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EVALUATION OF NUTRITIONAL REQUIREMENTS IN NURSERIES OF TROPICAL SPECIES USED IN URBAN GREENING

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ABSTRACT

One of the determining factors in urban tree development and growth is fertilization. We therefore studied the nutritional requirements of five tree species used in urban greening (Tabebuia chrysantha, Margaritaria nobilis, Hamelia patens, Apeiba aspera, Cupania americana) using the missing element technique. Differential responses by groups were found for nitrogen and sulfur deficiencies. The *T.chrysanta*, *M.nobilis*, and H.patens groups showed high sensitivity to nitrogen deficiencies. This was evident in a lower mean growth for all variables assessed: height, root neck diameter, aerial dry matter, and radical dry matter. The *C. americana* and *A. aspera* group showed the lowest mean growth for sulfur deficiencies. The HJ-Biplot representations, used to characterize the species' response to each treatment, showed low growth yields for nitrogen and sulfur deficiencies in every individual tree species assessed. The imbalance of calcium/magnesium bases and magnesium/potassium bases affected height growth in all species. This

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was evident in the high growth obtained for the calcium- and magnesium-deficient treatments. The treatments that added calcium and/or magnesium accentuated the imbalance and gave low growth in all variables.

KEYWORDS: Urban greening; Tropical species; Fertilization; Forest nutrition.

EVALUACIÓN DE REQUERIMIENTOS NUTRICIONALES EN VIVERO DE ESPECIES TROPICALES EMPLEADAS EN SILVICULTURA URBANA

RESUMEN

La fertilización es determinante del crecimiento y desarrollo de árboles urbanos. Por ello, Estudiamos, mediante la técnica del elemento faltante, los requerimientos nutricionales de cinco especies tropicales usadas en silvicultura urbana (*Tabebuia chrysantha, Margaritaria nobilis, Hamelia patens*, *Apeiba aspera, Cupania americana*). Se encontró algunas especies sensibles a la deficiencia de nitrógeno y otras a la deficiencia de azufre. El grupo de *T. chrysanta, M. nobilis* y *H. patens* mostraron alta sensibilidad a la deficiencia de nitrógeno, mientras que *C. americana* y *A. aspera* presentaron sensibilidad a la deficiencia de azufre, representada en menor crecimiento promedio para todas las variables evaluadas: altura, diámetro en el cuello de la raíz, materia seca radical y materia seca aérea. Las representaciones HJ-Biplot, utilizadas para caracterizar la respuesta por especie a cada tratamiento, en todas las unidades experimentales, evidenciaron los bajos rendimientos en crecimiento para las deficiencias en nitrógeno y azufre. El desbalance de bases calcio/magnesio y magnesio/potasio afectó el crecimiento en altura de todas las especies, evidenciado en los altos crecimientos obtenidos para los tratamientos deficientes en calcio y magnesio. Debido a esto, las fórmulas nutricionales utilizadas en vivero deben reajustarse a las exigencias individuales de las especies, para producir mejores árboles para la ciudad.

PALABRAS CLAVES: silvicultura urbana; especies tropicales; fertilización; nutrición forestal.

AVALIAÇÃO DE REQUERIMENTOS NUTRICIONAIS EM VIVEIROS DE ESPÉCIES TROPICAL EMPREGADAS EM SILVICULTURA URBANA.

RESUMO

A fertilização é determinante do crescimento e desenvolvimento de árvore urbanos. Por isso estudamos através da técnica do elemento faltante, os requerimentos nutricionais de cinco espécies tropicais usadas em silvicultura urbana (*Tabebuia chrysantha, Margaritaria nobilis, Hamelia patens, Apeiba aspera, Cupania americana*). Encontramos algumas espécies sensíveis à deficiência de nitrogênio e outras à deficiência de enxofre. O grupo de *T. chrysanta, M. nobilis* y *H. patens* mostraram alta sensibilidade à deficiência de nitrogênio, enquanto *C. americana* y *A. aspera* apresentaram sensibilidade à deficiência de enxofre, simbolizavam um menor crescimento promédio para todas às variáveis avaliadas: altura, diâmetro da raiz, matéria seca radical e matéria seca aéreo. As representações HJ-Biplot, utilizadas para caracterizar a resposta por espécie a cada tratamento, em todas as unidades experimentais, evidenciaram baixos rendimentos em crescimento para às deficiências em nitrogênio e enxofre. O desordem de bases cálcio/magnésio e magnésio/potássio afetou o crescimento em altura de todas as espécies, evidenciado nos altos crescimentos obtidos para os tratamentos deficientes em cálcio e magnésio. Devido a isso, as formulas nutricionais utilizadas em viveiros devem-se ajustar para produzir melhores árvores para a cidade.

PALAVRAS-CHAVE: Silvicultura urbana; Espécies tropicais; Fertilização; Nutrição florestal.

1. INTRODUCTION

The production and fertilization of urban trees has been studied in temperate and sub-tropical zones around the world (Watkins, 1998, Harris et al., 2008, Sæbø & Ferrini, 2006, Ferrini & Baietto, 2006). Each plant species draws nutrients from the soil according to its needs. Therefore, the edaphic fertility level is one of the main limiting factors for urban trees (Stanley & Montagnini, 1999, Schimann et al., 2008, Ferrini & Alesio, 2010). Soil and foliage fertility analyses have been used to study the nutrients used by plants in their growth (Salas & Ramírez, 2001). Aside from these studies, the missing element technique, described by Jenny et al. (1950), is used to reveal the nutrient deficiencies in soil where plants grow (Salas & Ramírez, 2001). It is also possible, however, to apply this technique in order to find the nutrients necessary for urban trees in two stages: nursery production and establishment in urban forests. In this way, it is possible to identify the nutrients that play a key role in the species' growth.

There is little knowledge regarding the key nutritional elements that limit the growth of tropical species used in urban greening. As world population increases, urban forests become vitally important due to the multiple benefits they provide (Madureira et al., 2011, Soares et al., 2011, Ferrini & Alesio, 2010, Molina & Vargas, 2007). In this context, trees are more susceptible to suffering attacks by blight, mechanical damage, and nutritional deficiencies, all of which cause high mortality rates (Ferrini & Alesio, 2010). One key aspect of urban greening is guaranteeing the survival of the trees that are produced and planted, which depends, among other factors, on the original fertility level of the soil and on the fertilization provided, whether during the production phase (nursery) or in the maintenance phase at the planting site. Knowledge of the particular nutritional requirements of native species used in urban greening programs can contribute to increasing the levels of radical growth, height growth, and biomass of the nursery seedlings, as well as reducing mortality rates once the trees have been planted in an urban environment. (Hoyos et al., 2007, Herrera, 2009). Therefore, it is essential to develop tools that allow for the identification of nutritional elements that limit the growth of tropical species that are produced in nurseries to create urban forests.

