Nutritional efficiency of plants as an indicator
of forest species for the restoration of forests, BrazilEficiência nutricional de plantas como indicadora
de espécies florestais para restauração de florestas, BrasilRosival Barros de Andrade Lima¹, Fernando José Freire², Luiz Carlos Marangon³,
Ana Lícia Patriota Feliciano¹, Roseane Karla Soares da Silva²,
Maria Betânia Galvão dos Santos Freire¹ and Clarissa Soares Freire²

Resumo

A escolha de espécies nativas na recuperação de áreas degradadas é importante por causa da relação peculiar com os sítios onde elas se estabeleceram e exigências nutricionais específicas. A eficiência de utilização dos nutrientes dessas espécies pode contribuir para a recomendação de seu uso em áreas degradadas da Floresta Atlântica. Assim, o objetivo desse estudo foi determinar os teores de N, P, K, Ca e Mg de espécies nativas em remanescente de Floresta Ombrófila Densa das Terras Baixas, estimar a biomassa foliar das espécies, calcular o conteúdo dos nutrientes armazenado na biomassa foliar e determinar a eficiência de utilização de nutrientes. Foi realizado um estudo fitossociológico do fragmento e definida dez espécies de maior densidade absoluta. As espécies florestais apresentaram altos teores de N e baixos de P, podendo se estabelecer em ambientes férteis em N e restritivos para P, com exceção das espécies *Myrcia silvatica* e *Tapirira guianensis* que podem ser recomendadas para solos com pouca disponibilidade de N. As espécies *Thyrsodium spruceanum* e *Protium heptaphyllum* podem ser recomendadas para ambientes com pouca disponibilidade de K e Mg, respectivamente. Em fragmentos florestais de solos com baixa disponibilidade de Ca, a espécie *Brosimum rubescens* pode ser utilizada para restauração florestal dessas áreas. A eficiência de utilização de nutrientes pode indicar fragmento florestal diversificado, estabelecido e equilibrado nutricionalmente.

Palavras-chave: Floresta Atlântica, nutrição florestal, restauração florestal.

Abstract

The choice of native species in the recovery of degraded areas is important because of the peculiar relation with the sites where they were established and specific nutritional requirements. The nutrient utilization efficiency of these species can contribute to recommendations of their use in degraded areas of the Atlantic Forest. Thus, the objective of this study was to determine the N, P, K, Ca, and Mg nutrient concentrations of native species in a remnant of Lowland Dense Shade Forest, to estimate foliar biomass; to calculate the stored nutrients and the nutrient utilization efficiency. A phytosociological study of the fragment was carried out and the ten species with the highest absolute densities were defined. The forest species presented high content of N and low of P, being able to be established in environments rich in N and low in P, with the exception of *Myrcia silvatica* and *Tapirira guianensis*, which can be recommended for soils with low N availability. *Thyrsodium spruceanum* and *Protium heptaphyllum* can be recommended for environments with low K and Mg availability, respectively. *Brosimum rubescens* can be used for forest restoration in fragments of soils with low Ca availability. The nutrient utilization efficiency may indicate a nutritionally balanced forest fragment, diversified and established.

Keywords: Atlantic forest, forest nutrition, forest restoration.

INTRODUCTION

The Atlantic Forest is responsible for a significant portion of Brazil's biological diversity and has been impacted by constant anthropogenic pressures, endangering the richness of endemic species

¹PhD in Forestry. UFRPE – Universidade Federal Rural de Pernambuco. Postal Code 2071 – 52171-900 – Recife, PE, Brazil. E-mail: rosival_barros@yahoo.com.br; roseanekarla.floresta@gmail.com; clarissa.sfreire@gmail.com.

²Associate Professor at Agronomy Department. UFRPE – Universidade Federal Rural de Pernambuco. Postal Code 2071 – 52171-900 – Recife, PE, Brazil. E-mail: fernandojfreire@uol.com.br; ana.feliciano@ufrpe.br; mbetaniafreire@ufrpe.br.

³Titular Professor at Forestry Department. UFRPE – Universidade Federal Rural de Pernambuco. Postal Code 2071 – 52171-900 – Recife, PE, Brazil. E-mail: luiz.marangon@ufrpe.br.

that make up the biome (BOSA et al., 2015). According to Chaves et al. (2013), due to the high degree of anthropogenic disturbances in this biome, its conservation represents one of the greatest challenges of the Brazilian tropical regions.

According to Hencker et al. (2012), one way of minimizing this environmental impact is by preserving what still exists and recovering what has already been degraded. In the recovery process, it is necessary to use native species while considering the characteristics of each region (NOFFS et al., 2000), and for this, it is essential to know the original floristic composition as well as the horizontal structure of the region. This information indicates the situation in the area, which helps in planning future activities to be performed to preserve the forest.

