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ORIGINAL ARTICLE – Silviculture

Compost Increases Soil Fertility and Promotes the Growth of Five Tropical Species Used in Urban Forestry

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Abstract

This study aims at assessing the impact of compost application on the physical (porosity, volumetric-moisture and bulk density) and the chemical traits of soil (pH, organic carbon, electrical conductivity, cation exchange capacity and soil nutrients) on the leaf nutrient concentration and growth (height, diameter, new leaf-structures and chlorophyll content) of five native species used in urban forestry. Using a two-way factorial design, we evaluated three substrates: i) Soil (ii) Soil-compost mixture SC-12.5 (12.5 % compost (v/v)) (iii) Soil-compost mixture SC-25 (25 % compost (v/v)) and five species: *Retrophyllum rospigliosii*, *Inga edulis, Citharexylum montanum, Caesalpinia spinosa,* and *Citharexylum sulcatum*. We found that SC-25 and SC-12.5 increased the electric conductivity, cation exchange capacity, organic carbon, and soil base saturation. Moreover, compost addition increased the growth of the five native species evaluated. Such results suggest that compost-application is a viable option to improve soil fertility and promote the growth of native trees.

Keywords: Urban soils, Physicochemical properties, Legumes, Native tree, Organic matter.

1. INTRODUCTION

An important consideration in urban forestry is assuring tree survival, which is influenced by tree management techniques both in the nursery and during transplanting. Managing soil quality is vitally important to successful vegetation establishment in urban environments (Hilbert *et al*., 2019). Besides providing support, soil stores water and nutrients and allows gas exchange to and from the root system of plants. Organic matter content, structure, bulk density, and available volume are important soil traits of soil quality and, therefore, for the development of urban trees (Hilbert *et al*., 2019). Unfortunately, the soil traits required to satisfy tree growth in urban environments are unknown (Scharenbroch *et al*., 2017).

Assuring soil fertility is even more important during the establishment of urban trees, in which trees undergo several stresses (Hilbert *et al*., 2019). According to Allen et al. (2017), root loss and desiccation, wounds, hole-position, loss of root-soil contact, and lack of irrigation are common factors that harm plant development during the early years of establishment. Additionally, heat stress during establishment, intensified by heat island effect and by water stress because of impervious soil, stimulates a physiological unbalance which can result in tree death (Chen *et al*., 2017).

Adding organic soil amendments like compost is considered a viable option to maintain or recover soil quality as well as promote vegetation establishment in urban areas because organic amendments improve growing conditions and increase the lifespan of trees and bushes that are frequently planted in poor or impervious soils (McGrath *et al*., 2020). Organic amendments used on degraded soils contribute to erosion control, the reduction of evaporation, increased percolation, improved water storage, and better nutrient release. These conditions create an environment that promotes the growth of healthy roots (McGrath *et al*., 2020).

Species selection is another important aspect for the successful establishment of urban trees: species are chosen considering their adaptability, function, and aesthetic (Watkins *et al*., 2021). In Colombia, using native species in urban landscaping has been promoted to strengthen the ecological identity and function of the city (Marin and Osorio, 2019). Considering the cultural importance and the ecological benefits of native species, like ecological integrity and resilience to climate change (Khan and Conway, 2020), one might expect that native species would be common in the majority of urban forests. However, exotic species still predominate in both tree number and species number (Tovar Corzo, 2016).

Although there have been efforts to plant native species in urban areas in Colombia (Moreno and Hoyos 2015), there is limited knowledge of the soil conditions needed to promote the establishment and adaptation of such species in the urban environment. Additionally, there is little research about the effect of compost on the establishment of native tree species. Therefore, we aimed to evaluate the effect of compost application on the chemical and physical fertility of soil represented by pH, effective cation exchange, nutrient concentration, organic matter, volumetric moisture and bulk density, and on tree growth (height, diameter, the number of leaf structures) and the chlorophyll content of five native species used in urban forestry: *Retrophyllum rospigliosii*, *Inga edulis*, *Citharexylum montanum*, *Caesalpinia spinosa* and *Citharexylum sulcatum*. We expected that compost application increases the physical and chemical fertility of the soil and consequently the growth of native trees.