The goal of this study was to identify the elements that play a key role in the nursery nutrition of five tropical species used in urban forests in Medellin, Colombia: these species are *Tabebuia chrysantha* (Jacq.) Nichol., *Cupania americana* L., *Hamelia patens* Jacq., *Margaritaria nobilis* L.f., and *Apeiba aspera* Aubl. The study aims to provide tools for formulating fertilization programs for these species both in the nursery and in urban forests which will contribute to optimizing the species' initial growth and development, as well as their establishment and survival in the field.

2. METHODS

The experiment consisted of applying the missing element technique described by Jenny et al. (1950) in five tree species used in urban greening in the city of Medellin, Colombia. These species are: *Tabebuia chrysantha* (Jacq.) Nichol., *Cupania americana* L., *Hamelia patens* Jacq., *Margaritaria nobilis* L.f., and *Apeiba aspera* Aubl. An independent experiment was established for each species with a random design, 10 treatments, and 10 repetitions per treatment. The experimental unit consisted of a plant seeded in a plastic bag 20cm in diameter and 30cm tall. The plants were germinated in quartz and transplanted to the bag when they were 10cm tall. The treatments were formulated according to the soil fertility analyses made on each of the soils used in the experiment (**Table 1**). Two very similar soils were used: the soils were derived from volcanic ash from cut material, horizon A, from outside the city of Medellin. Soil 1 was used for *T. chrysantha, C. americana*, and *H. patens*; and Soil 2 was used for *M. nobilis* and *A. aspera*. 200 cm^3 of the nutritional solution formulated for each specific treatment was applied to each plant after transplantation. They did not receive further fertilization. The treatments were: a control treatment (T0), which consisted only of the soil without fertilization; a complete treatment (TC), which consisted of fertilizing the soil with all the nutrients necessary for optimal plant growth; seven treatments to induce deficiencies (-N, -P, -K, -Ca, -Mg, -S, -B), each of which had the same complete

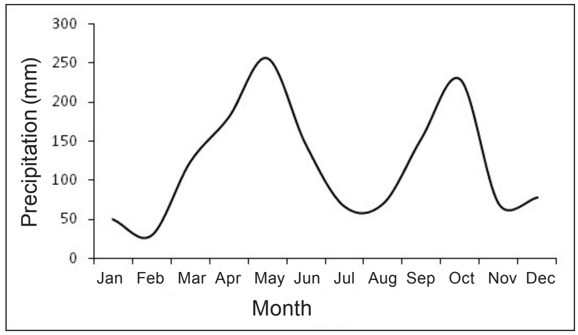
Table 1. Results of the soil fertility analyses used in the tests. Soil 1: *T. chrysantha*, *C. americana* and *H. patens*. Soil 2: *M. nobilis* and *A. aspera*. Substrate: material prepared traditionally in the nursery for seeing plants (ST treatment).

Material	pH (1:2)	N (%)	P (mg kg^{-1})	Ca	Mg	K	CIC
				---------------cmol(+) kg^{-1} soil---------			
Soil 1	5,4	0,45	2,6	2,86	0,59	0,32	3,74
Soil 2	4,8	0,63	1,5	1,73	0,59	0,25	2,94
Substrate	7,3	0,225	81,1	25,76	2,27	4,36	32,39

treatment formula minus de deficient nutrient to be evaluated; and finally, a comparative treatment (ST) which consisted of planting the seedlings in the substrate using the municipal nursery in Medellin in production activities. This substrate was made up of a 4:3:3 mix of earth, rice chaff, and compost, as well as triple 18 (N:P:K), respectively, without any other fertilizer added. The experiments were performed in the Medellin municipal nursery facilities; the precipitation regimen is bi-modal (**Figure 1**), and the temperature varies between 19 and 24°C. The height (A) and the diameter of the root neck (D) of each seedling was measured monthly for 4 months using a digital caliper on the mark made during the first measurement. After the 4 months, the plants were harvested, and the aerial dry matter (Ma) and the radical dry matter (Mr) of each plant was obtained through an oven drying process at 65°C until a constant weight was reached. Then the thinness index proposed by Villar (2003) was calculated as the ratio between the aerial dry matter (Ma) and the radical dry matter (Mr).

The height and diameter at the root neck were analyzed using a variance analysis (ANDEVA) with measurements repeated over time. This variance analysis contemplated two factors (treatments and time) and modeled the structure of co-variances with mixed models. In the ANDEVA treatments, the absolute outputs at the end of the experiments were used for these two variables. The co-variances were adjusted using mixed models, and the most appropriate standard errors for the different comparisons were estimated according to the characteristics of each set of data (Littell et al., 1998) using PROC MIXED by SAS, version 9.0. For the

Figure 1. Average annual precipitation pattern for the city of Medellin, Miguel Aguinaga Station (IDEAM).



aerial dry matter and radical dry matter variables, a simple ANDEVA was used. HJ-Biplot representations were obtained for each species (Galindo, 1986). This multi-variant technique simultaneously allows for a plane summary of variable data and of the experimental units (Correa et al., 2007), as well as an observation of the relationship between variables according to the angle between the factorial planes; to do so, a programmed routine in MATLAB® version 7.0 was used.

