Chapter 6

Ecological and Environmental Aspects of Nutrient Cycling in the Atlantic Forest, Brazil

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Abstract

In developing countries, where population growth is on the rise, intense anthropogenic actions in natural forests are observed usually in the form of burnings and shallow cuts. With aiming to deploy crops or even promote irrational exploitation of forest products. In this context, preservation of natural forests (tropical and subtropical forests) depends on the knowledge of their dynamics. This information is important to allow exploration of natural forests sustainably or to subsidize conservation actions. In planted and native forests, the biogeochemical cycling of nutrients predominantly occurs through production and decomposition of litterfall. The information provided in this chapter, in particular with regard to nutrient cycling, is an important basis for understanding the structure and dynamics of nutrients in the ecosystem. We characterized nutrient stocks and elucidate some aspects of forest growth and productivity. This information is important to enhance biodiversity conservation and generate ecosystem goods and services in the Atlantic Forest Biome. Even with the intense change of land use (from forest to agricultural, pasture and urbanization), the region has high diversity of endemic species, and is considered a priority area for biodiversity conservation.

Keywords: nutrient transfer, forest soils, biogeochemical cycling, tropical forests

1. Introduction

The Atlantic Forest biome is currently at an advanced change process from its original and primitive form, due to intensive occupation and exploitation over the past five centuries. The devastation of the Atlantic Forest, at large, has been attributed to intensive use of timber species of interest (mainly *Caesalpinia echinata*, popularly known as Brazilwood), and the establishment of areas for agriculture, pasture and urbanization. The advancement and establishment of agricultural areas and, consequently, fallen forests have reduced native forest massifs to fragmented forests, which has greatly compromised biological diversity and conservation of these forest ecotypes [1]. Even with the intense land-use change, with only 12.5% of the original cover remaining (only fragments larger than 3.0 ha), the Atlantic Forest currently shows more than 15,000 plant species and more than 2000 species of vertebrate animals [2]. The biome has high diversity of endemic species, and is considered a priority area for conservation (hotspots). In it, 383 species of animals threatened with extinction are found [2].

Studies on native forests are of vital importance for a better understanding of the behavior of intrinsic characteristics to the ecosystem and must be performed before these ecosystems have all their original area changed by men [3]. The understanding of intrinsic characteristics aids to adopt proper programs for the recovery of degraded ecosystems. Therefore, a significant part of the areas that were changed due to changes in land use can be recovered. They can present again the ecological interactions necessary to ensure the biodiversity of fauna and flora. The recovery of ecosystems as a strategy to reverse the degradation process and enhance biodiversity conservation and provide ecosystem goods and services is already being implemented [4].

Mainly in tropical and subtropical regions, it is of utmost importance to have further information concerning the dynamics of nutrients in different compartments of a forest ecosystem. It is important in order to employ silvicultural practices to effectively ensure sustainable long-term management of altered ecosystem by land-use change. Nutrient cycling occurs naturally, in part, by the throughfall of tree canopies and trunks by rainfall and through the deposition of senescent tissues (litter) and after their decomposition [5]. This process, nutrient cycling (plant-soil-plant), enables the development of forests in soils with low nutritional levels [6]. The organic material that accumulates under the forest works as a big sponge able to retain water, reduce evaporation and sudden variations of soil temperature, thus preventing erosion, improving soil structure and promoting the cycling of nutrients [7].

In addition to these benefits, the understanding of nutrient cycling through litterfall in forests is one of the key aspects to be studied for planning the use of tree species to recover degraded areas or for timber production [7]. The content of nutrients supplied to the forest soil can influence production capacity as well as the potential of environmental recovery, because the nutrients resulting from organic material cause changes to the chemical and physical characteristics of the soil [3].

In this chapter, we will present some information about the nutrients cycling in the Atlantic Forest biome, the most important biome in socio-economic terms of Brazil. We will show the current status and characterization of existing forest types in the biome, description of nutrient cycles and factors affecting cycling in forests and indication and analysis of results of studies carried out throughout the biome and the potential of practical use of the data in areas with land-use change.