2. MATERIALS AND METHODS

2.1. Plant and substrate material

This study was carried out from August 2017 to February 2018 in Chia, Colombia (4° 53' 06" N and 74° 00' 48.1" W). In a greenhouse with a daily mean temperature of 15°C and a relative humidity of 84.5 %. We planted five native species used in urban forestry: *Retrophyllum rospigliosii*, (pino romerón), *Inga edulis* (guamo santafereño), *Citharexylum montanum* (cajeto), *Caesalpinia spinosa* (dividivi) and *Citharexylum sulcatum* (cajeto de páramo). The planted trees had an average height of 1.2m and an age from 12 to 15 months.

We used a two-way factorial design in which the factors were the species and the substrates. There were fifteen trees per species, five trees per substrate, in which each tree was an experimental unit. The evaluated substrates were: i) Control (soil) (ii) Soil-compost mixture SC-12.5 (12.5 % of compost (v/v)) (iii) Soil-compost mixture SC-25 (25 % of compost (v/v)). Compost proportion of 10-25 % was chosen because of its benefits on tree growth and soil traits (McGrath and Henry, 2016). Before transplanting, we pruned girdling roots to avoid growth limitations. Then, the trees were planted in plastic bags of 60L, which were filled with each substrate specified for the treatment. Trees were placed 1.5m apart from each other.

In all substrates, the soil contained 10% of rice husk (v/v). Soil traits were: loam texture (45.5 sand, 43.3 silt, and 9.1 % clay) by Bouyoucos method; pH of 6.1 by soil:water 1:1; Organic Carbon of 3.13 % by Walkley & Black. Exchangeable bases by ammonium acetate method (245 mg kg^{-1} K, 2956 mg kg^{-1} Ca, 75 mg kg^{-1} Na, 397 mg kg^{-1} Mg; UNICAM 969 spectrophotometer); P of 48.2 mg kg^{-1} by Bray II (SHIMADZU UV1900i UV-VIS spectrophotometer); minor elements by DTPA 1:2 (123.9 mg kg^{-1} Fe, 6.0 mg kg^{-1} Mn, 1.53 mg kg^{-1} Cu, 2.43 mg kg^{-1} Zn); B of 0.15 mg kg^{-1} in saturated paste by the Azomethine-H method, mineral nitrogen of 10.6 mg kg^{-1} by Kjeldahl method; electrical conductivity of 0.54 dS m^{-1}; cation exchange capacity (CEC) of 39.1 cmol$^{(+)}$ kg^{-1} .

The compost (TerraViva LTDA Bogotá) traits were: pH 6.9 (saturated extract), organic carbon 9.94% (calcination at 550°C), K 0.31, Ca 9.50; Mg 0.32, Na 0.21; P 0.30 % (Bray II); minor elements by DTPA 1:2 (Fe 7485 mg kg^{-1}, Mn 119 mg kg^{-1}, Cu 9.9 mg kg^{-1}, Zn 47.9 mg kg^{-1}); B 24.8 mg kg^{-1} (calcination at 550°C); N total 0.94 % by Kjeldahl (KCL 1N), 2.0 dS m^{-1} electrical conductivity (saturated extract); 35.2 cmol$^{(+)}$ kg^{-1} Cation Exchange capacity (CEC); 10.54 C/N rate.

2.2. Physicochemical traits of substrates

In accordance with the methodology proposed by Arshad et al. (1996), after six months we measured porosity, volumetric moisture and bulk density by the equations 1, 2 and 3:

$$Porosity(\%) = \frac{VV}{TV} \tag{1}$$

$$Volumetric\ moisture(\%) = \frac{WV}{TV} * 100 \tag{2}$$

$$Bulk\ density\ (g\ cm^{-3}) = \frac{DW}{TV} \tag{3}$$

VV: Void Volume ($TV - SV$);
SV: Soil Volume (a particle density of 2.6 g cm^{-3} was assumed).
TV: Total volume;
DW: Dry weight of soil;
WV: Water volume;

Chemical analysis of substrates was performed in accordance with Zamudio Sánchez (2006). pH was measured by potentiometer method; organic carbon by Wakley and Black method (% p/v) (1934); exchangeable acidity by potassium chloride (KCl 1N) and quantification by volume; cation exchange capacity and base saturation (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) by neutral extraction with ammonium acetate (NH_4Ac 1M), and quantification by atomic absorption; total phosphorus (P) by fusion sodium-nitrate/potassium-nitrate and quantification by visible spectrometry (UNICAM 969).