3. RESULTS

3.1 *T. chrysantha*

The element with the greatest impact on the plants' growth and development was nitrogen. The treatment with deficient nitrogen levels caused lower performance in terms of the sample (performance in comparison with the complete treatment) in all variables; in regards to radical dry matter, no significant differences were observed between the -N, -S, and ST treatments (**Table 3**). No significant differences were observed in the thinness index for any treatment. However, the highest values were observed under the –N treatment (4.8), and the lowest values under the –P treatment (2.8) (**Table 3**). The ANDEVA with measurements repeated over time for height and root neck diameter showed significant differences between measurement times 1 and 4 in all treatments (**Figure 3**). The first factorial plane of the HJ-Biplot representation (**Figure 2A**) picked up 90.2 % of the total variability. This method achieves a reduction in the number of treatments since the treatments that showed behavior very near the center and created confusion were eliminated. All the experimental units that underwent the –N treatment showed low performance in all four variables, while the –Ca treatment benefited the majority of the experimental units in terms of radical dry matter and aerial dry matter with no statistical difference from the treatment deficient in Mg and P. The –P and –S treatments yielded the best results for height, while the –Mg gave the highest values for root neck diameter, only showing a difference in regards to -N (**Figure 2A**, **Table 3**). In addition, a positive relationship was found between the biomass variables and the biometrics variables (**Figure 2A**).

3.2 *C. americana*:

Several treatments showed low outputs with significant differences between them for all variables; however, -S gave the lowest results, though it never differed from the TC in any variables (**Table 3**). The plants that underwent ST treatment showed high performance in all variables, to the same degree as with the –N treatment for root neck diameter and –Ca for radical dry matter. *C. americana* was the only species that responded well to the comparative ST treatment, which showed a statistical difference from the rest of the treatments. The thinness index did not show statistical differences in any treatment, but the highest value was obtained for the –K treatment, and the lowest value for the T0 treatment. Time affected the height and root neck diameter between measurement times 1 and 4 in the experiment (**Figure 3**). The first factorial plane in the HJ-Biplot representation picked up 89.37% of the total variability (**Figure 2B**). The ST treatment affected the majority of the experimental units, improving their performance, in contrast with the -S and TC treatments, which showed low results, as did the majority of the treatments (**Figure 2B**, **Table 3**).

3.3 *H. patens*:

The plants that underwent ST and T0 treatments showed the greatest limitations for growth and development in all variables; -N only affected aerial dry matter, decreasing performance (**Table 3**, **Figure 2E**). The best performances were obtained with the complete treatment (TC) in terms of root neck diameter, aerial dry matter, and radical dry matter with no significant differences in regards to other treatments (**Table 3**). In height, the best performances were obtained with various treatments (-Mg, -Ca, -S, -B, and –K) with ST, T0, –N, TC, and –P being the most limiting treatments for the development of H, patens. The treatment that obtained the highest thinness index was –S, without showing statistical differences from the –B, -Mg, -Ca, and –K treatments; the treatments that obtained the lowest thinness index values were ST and T0, without showing differences from –N, -P, and –TC (**Table 3**). There were significant differences for root neck diameter and height between times 1 and 4 (**Figure 3**). The first factorial plane of the HJ-Biplot representation (**Figure 2E**) picked up 92.47% of the total variability. A close positive relationship was observed between aerial dry matter and root neck diameter (**Figure 2E**). The –S treatment had a positive effect on height for all experimental units (**Figure 2E**).

3.4 *M. nobilis*:

The plants that underwent ST, -N, and T0 treatments showed the lowest outputs for all variables (**Table 3**); for radical dry matter, no significant differences were observed in comparison with -S, -Mg, -B, -K, and -Ca treatments (**Table 3**). Therefore, in order to increase growth in dry root matter, the TC option should be chosen, lowering the level of phosphorous. The best results were obtained for the complete treatment and the phosphorous deficient treatment, with the exception of height; the best height results were obtained with the -Mg and -Ca treatments, which were also similar to the complete treatment (**Table 3**).

Figure 2. HJ-Biplot representations for each species. A) *T. chrysantha,* B) *C. americana,* C) *M. nobilis* D) *A. aspera* E) *H. patens*. The points are the experimental units for each treatment, and their distribution along the factorial planes is the magnitude of affectation for each treatment on the corresponding variable. Proximity between the axes for each variable indicates association between the variables.