The implementation of projects for the recovery of degraded ecosystems, through the reforestation of native species and guaranteeing the maintenance of biodiversity, also helps to reduce the concentration of carbon dioxide in the atmosphere, which increases the incentive for recovery projects using reforestation with native species (ANDRADE; BOARETTO, 2012). However, it is worth emphasizing that native forest species have peculiar nutritional requirements, because they relate to the sites where they were established. This is a determinant for the success of forest recovery projects (SORREANO et al., 2011). Thus, it is necessary to evaluate the nutritional utilization efficiency of the different forest species in order to help the forester to choose the most suitable species for the forest recovery projects (CALDEIRA et al., 2004).

The nutritional utilization efficiency is the ability of the plant to absorb and utilize nutrients, and it may vary according to genotype differences and genotype-environment interactions (BEHLING et al., 2014). Moura et al. (2006) defined the nutritional utilization coefficient as the amount of dry biomass (kg) produced per amount of nutrient absorbed and accumulated (kg). Thus, the lower the amount of accumulated nutrients in the tree component and the greater the amount of produced biomass, the higher the coefficients of utilization.

Due to the high diversity of forest species and their different nutritional behaviors, it is difficult to generalize their demands for nutrients and responses to fertilization. For this reason, the evaluation of mineral nutrition is important, since the adequate supply of mineral elements becomes essential for the successful growth of native species (ANDRADE; BOARETTO, 2012).

The nutrient demand by a plant depends on its growth rate and efficiency for converting the nutrients absorbed into biomass (DEL QUIQUI et al., 2004). Therefore, knowledge of the nutritional aspects of native species is an important tool for understanding the establishment of species, especially in soils with low nutritional availability (SOUZA et al., 2012).

Thus, the objective of this study was to determine the N, P, K, Ca, and Mg nutrient concentrations of native species in a remnant of Lowlands Dense Shade Forest, to estimate foliar biomass of the species, to calculate the content of nutrients stored in the foliar biomass, and to determine the utilization efficiency of these nutrients.

MATERIAL AND METHODS

The study was carried out in a Lowlands Dense Shade Forest fragment (MARTINS; CAVARARO, 2012), characterized as being in the middle successional stage, according to the National Environment Council of Brazil (BRASIL, 1994). The fragment has 42 ha under the following coordinates (UTM 25L) 263220, 263849, 263544 and 263967 of latitude and 9054184, 9054442, 9053691 and 9053725 of longitude, in Pernambuco, Brazil.

According to Köppen's classification, the region presents an Am monsoon climate (ALVARES et al., 2013), with an average annual temperature of 25.6 °C. The average altitude is 60 m and the period of greatest rainfall starts in April and ends in September. According to the pluviometric data of the last five years from the Pernambuco State Agency for Water and Climate (OLIVEIRA et al., 2016), the average annual rainfall was of approximately 1,800 mm.

The predominant soils in the study's region are Yellow Latosol, Yellow Argisol, Red-Yellow Argisol, Gray Argisol, Geissol, Cambisol, and Fluvic Neosols (SANTOS et al., 2013). The soil of the forest fragment was sampled at three depths (0.0-0.05; 0.05-0.20; and 0.20-0.40 m) and chemically and physically characterized (Table 1).

Table 1. Chemical and physical soil characterization of the Lowlands Dense Shade Forest fragment in Pernambuco, Brazil.

Tabela 1. Caracterização química e física do solo do fragmento de Floresta Ombrófila Densa das Terras Baixas em Pernambuco, Brasil.

Soil attribute	Depth (m)		
	0.0-0.05	0.05-0.20	0.20-0.40
pH (H ₂ O)	3.88	4.10	4.53
P (mg dm ⁻³)	1.37	1.30	1.10
Ca (cmol _c dm ⁻³)	0.30	0.12	0.05
Mg (cmol _c dm ⁻³)	0.83	0.46	0.40
K (cmol _c dm ⁻³)	0.06	0.05	0.04
Al (cmol _c dm ⁻³)	1.69	1.37	1.02
(H+Al) (cmol _c dm ⁻³)	8.94	7.00	5.47
SB	1.19	0.63	0.49
CEC effective (cmol _c dm ⁻³)	2.88	2.00	1.51
CEC potential (cmol _c dm ⁻³)	10.13	7.63	5.96
m (%)	58.68	68.50	67.55
V (%)	11.75	8.26	8.22
TOC (g kg ⁻¹)	34.15	22.43	17.71
Fe (mg dm ⁻³)	155.61	135.24	139.27
Cu (mg dm ⁻³)	1.82	1.81	1.87
Zn (mg dm ⁻³)	5.14	4.41	6.09
Mn (mg dm ⁻³)	9.92	8.79	9.39
Total Sand (g kg ⁻¹)	498.20	413.70	384.10
Coarse Sand (g kg ⁻¹)	420.70	321.11	296.60
Fine Sand (g kg ⁻¹)	77.50	92.60	87.50
Silt (g kg ⁻¹)	285.30	313.90	270.70
Clay (g kg ⁻¹)	216.50	272.40	345.20