2.3. Leaf nutrient concentration

In the last month, we sampled fully developed leaves from the middle part of each tree canopy and collected three leaves per species per substrate. The leaves were dried in an oven at 70°C until constant weight. Nitrogen was determined in accordance with the Kjeldhal method (Kjeldhal, 1883). Phosphorus and boron concentrations were evaluated by colourimetry Azomethine-H method. (Gaines and Mitchell, 1979). Macronutrients (Ca, Mg, and K) and micronutrients (Fe, Zn, Cu, and Mn) were evaluated by atomic absorption spectroscopy. Sulfur was determined by turbidimetry (Zamudio, 2006).

2.4. Growth and chlorophyll measurements

Tree growth was calculated monthly throughout six months period with these variables:

Stem growth (cm month^{-1}): Tree height was measured from root shank to apical bud. Monthly height increase was averaged for six months.

Radial stem growth (mm month^{-1}): Stem diameter was measured in the stem-base with a digital caliper, placing the instrument in the same position for each measurement. The radial stem growth was calculated by subtracting the diameter measured just after transplanting from the first to sixth months.

Number of new leaf-structures: Leaves, leaflets or twigs were counted considering the leaf structure of each species. Therefore, simple leaves were counted for *Citharexylum subflavescens* and *Citharexylum sulcatum*, compound leaves were counted for *Caesalpinia spinosa*, leaflets were counted for *Inga edulis,* and small twigs were counted for *Retrophyllum rospigliosii*. Finally, the number of new leaf structures per month was calculated by subtracting the number of leaf structures just after transplanting from the leaf structures of the second to sixth months.

Chlorophyll content (CCI): Using a chlorophyll meter MC 100 (Apogge Instruments, United Kingdom), the chlorophyll concentration was measured. We took three fully developed leaves per tree and the average of four measurements per leaf was calculated. The measurement was made in the middle part of the leaf blade. This procedure was carried out for all species except *Retrophyllum rospigliosii* whose leaves were too small to be measured by the instrument MC 100.

2.5. Statistical analysis

Shapiro-Wilk and Levene tests were performed to evaluate normality and homocedasticity, respectively. After, a two-way ANOVA test was performed to assess the effect of substrate, species and their interaction on height and radial stem growth. Then, Pairwise comparisons were carried out using a Tukey HDS test ($p<0.05$). Variables without a normal distribution nor homogeneity of variances (physicochemical traits of the soil and nutrient concentration in the leaves) were analyzed by a non-parametric Kruskal-Wallis test. Then, we conducted Dunn´s post hoc test ($p<0.05$) with Bonferroni correction according to McDonald (2009).

Variables measured over time but without a normal distribution nor homogeneity of variances (number of new leaves and chlorophyll concentration) were analyzed by a longitudinal profile analysis (Feys 2016), in which substrates and species were the between-subjects factors and time the within-subject factor. For this, we used rank-based nonparametric methods considering a F2-LD-F1 design of nparLD package (Noguchi *et al.*, 2012). After we had identified differences by factor, we used the same profile analysis to assess differences among levels of each substrate. All data were analyzed using R 4.0.2 (R Core Team 2020).

3. RESULTS

3.1. Changes in physicochemical soil properties

There were no significant differences in physical traits (porosity, bulk density, and volumetric moisture) between substrates and species (Table 1). On the other hand, significant differences in the soil's chemical traits were found among the levels of the substrate factor ($p \leq 0.05$). In substrates amended with compost, soil pH increased up to a maximum value of 7.8, a 23 % difference when compared with control (Table 1) but there were no significant differences in pH soil between compost treatments ($p>0.05$).

The application of compost increased electric conductivity, effective cation exchange capacity, soil organic carbon, and base saturation. According to the treatment, values of these

Table 1. Effect of the treatments on physical and chemical soil traits.