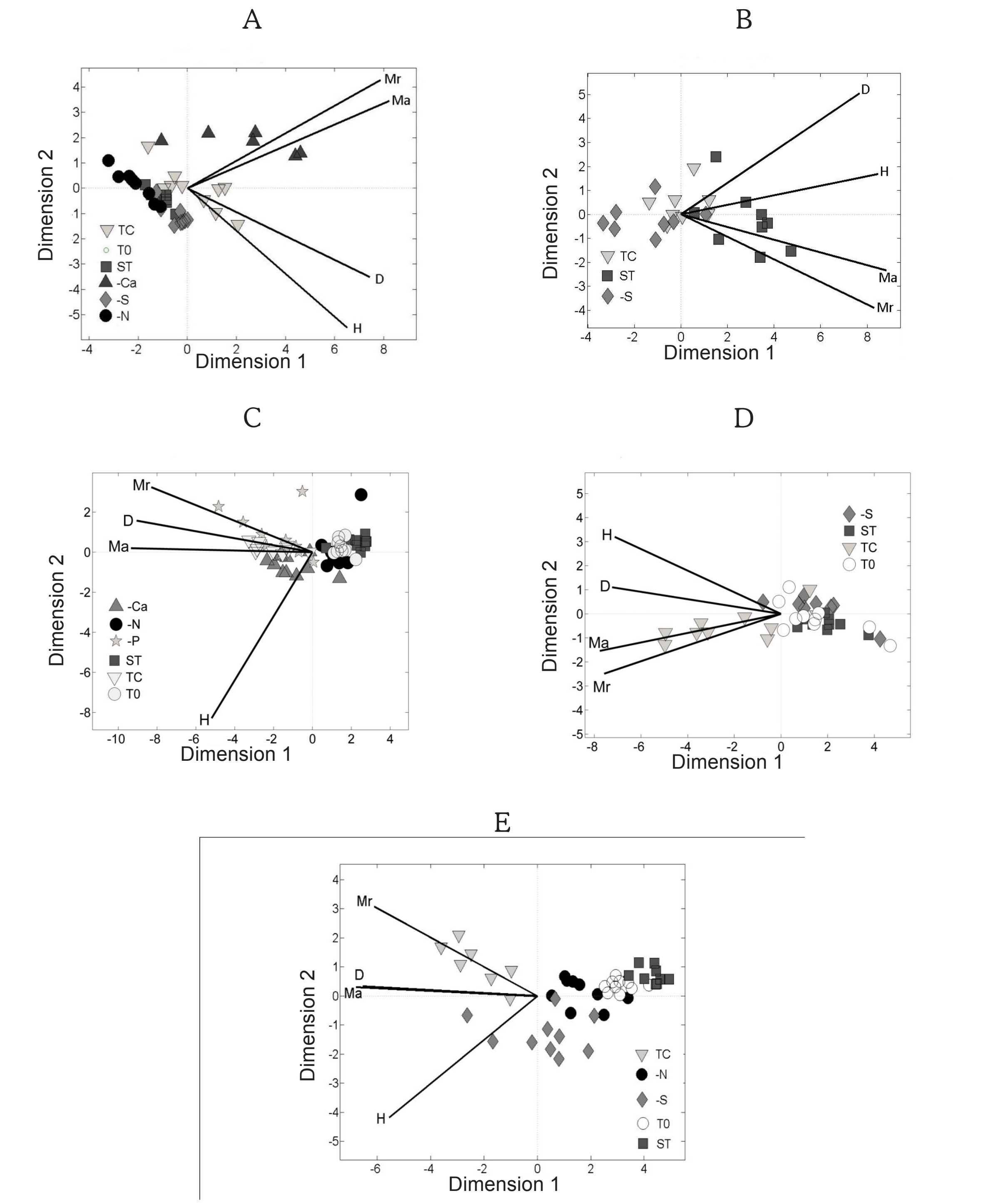


Figure 3: Monthly outputs for the species studied:
A) *T. chrysantha*, **B)** *C. americana*, **C)** *M. nobilis,* **D)** *A. aspera y* **E)** *H. patens*.

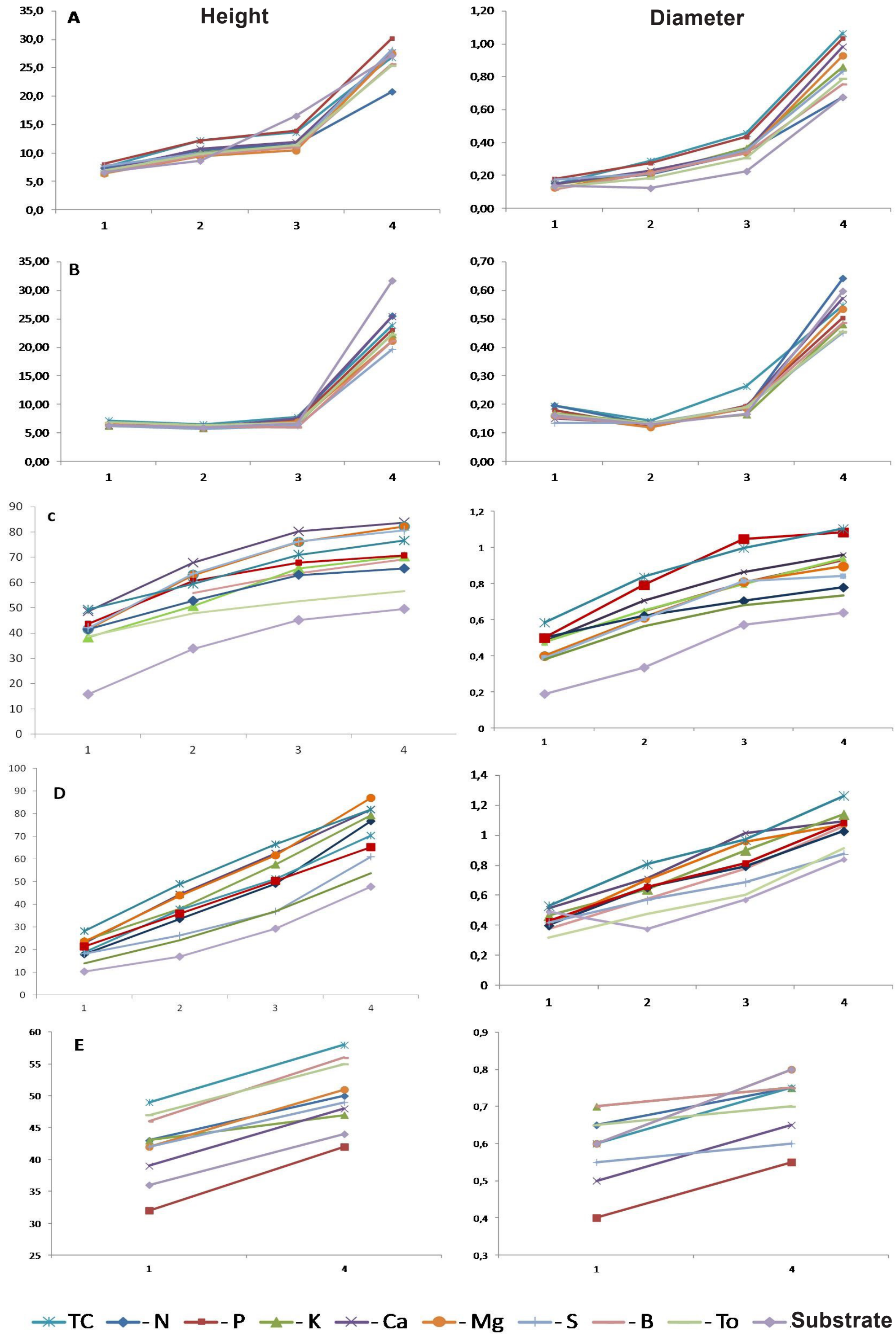


Table 2. Dosification of nutrients per treatment.

Source	Treatment								
	TC	–N	–P	–K	–Ca	–Mg	–S	–B	T0
Urea (N 46 %) (g)	2,14	-	2,14	2,14	7,76	-	2,14	2,14	-
KCl (g)	5,25	5,25	5,25	-	5,25	5,25	5,25	5,25	-
Calcium Nitrate $Ca(NO_3)_2.4H_2O$ (g)	21,80	-	21,80	21,80	-	21,80	21,80	21,80	-
Magnesium Sulfate $MgSO_4.7H_2O$ (g)	8,75	8,75	8,75	8,75	8,75	-	-	8,75	-
Magnesium Chloride $MgCl_2.6H_2O$ (g)	-	-	-	-	-	-	7,93	-	-
Calcium Chloride $CaCl_2.2H_2O$ (g)	-	13,60	-	-	-	-	-	-	-
Ammonium Sulfate $(NH_4)_2SO_4$ (g)	-	-	-	-	-	4,69	-	-	-
Solubor 20,8 % B (g)	0,14	0,14	0,14	0,14	0,14	0,14	0,14	-	-
Phosphoric Acid H_3PO_4 (85 %) (mL)	30	30	-	30	30	30	30	30	-

The thinness index varied considerably between treatments with –S and –Mg giving the best results and –P and TC being the most limiting, without differing from T0, -Ca, and –K. Significant differences in height and root neck diameter were only observed between measurement times 1 and 4. The other two variables did not differ over time (**Figure 3**). The first factorial plane on the HJ-Biplot representation (**Figure 2C**) picked up 89.38% of the total variability. A positive association was observed between the biomass and root neck diameter variables (**Figure 2C**). The–P, TC, and –Ca treatments increased growth in the majority of the experimental units in diameter, radical dry matter, and aerial dry matter (**Figure 2C**).

