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Article

Nursery production of coffee seedlings with root pruning in substrates

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Abstract

In order to improve the technified production of coffee plants, the effects of controlled-release fertilizer nutrition and chemical root pruning were evaluated in a nursery over 275 days in 2021. The use of soil was avoided, employing as substrate a mixture of pine sawdust, tezontle (volcanic slag), and vermicompost (3:1:2, V:V). The plants were established in 1 L containers with two grafted coffee seedlings (*Coffea arabica* var. Costa Rica onto *Coffea canephora* var. Robusta). The experimental design was completely randomized with a 3 × 2 factorial arrangement; the first factor corresponded to three doses of CRF (7, 9 and 11 g L^{-1}), and the second to the presence or absence of an internal coating of 7% $Cu(OH)_2$, applied to promote chemical pruning. The variables evaluated were plant height, stem diameter, dry weight of the aboveground and root parts, root volume and nutritional concentration in the aboveground part. Results showed significant differences ($p< 0.05$) between the levels of controlled-release fertilizers and chemical pruning, with a significant interaction only for stem diameter. The dose of 11 g L^{-1}combined with chemical pruning produced the highest values in plant height, stem diameter, dry weight of the aboveground part and root volume. The nutritional concentration did not differ statistically among the controlled-release fertilizer doses; however, treatments with $Cu(OH)_2$showed higher K, Fe, Mg and Cu values. The combination of controlled-release fertilizers and chemical pruning promoted the formation of plants with morphological characteristics desirable for field transplantation.

Keywords:

chemical root pruning, controlled-release fertilizer, root growth potential.

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Introduction

Traditional coffee seedling production is carried out through the use of bagged soil, without a standardized fertilization dose and with a high probability of transmitting soil pathogens to new regions (Tablas-González *et al* ., 2021). The production of plants in a nursery enables the provision of appropriate care and treatments to promote germination and growth in order to achieve high survival rates and optimal development in the field (Muñoz-Flores *et al*., 2014).

Sawdust and tezontle are suitable substrates to reduce the production costs of plants in the nursery (Aguilera-Rodríguez *et al*., 2017; Estrada-Botello *et al*., 2024). Fertilization in a nursery can positively modify plant development, both in the aboveground and in the root parts, by altering the nutritional content of tissues and accumulated reserves (Aimi *et al*., 2019; Heras-Marcial *et al*., 2023).

In forest species such as Pino Prieto (*Pinus greggii var. Australis*) and Teca (*Tectona grandis*), nutrition in nurseries has been optimized through the use of controlled-release fertilizers, which release nutrients gradually according to the formulation time (4 or 8 months) and composition (18-6-12 + 2MgO + micronutrients) (Escamilla-Hernández *et al*., 2015; Castro-Garibay *et al*., 2018). This type of fertilizer reduces leaching losses and eliminates the need for fertigation systems (Rose *et al*., 2004).

The action of the internal coating of containers with copper hydroxide salts $Cu(OH)_2$inhibits cell division in apical roots, which promotes the formation of more abundant and active secondary roots that absorb water and nutrients. This technology is widely used in forest nurseries and has shown outstanding results in the production of *Pinus patula* seedlings (Aguilera-Rodríguez *et al*., 2021).

Chemical root pruning is a novel alternative practice for producing coffee seedlings and can be complemented with the application of controlled-release fertilizers to improve production efficiency and plant quality in the nursery (Zhou *et al*., 2023; Wu *et al*., 2025). In this context, this work aimed to evaluate the effects of nutrition with controlled-release fertilizers and chemical root pruning on the production of coffee seedlings produced in a nursery.

Materials and methods

Experimental site

The experiment was conducted in the municipality of Ixhuatlán del Café, Veracruz, Mexico, located at 19° 03’ 05” north latitude and 96° 58’ 16” west longitude, at an altitude of 1 180 m. The nursery had a 70% shade-net cover, raised beds and racks with five cavities for 1 L cone-tainers and a drip tape irrigation system.

Plant material

The test lasted 275 days. The material used was grafted seedlings with a *Coffea canephora* var. Robusta rootstock and a *Coffea arabica* var. Costa Rica bud, before the appearance of the first true leaves (stage known as soldadito, Spanish for little soldier).