Parameter	Control	Compost 12.5 %	Compost 25 %
VM (%)	36.8±4.7 a	35.4±5.4 a	36.8±5.9 a
BD (%)	0.84±0.07a	0.85±0.03 a	0.87±0.09 a
PR (%)	67.9±2.9 a	67.2±2.6 a	66.6±3.6 a
pH	6.3±0.2 b	7.8±0.3 a	7.8±0.1 a
EC (dS m^{-1})	0.21±0.03 b	0.44±0.06 a	0.47±0.22 a
BS (%)	78.1±7.1 b	83.7±4.2 ab	85.5±6.6 a
OM (%)	5.0±9.1 a	5.8±1.1 a	5.5±1.6 a
OC (%)	2.9±0.8 b	3.4±0.6 ab	3.8±0.9 a
CECe (cmol $^{(+)}$ kg^{-1})	16.9±2.6 b	30.9±4.2 a	32.6±10.8 a
N-NH4 (mg kg^{-1})	12.6±11.7 a	7.4±5.4 a	17.5±19.3 a
N-NO3 (mg kg^{-1})	8.7±7.5 b	9.7±2.5 ab	16.4±13.0 a
N-Min (mg kg^{-1})	26.8±21.1 b	18.4±17.0 b	36.3±24.5 a
P (mg kg^{-1})	58.1±13.1 b	106.0±21.0 ab	114.1±36.5 a
K (mg kg^{-1})	465.0±93.0 b	896.0±160.0 ab	943.0±209.0 a
Ca (mg kg^{-1})	2392.0±569.0 b	4781.0±895.0 ab	5050.0±2038.0 a
Mg (mg kg^{-1})	481.0±71.0 ab	467.0±69.0 b	510.0±37.0 a
Na (mg kg^{-1})	48.0±19.0 b	180.0±128.0 ab	229.0±227.0 a
S (mg kg^{-1})	5.7±3.2 b	10.8±2.3 ab	15.0±10.3 a
Fe (mg kg^{-1})	121.7±65.8 a	74.3±19.2 b	97.6±28.8 ab
Mn (mg kg^{-1})	5.2±0.7 a	3.0±0.3 b	3.1±1.1 ab
Zn (mg kg^{-1})	3.1±1 b	7.5±2.8 ab	7.6±2.3 a
B (mg kg^{-1})	0.2±0.1 b	0.1±0.2 b	0.6±0.2 a

Results of each treatment are expressed as the median and interquartile range (25-75 %). Means followed by the same letter inside the same column are not significantly different ($p<0.05$, Kruskal- Wallis test); $n = 45$. NS symbolizes no significant differences. VM: Volumetric Moisture; BD: Bulk Density; PR: Porosity; EC: Electric Conductivity. BS: Base Saturation Percentage; OM: Organic Matter; OC: Organic Carbon; CECe: Effective Cation Exchange Capacity.

parameters, in descending order, were: SC-25 > SC-12.5 > Control (soil) (Table 1). However, compost addition did not significantly affect the organic matter.

Compared with the control treatment, SC-25 substrate had 35, 96, 103, 111, and 6 % more N, P, K, Ca, and Mg content, respectively (Table 1). Regarding the micronutrient concentration, the highest values of Fe and Mn were obtained with the control treatment (un-amended soil), while Zn and B concentrations were higher with SC-25 treatment (Table 1). With this treatment, the Ca/Mg relation increased by 88 %, while Mg/K relation decreased significantly compared to the control.

Contrasting with control treatment, NO$_3$ concentration increased by 88 % with the SC-25 treatment. In contrast, there were no significant differences in ammonium concentrations (NH$_4$) among the substrates ($p>0.05$).

3.2. Foliar nutrient concentration of species

Contrary to expectations, the increase in soil nutrient concentration following compost addition did not show any effect on foliar nutrient concentration ($p<0.05$). As a consequence, foliar nutrient concentration differences were explained by the species factor. N foliar concentration was significantly higher in *I. edulis*. This species had 63 and 73 % more N than *R. rospigliosii* and *C. spinosa,* respectively, and 85 % more than both *C.sulcatum* and *C. subflavescens* (Table 2). The highest Na foliar concentration was found in *Retrophyllum rospigliosii.* Additionally, the highest Ca, Mg, and micronutrients (except B) concentration were found in *C. subflavescens* and the lowest in *C. spinosa* (Table 2). P and K concentrations did not show significant differences for species factor.

3.3. Compost effect on species growth

In general, the addition of compost significantly affected all tree growth parameters. Stem height, radial stem growth and the number of foliar structures were higher with at least one of the compost treatments in comparison with the control treatment (Table 3). Additionally, there was an interaction between compost addition and the species for the number of foliar structures (Figure 1) and foliar chlorophyll concentration (Figure 2).

Application of the SC-12.5 soil-compost mixture increased the stem height and the radial growth by 86 and 67 % in comparison to the control treatment (Table 3). Regarding species, the growth rate, in descending order, was: *C. spinosa* > *I. edulis* > *C. subflavescens* > *R. rospigliosii* > *C. sulcatum.* For radial growth rate the order was: *C. subflavescens* > *C. sulcatum* > *R. rospigliosii* > *I. edulis* > *C. spinosa.*

Table 2. Concentration of macro and micro-nutrients in leaves of the evaluated species six months after transplanting.