3.5 *A. aspera*:

The plants that underwent ST and T0 treatments showed the lowest outputs in aerial dry matter and height, and those that underwent ST and –S treatments showed the lowest outputs in root neck diameter and radical dry matter; however, they did not show differences from other treatments in all variables (**Table 3**). The TC treatment showed the best outputs, but there were no significant differences from others like –K, -P for radical dry matter, -Ca for root neck diameter, and –Ca, -Mg, -K, and –B for height (**Table 3**). The –S, -N, -Mg, and –Ca treatments showed the best outputs for the thinness index, while the ST, -B, TC, -P, T0, and –K treatments showed the lowest outputs, without showing differences from –N, -Mg, and –Ca. Significant differences were only found between measurements times 1 and 4 for the height variable in the treatments deficient in nitrogen, potassium, calcium, sulfur, and the control treatment. The rest did not show significant differences over time (**Figure 3**). The first factorial plane of the HJ-Biplot representation (**Figure 2D**) picked up 92.88% of the total variability. A positive association was found between the biometric variables group and between the biomass variables group (**Figure 2D**). The complete treatment provided a clear benefit to growth in all variables for nearly all the experimental units (**Figure 2D**).

4. DISCUSSION

The key nutrients for growth in the five species studied in this test were nitrogen and sulfur. However, deficiencies in other elements also affected growth in the four variables evaluated for the five species (**Table 3**). This confirms the hypothesis that tropical species have complex, different, and contrasting nutritional needs. In very general terms, the species studied herein could be classified into two groups: *T. chrysantha*, *H. patens*, and *M. nobilis* as sensitive to a nitrogen deficiency and *A. aspera* and *C. americana* as sensitive to a sulfur deficiency. Some studies have found that nitrogen, phosphorus, and potassium deficiencies show the strongest limitation for growth in numerous species of tropical trees, given that these nutrients present problems of availability in the soil and are necessary for the plants in large quantities (Davidson et al., 1998, Salas & Ramírez, 2001, Pedrol et al., 2010). However, this study has found an assimilable quantity of sulfur to be a key element in the nutrition of *A. aspera* and *C. americana*, while for *T. chrysantha*, *H. patens*, and *M. nobilis*, the presence of sulfur seems to limit height growth. The results of this test suggest that the soils used were mainly deficient in nitrogen and sulfur, given that the growth of species when said elements were absent was similar to the control treatment and differed from the complete treatment and from the treatment that showed the best results (**Figure 1**, **Table 3**). These contrasting findings shown as nutritional deficiencies likely spring from the physiological conditions and particular demands of each species (Nussbaum et al., 1995, Stanley & Montagnini, 1999).

The majority of the species showed less growth under the comparative treatment (ST) with regards to the other treatments, except *C. americana*. This is a generic substrate that is used in nurseries and for planting trees in the city. In contrast, the complete treatment (TC) and some other treatments showed positive results for the growth of *T. chrysantha*, *H. patens*, *M. nobilis*, and *A. aspera* seedlings (**Figure 2**). This result illustrates the necessity of improving the fertilization formulas used in nurseries and in the planting of urban trees. They must therefore be adjusted to meet the basic needs of each species in order to reduce the time in the nursery and increase the survival and longevity of urban trees. To achieve these goals, we suggest using alternative fertilization formulas that will obtain greater growth in the nursery for the species studied: for the *T. chrysantha*, *H. patens*, and *M. nobilis* group, we suggest using a formula similar to that used in the complete treatment (TC, **Table 2**), but enriched with nitrogen and with a balance between bases that promote biomass growth; for *A. aspera*, we suggest using a formula similar to that used in the complete treatment, but enriched with sulfur and with a balance between Mg/K bases; and for *C. Americana*, we suggest using a formula similar to the complete treatment (ST). It is essential to move forward with future research in order to define the optimal quantities of these elements and better understand the nutrition of tropical trees. In some studies, it has been found that substrates similar to that used in the ST treatment correct phosphorous deficiencies and base imbalance (Macci et al., 2012, Pedrol et al., 2010). This could explain the higher performances obtained with the comparative treatment (ST) for all variables in *C. americana*, but it does not explain why the other species showed low performance with this treatment despite the high nutrient content of comparative treatment ST. In some organic substrates, like the one used in the comparative treatment, mineralization of the nitrogen contained in the organic material could be difficult, as it takes a long time to become available to the plants (Salifu & Timmer, 2001). We believe that another factor added to the affectation in growth of the other species could be the high potassium content in the comparative treatment (ST) (**Table 1**), which would suppose a very severe Mg/K base imbalance (0.52) and very far below what is reported as optimal (Mg/K = 3,3; Stover & Simmonds (1987). For *A. aspera*, nitrogen dependency was not pronounced, and the plant showed the same dependency on sulfur as *C. americana*. However, *C. americana* showed severe affectation when the magnesium supply was restricted. This deficiency had to be made up for in the comparative treatment (ST). On the other hand, *A. aspera* showed the best performance for potassium deficiency in the biomass variables, possibly due to its high sensitivity to the magnesium-potassium (Mg/K) base imbalance. We believe that the high potassium content present in the comparative treatment affected the growth of *A. aspera*, as has been found in other studies (dos Reis et al., 2012, Navarro, 2003). Likewise, the high performance of this species under the -Ca treatment showed that the excessive content of this base in the comparative treatment caused an imbalance of Ca/Mg bases that reduced growth in this species. It is possible that *A. aspera* may not have shown significant height growth during the first months of the test due to the magnitude of the limitation caused by the base imbalance in this species. This illustrates that the nutrition of tropical tree species requires particular attention not only in regards to the quantity of nutrients available in the soil, but also to the proportion between them.