The Ca²⁺, Mg²⁺, and Al³⁺ were extracted with 1.0 mol L⁻¹ KCl and dosed by titration. P, K⁺, Fe, Cu, Zn, and Mn were extracted with Mehlich⁻¹. P was dosed by spectrophotometry, K⁺ by flame photometry, and Fe, Cu, Zn, and Mn by atomic absorption spectrophotometry. Potential acidity (H+Al) was extracted with 0.5 mol L⁻¹ calcium acetate and dosed by titration. The total organic C (TOC) was determined by the potassium dichromate method. With the results of these chemical analyses were calculated: the sum of bases (SB), base saturation (V), saturation by Al (m), effective cation exchange capacity (CEC_{effective}), and potential cation exchange capacity (CEC_{potential}). The soil was physically characterized by granulometry. All the analytical procedures were according to Donagema et al. (2011).

A phytosociological study of the fragment was carried out in order to select the forest species and to evaluate the efficiency of biological utilization of N, P, Ca, Mg, and K nutrients by these species. Phytosociology was performed according to Müller-Dombois and Ellemberg (1974). The ten species that presented the highest Absolute Density (AD) were selected, which corresponded to the relation of the total individuals of one species per unit area.

To perform the phytosociological study, 40 plots of 10 m x 25 m (250 m²) were systematically implanted, with a distance between plots of approximately 42 m, where all tree individuals with diameter at breast height (DBH) ≥ 15 cm, at 1.30 m from the ground, were measured.

For foliar sampling, three individuals of each species with the highest AD that presented a DBH similar to the mean DBH of all individuals of that species were selected. The trees were also selected for their phytosanitary status and perfectly structured crowns, characterizing adequately the species.

Then, 25 leaves were collected from the middle part of the crown at the four cardinal points. The collected leaves were packed in plastic bags and stored in Styrofoam boxes with ice. Subsequently, the plastic bags were replaced by paper sacks which were brought to a forced air circulation chamber and kept at 65 °C to dry the foliar material. After reaching a constant weight, the material was milled, homogenized, and conditioned in previously cleaned and dried vials for further analysis.

The nutrients Ca, Mg, P, and K were extracted by nitro-perchloric digestion (BATAGLIA et al., 1983). Then Ca and Mg were dosed by atomic absorption spectrophotometry, P by colorimetry (BRAGA; DEFELIPO, 1974), and K by flame photometry (DONAGEMA et al., 2011). N was extracted by sulfur digestion and dosed by distillation and titration by the Kjeldahl method (BATAGLIA et al., 1983).

To estimate the foliar biomass, the equation of Golley et al. (1978), which establishes a relationship between DBH and leaf biomass, was used:

$$\sqrt[3]{\hat{y}} = 7.14 + 0.5081x, R^2 = 0.923$$

Where: $\hat{y}$ = foliar biomass estimation (Kg) and x = medium DBH (cm) of forest species.

The allometric equation of Golley et al. (1978) was used because it is specific for foliar biomass. Other allometric equations for tropical forests (BROWN et al., 1989; BURGER; DELITTE, 2008; SILDARRIAGA et al., 1988) were not developed specifically for leaves.

The average foliar biomass of each species (kg plant^{-1}) with highest AD was estimated by using the medium DBH. To obtain the medium DBH per species, the DBHs of all individuals of each species with highest AD were summed and divided by the number of individuals of the species. Then, in order to transform the biomass of each species by area (kg ha^{-1}), the biomass was multiplied by the AD. The total foliar biomass of the area was estimated by adding the biomass of all species (ESPIG et al., 2008a).

The nutrient content in the foliar biomass of the species in kg ha^{-1} was obtained by multiplying the concentration (g kg^{-1}) by the foliar biomass (kg ha^{-1}) (GAMA-RODRIGUES et al., 2008). The nutrient utilization efficiency of each species was calculated by the ratio between the foliar biomass of the species and the nutrient content stored in the biomass (ESPIG et al., 2008a).

The statistical procedure used to study the data of concentrations, contents, and utilization efficiencies of N, P, K, Ca, and Mg was the analysis of variance (ANOVA). Additionally, comparisons of averages by Scott-Knott's test at 5% probability were used when the effects were significant by the F test at a 5% probability level.

RESULTS AND DISCUSSION

The estimated total foliar biomass of the fragment was of $11,480 \text{ kg ha}^{-1}$ and the ten species with the highest AD contributed with $4,120.75 \text{ kg ha}^{-1}$, corresponding to 35.89% of the estimated total foliar biomass (Table 2).

