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NUTRIENT DEPOSITION BY LITTERFALL IN DIFFERENT-AGED RIPARIAN FORESTS UNDERGOING RESTORATION

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ABSTRACT – (NUTRIENT DEPOSITION BY LITTERFALL IN DIFFERENT-AGED RIPARIAN FORESTS UNDERGOING RESTORATION*)* The objective of this study was to assess litterfall and nutrient deposition during one year in an 18 and a 28-years-old riparian semideciduous forest community. The highest litterfall input occurred in the driest period of the year. Litterfall was generally higher in the 28-year-old community. The deposition of nutrients and Al followed the order Ca>N>K>Mg>S>P>Al>Fe>Mn>Zn>B>Cu in both communities. The monthly variation of nutrient concentration in the litter did not follow the pattern of the content on the litter or the litter production. The ecological processes related to nutrient cycling in the studied area were recovered before 18 years after planting.

Keywords: forest restoration; macronutrients; micronutrients; rainfall; seasonal forest; São Paulo.

RESUMO – (DEPOSIÇÃO DE NUTRIENTES PELA SERAPILHEIRA EM MATAS CILIARES EM RESTAURAÇÃO COM DIFERENTES IDADES) Objetivou-se avaliar a deposição de nutrientes pela serapilheira, no período de um ano, em comunidades de floresta estacional semidecídua ripária, uma com 18 anos e outra com 28 anos após o reflorestamento. A maior produção de serapilheira ocorreu no período mais seco do ano, sendo geralmente maior na comunidade com 28 anos. A deposição dos elementos seguiu a ordem Ca>N>K>Mg>S>P>Al>Fe>Mn>Zn>B>Cu nas duas comunidadas. A variação mensal da concentração de nutrientes na serapilheira não seguiu o padrão do conteúdo ou da produção de serapilheira. Os processos ecológicos relacionados à ciclagem de nutrientes foram recuperados antes dos 18 anos após o reflorestamento.

Palavras-chave: restauração florestal; macronutrientes; micronutrientes; pluviosidade; floresta estacional semidecídua; São Paulo.

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1. INTRODUCTION

The deposition of canopy residues and its consequent decomposition is the main pathway of organic matter and nutrient return to the soil (ABELHO, 2001; CORREIA; ANDRADE, 2008). Therefore, the cycles of carbon and of many macro and micronutrients are severely affected by changes in litterfall input. This is especially important in the tropics, where soils are naturally poor and the nutrient release from the decomposition of litter is crucial to the ecosystems' sustainability (ABELHO, 2001; HOU et al., 2012). In this regard, quantitative aspects of litterfall are important environmental indicators for land reclamation processes, providing information on the site productivity, species phenology, carbon cycling and nutrient supply to sustain forest growth (ABELHO, 2001; DIAS et al., 2002; SELLE, 2007; PINTO et al., 2008). However, studies dealing with functional aspects such as nutrient cycling of forests undergoing restoration are scarce in comparison to floristic studies (SCHIEVENIN et al., 2012).

In previous studies the success of the reclamation process of one riparian semideciduous forest buffer in southern state of São Paulo was inferred from vegetation growth, phytosociology and soil characteristics (PULITANO et al., 2004; 2013). The objective of this study was to assess litterfall and nutrient deposition in the same sites studied by Pulitano et al. (2004; 2013), in order to evaluate the sustainability of the ecological restoration process regarding nutrient cycling.

2. MATERIAL AND METHODS

This study was carried out in a small watershed where the riparian forest was recovered around the spring and margins of the Água Nova brook, a Paranapanema River tributary, in Cananéia Farm, Cândido Mota city, southern state of São Paulo, Brazil, within the coordinates 22º46' – 22º28'S and 50º27' – 50º29'W. The average altitude is 430 m. The local climate is of Cwa type, according to Köppen classification, i.e., mesothermal with dry winter and rainy summer, coldest month temperature between -3 and 18 ºC and hottest month temperature higher than 22 ºC. The average annual precipitation is 1,550 mm. The remaining native vegetation in the region is classified as seasonal semideciduous forest. The afforestation of a 20-ha area began in 1972 by planting exotic and native, most late successional tree species, in consortium with cassava, maize and rice in the first years.

