu + sys_i + subs_j + sys_i * subs_j + \varepsilon_{ijk} \qquad (1)$$

Where:

y_{ijk} = k^{th} variable in the i^{th} fertigation system of the j^{th} base substrate

μ = Population mean

sys = i^{th} fertigation system

subs = j^{th} base substrate

ε_{ijk} = Experimental error

Because the species have different growth habits, they were analyzed separately. The experimental unit was a grid with 25 seedlings. Four treatments per species were applied with four replications each.

The total height was measured with a flexometer model FH-5M Truper® and the basal diameter with a caliper model CALDI-6MP Truper®. Together, the Dickson's quality index (*DI*) was estimated, for which the dry weight of aerial and subterranean tissue samples was obtained. The Dickson's index (Dickson *et al*., 1960) was calculated with the formula:

$$DI = \frac{Tdw\ (g)}{\frac{Th\ (cm)}{Bd\ (mm)} + \frac{Adw(g)}{Udw\ (g)}} \qquad (2)$$

Where:

Tdw = Total dry weight

Th = Total height

Bd = Basimetric diameter

Adw = Aerial dry weight

Udw = Underground dry weight

The prototype consisted of a 1 100 L water tank to store the nutrient solution and was placed below ground level. To supply the solution to the four ditches, two submersible pumps with a power of 17 W each were placed inside; ½ inch PVC pipes were used. To control the flow of water, control valves were installed at the outlet end of the PVC pipes. The emptying of the trenches was carried out with siphons located at one end of the trenches. The siphons were connected to a two-inch diameter PVC pipe, which returned the solution to the tank (Figure 1).

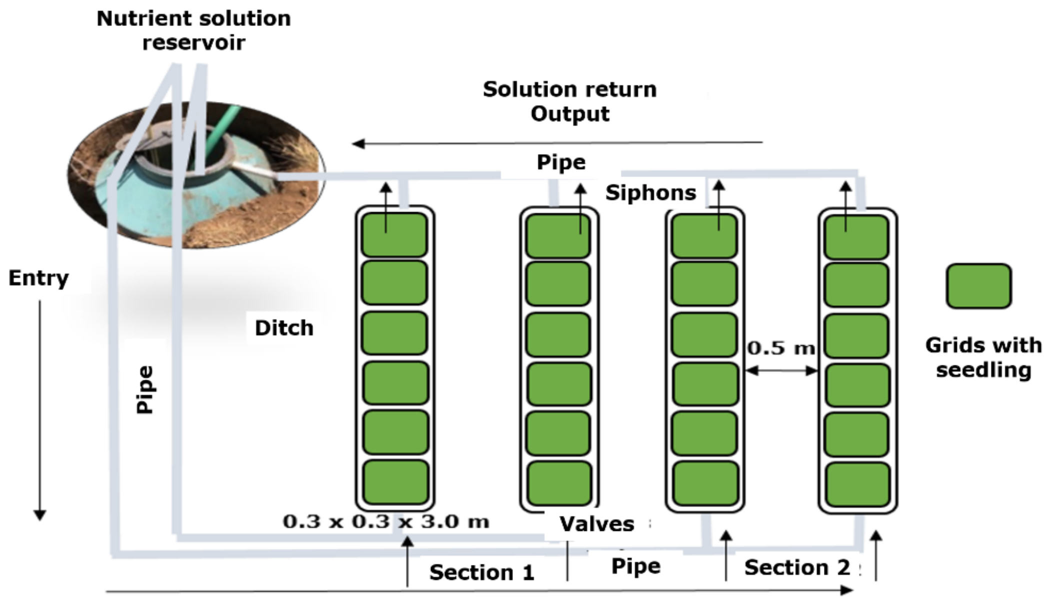

Figure 1. Diagram of the prototype of the sub-irrigation fertigation system.