Table 2. Species of highest Absolute Density (AD) and foliar biomass estimation per individual (kg plant^{-1}) and area (kg ha^{-1}) in Lowlands Dense Shade Forest fragment in Pernambuco, Brazil.

Tabela 2. Espécies de maior Densidade Absoluta (DA) e estimativa da biomassa foliar por indivíduo (kg planta^{-1}) e por área (kg ha^{-1}) em fragmento de Floresta Ombrófila Densa das Terras Baixas em Pernambuco, Brasil.

Forest species	Ecological group	Absolute density	DBH (medium)	Foliar biomass	
				(kg plant^{-1})	(kg ha^{-1})
<i>Thyrsodium spruceanum</i>	Si	246	10.89	5.43 ± 0.58	$1,335.78 \pm 22.00$
<i>Protium heptaphyllum</i>	Si	134	13.97	5.86 ± 0.01	785.24 ± 10.10
<i>Tapirira guianensis</i>	Si	68	22.19	6.96 ± 0.02	473.28 ± 7.34
<i>Brosimum guianense</i>	Si	55	9.33	5.20 ± 0.01	286.00 ± 5.37
<i>Eschweilera ovata</i>	Si	52	9.71	5.25 ± 0.07	273.00 ± 4.47
<i>Myrcia silvatica</i>	Si	43	7.64	4.94 ± 0.01	212.42 ± 6.48
<i>Brosimum rubescens</i>	Si	39	7.48	4.92 ± 0.01	191.88 ± 6.09
<i>Helicostylis tomentosa</i>	Si	36	9.61	5.24 ± 0.01	188.64 ± 5.10
<i>Casearia javitensis</i>	St	35	7.51	4.93 ± 0.008	172.55 ± 3.78
<i>Schefflera morototoni</i>	Si	33	15.82	6.12 ± 0.02	201.96 ± 3.25

Si: initial secondary; St: late secondary; DBH medium: diameter at breast height medium.

The total foliar biomass estimated in this study was lower than that observed by Espig et al. (2008a), because the fragment area studied by these researchers presented a more advanced successional stage, represented by larger quantities of late secondary species. However, the difference in estimated foliar biomass between the two fragments could have been even higher, because Espig et al. (2008a) selected species with highest importance value (IV). Therefore, species that were not abundant and without uniformity in the distribution were selected, even those with few individuals, only because the basal area was much higher than the others', making the Dominance parameter high.

The fragment studied by Espig et al. (2008a) presented a more advanced stage of succession, due to the observance of several parameters that are contained in the Resolution of the National Coun-

cil of the Environment (CONAMA) n° 31, of 12/07/1994 (BRAZIL, 1994). However, if the authors had used greatest AD instead of highest IV, the estimated total foliar biomass of the fragment would have been even higher, for example: *Lecythis pisonis*, with only four ind. ha⁻¹, was selected instead of *Protium heptaphyllum*, with 26 ind. ha⁻¹, and *Brosimum conduru*, with 25 ind. ha⁻¹, which were not within the ten species with highest IV and had larger foliar biomass estimates per area than *Lecythis pisonis* (ESPIG et al., 2008a).

The foliar biomass of the tree species with the highest AD presented a variation of 4.92 to 6.96 kg plant⁻¹ and 172.55 to 1,355.78 kg ha⁻¹ (Table 2). The species *Thyrsodium spruceanum* showed a higher amount of biomass per area (1,335.78 kg ha⁻¹), due to the higher AD of the species. There was little variation in individual foliar biomass, with total biomass being directly related to density. Except for *Casearia javitensis*, which, despite having a higher AD than *Schefflera morototoni*, presented lower biomass per area due to its little individual foliar biomass (Table 2).

It should be noted that this variation in biomass could be attributed to floristic composition, topography, soil fertility, and seasonality of species (BRUN et al. 2010). Watzlawick et al. (2012) explained that this difference is also related to the minimum diameter stipulated in the surveys, because the lower the inclusion criterion, the greater the number of individuals per species, and, consequently, the greater the amount of biomass per hectare.

Although it is very variable, biomass represents one of the main components of the nutritional balance, thus becoming an indicator of environmental impacts as well as the nutritional status of the site, helping to understand the structure of an ecosystem (BRUN et al., 2010).

The nutrient concentrations in the leaves of the forest species presented the following decreasing order: N>Ca>Mg>K>P (Table 3). The species concentrated more N than P in their foliar biomass as a consequence of the mineralization of the organic matter of the soil (Table 1) and the cycling of N (SOUZA et al., 2012). In the case of P, soil contents were very low (Table 1) and the phosphate nutrition of the fragment depended almost exclusively of the cycling of P (ESPIG et al., 2008b). Ellsworth et al. (2017) showed that even increasing the atmospheric CO₂ concentration in a mature broadleaved evergreen eucalypt forest for three years in soil poor in P, there was no increase in productivity because soil P content was limiting, as in most of the world's tropical soils.