Substrate preparation

The substrate was prepared using a mixture of three parts pine sawdust (v/v), one part tezontle with particles smaller than 2 cm in diameter, and two parts vermicompost made from 25% filter cake, 25% cow manure and 50% coffee pulp. Two grafted seedlings were transplanted into each container.

The substrate’s characteristics were as follows: pH 4.7, electrical conductivity 3.44 dS m^{-1}, total porosity (Pt) 53%, aeration porosity (Pai) 15%, water retention porosity (Pwr) 38%, weighted mean particle diameter (WMD) 2.94 mm, thickness index (I) 44 and bulk density (BD) 0.35 g cm^{-3}.

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Nutritional management

Nutrition was provided by applying controlled-release fertilizer (*Multicote* ®) with the formula 18-6-12 + 2MgO +1S + micronutrients (0.4Fe + 0.055Mn + 0.03B + 0.06Zn + 0.045Cu + 0.01Mo) (Haifa Chemicals Ltd.), in a proportion of 50% with a release time of four months and 50% with a release time of eight months. Of this mixture, three doses were applied: 7, 9, and 11 g L^{-1}, which were considered three levels of the fertilization factor. In addition, biweekly foliar applications of the fertilizer Bonus Haifa® (13-02-44 + micronutrients) were made at a concentration of 2.5%, initiated after the appearance of the second pair of true leaves and maintained until the end of the test.

Chemical root pruning

Chemical root pruning was performed by impregnating the inner walls of the containers with a solution of 7% $Cu(OH)_2$dissolved in commercial acrylic sealant. This treatment was considered a second factor, with two levels: coated and uncoated containers.

Experimental design

The combination of the three levels of controlled-release fertilization and the two levels of copper coating on cone-tainers resulted in a total of six treatments (3 x 2), as shown in Table 1 , each with five replications. The experimental unit consisted of 20 cone-tainers, with 2 plants cone-tainer^{-1}.

Table 1. Treatments for producing grafted coffee seedlings*.

Treatments	Dose of controlled-release fertilizer (CRF) (g L^{-1})	Coating on the inner walls of the cone-tainer
1	7	7% $Cu(OH)_2$
2	9	7% $Cu(OH)_2$
3	11	7% $Cu(OH)_2$
4	7	Uncoated
5	9	Uncoated
6	11	Uncoated

*= developed on substrates composed of three parts pine sawdust, one part tezontle, and two parts vermicompost, using one-liter containers (cone-tainers) impregnated inside with a copper hydroxide solution and not impregnated.

The evaluation was conducted after 275 days (nine months) in the nursery. The variables considered were plant height from the base of the plant and stem diameter at a distance of 2 cm from the base of the plant. Subsequently, the plants were separated into aboveground and root parts. The latter were carefully washed to remove any substrate particles, and their volume was determined using Archimedes' principle, which considers the weight of the volume displaced when the roots were immersed in water (Cisneros-Rojas *et al*., 2016). Both the aboveground part and the roots were dried at 70 °C until they reached a constant weight. The dry weight was obtained with an analytical balance.

Concentration of nutrients in the aboveground part

The dry material from the aboveground part was ground and passed through a No. 40 mesh sieve to obtain a homogeneous sample. Nitrogen concentration was determined by the semimicro-Kjeldahl method. Concentrations of P, K, Mg, Fe, Cu and Mn were determined by wet digestion with a mixture of perchloric and nitric acids (Jones *et al*., 1991). Macro- and micronutrients were quantified with a 725-ES Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy Equipment (Varian®).

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Determination of substrate characteristics

The physical properties of the substrate included total porosity (Pt), aeration porosity (Pa), water-retention porosity (Pwr), granulometry and water-retention curves. The chemical properties considered were pH and electrical conductivity (EC), which were determined in a water:substrate ratio of 3:1 (v/v). The organic matter content was determined by incineration at 450 °C for 1 h.

Statistical analysis

The data obtained were subjected to an analysis of variance (Anova) and Tukey's test for comparison of means (p≤ 0.05), considering the level of fertilization and the presence of a copper coating as factors. The analyses were performed with the SAS® statistical package, version 9.4 (SAS Institute Inc., 2013).