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2. Atlantic Forest biome

The Atlantic Forest biome consists of forest formations [Dense Ombrophilous Forest, Mixed Ombrophilous Forest (also known as Araucaria Forest), Open Ombrophilous Forest, Semideciduous Seasonal Forest, Deciduous Seasonal Forest and Evergreen Seasonal Forest] and pioneer formations, such as Sandbanks, Mangroves and Grassland [8]. The biome represents 13.04% of the Brazilian territory of which only 22% are in native vegetation at different regeneration stages [9].

The significant biodiversity of the Atlantic Forest biome is related to geographical variations in this region. Longitude, latitude and altitude affect the climatic variables, forming regions with distinct characteristics, increasing species diversity. The area of the Brazilian Atlantic Forest covers a large latitudinal extent (from 3°S to 30°S) and longitudinal (approximately 17°) and significant altitudinal variations (from sea level to altitudes above 2700 m in the Mantiqueira Hills) [10, 11] (**Figure 1**).

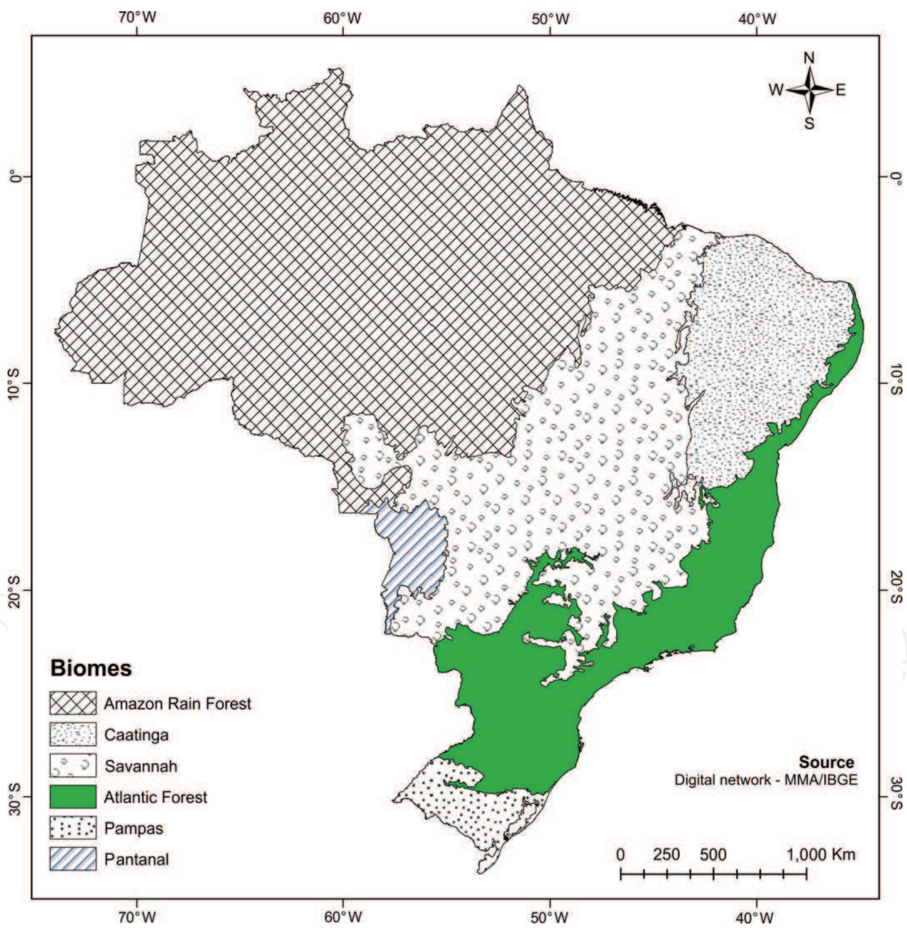

Figure 1. Distribution of Atlantic Forest Biome in Brazil. Adapted from Ref. [9].

The main forest types found in the Atlantic Forest biome are classified according to the floristic composition and environmental variables, such as precipitation and temperature. In the following section, we show some features of the main forest formation in the Atlantic Forest according to Veloso [12] and the Brazilian Institute of Geography and Statistics [13, 14].