The dimensions of the sub-irrigation trenches were: 0.30×0.30×3.0 m with a 0.5 m space between ditches. The bottom of each ditch was leveled to avoid ponding and they were covered with plastic to prevent infiltration of the solution. The plants received water and nutrients through the flooding of ditches. Irrigation was scheduled daily by sections. Each section consisted of two ditches. Once the first section was flooded, the ditches were gradually emptied through the siphons and the filling of the other section began (Figure 1). The loading time per section was one hour and 20 minutes and the unloading time was 40 minutes. Controlled release fertilizer was not incorporated into the substrate as it would have altered the composition of the solution. The nutrient solution applied was the one proposed by Landis (1989) and was prepared with soluble fertilizers (Table 1).

Table 1. Fertilizer materials used to make up the nutrient solution (Landis, 1989).

Phase	Nutriment	Nutritive solution concentration (mg L^{-1})	Fertilizing material	Fertilizer amount (g L^{-1})
Start	Nitrogen	50	Peters® 9-45-15	0.510
	Phosphorus	100		
	Potassium	100	K sulfate	0.090
	Calcium	80	Sagaquel® Ca	0.800
	Magnesium	40	Mg sulfate	0.330
Exponential growth	Nitrogen	150	Peters® 20-20-20	0.750
	Phosphorus	60	Urea	0.027
	Potassium	150	K sulfate	0.086
	Calcium	80	Sagaquel® Ca	0.800
	Magnesium	40	Mg sulfate	0.340
Hardening	Nitrogen	50	Peters® 4-25-35	0.390
			Urea	0.075
	Phosphorus	60	Phosphoric acid	0.070
	Potassium	150	Potassium sulfate	0.090
	Calcium	80	Sagaquel® Ca	0.800
	Magnesium	40	Mg sulfate	0.280

Three samples of the solution were chemically analyzed every two weeks during the three growth phases to replenish missing nutrients and maintain the solution in optimal concentrations (Landis, 1989). For each growth stage in this system, 600 L of nutrient solution were prepared. By watering can, 40 L of water were used for each occasion. Two days a week, fertigation was added with the nutrient solution, after considering the presence of slow-release fertilizer in the substrate, while the other days only water was applied. The amount of water and fertilizer used during production in both systems was estimated.

The amount of water used in the manual system with a watering can was 219 % higher than in sub-irrigation (8 960 and 2 808 L, respectively). Jani *et al.* (2021), who conducted a study by comparing irrigation systems, reported 87 % saving in sub-irrigation compared to sprinkling, while in the present investigation it was 69

%. The water used in sub-irrigation, with the exception of evaporated from the ditches, of the substrate and the perspired by the plants, was recovered daily and reused for the fertilization of a fruit tree orchard, at the end of each stage of growth. The daily water supply in the prototype implemented was 4.7 L and 40 L in shower. In sub-irrigation, 11.25 % water was consumed, compared to the watering can system. Despite the water savings in sub-irrigation, it represented more fertilizer expense (11.9 %) (Table 2).

Table 2. Fertilizer amount used in two fertigation systems.

Fertigation system	Growth stage	g/etapa	Total (g)
Watering can	Initial	1 159.2	4 779.4
	Exponential	2 358.0	
	Lignification	1 247.4	
Sub-irrigation	Initial	1 086.8	5 347.6
	Exponential	3 196.3	
	Lignification	1 064.5	

The greatest amount of fertilizer used in sub-irrigation was due to the fact that at the beginning of each stage 600 L of new nutritional solution were prepared, but when analyzing them, the missing nutrients were added, because by chemical analysis of the nutrient solution or through the analysis of plant growth, it is possible to develop techniques in order to prepare a new solution from the previous one. These techniques imply greater water and fertilizers savings (Dumroese *et al.*, 2011).

Table 3 shows that fertigation systems did not affect height (*At*) or basimetric diameter (*Db*) in pine species, but they did the height of *F. uhdei* plants. According to Dickson's index, fertigation systems influenced the plant quality of pine species, but they had no effect upon ash. The mixture of substrates had an impact on the total height and Dickson's index on both pine species. In ash specimens, this factor had an effect on the basimetric diameter. The fertigation systems-substrates mixtures interaction was not significant in any of the species or evaluated variables (Table 3).

