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Research article

Crecimiento de *Quercus durifolia* Seemen en sustratos con turba, corteza, aserrín y fertilizante de liberación controlada

Growth of *Quercus durifolia* Seemen in substrates with peat, bark, sawdust and controlled-release fertilizer

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Abstract

Fertilizer dosage in nursery plant production depends on the type of substrate used since during this growth stage, both factors interact positively or negatively on the plant's morphological and physiological attributes. The objective of the present study was to determine the efficiency of three substrates and two doses of controlled-release fertilizer (CRF) on the nursery growth of *Quercus durifolia*. The substrate components (S) evaluated were peat moss, composted pine bark, and fresh pine sawdust, in the following proportions: S1 (60-20-20), S2 (50-25-25), and S3 (33-33-33), with two doses of fertilizer (7 and 10 g L^{-1} of Multicote 8™ 18-6-12 N, P and K). It was determined that the three assessed substrates showed statistically similar results; however, plants fertilized with 10 g L^{-1} had greater height, diameter, dry biomass, and more allocation of dry biomass in leaves and stem. Therefore, the inclusion of fresh pine sawdust combined with peat and composted pine bark in equal parts, with doses of 10 g L^{-1} allows the production of *Q. durifolia* plants with quality morphological characteristics; this also reduces the cost of production. This is crucial to obtain quality plants for reforestation and restoration projects.

Keywords: Biomass allocation, plant quality, growth, oak, nutrition, alternative substrates.

Resumen

La dosis de fertilizante en la producción de plantas en vivero depende del tipo de sustrato empleado, ya que ambos factores interactúan de manera positiva o negativa en los atributos morfológicos y fisiológicos de las plantas durante esta etapa de crecimiento. El objetivo del presente estudio fue determinar la eficiencia de tres sustratos y dos dosis de fertilizante de liberación controlada (FLC) en el crecimiento en vivero de *Quercus durifolia*. Los componentes de los sustratos (S) evaluados fueron turba de musgo, corteza compostada de pino y aserrín fresco de pino, en las siguientes proporciones: S1 (60-20-20), S2 (50-25-25) y S3 (33-33-33), con dos dosis de fertilizante (7 y 10 g L^{-1}

de *Multicote 8*™ 18-6-12 de N, P y K). Se determinó que los tres sustratos evaluados mostraron resultados similares estadísticamente; sin embargo, las plantas fertilizadas con 10 g L^{-1} tuvieron mayor altura, diámetro, biomasa seca y más asignación de biomasa seca en hojas y tallo. Por lo tanto, incluir aserrín fresco de pino combinado con turba y corteza compostada de pino en partes iguales, con dosis de 10 g L^{-1} permite producir plantas de *Q. durifolia* con características morfológicas de calidad; además, el costo de producción disminuye. Esto es crucial para obtener plantas de calidad para proyectos de reforestación y restauración.

Palabras clave: Asignación de biomasa, calidad de planta, crecimiento, encino, nutrición, sustratos alternativos.

Introduction

In Mexico, the forest area amounts to 137.8 million hectares, 65.7 million of which correspond to forests and tropical forests; 37 % of this area is occupied by oak and pine-oak forests (Comisión Nacional Forestal [Conafor], 2021), where 161 taxa of the *Quercus* L. genus are found; 109 of these are endemic (Flores & Romero, 2021). Most oak species are distributed within an altitude range of 1 200 to 2 800 m across the country, except in the *Yucatán* Peninsula (De Jesús et al., 2021).

Pine-oak forests have been subjected to strong anthropogenic pressure due to excessive logging, grazing, and land use change (Alfaro et al., 2019); this has modified the forest composition and structure through ecological alterations that hinder natural oak regeneration processes (Brizuela-Torres et al., 2023).

Three decisive factors influence the scarcity of natural regeneration of oak trees (Pérez et al., 2013): (I) Low acorn production, which can occur every two to six years, (II) Mortality of acorns due to predation and desiccation before germinating, and (III) Low plant vigor; which results in few plants being able to grow in open places outside the tree canopy, given that some of them, at juvenile stages, are tolerant to a certain level of shade, which allows them to grow under low light conditions (Flores et al., 2021).