In this study, Mg concentrations in leaves of the species were higher than K concentrations. Studies on fragments of tropical forests carried out by Brown et al. (1994), and also in Lowlands Dense Shade Forest fragments by Leão and Silva (1991) and Espig et al. (2008a) reported the following decreasing order: N>Ca>K>Mg>P. The concentration of K in the leaves of forest species in tropical environments is very variable because K is a very soluble element, being easily leached directly from the leaf surface (ROSOLEM et al., 2003), especially in regions with high rainfall indexes, as the fragment of this study.

The exchangeable Mg concentrations in the soil in this fragment were very high and much larger than the exchangeable K concentrations (Table 1), causing the Mg uptake by the plants to have been greater than K. The soil exchangeable Mg concentrations of the soil were so high that they were also higher than the exchangeable Ca concentrations, which could have caused the plants to absorb more Mg than Ca. However, the plants have specific absorption mechanisms, which can cause preferential absorption of one cation over another (SILVERTOWN, 2004).

The species with the highest N concentration was *Protium heptaphyllum*, differing of the other species. The species with the lowest N concentration was *Tapirira guianensis* (Table 3). The P concentrations ranged from 1.17 g kg⁻¹ in *Myrcia silvatica* to 1.75 g kg⁻¹ in *Helicostylis tomentosa* and were, on average, 1.53 g kg⁻¹ (Table 3).

The highest K concentrations were found in *Brosimum guianense* and *Helicostylis tomentosa*, which did not differ statistically (Table 3). The Mg concentrations did not vary much; the highest concentration was determined in *Brosimum guianense*, which was of 7.25 g kg⁻¹. The other species presented intermediate concentrations, ranging from 1.92 g kg⁻¹ to 4.11 g kg⁻¹ and had, on average, 3.66 g kg⁻¹ (Table 3).

Santos-Filho et al. (2007) reported that adequate N concentrations vary from 12 g kg⁻¹ to 35 g kg⁻¹, so the N concentrations determined in this study varied within this range. N is a structural element for plants, as well as a constituent of chlorophyll molecules. Thus, their deficiency decreases chlorophyll concentration in the plant (MALAVOLTA et al. 2006), which results in the symptom of generalized chlorosis (yellowing of the leaves), especially in older leaves (first symptom) (CONCEIÇÃO et al., 2013).

Table 3. Nutrient concentrations in leaves and stock in foliar biomass of forest species with highest Absolute Density in Lowlands Dense Shade Forest fragment in Pernambuco, Brazil.**Tabela 3.** Teores e conteúdo de nutrientes nas folhas das espécies florestais de maior Densidade Absoluta em fragmento de Floresta Ombrófila Densa das Terras Baixas em Pernambuco, Brasil.

Forest species	N	P	K	Ca	Mg
	Concentration (g kg ⁻¹)				
<i>Thyrsodium spruceanum</i>	16.85 c	1.41 c	1.39 c	5.89 c	3.66 b
<i>Protium heptaphyllum</i>	25.29 a	1.64 b	2.76 b	2.97 d	1.92 b
<i>Tapirira guianensis</i>	15.07 d	1.59 b	1.86 c	11.86 a	4.11 b
<i>Brosimum guianense</i>	21.14 b	1.63 b	6.41 a	3.44 d	7.25 a
<i>Eschweilera ovata</i>	18.11 c	1.64 b	2.05 c	2.98 d	3.43 b
<i>Myrcia silvatica</i>	15.21 d	1.17 d	1.82 c	7.46 b	2.77 b
<i>Brosimum rubescens</i>	17.36 c	1.36 c	1.66 c	2.00 d	3.32 b
<i>Helicostylis tomentosa</i>	22.49 b	1.75 a	5.47 a	4.31 d	3.12 b
<i>Casearia javitensis</i>	18.67 c	1.42 c	2.80 b	3.00 d	3.28 b
<i>Schefflera morototoni</i>	17.17 c	1.72 a	3.43 b	7.08 b	3.76 b
Average	18.74	1.53	2.96	5.09	3.66
Fcalculado	30.62**	28.96**	25.72**	46.91**	11.23**
CV (%)	6.31	3.88	19.59	14.99	19.67
Forest species	Stock (kg ha ⁻¹)				
<i>Thyrsodium spruceanum</i>	22.51 a	1.88 a	1.86 a	7.87 a	4.89 a
<i>Protium heptaphyllum</i>	19.86 b	1.29 b	2.17 a	2.33 c	1.51 b
<i>Tapirira guianensis</i>	7.13 c	0.75 c	0.88 b	5.61 b	1.95 b
<i>Brosimum guianense</i>	6.05 c	0.47 d	1.83 a	0.98 e	2.07 b
<i>Eschweilera ovata</i>	4.94 d	0.45 d	0.56 c	0.81 e	0.94 c
<i>Myrcia silvatica</i>	3.23 d	0.25 f	0.39 c	1.58 d	0.59 c
<i>Brosimum rubescens</i>	3.33 d	0.26 f	0.32 c	0.38 e	0.64 c
<i>Helicostylis tomentosa</i>	4.24 d	0.33 e	1.03 b	0.81 e	0.59 c
<i>Casearia javitensis</i>	3.22 d	0.25 f	0.48 c	0.52 e	0.57 c
<i>Schefflera morototoni</i>	3.47 d	0.35 e	0.69 b	1.43 d	0.76 c
Average	7.80	0.63	1.02	2.23	1.45
Fcalculado	144.57**	1,326.40**	34.00**	109.28**	42.64**
CV (%)	13.30	4.13	19.88	18.55	24.49