Litterfall deposition was assessed in two sites within the forest undergoing restoration, 1,000 m distant from each other, where the age of the planted trees was 18 years (22º46’60”S and 50º27’46”W) and 28 years (22º47’31”S and 50º28’06”W). The sites occupied approximately 30,000 m² and 4,400 m², respectively. By the time of data collection, the upper layer (dbh≥5 cm) of the 18-year-old community was characterized by a density of 620 trees ha^{-1} of 23 species; the canopy cover was 84 %, the basal area was 37.0 m² ha^{-1} and the mean height was 12.6 m (PULITANO et al., 2004). In the 28-year-old community, a density of 1,170 trees ha^{-1} of 38 species was recorded (dbh≥5 cm); the canopy cover was 93 %, the basal area was 51.3 m² ha^{-1} and the average height was 9.3 m (PULITANO et al., 2004). In both sites the soil was categorized as eutrophic Oxisol with high organic matter content (PULITANO et al., 2013).

Ten 50 x 50 cm litterfall collectors made of nylon nets and wooden clapboards were randomly placed at ground level in each site. The litter on the collectors was collected monthly from March 1999to February 2000, and weighted after oven drying at 70 ºC to constant weight. Samples from the dried material were collected for nutrient (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn) and Al content determination according to Malavolta et al. (1997). The analyses were made in the Laboratório de Fertilidade de Solos of Universidade Federal de São Carlos (Araras Campus). Pluviometric data were obtained from a local sugar factory. For each site, the mean litterfall dry weight and the contents of nutrient and Al in the litter were calculated on a monthly and annual basis, and expressed as Mg ha^{-1} (litterfall), kg ha^{-1} (macronutrients) or g ha^{-1} (micronutrients). The results for each site were contrasted between themselves and among other forest sites using information available in literature.

3. RESULTS AND DISCUSSIOIN

The monthly fall of litter and rain throughout the studied period in the different-aged communities are shown in Figure 1. The highest litterfall was registered between July and September, which corresponded to the driest period of the year (winter). With exception of July and October, litterfall was higher at the 28-year than at the 18-year-old community. The total rainfall registered in the studied period was 1,153 mm.

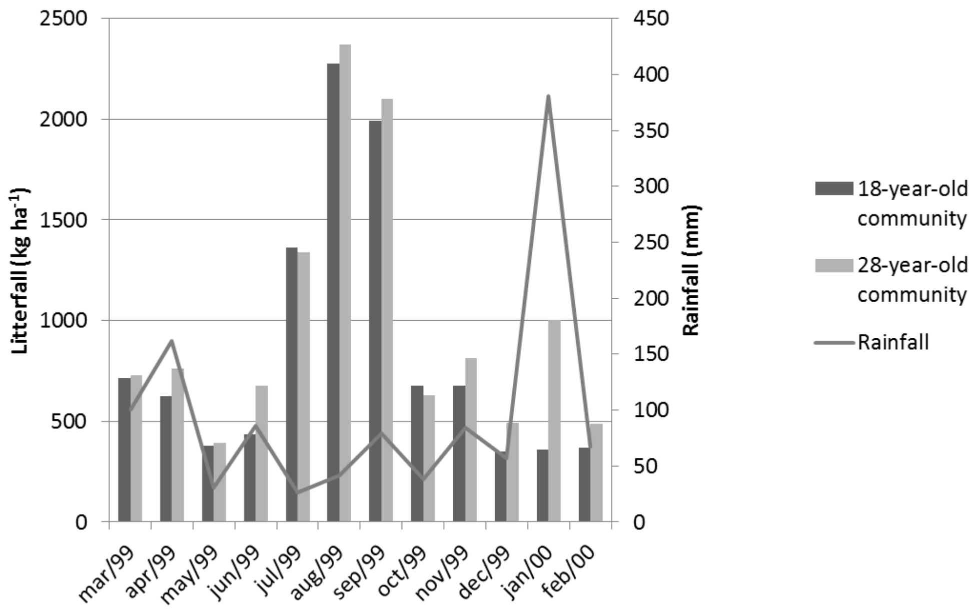

Figure 1. Monthly litterfall (bars) and rainfall (line) at the 18 and 28 year-old forest communities in the afforested riparian buffer of Cananéia Farm between March 1999 and February 2000.