Based on the above, quality nursery-grown *Quercus durifolia* Seemen plants are an important source of raw material for reforestation and restoration to preserve forests and recover natural oak populations. However, basic information on the nursery propagation of plants of this species is scarce. Most of the studies on forest plant production in Mexico, especially on the use of substrates and fertilization, correspond to conifers from the Center and North of the country (Domínguez et al., 2023). On the other hand, the only information available regarding the *Quercus* genus from the point of view of plant quality is for *Quercus canbyi* Trel., *Quercus rugosa* Née y *Quercus crassipes* Bonpl. (De Jesús et al., 2021; Venancio et al., 2022; Villalón-Mendoza et al., 2016).

The cultural practices and inputs utilized during the nursery production phase contribute to the morphological and physiological attributes of the plant produced and, in turn, are related to its growth and development in the field (Aldrete et al., 2024). Substrates and fertilization are two important components in producing quality plants; however, they are the costliest, especially if imported (Conafor, 2013).

The use of low-cost alternative substrates such as fresh sawdust and composted pine bark has been evaluated with satisfactory results in the production of conifers and broadleaves in containers (Aguilera-Rodríguez et al., 2021; De Jesús et al., 2021; Domínguez et al., 2023; González et al., 2018; Madrid-Aispuro et al., 2020). Furthermore, they have appropriate physical and chemical properties to produce quality plants (Castro et al., 2019) and are local, inexpensive, and abundant organic materials (Aguilera-Rodríguez et al., 2021).

Fertilization is defined according to the type of substrate used, both of which have a positive or negative influence on the morphological and physiological attributes of the plants. For example, for *Pinus cooperi* C. E. Blanco, a dose of 6 g L^{-1} of controlled-release fertilizer (CRF) Multicote 8^{TM} is recommended for a substrate composed of peat (50 %), perlite (25 %) and vermiculite (25 %) (Martínez-Nevárez et al., 2023); for the same species, González et al. (2018) recommend 8 g L^{-1} of Multicote^{TM} in a substrate mixture based on fresh sawdust (50 %), peat (30 %), and composted bark (20 %). This is because, when considering fresh sawdust as the main component of the substrate, the fertilizer dose must be increased, as it has a high carbon/nitrogen (C/N) ratio that promotes competition for nitrogen between the plant and the bacteria that decompose the sawdust during its function as part of the substrate (Aguilera-Rodríguez et al., 2021; Barrett et al., 2016; González et al., 2018; Madrid-Aispuro et al., 2020).

CRFs are an effective, technically advanced alternative for supplying mineral nutrients in the required amount for various species of the *Pinus* L. genus and certain tropical taxa at different growth stages during nursery production (Aguilera-Rodríguez et al., 2016; Madrid-Aispuro et al., 2020; Martínez-Nevárez et al., 2023; Vicente-Arbona et al., 2019); CRFs allow a gradual release of nutrients, which optimizes their absorption by plants and increases the efficiency of the process (Camarena-Yupanqui et al., 2024). Although different fertilization schemes have been evaluated to estimate the appropriate dose, this response will depend on the substrate utilized and the nutrient needs of each species (Martínez-Nevárez et al., 2023). Therefore, it is necessary to develop cultural practices focused on the propagation of forest plants using economically viable and available inputs.

In this sense, the objective of the present study was to evaluate three mixtures of substrates based on fresh pine sawdust, peat, and composted pine bark, with two doses of controlled-release fertilizer (CRF) on the growth of *Quercus durifolia*. The hypothesis was that at least one substrate mixture and one dose of CRF have a significant effect on the nursery growth of *Quercus durifolia*.