CV: coefficient of variation = standard deviation/Average × 100. Averages followed by equal letters in the columns do not differ at 5% probability level by the Scott-Knott's test. ** Significant at 1% probability by the F test.

Barroso et al. (2005), studying macronutrient deficiencies in *Tectona grandis* seedlings, found that N deficiency caused, in addition to chlorosis, a drastic reduction in growth because according to Silveira et al. (2002), the absence or deficiency of N also causes the shoot emission to stop.

The concentrations of P in leaves of the species in this study were higher than those found by Espig et al. (2008a), which showed P concentrations ranging from 0.61 g kg⁻¹ to 1.37 g kg⁻¹ and were, on average, 0.95 g kg⁻¹. According to Faquin (2005), P is quite mobile in the plant, being redistributed by the phloem from older tissues to younger ones. Malavolta et al. (2006) pointed out that low P concentration may be related to the age of the plants, because, the older they are, the lower the concentration of this nutrient. Thus, it is possible that the P concentrations found in this work were higher than those of Espig et al. (2008a) due to the structure of the plants, composed mostly by young individuals and formed by initial secondary species (Table 2). In addition, low P concentrations were observed in the soil (Table 1), suggesting that in this fragment a greater cycling of this nutrient occurs, making the species better nourished in P.

The species *Brosimum guianense* and *Helicostylis tomentosa* presented high K concentrations in this study and these two species also excelled in the study by Espig et al. (2008a), but it was found that the average concentration found by Espig et al. (2008a) was 12.23 g kg⁻¹, well above of that determined in this study, which was 2.96 g kg⁻¹. According to Malavolta et al. (2006), the average K concentration is 10 g kg⁻¹; therefore, the low concentration of this nutrient may be related to the chemical characteristics of the soil. Indeed, K concentrations were low (Table 1), but this is a common feature in tropical soils. For this fragment, the Ca/K and especially Mg/K ratios may have influenced the low K uptake by plants.

According to Perez et al. (2016), K has no structural function and its main function is to activate enzymes. As a result, K is also related to the osmotic potential of the plant, which influences cellular expansion and ion transportation, being fundamental in the stomata movement. Thus, K deficient plants have lower photosynthetic performance, due to the stomata opening not occurring regularly, which reduces CO₂ entry (PRADO, 2008).

It was found that the mean Ca concentration was within the criteria established by Malavolta et al. (2006), which is of 5.0 g kg⁻¹. Even though the present value was within the limit established by the author, the average Ca concentration found in this study was three times lower than that reported by Espig et al. (2008a). This may be related to the time period of material collection. Laviola et al. (2007), studying Ca dynamics, found that during the flowering period, the leaves showed a tendency to present a lower Ca concentration due to the nutrient dilution. In the reproductive phase, after reaching the minimum concentration, Ca concentrations in the leaves increased again until reaching maximum concentration of the element.

Malavolta et al. (2006) reported that the flowers constitute of a strong temporary drain of nutrients, extracting approximately ¼ of Ca in relation to the total Ca allocated in the aerial part of the plant. Thus, as 70% of the species' leaf sample in this study occurred during the flowering period. The Ca concentrations of the leaves might have been influenced by this high Ca demand during the flowering of the species of fragment.

Additionally, when evaluating the nutrient translocation in the leaves of *Hevea brasiliensis*, Silva et al. (1998) found that Ca concentrations in the leaves increased with the age of the leaf, presenting significantly lower concentrations in the young leaves. As the studied fragment is in the middle stage of succession, formed mainly by young individuals (Table 2), it is possible that this is also the cause of low Ca concentrations found in the leaves. The fragment of the work of Espig et al. (2008a) was in a more advanced stage of succession when compared to this fragment of study, and, therefore, the concentration found by those authors was higher.