Parameter	*R. rospigliosii*	*I. edulis*	*C. sulcatum*	*C. spinosa*	*C. subflavescens*
N (%)	1.6±0.16 b	2.6±0.23a	1.4±0.3b	1.5±0.3b	1.4±0.2 b
P (%)	0.14±0.08 a	0.17±0.02 a	0.19±0.01 a	0.17±0.04 a	0.19±0.03 a
K (%)	1.1±0.2 a	0.9±0.2 a	1.0±0.27 a	0.9±0.12 a	0.9±0.09 a
Ca (%)	1.5±0.4 ab	0.7±0.67 bc	1.1±0.53 abc	0.7±0.2 c	1.7±0.4 a
Mg (%)	0.29±0.07 ab	0.15±0.07c	0.21±0.1 abc	0.13±0.04 c	0.35±0.09 a
S (%)	0.08±0.02 bc	0.11±0.02 ab	0.08±0.02 abc	0.06±0.01c	0.13±0.06 a
Na (mg kg^{-1})	350±490 a	80±20 bc	70±50 c	70±70 bc	70±40 bc
Fe (mg kg^{-1})	293±162 a	247±94 a	188±37 a	233±123 a	269±101 a
Mn (mg kg^{-1})	51.8±67.5 ab	52.3±23.5 a	22.6±13.9 ab	17.0±11.9 b	29.2±7.3 a
Cu (mg kg^{-1})	12.7±3. a	6.8±1.1 b	11.9±3.9 a	4.90±1.9 b	12.9±6.5 a
Zn (mg kg^{-1})	17.2±2.5 bc	32.4±10.1 b	62.7±28.2 a	16.2±3.4 c	62.1±37.2 a
B (mg kg^{-1})	27.3±8.1 a	32.4±10.7 a	45.7±24.6a	10.7±4.1 b	50.6±3.6 a

Results of each treatment are expressed as the median and interquartile range (25-75 %). Means followed by the same letter inside the same column are not significantly different (p<0.05, Kruskal-Wallis test); n = 45. NS symbolizes no significant differences.