Table 3. Average performance for biometric variables of the five species at the end of the study. The means of treatment that have the same letter in Dif do not show significant differences from 95%.

T	*T. chrysantha*	Dif	T	*C. americana*	Dif	T	*H. patens*	Dif	T	*M. nobilis*	Dif	T	*A. aspera*	Dif
Height (cm)														
–N	18,9	a	–S	19,7	a	ST	35,5	a	ST	49,6	a	ST	47,8	a
–B	24,6	ab	–Mg	21,2	a	T0	50	ab	T0	56,6	a	T0	53,7	a
T0	26,8	ab	–B	21,2	a	–N	60,7	b	–N	65,6	b	–S	61	ab
TC	26,9	ab	–K	22,3	a	TC	72,6	bc	–P	67,9	bc	–P	65,2	ab
ST	27,6	ab	–P	23,1	a	–P	74,4	c	–B	69,3	bc	–N	68,7	ab
–K	28	ab	T0	23,7	a	–K	87,4	d	–K	70,4	bc	–B	73,6	b
–Ca	28,3	ab	TC	25,3	a	–B	88,7	d	TC	76,6	cd	–K	75,6	b
–Mg	29,8	ab	–Ca	25,5	ab	–S	92,6	d	–S	80,6	cd	TC	81,8	b
–P	30,2	b	–N	25,6	ab	–Ca	98,3	d	–Mg	82,1	d	–Ca	81,9	b
–S	31,5	b	ST	34,4	b	–Mg	99,1	d	–Ca	83,8	d	–Mg	87	b
Root Neck Diameter (cm)														
–N	0,64	a	–S	0,45	a	ST	0,62	a	ST	0,64	a	ST	0,84	a
ST	0,68	ab	T0	0,48	a	T0	0,73	a	T0	0,74	ab	–S	0,88	a
–B	0,71	b	–K	0,48	ab	–N	0,93	b	–N	0,78	ab	T0	0,92	ab
T0	0,83	b	–B	0,49	ab	–S	0,96	b	–S	0,84	b	–N	1,02	ab
–K	0,86	b	–P	0,5	ab	–Mg	1,1	b	–Mg	0,9	b	–B	1,03	ab
–S	0,86	b	–Mg	0,54	ab	–K	1,11	bc	–B	0,93	bc	–K	1,11	ab
TC	0,97	b	TC	0,57	ab	–Ca	1,19	c	–K	0,94	bc	–Mg	1,11	ab
–Ca	0,97	b	–Ca	0,57	ab	–B	1,21	c	–Ca	0,96	bc	–P	1,17	ab
–P	1,04	b	ST	0,64	b	–P	1,24	c	–P	1,05	c	–Ca	1,18	b
–Mg	1,05	b	–N	0,64	b	TC	1,26	c	TC	1,11	c	TC	1,27	b
Aerial Dry Matter (g)														
–N	3,5	a	–S	2,8	a	ST	2,8	a	ST	6	a	ST	5,7	a
ST	5,7	ab	–P	3,3	a	T0	4,7	a	T0	8,2	a	T0	5,9	a
–S	6,3	ab	–B	3,4	a	–N	6,6	a	–N	10	ab	–S	6,2	ab
–K	6,4	ab	T0	3,6	a	–S	12,2	b	–B	16,3	b	–B	9,1	ab
T0	6,9	ab	–K	3,8	a	–B	15,9	bc	–Mg	16,8	b	–N	9,2	ab
TC	10,4	ab	–Mg	3,9	a	–Mg	18	c	–S	17,5	bc	–Mg	10,5	ab
–B	12,6	ab	TC	4,1	a	–P	18,3	c	–K	18,4	bc	–Ca	11,4	ab
–P	12,7	b	–Ca	4,7	ab	–K	18,9	c	–Ca	21,2	bc	–P	12,6	b
–Mg	14,2	b	–N	4,9	ab	–Ca	19	c	TC	23,4	c	–K	13,8	b
–Ca	21,3	b	ST	7,7	b	TC	21,1	c	–P	25,5	c	TC	17,2	b
ST	4,50	a	-N	3,93	a	-B	2,42	ab	-P	4,56	ab	-N	2,64	ab
-N	4,89	a	-K	4,11	a	-S	2,53	a	TC	4,79	a	-S	3,39	a

T: Treatments

Dif: Differences between treatments

Table 3. Average performance for biometric variables of the five species at the end of the study. The means of treatment that have the same letter in Dif do not show significant differences from 95%.

Radical Dry Matter (g)														
–N	1	a	–B	0,9	a	ST	2,9	a	T0	2	a	–S	2	a
–S	1,5	a	–S	0,9	a	T0	3,7	a	–N	3,1	a	ST	2,6	a
ST	1,7	a	–P	0,9	a	–N	4,7	ab	ST	4	a	T0	3	ab
T0	2,3	ab	–K	1	a	–S	4,9	ab	–S	4,1	a	–N	3,6	ab
–K	2,9	ab	TC	1,1	ab	–B	6,6	ab	–Mg	4,1	a	–B	4,2	ab
TC	3,9	ab	–Mg	1,2	ab	–Mg	8,2	b	–B	5,5	a	–Mg	4,4	ab
–P	4,5	ab	T0	1,3	ab	–Ca	9,5	b	–K	6,9	a	–Ca	5,3	ab
–B	4,9	ab	–N	1,3	ab	–K	9,8	b	–Ca	9,2	ab	–P	6,1	b
–Mg	5,3	b	–Ca	1,8	b	–P	11,9	bc	TC	15,6	b	–K	7,1	b
–Ca	9	b	ST	2,2	b	TC	14,3	c	–P	20,8	b	TC	8,5	b
Thinness Index														
-P	2,80	a	T0	2,64	a	T0	1,26	d	-S	1,57	c	-K	2,09	b
-Mg	2,89	a	-Ca	2,81	a	ST	1,32	d	-Mg	1,70	c	-P	2,11	b
TC	2,89	a	-P	3,47	a	-N	1,43	**cd**	ST	2,31	bc	T0	2,11	b
-Ca	3,06	a	-Mg	3,58	a	-P	1,60	cd	-N	2,81	bc	TC	2,18	b
T0	3,43	a	ST	3,60	a	TC	1,68	bcd	-B	2,94	bc	-B	2,27	b
-B	3,48	a	-S	3,72	a	-K	1,92	abcd	-K	3,41	b	ST	2,44	b
-K	3,49	a	TC	3,73	a	-Ca	2,14	abc	-Ca	3,43	b	-Ca	2,50	ab
-S	4,44	a	-B	3,88	a	-Mg	2,40	ab	T0	3,50	b	-Mg	2,59	ab