Materials and Methods

Study area

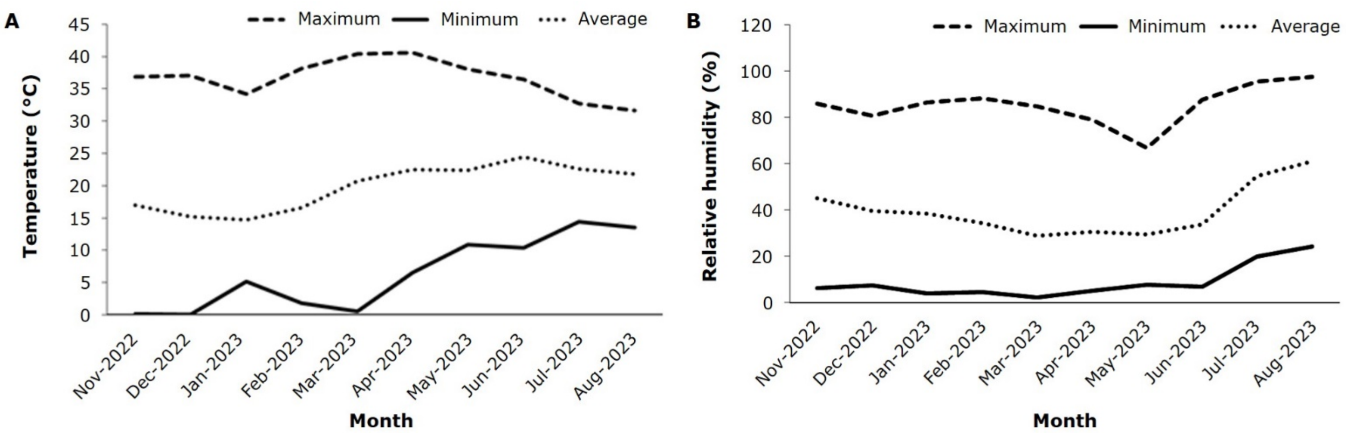
The trial was conducted within the facilities of the Graduate School of Forest and Environmental Sciences of the *Universidad Juárez del Estado de Durango*, *UJED* (*Juárez* University of the State of *Durango*), in the city of *Durango*, *Durango*, Mexico (24°00'48.3” N and 104°41'10.36” W), at 1 870 masl.

Plant production and treatments

The plants grew in the nursery for 10 months, from October 26th, 2022, to August 31st, 2023. *Quercus durifolia* acorns collected in a natural stand with predominantly pine-oak vegetation, located in *Otinapa*, *Durango*, Mexico (24°03'27'' N and 105°00'54'' W), at an 2 397 masl, were used. The acorns were not subjected to any pre-germinative treatment; they were only disinfected with a solution of water and 10 % sodium hypochlorite prior to sowing.

The plants were sown in small black plastic trays 59 cm long, 36 cm wide, and a 13 cm tall, with 60 cavities (10×6), each one of which held a volume of 200 mL; two seeds were planted directly in each cavity. During the first six months, the plant was grown in a greenhouse covered with 720 *µ*-gauge polyethylene sheets treated against ultraviolet rays; subsequently, from April to September, the plants were kept in an area with metal structures covered with 60 % light retention shade netting.

During the plant growth, the microclimatic variables temperature (°C) and relative humidity (%) were recorded using a model U12-012 Onset Hobo® data logger (Figure 1A and B).



A = Temperature; B = Relative humidity.

Figure 1. Monthly record of maximum, minimum, and average values in the growing area of *Quercus durifolia* Seemen.

Six treatments derived from three substrate mixtures with different proportions of peat moss, composted pine bark and fresh pine sawdust were assessed: S1: 60-20-20, S2: 50-25-25, and S3: 33-33-33; two doses (7 and 10 g L^{-1}) of CRF Multicote 8™ 18-6-12+2Mg+M.E. (Haifa Chemicals Ltd.-Haifa, Israel), released during eight months, were also evaluated and incorporated during the preparation of the substrate mixtures. The physical and chemical properties of the assessed mixtures were determined (Table 1).

Table 1. Physical and chemical properties of substrates evaluated in the production of *Quercus durifolia* Seemen.