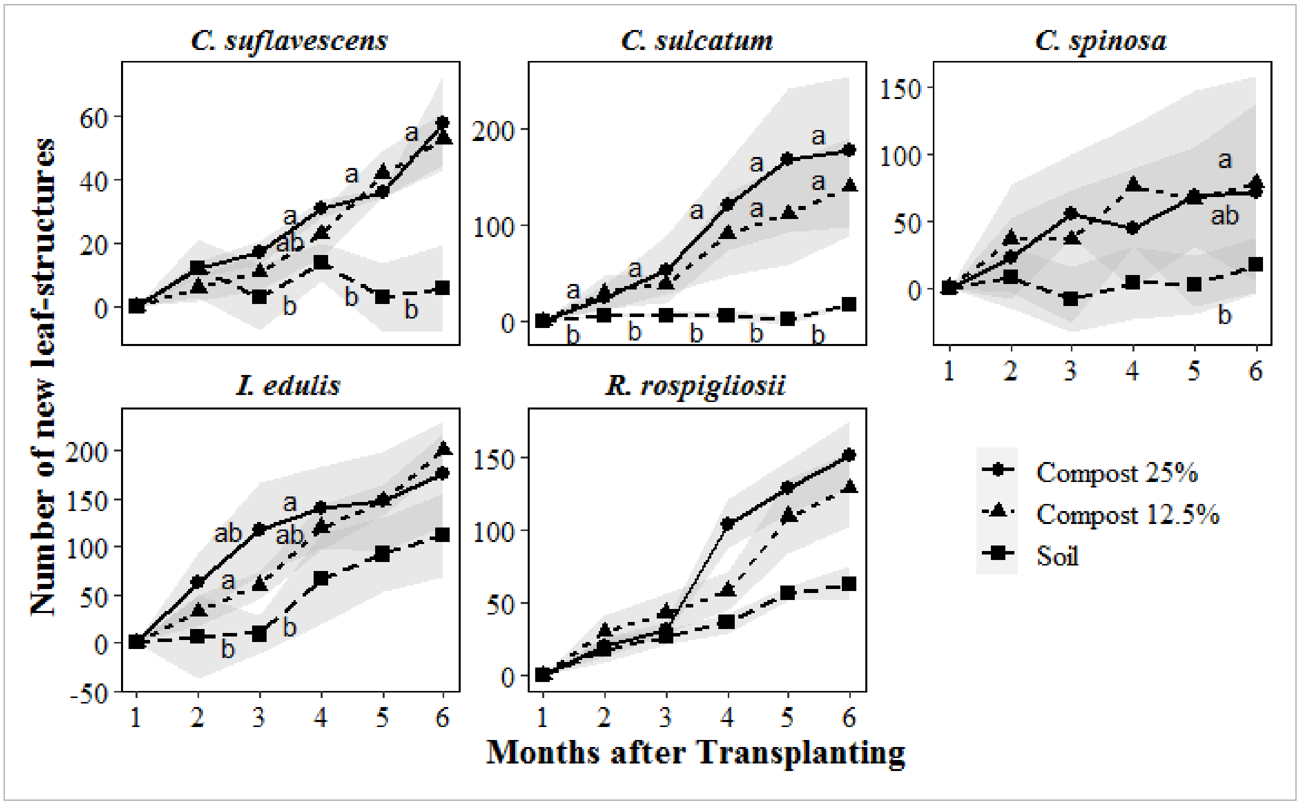

Figure 1. Number of new leaf structures of five tropical species during the first six months after transplanting. The gray ribbon represents the interquartile rank. Medians-segments of each treatment, marked with different letters, are significantly different at p<0.05(n = 5).

Table 3. Effect of treatment, species, and their interaction (Treatment*species) on stem growth and radial stem growth.

Source of variation/ variable	SG (cm month^{-1})	RSG (mm month^{-1})
Substrate		
SC-12.5	3.03 a	1.12 a
SC-25	2.42 ab	1.07 a
Soil	1.63 b	0.67 b
Significance	*	**
Specie		
R. rospigliosii	2.06ab	0.87 bc
I. edulis	2.9ab	0.83 bc
C. sulcatum	1.25b	1.21 ab
C. spinosa	3.43 a	0.67 c
C. subflavescens	2.12ab	1.30 a
Significance	*	**
Substrate*Species	NS	NS

In each column, means followed by different letters represent significant differences according to Tukey's test ($p \leq 0.05$; n = 5). NS = non-significant differences. ***p*<0.001; **p*<0.05. SG: stem growth, RSG: Radial stem growth.

Additionally, compost application, species, and their interaction significantly affected the number of leaves. An increase in the number of leaves was observed when compost was added, compared with the control treatment. The monthly gain in the number of leaves did not show significant differences between the amended treatments but did with the control treatment.

In all species, the addition of compost promoted leaf growth at different moments depending on the species. However, the species of the *Citharexylum* genus benefitted the most compared to legumes (*I. edulis* y *C. spinosa*) (Figure 1).

3.4. Chlorophyll Content

The relative concentration of chlorophyll also showed differences among species, substrates, the month after transplanting, and their interaction. *I. edulis* had the highest median (73.8 CCI), followed by *C. spinosa* and *C. sulcatum* (42.3 and 33.28 CCI respectively); in contrast, *C. subflavescens* showed the lowest chlorophyll concentration (23 CCI). The application of compost increased chlorophyll concentration in the first month in all species except *I. edulis*. However, these increases were more stable over time with SC-12.5 than with SC-25 (Figure 2). For *C. subflavescens,* the increase in chlorophyll concentration promoted by compost application lasted until the fifth month after transplanting (Figure 2).