The literfall dynamics in forests vary with species composition, age, edaphoclimatic characteristics and management practices (ABELHO, 2001; HÜLLER et al., 2009; SANCHES et al., 2009; SCHEER et al., 2009; NOUVELLON et al., 2011; ROHR et al., 2013; ZHOU et al., 2013; GONÇALVES et al., 2014). Usually, older forests have higher litterfall than forests in early successional stages (EWEL, 1976; LUIZÃO; SCHUBART, 1986; PINTO et al., 2008; NOUVELLON et al., 2011; LARSON, 2013). However, depending on the species composition, litterfall might decrease with age (LEITÃO-FILHO; PAGANO, 1993; VENDRAMI et al., 2012). In this study, the higher litterfall in the 28-year-old community is probably a consequence of its higher plant density and canopy cover or biomass (basal area) (PULITANO et al., 2004), indicating that litterfall in the younger community may increase with time.

The higher litterfall in the dry season observed in the forest communities studied at Cananéia Farm was similar to those found in other semideciduous forest studies (MARTINS; RODRIGUES, 1999; DIAS et al., 2002; PINTO et al., 2008; VENDRAMI et al., 2012). The inverted relationship between rainfall and litterfall is frequently observed in tropical regions (SPAIN, 1984; DURIGAN et al., 1996; MORAES et al., 1999; CHAVE et al., 2010), reflecting a strategy to minimize the effects of drought by reducing evapotranspiration through leaves.

The annual litterfall in Cananéia Farm was 10.2 Mg ha^{-1} in the 18-year-old and 11.8 Mg ha^{-1} in the 28-year-old community. These values were the highest among the communities of native riparian forests researched in the state of São Paulo, with exception of the one studied by CARPANEZZI (1980), in Lençóis Paulista (Table 1). This is a positive indicator for the recovery of ecological processes in the forests being restored.

The total amount of macronutrients found in the litter was 503 kg ha^{-1} and 519 kg ha^{-1}; the total amount of micronutrients (B, Cu, Mn, Fe and Zn) was 8.034 kg ha^{-1} and 8.971 kg ha^{-1}; and the total Al content was 5.002 kg ha^{-1} and 7.108 kg ha^{-1} in the 18 and 28-year-old communities, respectively. These amounts are in the range of values observed by other authors in riparian forests in the state of São Paulo (Table 1). With exception of N, K, Cu and Mn, the content of elements in the litter of the older community was higher than in the younger community which is consequence of the higher litterfall in the older community.

The amount of nutrients returned to the soil is noteworthy. It is equivalent to the application of more than 300 kg ha^{-1} of urea, 40 kg ha^{-1} of concentrated superphosphate, 100 kg ha^{-1} of potassium chloride and 600 kg ha^{-1} of dolomitic lime only to supply the forest with N, P, K and Ca. It is worth remembering that the litter turnover rate in the soil is usually less than one year in tropical forests (CORREIA; ANDRADE, 2008). Therefore, the communities might have become self-sustainable in regard to the nutritional demand of the vegetation.

In both sites, the nutrients Ca and N represented more than 70 % of the total content of nutrients in the litter (Table 1). The most abundant nutrient was Ca, corresponding to 39 and 48 % of the total amount of nutrients in the 18 and 28-year-old communities, respectively. The second nutrient in quantity was N, with 35 and 28 % of the total amount of nutrients in the 18 and 28-year-old communities, respectively.

The macronutrient rank, in order of amount, was Ca>N>K>Mg>S>P in both communities. This sequence was also reported in three of the earlier studies (Lençóis Paulista, Campinas and Marília), whereas in the other three studies (Mogi Guaçu, Itirapina and Tarumã), N was more abundant than Ca (Table 1).

The content of nutrients in plant tissues varies with genetic and edaphoclimatic characteristics, such as plant nutrient use efficiency, nutrient availability in soil and hydric regime

(MARSCHNER; MARSCHNER, 2012). In tropical forests, the most limiting soil nutrient is usually phosphorus (VITOUSEK, 1984) due to the high fixation capacity of tropical soils (NOVAIS et al., 2007), and plants usually do not accumulate large amounts of P in comparison to the other macronutrients. On the other hand, N and Ca tend to be more abundant in the litter than in soil, since these nutrients are represented in several molecules abundant in plant tissues and N is more abundant in nitrogen-fixing leguminous trees, which are relatively numerous in tropical forests (VITOUSEK, 1984; MARSCHNER; MARSCHNER, 2012). The higher content of N, K, Cu and Mn in the 18-year-old-community, compared to the older community, is probably a result of the different species composition, since the soils of the two sites were chemically similar (PULITANO et al., 2004, 2013).