Substrate (PM-CB-FPS)	*AP*	*WRP* (%)	*TP*	C/N	pH	*EC* (dS m^{-1})	*CEC* (mEq 100 g)
S1: 60-20-20	25.31	30.15	55.46	37.31	3.88	3.98	70.1
S2: 50-25-25	31.40	24.22	55.62	18.67	4.00	3.57	60.8
S3: 33-33-33	27.18	31.35	58.53	20.56	4.03	3.55	60.4
RV	20-35	25-55	60-80	50-70	5.5-6.5	<1.0	

PM = Peat moss; CB = Composted pine bark; FPS = Fresh pine sawdust; *AP* = Aeration porosity; *WRP* = Water retention porosity; *TP* = Total porosity; C/N = Carbon/nitrogen ratio; *EC* = Electrical conductivity; *CEC* = Cation exchange capacity; RV = Recommended values for substrates utilized for growing forest species in containers (Landis et al., 1990, Vol. 2).

Assessed morphological variables

The plants were evaluated at ten months of age (Figure 2). Ten plants per experimental unit (40 per treatment) were randomly drawn from each tray. The substrate was carefully removed from each plant to prevent loss of fine root segments; subsequently, the height from the base of the stem to the terminal bud (model RAS-30 PILOT® graduated ruler), the diameter at the base of the stem (model CAL-6MP Truper® digital caliper), and the aboveground, root, and total biomass were measured. The biomass was estimated by separating the aboveground part (leaves and stem) from the root component. Both parts were placed inside Kraft paper bags and then dried in a model 9024A Ecoshel® oven at 70 °C for 72 h; subsequently, they were weighed on a model Pionner PA512 Ohaus® analytical balance. With the above values, the proportion of leaf biomass (*PLB* %; Equation 1), the proportion of stem biomass (*PSB* %; Equation 2), and the proportion of root biomass (*PRB* %; Equation 3) were estimated (Andivia et al., 2014):

Figure 2. *Quercus durifolia* Seemen plant production 10 months after sowing.

$$PLB\ (\%) = \frac{Leaf\ dry\ weight}{Total\ dry\ weight} \times 100 \qquad (1)$$

$$PSB\ (\%) = \frac{Stem\ dry\ weight}{Total\ dry\ weight} \times 100 \qquad (2)$$

$$PRB\ (\%) = \frac{Root\ dry\ weight}{Total\ dry\ weight} \times 100 \qquad (3)$$

Leaf nutrient concentration

Based on the leaves of the 40 plants evaluated for each treatment, a composite mixture was formed (six samples total), which was crushed in a mill and sieved at 1.0 mm mesh. The nitrogen content was determined by the Kjeldahl method (Kjeldahl, 1883); the phosphorus content, by vanadomolybdate yellow complex colorimetric analysis (Murphy & Riley, 1962), and the potassium content, by atomic absorption spectrophotometry (Mckean, 1993). The nutrient content was estimated based on the product of concentration (mg g^{-1}) by aboveground dry biomass (g) (Andivia et al., 2014). The nutritional analysis of plant foliage was performed at the Laboratory of the National Center for Interdisciplinary Research on Water, Soil, Plant and Atmosphere Relations (Cenid-RASPA) of the *Instituto Nacional de Investigaciones Forestales*, *Agrícolas y Pecuarias* (National Institute for Research on Forestry, Agriculture and Livestock) (*INIFAP*).

Experimental design and statistical analysis

A completely randomized experimental design with a 3×2 factorial arrangement (three substrate mixtures and two fertilization doses) was used for a total of six treatments derived from the combination of both factors; each treatment had four replicates. With the values of the variables height, diameter, aboveground, root, and total dry biomass, as well as the biomass allocation, analyses of variance were performed using the PROC

GLM procedure of SAS 9.2® (Statistical Analysis System [SAS] Institute, 2009). For variables where significant differences between treatments were found, multiple mean comparison tests were performed using Tukey's method ($p \leq 0.05$). In all cases, the assumption of normality was verified with the Shapiro-Wilk test, and the homogeneity of variances, with Levene's test (Contreras-Cruz, 2023).