T: Treatments

Dif: Differences between treatments

Imbalances in the exchangeable bases in the soil affect plant growth and development (Wilmot et al., 1996). Large amounts of exchangeable bases in the soil can cause a nutritional imbalance for the plants and reverse their growth and development (Pedrol et al., 2010). This seems to have occurred in the production of aerial and radical dry matter in the *T. chrysantha* and *C. americana* species, which showed the best performance without a calcium supply (–Ca), even above the complete treatment (**Table 3**). It is important to note that the calcium and magnesium levels in the soil used for the test were very low (**Table 1**), and this situation was therefore not expected. Sometimes it is not the quantity of nutrients that limit plant development, but rather the proportion of these nutrients in the soil. For exchangeable bases, then, an inadequate calcium-magnesium (Ca/Mg) relationship causes the main imbalances that limit growth (Pedrol et al., 2010). It has been shown that corrections using chemical fertilizers can create Ca/Mg imbalances due to the excessive supply of one of these two cations (Wilmot et al., 1996), which may have occurred in the tests when calcium or magnesium were added. The values of the Ca/Mg relationship for the soils used (5,1 and 3,1 for soils 1 and 2, respectively) were far above those indicated as appropriate (Ca/Mg = 2). It is possible to conclude that: the addition of calcium accentuated the base imbalance in the soil, which was more noticeable in soil 1 than in soil 2, in which the Ca/Mg value = 3,1. This could be one of the causes that determined the higher performances obtained for the three species planted in soil 1 using the calcium-deficient treatment. The species *A. aspera* and *M. nobilis*, planted in soil 2, did not show noteworthy effects due to changes in the contents of these interchangeable bases, possibly due to the fact that the values of the relationship between these bases in the soil were not very far above optimal levels. In some soils, the magnesium-potassium (Mg/K) imbalance caused problems regarding the capacity for cations exchange (CIC) and for nutrient absorption (Pedrol et al., 2010). In the soils used in this study, the potassium content was medium to high, and its relationship to magnesium was relatively balanced. However, *A. aspera* increased its radical dry matter (Mr) production in the potassium-deficient treatment, which could indicate its higher sensitivity to the Mg/K balance, which is even more pronounced in regards to root production.

The thinness index (Ma/Mr) was coherent with the results already found for the majority of the species in some of the biometric parameters. The deficiencies that most greatly limited growth also showed the most imbalanced Ma/Mr relationships, except for in the case of *M. nobilis*, which showed the greatest imbalance for the less limiting treatments. This is the first research project that compares thinness indices for each of these species in their production and fertilization in the nursery. Low values obtained from the ratio between aerial dry matter and radical dry matter usually indicate, on an inter-specific level, greater efficiency in water use (Stewart & Bernier, 1995, Villar, 2003) since the plants can maintain a better hydrological state with lower water consumption in situations of water shortage. This improves the survival of plants raised in nurseries and later planted in hostile environments, like the majority of urban spaces (Lloret et al., 1999). In this study, it was observed that each species has a range of associated average values for Ma/Mr and different sensitivities to nutritional deficiencies. For example, *T. chrysantha* and *C. americana* were not sensitive to nutritional deficiencies since no treatment showed differences for this relationship; *A. aspera* was somewhat sensitive since only one treatment (-N) had a positive effect on the Ma/Mr relationship; and *H. patens* and *M. nobilis* were sensitive to nutritional deficiencies, which significantly affected their Ma/Mr relationship. *M. nobilis* was the species that showed the greatest Ma/Mr imbalance in the treatments that optimized its growth (TC and –P). However, the optimal Ma/Mr values for these species should be evaluated through survival and growth studies, which could help to more precisely determine the optimal type of plant for urban use and its associated fertilization treatment, since the scope of this research did not allow us to reach this conclusion.

Finally, the growth of an urban tree implies a nutritional cost for the site, an opportunity cost, and a logistical cost, among others. Therefore, if the tree's survival is not assured, significant economic losses will be incurred. It is thereby necessary to increase research regarding multiple aspects of urban greening that will contribute to the knowledge required to build sustainable urban forests. One important aspect in terms of tropical urban tree survival is nutrition. Applying optimal amounts of limiting nutritional elements for each species increases their chances of survival and contributes to the sustainability of urban forests. It is necessary to continue this type of research to develop nutritional supplements for each species used in urban greening and produced in nurseries for this purpose.

5. CONCLUSIONS

Tropical tree species have complex nutritional behaviors which are not only limited to the quantities of nutritional elements available in the soil, but which also depend on the relationship between these elements. It is possible to identify groups of species that respond to common nutritional patterns, as was found in this study for nitrogen and sulfur deficiencies. Some species, such as *A. aspera*, *T. chrysantha*, and *C. Americana*, are highly sensitive to base imbalances, which affects radical and aerial dry matter production. This implies that providing precise and appropriate nutritional formulas for species that are very sensitive to base imbalances is fundamental.

The missing element technique is useful for understanding the way in which plants use different nutrients available in the soil. Based on these results, we recommend using specific fertilization formulas for each species that are similar to the formulas used in the complete treatment (TC) with adjustments for the deficiencies and base imbalances that negatively affect species' growth and development. These formulas must also be based on a previous fertility analysis of the soil or the substrate where the plants will be seeded. These formulas could work very well in nursery production of plants and give a nutritional reference for planning urban trees.

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REFERENCES

Correa, L.; Lavalett, O.; Galindo, V. (2007). Uso de métodos multivariantes para la agrupación de aislamientos de *Colletotrichum spp.* con base en características morfológicas y culturales. *Revista Facultad Nacional de Agronomía* 60**,** pp. 3671-3690.

Davidson, R.; Gagnon, D.; Mauffette, Y. & H., H. (1998). Early Survival, Growth and Foliar Nutrients in Native Ecuadorian Trees Planted on Degraded Volcanic Soil. *Forest Ecology and Management* 105, 1-19.