Considering the micronutrients and Al, the rank in decreasing order of amount was Al>Fe>Mn>Zn>B>Cu. Aluminum is the main element, followed by Fe or Mn, B, Zn and Cu, the least abundant. These results are consistent with the content of these elements usually found in soils and plant tissues in general (ABREU et al., 2007; MALAVOLTA, 2006).

Table 1. Annual litterfall and content of nutrients and aluminum in the litter collected at the 18 and 28 year-old forest communities in the afforested riparian buffer of Cananéia Farm between March 1999 and February 2000 and other riparian forests in the state of São Paulo, Brazil. [a] Semideciduous forest domain. [b] Cerrado domain. * Native forests

Location	Litterfall	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Al
	Mg ha^{-1}	------------						kg ha^{-1}					------------
Cândido Mota 18-year-old community [a 11]	10.2	179	8	80	201	25	10	0.508	0.208	4.589	2.122	0.607	5.002
Cândido Mota 28-year-old community [a 11]	11.8	149	9	68	254	29	10	0.526	0.135	6.007	1.693	0.610	7.108
Lençóis Paulista [a * 2]	10.5	202	11	72	240	32	-	-	-	-	-	-	-
Mogi Guaçu [b * 3]	6.7	107	4	29	51	17	9	0.312	0.097	3.612	2.467	0.169	20.100
Campinas [a * 4]	9.6	165	8	47	187	22	18	-	-	-	-	-	-
Itirapina [b * 5]	5.7	102	4	19	79	14	8	-	-	-	-	-	-
Luiz Antônio [a * 6]	-	262	12	47	190	35	15	-	-	-	-	-	-
Marília[a * 7]	10.0	206	7	57	184	42	15	0.490	0.189	2.179	2.909	0.328	3.519
Tarumã [a * 7]	9.7	180	8	59	324	56	18	0.558	0.157	5.983	2.978	0.327	9.047

Data sources: [1] This study; [2] Carpanezzi (1980); [3] Delitti (1984); [4] Santos (1988); [5] Lamparelli (1989); [6] Pinto (1992); [7] Pagano and Durigan (2000).

There was a clear seasonality in the amount of nutrients and Al released by the vegetation through litter in both sites, which followed the litterfall pattern (Figure 2). Therefore, almost all elements had their deposition peaks in August or September, in the middle of the dry season. The only exception was Zn in the 18-year-old community, whose peak was in January, the month with the highest precipitation.

The monthly variation of the concentration of nutrients and Al in the litter was not as clear as the content variation (Figure 3). For most nutrients the difference in the monthly concentration of elements in the litter between sites was relatively small and it is hard to depict a pattern on this issue. The N concentration is an exception, since it was higher in the 18-year-old community in all months.

Despite the apparent lack of seasonality regarding nutrient concentration in the litter, P, Ca, S, Cu and Zn showed a remarkable peak of concentration in January in the 18-year-old-community, the month with higher precipitation (Figure 3). This might be due to the higher availability of these nutrients under higher soil moisture, which improves their transport to the plant roots (NOVAIS; MELLO, 2007). Conversely, these peaks were not observed in the 28-year-old community (Figure 3). This might be related to undetected differences in soil nutrient availability, plant composition or the higher production of litter in the older sector (Figure 1), which possibly diluted the nutrient content. Another possibility would be the increase of green debris in the litter of the younger community, dropped by the impact of rain and wind. However, this would have affected the concentration of other nutrients and increased litterfall accordingly, which did not occur.

It is hard to draw a pattern on the variation of nutrient concentration in the litter of tropical forests, since the results vary with location and vegetation type (DIAS et al., 2002; LUSK et al., 2003; VITAL et al., 2004; WOOD et al., 2005). Isolating the factors which drive nutrient variation in forest ecosystems would improve knowledge on nutrient cycling and the monitoring and management of reclaimed areas.

The litterfall in the riparian forest of Cananéia Farm is another indication of the success of its restoration. Together with other vegetation indicators (PULITANO et al., 2004) and soil (PULITANO et al., 2013), the litterfall proved to be a valuable tool to assess the recovery of ecological processes due to afforestation. The assessment of this variable is hampered, however, by the need of a long period of collecting and later oven-drying plant material. Other relationships between nutrient deposition and plant community attributes, such as canopy cover or basal area, which are easily obtained, should be modeled, in order to indirectly estimate nutrient cycling.