Results and Discussion

Interaction of substrates and fertilizer doses on plant growth

The average values of the evaluated variables were statistically equal in the three assessed substrates; on the other hand, for the fertilization factor at the higher dose (10 g), the variables of height, diameter, aboveground dry biomass, and root biomass stood out. The substrate-fertilizer dose interaction significantly influenced the height, diameter, and aboveground dry biomass variables ($p<0.05$). In substrates S1 (60-20-20) and S2 (50-25-25) with 10 g L^{-1} of fertilizer, the plants exhibited higher values, unlike those produced in both substrates with the dose of 7 g L^{-1}. In the S3 substrate (33-33-33), the plants had similar values with both fertilizer doses (Table 2).

Table 2. Mean values, standard error and significance of the morphological variables evaluated in *Quercus durifolia* Seemen plants.

Factor	Height (cm)	Diameter (mm)	Dry biomass (g)		
			Aboveground	Root	Total
			Substrate		
S1	29.3±0.8 a	5.1±0.1 a	2.5±0.1 a	2.8±0.1 a	5.3±0.2 a
S2	28.0±0.9 a	4.9±0.2 a	2.5±0.1 a	3.0±0.2 a	5.5±0.2 a

S3	27.9±0.9 a	5.1±0.1 a	2.4±0.1 a	3.0±0.1 a	5.4±0.2 a
***p* value**	0.2475 ns	0.4365 ns	0.6871 ns	0.3557 ns	0.7735 ns
			Fertilizer dosage		
7 g L^{-1}	26.0±0.8 b	4.8±0.1 b	2.3±0.1 b	3.1±0.2 a	5.4±0.2 a
10 g L^{-1}	30.8±0.9 a	5.3±0.1 a	2.7±0.1 a	2.8±0.1 b	5.5±0.2 a
***p* value**	0.0001***	0.0001***	0.0001***	0.0166*	0.5804 ns
			Interaction		
S1+7 g L^{-1}	25.5±0.8 c	4.8±0.1 bc	2.2±0.1 b	2.9±0.1 a	5.1±0.2 a
S1+10 g L^{-1}	33.0±0.9 a	5.4±0.1 a	2.8±0.1 a	2.7±0.1 a	5.6±0.2 a
S2+7 g L^{-1}	25.5±0.8 c	4.6±0.2 c	2.4±0.12 b	3.2±0.2 a	5.6±0.3 a
S2+10 g L^{-1}	30.5±1.1 ab	5.3±0.1 ab	2.6±0.11 ab	2.7±0.1 a	5.4±0.2 a
S3+7 g L^{-1}	27.0±0.9 bc	4.9±0.1 abc	2.3±0.11 b	3.1±0.1 a	5.4±0.2 a
S3+10 g L^{-1}	28.9±0.9 bc	5.2±0.1 ab	2.6±0.12 ab	2.9±0.1 a	5.4±0.2 a
***p* value**	0.0001***	0.0002**	0.0005**	0.0977 ns	0.6322 ns

S1 (60-20-20), S2 (50-25-25), and S3 (33-33-33) of PM-CB-FPS (PM = Peat moss, CB = Composted pine bark, FPS = Fresh pine sawdust), respectively; *p* = Probability bounds in ANOVA; * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns = Not significant. Different letters in the same column indicate differences ($p\leq0.05$).

Based on the results, the plants exhibited morphological characteristics of quality in all the treatments used; for broadleaf species, Domínguez et al. (2023) recommend a height of over 15 cm for transplanting to the field; this was the case for all the plants transplanted in this study; however, the tallest plants were produced with 10 g L^{-1} of CRF. In this sense, Niemiera et al. (2014) indicate that plants produced on fresh sawdust-based substrates require more fertilizer to match the growth of plants grown on organic substrates, such as peat and bark. De Jesús et al. (2021) cite lower values than those of the present study for *Quercus rugosa* plants (heights from 15.9 to 24.4 cm) at 11 months of age grown on a substrate mixture of vermiculite (36 %), agrolite (16 %), and peat moss (48 %) with 4 kg m^{-3} of Osmocote® fertilizer (15-9-12, NPK, 5-6 months' release). In addition, they applied a (Peters®) water-soluble fertilizer at each growth stage to supplement their nutrition; their results are attributable to the fact that the CRF dose and nutrient release time were lower than those used in the trial with *Q. durifolia* (eight months of release).