Results

Morphological variables of coffee plants

The analysis of variance showed statistically significant differences (p< 0.05) among the doses of controlled-release fertilizer (CRF) and chemical root pruning across most of the morphological variables evaluated (Table 2), except for the root dry weight (RDW) for the CRF factor. The interaction between the two factors was significant only for stem diameter.

Table 2. Average values of morphological characteristics in coffee plants grown for 275 days in a nursery using one-liter containers (cone-tainers) and substrate composed of sawdust, tezontle and compost.

Treat.	CRF dose ($g\ L^{-1}$)	Chemical pruning	Plant height (cm)	Stem diameter (mm)	DWAP (g)	RV (cm^3)	RDW (g)
T1	7	Pruned	26.91 ±3.5ab*	2.71 ±1.1b	5.76 ±1.4b	8.39 ±2.4abc	2.63 ±0.63a
T2	9	Pruned	26.78 ±3.3b	2.8 ±1.2b	5.63 ±1.3b	9.37 ±2.8ab	2.34 ±0.95a
T3	11	Pruned	28.11 ±3.3a	3.19 ±0.6a	6.73 ±1.4a	9.55 ±2.7a	2.52 ±0.78a
T4	7	Unpruned	23.79 ±3c	2.59 ±0.6bc	4.79 ±1.2c	7.36 ±2.1 c	1.6 ±0.44a
T5	9	Unpruned	24.25 ±3.3c	2.34 ±0.6c	4.85 ±1.1c	8.01 ±2.5bc	1.53 ±0.56a
T6	11	Unpruned	24.86 ±3.2c	2.59 ±0.7bc	5.23 ±1.4cb	7.95 ±2.6bc	1.64 ±0.64a
HSD			1.31	0.337	0.76	1.45	0.56

*= identical letters in the same column indicate no significant differences (Tukey< 0.05); CRF= controlled-release ferti lizer; DWAP= dry weight of the aboveground part; RV= root volume; RDW= root dry weight. Values expressed as mean ± standard deviation (n= 5).

CRF influenced plant height, stem diameter, root volume and root dry weight, with statistically significant responses. Franco-Junior *et al*. (2019) ; Reis *et al*. (2023) reported positive effects on the morphological variables of coffee seedlings produced in cone-tainers and when applying *Multicote* ® controlled-release fertilizer.

Chemical root pruning generated highly significant differences (p< 0.0001) in all morphological variables, except for RDW. Chemical pruning had a positive influence on plant height (treatments 1, 2 and 3). In the stem diameter variable, the treatment with the highest value was T3, with chemical pruning. In the DWAP variable, the treatment with the highest value was the one with chemical pruning (T3); a similar case was observed for RV. Chemical pruning did not influence RDW. In general, treatments without copper application (T4, T5 and T6) had the lowest heights.

Arizaleta and Pire (2008) observed that using soil as a substrate did not yield significant differences in coffee seedling height at fertilization doses comparable to those of the present study. On the contrary, Marana *et al*. (2008) ; Bachião *et al*. (2018) obtained plants with favorable morphological characteristics when applying CRF doses close to 10 kg m-3 in alternative substrates without root pruning.

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Regarding stem diameter, there were significant differences between treatments. Treatment T3 (11 g $L^{-1}$of CRF with chemical pruning) presented the highest value, whereas treatment T5 (9 g $L^{-1}$of CRF and without chemical pruning) obtained the smallest diameter. A thicker stem contributes to plant stability during transplanting into the field (Marana *et al*., 2008) and is associated with a higher probability of survival (Birchler *et al*., 1998).

The total dry weight ranged from 7.36 to 9.55 g, with significant differences between treatments. The maximum value corresponded to treatment T3, with the highest CRF dose (11 g L^{-1}). Previous studies reported similar increases in dry matter with CRF doses near 10 g L^{-1}(Bustamante-González and Ferrás-Negrín, 2020; Sánchez-Esmoris *et al*., 2024).

Treatments that included chemical pruning with $Cu(OH)_2$resulted in greater root volume and dry weight, an effect consistent with what was observed in *Pinus greggii* (Barajas-Rodríguez *et al*., 2004) and *Physalis peruviana* (Marchioretto *et al*., 2020), where contact with copper salts increased root density and biomass.