Dos Reis, B.E.; De Paiva, H. N.; Barros, T. C.; Ferreira, A. L. & Cardoso, W. D. (2012). Growht and Seedling Quality of Jacaranda-da-Bahia in Response to Potassium and Sulfur Fertilization. *Ciencia Florestal,* 22, 389-U1505.

Ferrini, F. & Alesio, A. (2010). Sustainable Management Techniques for Trees in the Urban Areas. *Journal of Biodiversity and Ecological Sciences* 1, pp. 1-20.

Ferrini, F.; & Baietto, M. (2006). Response to Fertilization of Different Tree Species in the Urban Environment. *Arboriculture & Urban Forestry* 32(3), May, pp. 93-99

Galindo, M. P. (1986). Una alternativa de representación simultánea: HJ-biplot. *Questió,* 10, pp. 13-23.

Harris, J. R.; Day, S. D. & Kane, B. (2008). Nitrogen Fertilization During Planting and Establishment of the Urban Forest: A Collection of Five Studies. *Urban Forestry & Urban Greening,* 7, pp. 195-206.

Herrera, S. (2009). Árboles de la Universidad del Valle. Santiago de Cali, Colombia, Cali, Colombia, Programa Editorial Universidad del Valle.

Hoyos, M.; Cogollo, A. & Villa, D. (2007). *Silvicultura Urbana para Medellín,* Medellín, Fondo editorial Jardín Botánico de Medellín.

Jenny, H.; Vlamis, J. & Martin, W. (1950). Greenhouse assay of fertility of California soils. *Hilgardia,* 20, pp. 1-18.

Littell, R.; Henry, P. & Ammerman, C. (1998). Statistical Analysis of Repeated Measures Using SAS Procedures. *Journal of Animal Science* 76, pp. 1216-1231.

Lloret, F.; Casanovas, C. & Peñuelas, J. (1999). Seedling Survival of Mediterranean Shrubland Species in Relation to Root: Shoot Ratio, Seed Size and Water and Nitrogen Use. *Functional Ecology,* 13, pp. 210-216.

Macci, C.; Doni, S.; Peruzzi, E.; Masciandaro, G.; Mennone, C. & Ceccanti, B. (2012). Almond Tree and Organic Fertilization for Soil Quality Improvement in Southern Italy. *Journal of environmental management,* 95 Suppl, pp. S215-22.

Madureira, H.; Andresen, T. & Monteiro, A. (2011). Green Structure and Planning Evolution in Porto. *Urban Forestry & Urban Greening,* 10, pp. 141-149.

Molina, L. & Vargas, E. (2007). Árboles para Villavicencio: Especies que fortalecen la estructura ecológica principal. *Revista Nodo* 2, pp. 85-98.

Navarro, G. (2003). *Química Agrícola,* Madrid, España, Mundi-Prensa.

Nussbaum, R.; Anderson, J. & Spencer, T. (1995). Factors Limiting the Growth of Indigenous Tree Seedlings Planted on Degraded Rainforest Soils in Sabah, Malaysia. *Forest Ecology and Management* 74, pp. 449-459.

Pedrol, N.; Puig, C. G.; Souza, P.; Forján, R.; Vega, F. A.; Asensio, V.; González, L.; Cerqueira, B.; Covelo, E. F. & Andrade, L. (2010). Soil Fertility and Spontaneous Revegetation in Lignite Spoil Banks under Different Amendments. *Soil and Tillage Research,* 110, 134-142.

Sæbø, A. & Ferrini, F. (2006). The Use of Compost in Urban Green Areas – A Review for Practical Application. *Urban Forestry & Urban Greening,* 4, pp. 159-169.

Salas, E. & Ramírez, C. (2001). Determinación del N y P en abonos orgánicos mediante la técnica del elemento faltante y un bioensayo microbiano. *Agronomía Costarricense* 25**,** 25-34.

Salifu, K. F. & Timmer, V. R. (2001). Nutrient Retranslocation Response of Picea mariana Seedlings to Nitrogen Supply. *Soil Science Society of America Journal,* 65, pp. 905-913.

Schimann, H.; Ponton, S.; Hättenschwiler, S.; Ferry, B.; Lensi, R.; Domenach, A.-M. & Roggy, J.-C. (2008). Differing Nitrogen Use Strategies of Two Tropical Rainforest Late Successional Tree Species in French Guiana: Evidence from 15N Natural Abundance and Microbial Activities. *Soil Biology and Biochemistry,* 40, pp. 487-494.

Soares, A. L.; Rego, F. C.; Mcpherson, E. G.; Simpson, J. R.; Peper, P. J. & Xiao, Q. (2011). Benefits and Costs of Street Trees in Lisbon, Portugal. *Urban Forestry & Urban Greening,* 10, pp. 69-78.

Stanley, W. G. & Montagnini, F. (1999). Biomass and Nutrient Accumulation in Pure and Mixed Plantations of Indigenous Tree Species Grown on Poor Soils in the Humid Tropics of Costa Rica. *Forest Ecology and Management,* 113, pp. 91-103.

Stewart, J. & Bernier, P. (1995). Gas Exchange and Water Relations of 3 Sizes of Containerized Picea Mariana Seedlings Subjected to Atmospheric and Edaphic Water Stress Under Controlled Conditions. *Annals of Forestry Science,* 52, pp. 1-9.

Stover, R. & Simmonds, N. (1987). *Bananas,* London, UK, Longman Scientific and Tecnichal.

Villar, P. (2003). Importancia de la calidad de planta en los proyectos de revegetación *En:* Rey-Benayas, J. M.; Espigares, T. & Nicolau-Ibarra, J. M. (eds.) *Restauración de Ecosistemas Mediterráneos*. Alcalá de Henares: Universidad de Alcalá / Asociación Española de Ecología, Terrestre.

Watkins, J. R. 1998. *Fertilization and Woody Plant Nutrition in the Context of the Urban Forest*. Master of Forestry Ms.c., Virginia Polytechnic Institute and State University.

Wilmot, T. R.; Ellsworth, D. S. & Tyree, M. T. 1996. Base Cation Fertilization and Liming Effects on Nutrition and Growth of Vermont Sugar Maple Stands. *Forest Ecology and Management,* 84(1), pp. 123-134.

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