According to Pinchot et al. (2018), the initial size of the plants is decisive for survival in the field, as shown for *Quercus rubra* L., whose plants with a larger height and diameter had greater survival rate and competitive ability in a dry environment in Pennsylvania, USA. In addition, larger individuals can resprout after damage caused by herbivores (Clark et al., 2015); this interaction is common during the vegetative period, due to the damage caused by fauna in oak regeneration (Perea et al., 2014).

Significant statistical differences ($p<0.05$) in diameter were observed between the fertilization doses and in the interaction between substrate and fertilization dose, with more favorable results in the S1+10 g L^{-1}, S2+10 g L^{-1}, and S3+10 g L^{-1} interactions (Table 2). The plants showed greater growth in diameter as the dose was increased from 7 to 10 g L^{-1}. In *Quercus crassipes*, Venancio et al. (2022) recorded values lower than those of the present study (3.6 to 4.3 mm) for a substrate mixture based on pine bark compost (60 %), vermiculite (30 %), and perlite (10 %) to which 3 kg m^{-3} of CRF Osmocote® were added; the fertilization was supplemented with Peters® water-soluble fertilizer. The lower values may be due to the fact that the plant was seven months old; a low dose of controlled-release fertilizer was applied to the soil. In the study with *Q. durifolia*, it was not necessary to apply water-soluble fertilizers because the doses of CRF were high and sufficient to favor proper plant growth; when low doses of CRF are used, it is necessary to supplement with water-soluble fertilizers as with CRFs the period of nutrient release varies (months), due to the effect of the temperature and the substrates used (organic substrates) (Madrid-Aispuro et al., 2020). It should also be considered that each species responds differently to the fertilizers and substrates used in this study.

Fertilization is a determining factor in the nursery production of holm oak plants, as it produces better growth in diameter, which will result in a greater competitive capacity than that of other fast-growing species in the sites where they are established, as pointed out by Pinchot et al. (2018). This has been confirmed by Ramírez-Contreras y Rodríguez-Trejo (2004), who planted *Q. rugosa* with two diameter sizes; plants with a diameter of 2 to 4 mm achieved higher survival (63 %), while plants with a diameter of less than 2 mm did not survive. Likewise, for *Quercus canbyi* Villalón-Mendoza et al. (2016) recommend larger diameters for reforestation in arid and semi-arid zones because a larger diameter size results in better lignification and denser roots.

Significant statistical differences ($p<0.05$) were observed in the aboveground dry biomass according to the fertilization dose and the interaction between the substrate and the fertilization dose, with more favorable results in plants fertilized with a dose of 10 g L^{-1} (2.8, 2.6, and 2.6 g, respectively), regardless of the substrate used. However, there were no significant differences in the root and total dry biomass variables or in the interaction between the factors. Villar-Salvador et al. (2012) document that plants fertilized with high doses tend to survive and grow longer after planting than poorly fertilized plants because they have reserves of mineral nutrients in their tissues —resources needed for their initial growth. This has been confirmed by Sáenz et al. (2014), who point out a high correlation between plant biomass and field survival.

The high dose of fertilizer influenced plant growth by allocating more resources to aboveground dry biomass. The results of the treatments with fertilization doses of 10 g L^{-1} (5.5 g total dry weight, 2.7 g aboveground dry weight, and 2.8 g root dry weight, on average) were superior to those cited by De Jesús et al. (2021) for *Quercus rugosa* (4.3 g total dry weight, 2.4 g aboveground weight, and 1.9 g root weight) grown on a substrate composed of vermiculite (36 %), perlite (16 %), and peat moss (48 %), to which 4 kg m^{-3} of CRF Osmocote® substrate were added. Venancio et al. (2022) obtained lower values in *Q. crassipes* (2.8 g total dry weight, 1.3 g aboveground weight, and 1.5 g root weight) in a mixture consisting of pine bark compost (60 %), vermiculite (30 %), and perlite (10 %) with 3 kg m^{-3} of Osmocote® CRF; the low values may be due to the fact that the plant was seven months old and a low dose of controlled-release fertilizer was applied.