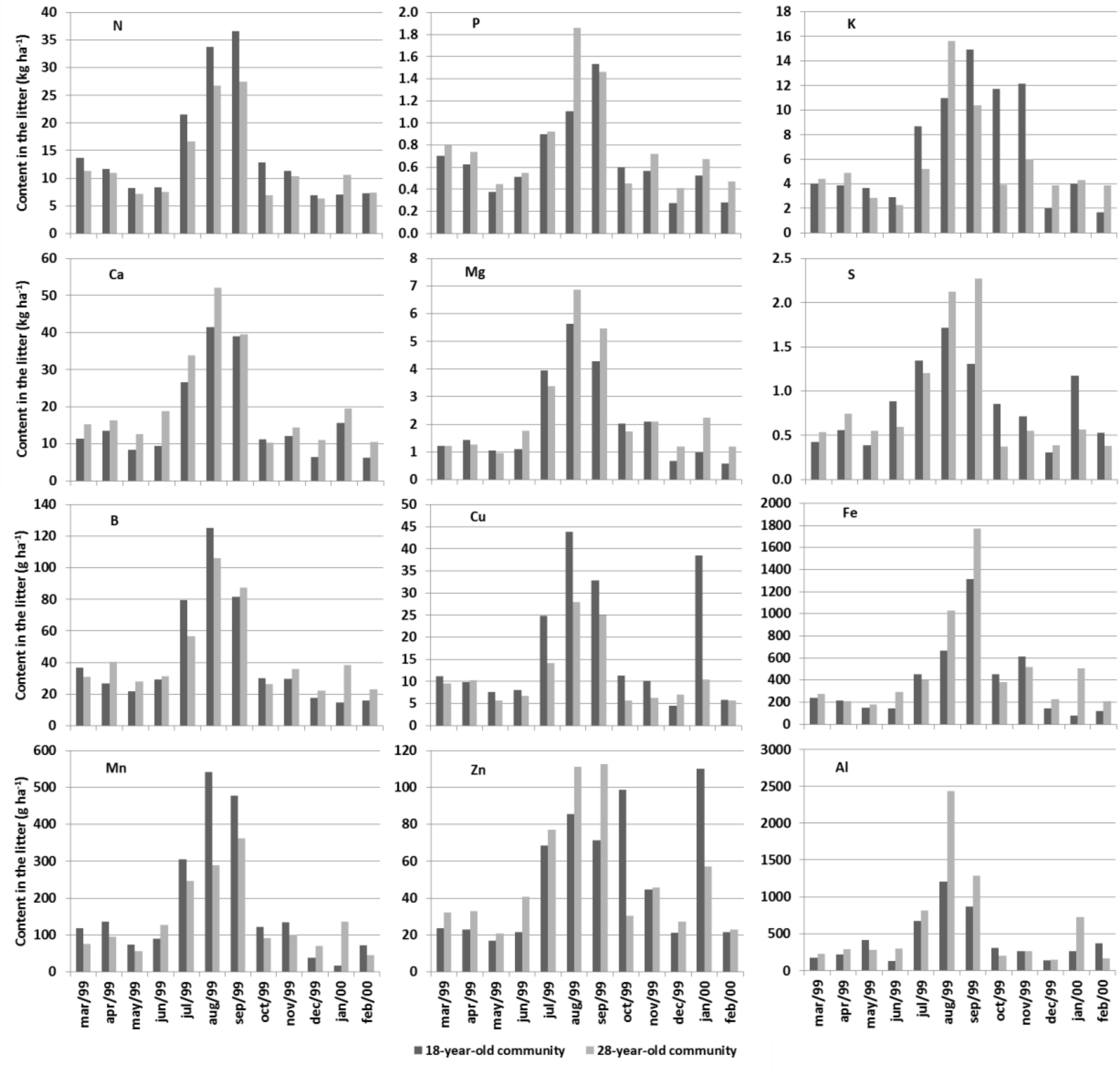

Figure 2. Monthly nutrient and Al content of the litterfall at the 18 and 28 year-old forest communities of Cananéia Farm between March 1999 and February 2000.