Table 3. Morphological and plant quality variables ($p \leq 0.05$) of three forest species in two fertigation systems and two substrate mixtures.

F.V.	***Pinus patula* Schltdl. & Cham.**			***Pinus pseudostrobus* Lindl.**			***Fraxinus uhdei* (Wenz.) Lingelsh.**		
	Th	***Bd***	***DI***	***Th***	***Bd***	***DI***	***Th***	***Bd***	***DI***
sys	0.850	0.152	0.021	0.672	0.188	0.007	0.002	0.944	0.246
sus	0.004	0.124	0.005	0.001	0.057	0.006	0.358	0.046	0.822
*sys*sus*	0.205	0.822	0.143	0.208	0.470	0.155	0.918	0.944	0.569

F.V. = Variation source; *Th* = Total height; *Bd* = Basimetric diameter; *DI* = Dickson's index; *sys* = Fertigation system; *sus* = Substrate mixture.

Table 4 shows that in pine species, Dickson's index was better with fertigation through a watering can (Reg), which was not verified in *F. uhdei*. The mixtures of substrates affected Dickson's index and height in pine species and the basal diameter in that of ash.

Table 4. Tukey's tests (a=0.05) for morphological and plant quality variables of three forest species when production finshed.

F.V.	***Pinus patula* Schltdl. & Cham.**			***Pinus pseudostrobus* Lindl.**			***F. uhdei* (Wenz.) Lingelsh.**		
	Th	***Bd***	***DI***	***Th***	***Bd***	***DI***	***Th***	***Bd***	***DI***
Wc	36.96a	5.47a	0.64a	32.64a	5.16a	0.68a	30.46a	8.42a	2.41a
Sub	37.40a	4.92a	0.47b	31.96a	4.77a	0.44b	22.91b	8.39a	1.68a

Pm	41.26a	5.49a	0.66a	35.57a	5.26a	0.68a	27.60a	8.99a	2.11a
Sd	33.10b	4.90a	0.44b	29.02b	4.67a	0.44b	25.77a	7.82b	1.98a

F.V. = Variation source; *Th* = Seedling total height (cm); *Bd* = Seedling basimetric diameter (mm); *DI* = Dickson's index; Wc = Fertigation by watering can; Sub = Fertigation by sub-irrigation; Pm = Peat substrate; Sd = Sawdust substrate.

The average values in height and basal diameter of the seedlings (Table 4), at seven (conifers) and five months (*F. uhdei*), exceeded the values indicated by Prieto *et al.* (2009); 15-20 cm for height and >5 mm for basal diameter, regardless of the type of fertigation.

Plant production by sub-irrigation has been implemented for research purposes, for example, in Brazil for the production of 200 plants of *Eucalyptus grandis* W. Mill ex Maiden in a system called "Aquatic Forest". The seedlings grew in pools with water at a depth of 0.6 m and the containers were submerged 0.2 m deep. The prototype consisted of a structure made of wood, polystyrene, shade mesh and transparent plastic (Celentano *et al.*, 2004).

Other authors such as Ribeiro *et al.* (2014) evaluated the efficiency of irrigation by sub-irrigation to produce 226 800 clones of *Eucalyptus* spp. In the cited study, a total of 36 500 L of water was used. Dumroese *et al.* (2006) mentioned that sub-irrigation is a viable option for areas where there is no permanent source of water or in arid regions.

In the experiment here described, by using the sub-irrigation system, coniferous plants of the same size were produced, although with a lower Dickson index, and water savings of more than 50 % were achieved. This system allowed the production of *Fraxinus uhdei* plants with the same Dickson index as with fertigation by means of a watering can, although with a lower height. Although the consumption of fertilizers was higher in sub-irrigation, the nutrient solution was reused for the fertigation of other crops at the end of the production cycle.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Karla Ramírez Galicia and Miguel Ángel López López: research approach, direction of the experiment and writing of the manuscript; Víctor Manuel Cetina Alcalá and Leopoldo Mohedano Caballero: writing of the manuscipt.

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