The fertilizer dose employed herein (7 and 10 g L^{-1}), reflected in greater aboveground growth, may have caused these contrasting results. Also, the substrates used (fresh sawdust and composted pine bark) require higher doses of fertilization during plant growth because there is greater immobilization of soluble nitrogen (Aguilera-Rodríguez et al., 2021). Furthermore, supplementing with a water-soluble fertilizer was not necessary as suggested by Madrid-Aispuro et al. (2020) for use with lower doses of controlled-release fertilizer.

The substrate factor significantly influenced ($p<0.05$) the proportion of stem biomass, with the S1 treatment being the most important. The fertilizer dose influenced the proportion of leaf, stem, and root biomass; the dose of 10 g L^{-1} stood out, except in the proportion of root biomass. Regarding the substrate-fertilizer dose interaction, there were significant differences in the proportion of stem and root biomass, with the best interaction in S1+10 g L^{-1}, whereby more biomass was allocated to the stem and less to the root. The opposite occurred with the treatments with fertilizer doses of 7 g L^{-1}, in which the plants assigned a smaller percentage of biomass to the stem, but more than 50 % to the root biomass, while the leaf biomass was similar in all treatments (25.5 to 28.6 %) (Table 3).

Table 3. Aboveground and root biomass allocation patterns in *Quercus durifolia* Seemen plants in response to substrate mixtures and controlled-release fertilizers.

Factor	Proportion of leave biomass (%)	Proportion of stem biomass (%)	Proportion of root biomass (%)
		Substrate	
S1	27.4±0.9 a	20.4±0.8 a	52.2±1.4 a
S2	27.1±0.8 a	19.1±0.7 ab	53.8±1.1 a
S3	27.0±1.0 a	18.2±0.8 b	54.8±1.2 a
***p* value**	0.9043 ns	0.0171*	0.1272 ns

		Fertilizer dose	
7 g L^{-1}	25.8±1.1 b	17.5±0.7 b	56.7±1.4 a
10 g L^{-1}	28.6±0.8 a	21±0.8 a	50.5±1.1 b
***p* value**	0.0004**	0.0001***	0.0001***
		Interaction	
S1+7 g L^{-1}	26.3±1.2 a	17.8±0.6 c	55.9±1.7 a
S1+10 g L^{-1}	28.6±0.7 a	23.0±0.9 a	48.4±1.2 b
S2+7 g L^{-1}	25.7±0.9 a	16.9±0.7 c	57.4±1.1 a
S2+10 g L^{-1}	28.5±0.7 a	21.3±0.7 ab	50.2±1.1 b
S3+7 g L^{-1}	25.5±1.1 a	17.7±0.7 c	56.8±1.3 a
S3+10 g L^{-1}	28.6±1.0 a	18.7±0.8 bc	52.7±1.1 ab
***p* value**	0.0246*	0.0001***	0.0001***

S1 (60-20-20), S2 (50-25-25), and S3 (33-33-33) of PM-CB-FPS (PM = Peat moss, CB = Composted pine bark, FPS = Fresh pine sawdust), respectively; *p* = Probability bounds in ANOVA; * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns = Not significant. Different letters in the same column indicate differences ($p \leq 0.05$).

Similar results were recorded by Andivia et al. (2014) for *Quercus ilex* L.: with low nitrogen doses, the plants allocated more biomass to the roots (80 %) than to the stem (5 %) or the shoots (15 %). According to Villar et al. (2008), the plant invests its resources differently among the organs, that is, with a greater amount of biomass in the leaves, the area for photosynthesis increases and carbon assimilation is greater; however, this makes the plants more susceptible to death by drought at early ages. On the other hand, the greater the allocation of biomass to the roots, the more water and nutrients the plants take up from the soil. With most treatments, the plants in the study documented herein allocated more than 50 % of biomass to the root, which may provide some advantages by increasing their water absorption area, mainly in areas with a shortage of moisture and nutrients (Dey et al., 2008).