Low exchangeable Ca concentrations were observed in soil analyses of the fragment (Table 1), demonstrating the chemical poverty of this nutrient in the soil. The concentrations and nutrients distribution in the soil vary during the growth phase of the forest species (NOVAIS et al., 1986). The nutritional requirement is related to the mobility of nutrients in the plant. Because Ca is not a very mobile element, an increase in Ca concentration is expected throughout the growing time of the plant and possibly a little more in the soil, especially in the superficial layer.

The Mg concentration found in this study was similar that determined by Espig et al. (2008a), which was of 3.65 g kg⁻¹. This element presented concentrations within the range of concentrations mentioned in the literature, which is from 1.5 g kg⁻¹ to 5.0 g kg⁻¹ (SANTOS-FILHO et al., 2007). According to Kozłowski et al. (1991), it is common for the highest Mg concentrations to be observed in the leaves because Mg is part of the photosynthetic complex, and is part of the chlorophyll structure.

The exchangeable Mg concentration in the soil was three times higher than that found by Espig et al. (2008a) for the first two depths, and five times higher when compared to the third depth. Such high exchangeable Mg concentration in the soil may have inhibited the absorption of exchangeable K, causing the K concentration in the plants to be low. According to Moreira et al. (1999) high concentrations of exchangeable Ca and Mg in soil generated competitive inhibition with exchangeable K. Clark et al. (1997) observed in agricultural crops that, with the increase of Mg application to the soil, there was a reduction in the Ca concentration of the aerial part.

The N was the nutrient that presented the highest content in the leaves of the species with highest AD (Table 2 and Table 3). The species *Thyrsodium spruceanum* presented the highest N content, which was 22.51 kg ha⁻¹, and *Casearia javitensis*, *Myrcia silvatica*, *Brosimum rubescens*, *Schefflera morototoni*, *Helicostylis tomentosa* and *Eschweilera ovata* presented the lowest N contents, which were: 3.22; 3.23; 3.33, 3.47, 4.24, and 4.94 kg ha⁻¹, respectively

The species *Thyrsodium spruceanum* was the species that most accumulated N in the fragment due to its high foliar biomass per area (1,335.78 kg ha⁻¹) (Table 2). *Protium heptaphyllum*, while having a relatively high foliar biomass (Table 2), also had the highest N concentration in the leaves, which was of 25.29 g kg⁻¹ (Table 3), causing the N content of this species to also have been elevated (Table 3). *Thyrsodium spruceanum* elevated leaf production caused this species to have the highest contents

of P (1.88 kg ha⁻¹), Ca (7.87 kg ha⁻¹), and Mg (4.89 kg ha⁻¹). For K, *Protium heptaphyllum*, *Thyrsodium spruceanum*, and *Brosimum guianense* were the same, presenting the highest contents (2.17; 1.86; and 1.83 kg ha⁻¹, respectively).

The species *Casearia javitensis*, *Myrcia silvatica*, and *Brosimum rubescens* presented low P contents (0.25; 0.25; and 0.26 kg ha⁻¹, respectively). *Casearia javitensis* was also the species with the lowest contents of Mg, Ca, and K. *Brosimum rubescens* presented lower contents of K (0.32 kg ha⁻¹) and Ca (0.38 kg ha⁻¹) (Table 3).

Espig et al. (2008a) reported accumulations of N, P, and Mg in species of the Lowlands Dense Shade Forest to be lower than those found in this study. However, for the nutrients K and Ca, also studied by these same authors, the accumulations were larger than those in this study. The variation in efficiency may be related to the nutrient availability in the soil or may be an intrinsic characteristic of the species. The low utilization efficiency is due to higher absorption of these nutrients, because, as the nutrient concentration increases in the plant, the utilization efficiency index decreases (MACHADO et al., 2001). In fact, the highest concentrations presented by the species were those of N and Ca (Table 3).

The forest species presented different efficiencies of nutrient utilization. They were more efficient in using one nutrient over another. The forest species presented the following decreasing order of nutritional efficiency: P>K>Mg>Ca>N (Table 4).

Table 4. Nutritional utilization efficiency of the forest species with the highest Absolute Density in Lowlands Dense Shade Forest fragment in Pernambuco, Brazil.

Tabela 4. Eficiência de utilização de nutrientes das espécies florestais de maior Densidade Absoluta em fragmento de Floresta Ombrófila Densa das Terras Baixas em Pernambuco, Brasil.