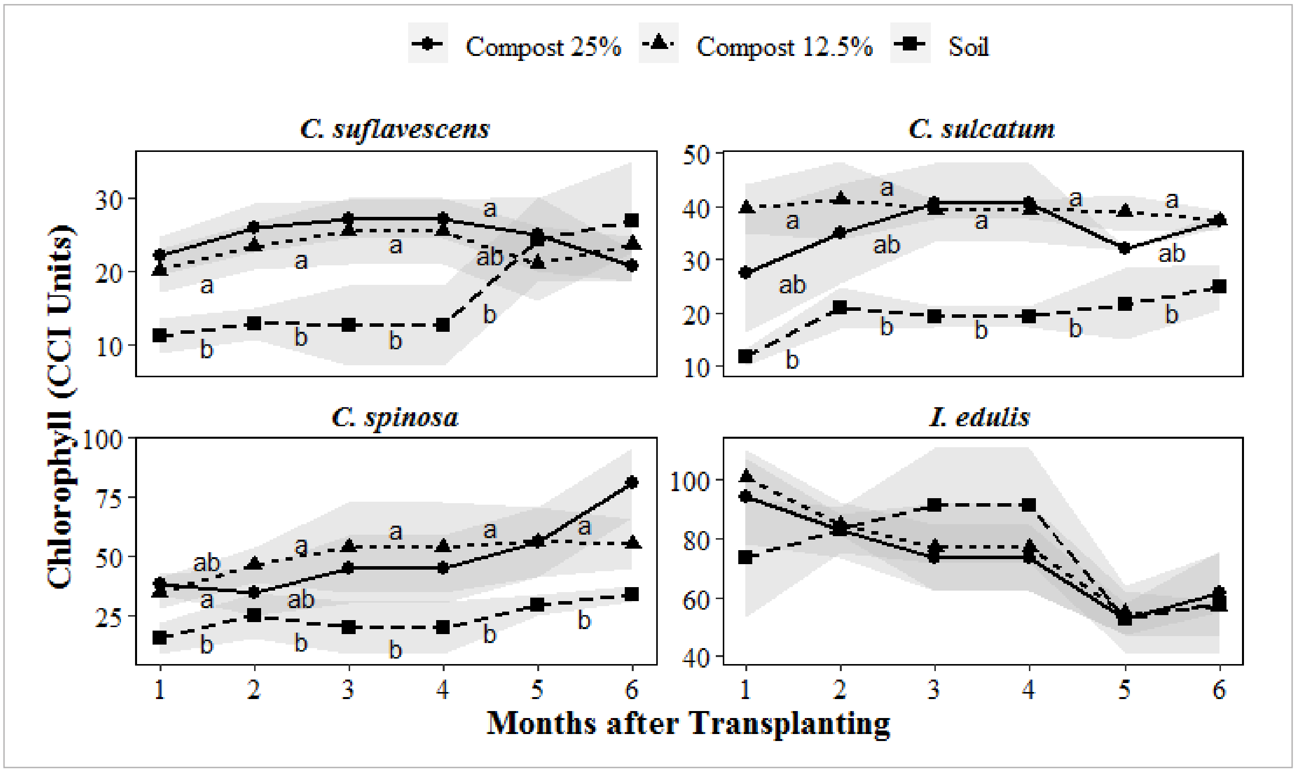

Figure 2. Chlorophyll concentration of four tropical species during the first six months after transplanting. The grey ribbon represents the interquartile rank. Medians-segments of each treatment, represented by different letters, are significantly different at *p*<0.05(n = 5).

4. DISCUSSION

4.1. Compost effect on physicochemical soil properties

The significant increase of soil pH after compost application might be related to the input of basic cations such as K^+, Ca^+, and Mg^+ and to the complexation of free H^+ and Al^{3+} ions with organic ligands (McGrath et al. 2020). These reactions are consequences of the dissolution of alkaline compounds found in the compost, including ash (Cogger 2005; Ghosh et al. 2014). In this study, pH changed from slightly acidic (6.3) to slightly alkaline (7.8), an increase of 1.5 units. Most studies report that the addition of compost increases the pH between zero and one unit (Cogger, 2005; Roberts, 2006). However, the changes are proportional to the application rate and the initial pH value (Nanda and Berruti, 2021) and also depend on the origin and composition of the waste (Bhunia *et al*., 2021).

The increase of effective CEC and base saturation in compost treatments is directly related to the increase in pH. According to Sayara et al. 2020, the increase in charge density of carboxylic and phenolic groups of the soil's organic matter after the increase in the pH due to the addition of organic amendments may be related to the increase in the CEC. This relationship has also been described by do Carmo *et al.* (2016), who reported that soils treated with organic waste compost and animal manure had significant higher base saturation, pH, and CEC compared to soils treated with peat, sewage sludge, and those without amendments; according to this study, this effect was probably due to the base cation entry and alkaline potential of the waste.

The increase in the organic carbon content is related to CEC rise because of the high negative charge of organic matter, which is important to retain nutrients and transform them into available forms for the plants (Bhunia *et al*., 2021). The organic carbon increase with compost addition may occur due to the extra organic material that stimulates microbiological activity in the soil and leads to fast mineralization of organic matter (Curci *et al*., 2020).

Compost also stimulates soil microbiological activity like N mineralization, which makes nutrients more available at slower rates than mineral fertilizers (Li *et al*., 2018). Previous research reports the benefits of compost addition to the soil with respect to its physicochemical properties and its relation with the improvement of morpho-physiological traits of different tree species (Ghosh *et al*., 2014). This may suggest that the positive effects are specific according to the region, environment, and species evaluated. It is worth noting that the positive effects of compost on soil conditions and the growth of species take less than a year to visualize.