Finally, fertilization was a key factor in biomass allocation, as this varied according to the amount of fertilizer applied; the lower dose prompted greater root and stem development. In this sense, Aldrete et al. (2024) point out that a high-quality plant must maintain a balanced proportion between the size of the aboveground part and that of the root system while the number of leaves must be sufficient to maximize the absorption of sunlight, but without exceeding the energy expenditure associated with the transpiration process.

Leaf N, P, and K concentration and content

In all treatments, the percentages of N, P, and K were within the ranges recommended by Jacobs and Landis (2014) for tropical species produced in containers. Overall, increasing the fertilizer dose generated more proportional nutrient content in the leaves (Table 4).

Table 4. Leaf concentration and content N, P, and K in nursery-grown *Quercus durifolia* Seemen plants.

Treatment	**Concentration (%)**			**Content (mg plant^{-1})**		
	N	**P**	**K**	**N**	**P**	**K**
S1+7 g L^{-1}	2.35	0.13	1.11	30.88	1.71	14.59
S1+10 g L^{-1}	2.32	0.15	1.30	36.45	2.36	20.43
S2+7 g L^{-1}	1.85	0.13	1.25	26.70	1.88	18.04
S2+10 g L^{-1}	2.36	0.14	1.21	35.71	2.12	18.31
S3+7 g L^{-1}	2.02	0.16	1.28	27.24	2.16	17.26
S3+10 g L^{-1}	2.31	0.12	1.32	35.20	1.83	20.11
RV	1.5-3.5	0.10-0.25	0.60-1.80			

S1 (60-20-20), S2 (50-25-25), and S3 (33-33-33) of PM-CB-FPS (PM = Peat moss, CB = Composted pine bark, FPS = Fresh pine sawdust), respectively. RV = Recommended values (Jacobs & Landis, 2014).

De Jesús et al. (2021) reported values of 1.3, 0.15, and 0.97 N, P, and K in *Quercus rugosa* plants grown in a substrate composed of vermiculite, perlite, and peat moss to which they added 4 kg m^{-3} of CRF Osmocote® and Peters® water-soluble fertilizer. In this case, higher values of nitrogen (1.85 to 2.36 %) and potassium (1.11 to 1.32 %) were obtained, while phosphorus values were similar (0.12 to 0.16 %); it should be mentioned that the substrates used were organic and no water-soluble fertilizer was applied.

In all treatments, the fertilizer doses used can be considered adequate to produce plants with size proportions indicative of good quality. Grossnickle and Ivetić (2022) suggest that high doses of fertilizers will provide the plants with nutrient reserves that will improve their physiological state, growth, and survival after planting, especially in soils with low fertility and competition with weeds; however, there is also the risk of promoting the proliferation of fungi that cause damping-off (García, 2022).

Conclusions

A substrate composed of peat moss (60 %), composted bark (20 %), and fresh sawdust (20 %) with 10 g L^{-1} of CRF produces plants with adequate attributes in terms of height, diameter, and aboveground dry biomass; also, it increases the stem biomass. The substrate mixture of equal parts of peat, composted bark, and fresh sawdust (33-33-33) with 10 g L^{-1} of fertilizer also results in plants with high-quality morphological characteristics. These results suggest that fresh pine sawdust, incorporated into the substrate in a proportion of up to 33 %, is a viable alternative to produce *Quercus durifolia* plants in nursery. However, further research on the use of alternative substrates and fertilization rates is needed due to the paucity of information available for nursery propagation of *Quercus* species. This is crucial to obtain quality plants for reforestation and restoration projects with *Quercus durifolia*, a species that is mainly distributed in transition zones of the *Sierra Madre Occidental*.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Rosa Elvira Madrid-Aispuro: experiment design and setup, statistical analysis of data, and drafting of the manuscript; Marina Danaee Cordova-Saucedo: experiment setup and data collection and capture; José Ángel Prieto-Ruíz: experimental design, setup, and supervision and revision of the manuscript; Arnulfo Aldrete: experimental design, and supervision and revision of the manuscript; Silvia Salcido-Ruiz: experiment setup and supervision, and revision of the manuscript; Alberto Pérez-Luna: experiment supervision and revision of the manuscript.

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