The Ombrophilous Forest is classified as Dense, Open and Mixed formation. Dense Ombrophilous forest is characterized by the presence of medium and large trees, in addition to lianas and epiphytes in abundance, due to the constant moisture from the ocean. The coastline extends from the Northeast to the extreme South of Brazil. Its occurrence is connected to hot and humid tropical climate without dry season, with rainfall well distributed throughout the year (eventually there may occur in some regions dry periods until 60 days) and average temperature is 25°C. In Open Ombrophilous Forest, we find arboreal vegetation more sparse and with lower shrubby density. It occupies areas with climatic gradients ranging between two and four dry months. Average temperatures range between 24°C and 25°C. Finally, Mixed Ombrophilous Forest is strongly characterized by the predominance in the upper stratum of *Araucaria angustifolia* and genera of the family Lauraceae (e.g., *Ocotea* and *Nectandra*). It consists of 2776 forest species, and 946 are endemic [10]. The physiognomy occurs in areas of wet climate and without water deficit. The average annual temperature is around 18°C. The Dense and Open Ombrophilous Forests had most forest species (9661) as well as most endemic species (5164) [10].

Seasonal Forest is classified as Deciduous, Semideciduous and Evergreen. For the first, Deciduous Seasonal Forest, it is characterized by a large number of deciduous trees, accounting for more than 50% of individuals of the forest component. It consists of 165 endemic forest species of the total of 1113 found in the forest typology [10]. In the tropical region, its occurrence is conditioned to a long dry period (more than seven months). In the subtropical region, however, this forest formation occurs in areas with long cold periods, for more than five months with average temperatures below 15°C. On the other hand, Semideciduous Seasonal Forest is composed of deciduous trees, which represent 20–50% of individuals of the forest component. It has the second largest number of forest species (3841) of the Atlantic Forest of which 1081 are endemic [10]. Their occurrence in the tropical region is defined by two well-defined pluviometric periods, one dry and one rainy with average annual temperature around 21°C. However, in the subtropical region, this formation occurs in a short dry period followed by a sharp drop in temperature, with averages below 15°C in the cold period. The last type is the Evergreen Seasonal Forest, which is composed of deciduous trees, which account for less than 20% of individuals of the forest component. This forest occurs under tropical climate with a rainy and dry season, with about four to six months of dry weather. Still, the arboreal component does not seem to undergo water stress, which causes low leaf shedding.

Currently, approximately 7% of the biome natural areas are well preserved in fragments larger than 100 ha [15]. The biome consists of about 20,000 plant species of which 8000 (i.e., 40%) are endemic [16]. The analysis of species distribution in the different forest formations [10] showed that more than half of the wealth (60%) and most endemics (80%) are found in the Atlantic Forest. Due to their high levels of richness and endemism, the Atlantic Forest is among the top five hotspots in the world [16].

This region is of great importance for Brazil, because more than half of the national population is spread across the Atlantic Forest biome and this region accounts for much of the economic activity in the country. In addition, water resources that serve about 70% of the Brazilian population are located in this biome [17]. However, with the intense land-use change and the consequent fragmentation of this biome, biodiversity loss is noticeable and there is an eminent need for conservation. Due to the importance of this vegetation component, law n. 11,428 was enacted in 2006 [8] to regulate the use of native plants in the Atlantic Forest biome.

3. Nutrient cycling in forests

Biomass production in a forest ecosystem is conditioned to several factors, namely light, water, CO_2 concentration, chlorophyll content, temperature, nutrients, genetic adaptation and competition, among others [18, 19]. Among these factors, nutrients stand out as an essential element for the primary productivity of the forest ecosystem [20]. Nutrient cycling in forests is defined as the transfer of elements between the different components of the ecosystem. This transfer is controlled by climate, site, abiotic factors (topography, source material) and biotic agents [21]. Therefore, nutrient cycling in tropical forests is distinct from that in temperate zones. For example, the amount of nutrients on the forest floor and the length of deposition are shorter in tropical forests than in boreal forests, due to slow decomposition in regions of cold climate and high altitudes [21].