Nutrient content in the aboveground part

The CRF dose did not have a statistically significant effect on nutrient concentrations in the above ground part (Table 3). Nonetheless, treatments with $Cu(OH)_2$internal coating had higher concentrations of most of the nutrients tested, except for nitrogen. This behavior coincides with the data found by Marchioretto *et al*. (2020) in *Physalis peruviana* plants, where the increase in the concentration of copper salts for pruning increased N absorption.

Table 3. Response in nutrient content in the aboveground part of coffee plants grown in cone-tainers for 8 months in a nursery.

Treat.	CRF (g L^{-1})	Chemical pruning	N	P	K	Mg	Fe	Cu	Mn
			(%)		(mg kg-1)				
1	7	Pruned	2.85 ±0.14b*	0.35 ±0.02a	1.96 ±0.05a	0.27 ±0.01a	146 ±9ab	3 ±0.6a	81 ±1.79b
2	9	Pruned	2.91 ±0.05ab	0.3 ±0.02b	1.81 ±0.14a	0.24 ±b	149 ±16ab	4 ±0.2a	102 ±13a
3	11	Pruned	2.88 ±0.03ab	0.29 ±0.01b	1.6 ±0.03b	0.22 ±b	155 ±14a	4 ±0.7a	118 ±2a
4	7	Unpruned	3.01 ±0.03ab	0.24 ±0.02c	1.15 ±0.03c	0.17 ±c	121 ±10bc	2 ±0.08b	69 ±3b
5	9	Unpruned	3.05 ±0.01a	0.22 ±0.01d	1.08 ±0.02c	0.17 ±c	102 ±2c	2 ±0.17b	72 ±3b
6	11	Unpruned	3.07 ±0.05a	0.22 ±0.01d	1.07 ±0.01c	0.16 ±c	129 ±8bc	2 ±0.16b	72 ±3b
HSD			0.2	0.016	0.18	0.019	31.01	1.11	15.39

Treat.= treatment; CRF= controlled-release fertilizer; *= identical letters in the same column indicate no significant difference (Tukey <0.05). Values are expressed as mean ± standard deviation (n= 3).

In the case of nitrogen, there were significant differences between treatment T1 and treatments T5 and T6, with the latter showing higher values. Chemical pruning increased the concentration of N in the aboveground part by an average of 0.18%, although this increase was not statistically significant. According to Jones *et al* . (1991) , K, Mg and Cu showed concentrations below optimal levels, although plants did not exhibit visible deficiency symptoms (Alcántar-González and Trejo-Téllez, 2016).

Phosphorus levels were classified as low (Jones *et al*., 1991), with no visible deficiencies. Treatment T1 (7 g $L^{-1}$of CRF with chemical pruning) showed significant differences for this element. Chagas *et al*. (2016) reported that controlled-release fertilizers can improve the agronomic efficiency of phosphorus in coffee plants.

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Mg concentration was considered deficient, although with no visible symptoms. Its value was significantly higher ($p < 0.05$) in treatment T3 and lower in treatments without chemical pruning. A similar pattern was observed for K, which was statistically higher in treatments with chemical pruning; nevertheless, at the CRF level, there were no statistically significant effects.

Regarding Fe, treatment T5 had the lowest value, whereas the chemical pruning treatments showed similar concentrations within the optimal range (Jones *et al*., 1991). For Cu, the values are higher in the chemical pruning treatments and are close to the concentration values in plant tissue considered normal, which are between 5 and 30 mg kg-1 (Napoli *et al*., 2019). Mn contents were higher in treatments T2 and T3, with significant differences compared with the other treatments; however, these values are not considered deficient according to the reference ranges established by Jones *et al*. (1991) .

Conclusions

The effect of nutrition with slow-release fertilizer, composed of three parts pine sawdust (v/v), one part volcanic slag (tezontle) with particles less than 2 cm in diameter, and two parts vermicompost, on nursery coffee plants grown in containers and in substrate was observed at one of the three doses tested (11 g L^{-1}), which produced plants with thicker stem diameters and increased dry weight of the aboveground part. Chemical root pruning promoted an increase in root biomass and a greater root volume, resulting in desirable conditions for transplantation and survival in the field.

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