The increase in soil EC after the application of compost may be associated with the increase in pH and with the nutrients and salt of the compost (do Carmo *et al*., 2016). The value of EC of this study didn't reach noxious salinity levels for sensitive species (Arora and Dagar, 2019).

The physical properties (volumetric moisture, bulk density, and porosity) of the treatments evaluated in this study did not show differences among them. According to McGrath et al. (2020), the benefits of compost addition on physical soil properties are less evident in the short term; this indicates that an increase in the study duration would probably have shown a positive trend in these traits.

4.2. Compost effect on nutrients accumulation

Just like other chemical properties of substrates, the macronutrient content of soil, mainly P and K, was affected by the addition of compost. According to the compost proportion applied to the substrates, SC-25 was the treatment that, in general, caused the highest increase in the chemical fertility of the substrates. The capacity of compost to increase the nutrient availability for plants has been reported in other studies. For example, Curci et al. (2020) reported that an increase in the field capacity, the N and P concentration in the soil, increases the quantity of compost. Likewise, Oechaiyaphum et al. (2020) reported that, during the first year of application, the P and K concentrations on soil increased after the application of compost at rates of 225 and 24 %, respectively.

4.3. Foliar nutrient concentration of evaluated native species

Differences in foliar concentration of N are directly related to the capacity of fixation of this nutrient that some species have (Drechsel and Zech, 1991). The capacity of *I. edulis* for fixing N_2 biologically would explain the high N concentration in leaves (Azani et al. 2017). In contrast, most species of Caesalpinioideae subfamily, including *C. spinosa,* are non-nodulating species (Azani et al., 2017) which may be the reason why *C. spinosa* obtained a lower foliar nitrogen concentration than *I. edulis*, and statistically equivalent to that of the other species (Aidar *et al*., 2003). The low foliar nutrient concentration obtained in *C. spinosa* may be related to a high foliar concentration of polyphenolic compounds, mainly tannins, which are related to its protective function against insects and herbivores (Dhivya, 2022)

Calcium foliar concentration in *C. subflavescens* and *C. sulcatum* was equivalent to 57 and 47 % of the total accumulated cations for these species, respectively, which indicates that these species accumulate more foliar Ca at the expense of K and Mg when compared with the other evaluated species. Except for Zn, Ca, Mg, and micronutrient concentrations in *C. subflavescens*, all the nutrients were within the proposed range for tropical species of the same family (Drechsel and Zech, 1991; Murillo *et al.*, 2013).

Although K and P concentrations were more abundant in both substrates with compost, this was not reflected in the foliar concentration. However, foliar concentrations of these nutrients were between the reported range for other tropical leguminous and Verbenaceae species (Drechsel and Zech, 1991).

4.4. Compost effect on growth traits of the species

The results of this study prove that the addition of compost to the substrate had a positive effect on the growth traits (height, stem diameter and number of leaves) of the evaluated species. Compost effects on tree growth could be associated with the increase in pH, the optimal organic matter concentration, the availability of nutrients due to the chelating action of organic matter, and the slow rate of nutrient release (Bhunia *et al.*, 2021).

Monthly growth in height and diameter were significantly higher with the lower compost concentration (12.5 %); meanwhile the monthly number of leaves was higher with a higher compost addition (25 %). Several authors report the dependence of species growth on the proportion in which the compost is mixed with the substrate and also indicate that the best results are obtained with smaller proportions of compost (McGrath and Henry, 2016, Sæbø and Ferrini, 2006).

Our results indicate that growth differences among species can be attributed to their morphological traits, growth habits, and nutritional needs; however, some oddities were found in the performance of the species studied here. For example, Mahecha Vega et al. (2012) mention that *C. subflavescens* and *C. sulcatum* are fast growing species and require abundant amounts of light for their growth. However, their average height growth was found to be the lowest among the species. In contrast, the stem growth of *C. spinosa* coincided with observations by Perez Vargas and Núñez Jiménez (2017), who indicate that this species invests its resources mainly in height and, to a lesser extent, in stem diameter.

5. CONCLUSION

The incorporation of compost into the soil increased its chemical fertility and the growth of the five native species evaluated, particularly with the smaller proportion of compost (12.5 %). Since the results of this study show the benefits of compost addition during tree establishment, additional research is needed to evaluate the impacts of compost application on the soil and tree growth during and after its establishment in urban environments in the long term.

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