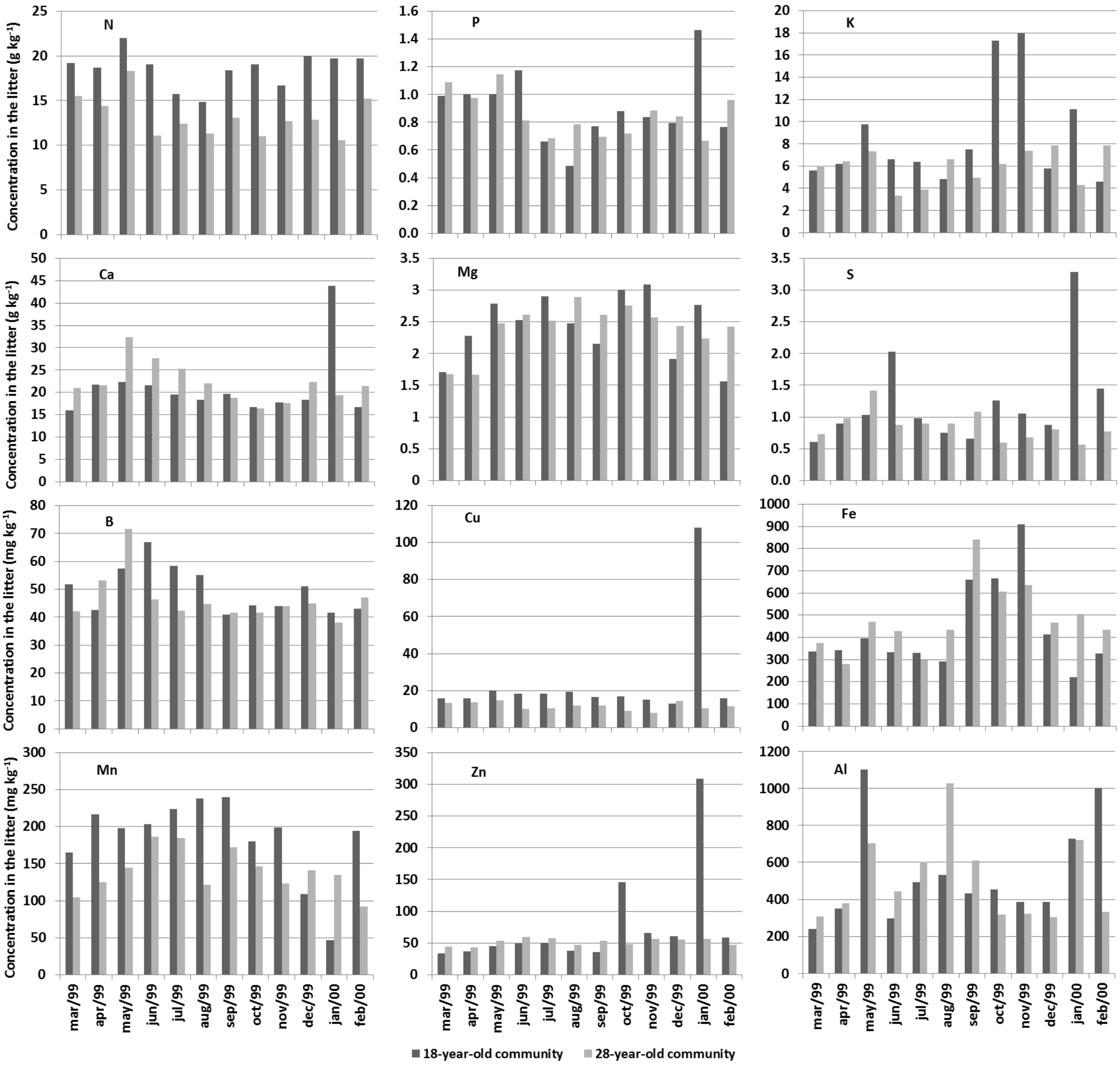

Figure 3. Monthly nutrient and Al concentration of the litterfall at the 18 and 28 year-old forest communities of Cananéia Farm between March 1999 and February 2000.

4. CONCLUSION

The amount of litterfall and its seasonality in the riparian forests undergoing restoration in Cananéia Farm are high and congruent with the results obtained from native forest remnants in the same region, indicating that the ecological processes related to nutrient cycling were recovered before 18 years after planting.

The older community, with higher density, biomass and canopy cover, produces more litter and returns more nutrients (except N, K, Cu and Mn) and Al to the soil than the younger community.

The deposition of nutrients and Al occurs in the order Ca>N>K>Mg>S>P>Al>Fe>Mn>Zn>B >Cu and does not depend on the age of the forest.

The monthly variation of nutrient concentration in the litter does not follow the pattern of the content on the litter or the litter production.

5. ACKNOWLEDGEMENTS

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