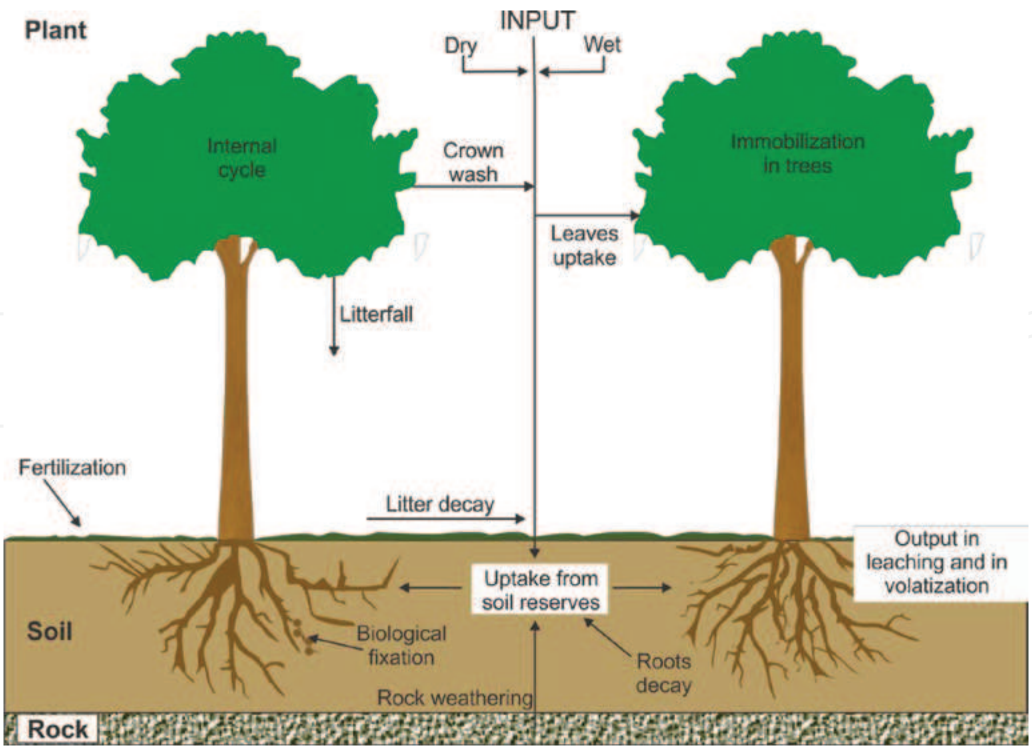

Figure 2. Scheme of nutrient cycling dynamics in a forest. Adapted from Refs. [24, 25].

Nutrient cycling in forests can be generalized into three models: geochemical, biogeochemical and biochemical cycling [22]. Geochemical cycling is characterized by the input and output of nutrients in the ecosystem. Atmospheric deposition (wet and dry), fertilization, biological fixation and rocks weathering are responsible for most nutrients input [23]. While, leaching, volatilization and harvest biomass are responsible for most nutrients output [24]. The biogeochemical cycle is characterized by the transfer of nutrients between the plant and the soil. In this cycle, plants absorb nutrients form soil reserves and then return them to the soil via litterfall (litter decay), roots decay or plant death [24]. Biochemical cycling is the translocation of nutrients inside the plant (internal cycle). Once soil nutrients are absorbed, some of these elements are in constant mobilization within the plant, mostly from older to younger tissues.

The dynamic process of nutrient cycling in native or exotic forest ecosystems is shown in **Figure 2**.

4. Nutrient cycling in the Atlantic Forest

The biogeochemical cycling is one of the most studied nutrient cycles in the Atlantic Forest, mainly in terms of deposition, accumulation and decomposition of litterfall. This litter is composed predominantly of leaves, branches, bark, trunks of fallen trees, flowers, fruit, dead animals, etc. In general, the percentage of leaves in relation to the other litter components ranges from 60% to 80% of the total material. The biomass of senescent leaves that fall onto the forest floor represents part of net primary production (NPP) of vegetation [26, 27].

Most nutrients uptaken by the trees return to the soil through senescence of their organic components. The intensity of nutrient cycling depends mainly of the deposition of organic material. It is considered the most important form of nutrient transfer from the plant to the forest soil in the ecosystem [28]. According to Viera and Schumacher [28], there is variation between species regarding the amount of nutrients retained and returned. For them, there are species that retain most nutrients absorbed, while others return most nutrients absorbed, and there are also those in which retention is equal to return. This retention and return ratio is linked to different translocation rates of species [29], age, soil and climate conditions [3], as well as environmental aspects, varying from species to species [5].