Forest species	N	P	K	Ca	Mg
<i>Thyrsodium spruceanum</i>	59.34 b	710.52 b	718.16 a	169.73 d	273.17 b
<i>Protium heptaphyllum</i>	39.54 c	608.71 c	361.86 c	337.01 b	520.03 a
<i>Tapirira guianensis</i>	66.38 a	631.04 c	537.82 b	84.36 e	242.71 b
<i>Brosimum guianense</i>	47.27 c	608.51 c	156.28 d	291.84 b	138.16 c
<i>Eschweilera ovata</i>	55.26 b	606.67 c	487.50 b	337.04 b	290.43 b
<i>Myrcia silvatica</i>	65.76 a	849.68 a	544.67 b	134.44 d	360.03 b
<i>Brosimum rubescens</i>	57.62 b	738.00 b	599.63 b	504.95 a	299.81 b
<i>Helicostylis tomentosa</i>	44.49 c	571.64 d	183.15 d	232.89 c	319.73 b
<i>Casearia javitensis</i>	53.59 b	690.20 b	359.48 c	331.83 b	302.72 b
<i>Schefflera morototoni</i>	58.20 b	577.03 d	292.70 c	141.23 d	265.74 b
Average	54.75	659.20	424.12	256.53	301.25
Fcalculado	15.74**	35.14**	15.24**	44.00**	11.54**
CV (%)	7.01	3.90	19.47	12.96	15.83

CV: coefficient of variation = standard deviation/Average x 100. Averages followed by equal letters in the columns do not differ at 5% probability level by the Scott-Knott's test. ** Significant at 1% probability by the F test.

The lowest utilization efficiencies observed were pertained to N and Ca, ranging from 39.54 to 66.38 and 84.36 to 504.95, respectively (Table 4). The species *Myrcia silvatica* showed the ability to get established in environments with low P and N availability (Table 1) due to the high efficiency of this species (Table 4) in producing biomass (Table 2) using smaller amounts of these nutrients (Table 3). Likewise, in environments with low K and Mg availability (Table 1), *Thyrsodium spruceanum* and *Protium heptaphyllum*, respectively, can be introduced because they present high utilization efficiency for these nutrients, as well as *Brosimum rubescens* for Ca and *Tapirira guianensis* for N (Table 4).

The forest species in this fragment were established under the same conditions of poor soil and low natural fertility, common in tropical environments (Table 1). The establishment of the species in this nutrient-poor environment could have been reflected in the contents of the nutrients in the leaves without differentiating the species. However, this did not occur and the species clearly differed in their ability to concentrate nutrients. For example: *Protium heptaphyllum* concentrated more N, *Helicostylis tomentosa* and *Schefflera morototoni* concentrated more P, *Brosimum guianense* and *Helicostylis tomentosa* concentrated more K, *Tapirira guianensis* concentrated more Ca and *Brosimum guianense* concentrated more Mg (Table 3).

In tropical soils, the relationships between nutrient contents in the soil and leaf contents are low (ESPIG et al., 2008b) because the contribution of the litter to the forest nutrition is very high, with nutritional cycling being the main responsible for the nutrient supply (DINIZ et al., 2015). This is very important because through the natural chemical poverty of the tropical soils, they would not be able to supply the nutritional needs of the forest species. Thus, as observed in this study, in a nutritionally balanced environment, some species individually or in groups are responsible for the cycling of different nutrients.

This may be better evidenced by the different nutritional efficiencies of the species: *Tapirira guianensis* and *Myrcia silvatica* are more efficient for N, *Myrcia silvatica* also for P, *Thyrsodium spruceanum* for K, *Brosimum rubescens* for Ca and *Protium heptaphyllum* for Mg (Table 4). It is as if in the forest community of the fragment there was a nutritional function for each species, independent of the soil. Therefore, the more established the forest community, the greater the nutritional balance and the cycling of nutrients.

Another important aspect that can be observed is that in naturally poor soil environments, the greater the diversity of species, the more nutritionally balanced nutrient cycling should be, because this study showed specificity in the nutritional efficiency of the species. Some species or groups were more responsible for the cycling of the different nutrients.

The highest nutritional utilization efficiencies occurred due to the maintenance of a good production of dry matter (Table 2) even under lower concentrations of P and K in the tissue (Table 3), resulting in a lower P and K accumulation (Table 3). In other words, even under low nutrient concentrations in the tissues, the species showed good efficiency in converting these nutrients into biomass (LUCA et al., 2002).

According to Saidelles et al. (2010) nutrient utilization efficiency makes it possible to recognize species that contribute to forest sustainability. When the efficiency of use of a nutrient and the expected biomass production are known, it becomes possible to estimate the amount of nutrients required for an adequate nutritional balance.

CONCLUSIONS

The forest species presented high content for N and low for P, being able to get established in environments abundant in N and restricted in P, except for *Myrcia silvatica* and *Tapirira guianensis*, which can be recommended for soils with little N availability;

The species *Thyrsodium spruceanum* and *Protium heptaphyllum* can be recommended for environments with low K and Mg availability, respectively;

In forest fragments of soils with low Ca availability, *Brosimum rubescens* can be used for forest restoration of these areas;

The nutritional utilization efficiency may indicate a diversified, established, and nutritionally balanced forest fragment, especially when there is a diversified contribution of the species to the nutrient cycling.

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