The continuous supply of litterfall enables storage of soil organic carbon (SOC) and nutrient availability. These nutrients, after litter decomposition, help to keep soil fertility in native forests [30, 31]. Litter provides nutrients, energy and matter to microorganisms in the soil and roots, which is important in tropical forests where litterfall is intense and decomposition is faster [30, 32] than in temperate forests. Litterfall is responsible for important environmental services. It helps intercept rainfall and its storage in the soil increases infiltration rate and surface flow conditioning of water and soil [33], thus avoiding the beginning of erosion processes.

In the Atlantic Forest, due to the different types of forest formations, we can observe a diversity of environments, where each one offers a distinct pattern of litter deposition and accumulation

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(**Table 1**). For example, seasonal forests have a seasonal deposition pattern due to a period of lower precipitation and low temperatures, triggering leaf abscission. The amount of litter is also influenced by the replacement of mature, older and less efficient foliar tissue by new leaves [27, 34, 35].

Forest type	Succession	Deposition	Accumulation	Reference
		(Mg ha^{-1})		
Dense Ombrophilous	Primary	7.4	7.3	[36]
Dense Ombrophilous	Secondary	5.6	–	[37]
Dense Ombrophilous	Secondary	–	8.6	[38]
Dense Ombrophilous	Early[1]	–	4.5	[39]
	Intemediate[2]	–	5.0	
	Advanced[3]	–	5.2	
Dense Ombrophilous	Early[1]	5.2	–	[40]
	Intermediate[2]	5.4	–	
	Advanced[3]	5.3	–	
Dense Ombrophilous	Secondary	9.8	–	[41]
Dense Ombrophilous	Secondary	10.0	–	[42]
Dense Ombrophilous	Secondary	4.7	–	[35]
Mixed Ombrophilous	Primary	6.0	–	[43]
Mixed Ombrophilous	Secondary	6.3	–	[44]
Mixed Ombrophilous	Primary	10.3	14.3	[34]
Mixed Ombrophilous	Secondary	–	8.0	[45]
Semideciduous Seasonal	Secondary	–	5.5	[46]
Semideciduous Seasonal	Secondary	9.3	–	[47]
Semideciduous Seasonal	Primary	8.2	–	[48]
Semideciduous Seasonal	Secondary	11.7	–	[49]
Deciduous Seasonal	Secondary	5.9	–	[50]
Deciduous Seasonal	Secondary	–	8.0	[51]

Note: Secondary forest in early (1), intermediate (2) and advanced (3) stages of succession.

Table 1. Annual deposition and accumulation of litterfall in the soil in different forest types in the Brazilian Atlantic Forest.

In tropical forests, such as the Atlantic Forest, litterfall deposition is influenced by latitude and altitude. According to Alves et al. [52], the vegetation structure can vary greatly according to the altitude, since lower altitudinal gradients can present significant changes in edaphic conditions, due to topographic and climate variations. Thus, species that grow in environments with adequate light, water and nutrient availability have high productivity compared to those that develop in environments with low availability of these resources. For example, Montane Forests are less productive than Lowland Forests, since temperature reduction, increased cloudiness, lower reserves of nutrients in the soil and water saturation of the soil are factors that limit the NPP in Montane Forests [26, 53]. In addition, the Atlantic Forest located at higher altitudes is more susceptible to the action of winds, more intense thermal inversions and greater terrain slope. All these aspects, along with its solar orientation, can increase or reduce incident radiation that will affect the phytosociological structure and composition of the forest.

The different types of the Atlantic Forest biome feature a distinct nutrient transfer via litter deposition. This may be linked to the different developmental stages of the forest. In each stage, the vegetation displays distinct control forms of nutrient demands through storage and redistribution in biomass [54] (**Table 2**).

Forest type	Succession	N	P	K	Ca	Mg	S	Reference
		kg ha^{-1} year^{-1}						
Semideciduous Seasonal	Secondary	150.3	7.3	45.2	291.5	30.5	10.7	[55]
Semideciduous Seasonal	Secondary	172.2	8.9	67.7	216.9	27.3	13.6	[47]
Semideciduous Seasonal	Primary	294.2	3.2	108.3	462.2	33.9	–	[48]
Semideciduous Seasonal	–	217.8	11.6	52.8	199.8	38.7	–	[56]
Deciduous Seasonal	Secondary	123.2	5.1	26.4	131.6	15.6	7.1	[50]
Dense Ombrophilous	Secondary	–	5.0	49.7	170.7	26.4	–	[42]
Dense Ombrophilous	Secondary	123.7	14.4	4.9	–	–	–	[57]

Table 2. Nutrients transferred to the soil annually via litter deposition in different forest types in the Brazilian Atlantic Forest.

Under similar climate and soil conditions, variation in litter accumulation occurs by both the amount and the composition (contents of lignin, polyphenols and nutrients) of the material deposited, influencing decomposition speed and nutrient release [58]. In general, N and Ca are the nutrients that are most accumulated on the soil in the Atlantic Forest (**Table 3**). In forests established in weathered soils, accumulated litterfall ensures nutrient cycling. This litter, along with the soil, regulates many fundamental processes in the dynamics of ecosystems, such as primary production and nutrient release [59].

The amount of nutrients in litter deposed or accumulated varies according to the forest type and edafoclimatic conditions. Abiotic and biotic factors affect litter production, namely the vegetation type, altitude, latitude, rainfall, temperature, light incidence, relief, water availability and soil characteristics [60]. Likewise, nutrient concentration and content in this litter vary according to the soil type, vegetation, population density, the ability of species to absorb, use and translocate nutrients before leaf senescence, as well as the percentage of leaves in

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relation to other components of the natural habitat (soil and climate conditions) and the tree age [29, 61].

Forest type	Succession	N	P	K	Ca	Mg	S	Reference
		kg ha^{-1} year^{-1}						
Semideciduous Seasonal	Secondary	105.9	4.4	12.9	249.1	16.5	7.1	[55]
Semideciduous Seasonal	Secondary	94.9	4.1	14.0	161.0	12.1	7.4	[46]
Dense Ombrophilous	Secondary	218.0	3.4	8.5	61.0	14.9	–	[38]
Dense Ombrophilous	Early[1]	67.5	2.6	11.8	40.2	12.9	7.1	[39]
	Intermediate[2]	73.1	2.8	11.7	60.9	13.1	7.3	
	Advanced[3]	88.8	2.8	9.0	41.2	13.9	9.4	
Mixed Ombrophilous	Secondary	95.7	5.4	45.3	36.8	7.6	14.8	[45]

Note: Secondary forest in early (1), intermediate (2) and advanced (3) stages of succession.

Table 3. Nutrients stored in accumulated litter on the soil in different forest types in the Brazilian Atlantic Forest.

The availability of nutrients in the accumulated litterfall occurs during decomposition. Decomposition is controlled by the nature of the scavenging community (animals and microorganisms), by the organic matter characteristics, which determines its degradability (quality) and by the physical-chemical aspects of the environment, which operates in the edaphic or microscale conditions [62].

Similar to litter decomposition, the rate at which nutrients are released depends on the chemical composition of the litter, the structural nature of the nutrient in the litter and the availability of external nutrient sources [63]. The release of nutrients in the litter depends on its quality, on macro- and micro-climatic variables and on biotic activities. The climate factors that influence litter decomposition the most are temperature and soil moisture [63]. According to the authors, another primordial factor responsible for higher or lower decomposition rate is the structural composition of tissues because tissues that contain higher contents of cellulose, hemicellulose and lignin are more resistant to decomposition than tissues with lower contents of these compounds.

5. Final remarks

The lessons learned with landscape change in the Atlantic Forest, especially during the last few decades, indicate the need to develop programs of environmental conservation and restoration. Environmental education and scientific research are also important to allow a sustainable management of world forests. Therefore, knowing the different factors that influence the development and maintenance of a natural forest ecosystem is necessary to prevent fragmentation of new forest areas.

Nutrient cycling is one of the fundamental processes in the functioning of forests. It helps to understand the great complexity of relationships and flows between different compartments of nutrients and carbon to manage forest ecosystems sustainably. This means that mechanisms in this ecosystem have not been thoroughly understood, hindering the proper management of this resource. Therefore, there is the need to understand the nutrient cyclic processes in different forest ecosystems, as identified for the Atlantic Forest, where the amount of nutrients in litter deposed or accumulated varies according to the forest type and edafoclimatic conditions. Understanding these characteristics aids to adopt programs for the recovery of fragmented and degraded ecosystems specific for each forest type.

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