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Nutrient cycling and carbon dynamics in an early successional forest in Turrialba, Costa Rica

Movimiento de nutrientes y dinámica de carbono de un bosque temprano en regeneración en Turrialba, Costa Rica

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RESUMEN

La cuantificación del movimiento de nutrientes es importante para generar lineamientos técnicos asociados con la conservación y manejo de bosques tropicales bajo el marco de fenómenos como el cambio climático. El presente estudio provee los datos base sobre el flujo de nutrientes en sistemas forestales de alrededor de 30 años que comenzaron como un agregado de subsuelo que fue reforestado después de la construcción de una represa en la zona de Turrialba, Costa Rica. El crecimiento de los árboles y los flujos parciales de nutrientes fueron determinados a partir de mediciones de árboles y camas de mantillo. Los valores observados de flujo de carbono y nitrógeno se vinculan con la historia de reforestación del sitio estudiado y mostraron la rápida y resiliente dinámica de nutrientes en el contexto tropical tras la implementación de un plan de reforestación asistida. Otros nutrientes mostraron valores dentro de lo esperado y señalaron que los bosques estudiados son el producto de una serie de decisiones técnicas apropiadas que han permitido que el sistema se haya desarrollado de la forma como lo hizo.

Palabras clave: cambio climático, conservación forestal, manejo, resiliencia, tropical.

ABSTRACT

The quantification of nutrient cycling is important to generate technical guidelines for the conservation and management of tropical forests under the scope of global phenomena such as climate change. The present study provides the baseline data on the current fluxes of nutrients in a 30-year-old forest system that started as a reforested subsoil mount generated when a dam project was built in the general area of Turrialba, Costa Rica. Tree growth and partial nutrient fluxes were determined by measuring trees and using litterfall beds between 2018-2020. Carbon and nitrogen displayed values that can be linked to the history of reforestation in the studied location and demonstrated the fast and resilient dynamics of nutrients in tropical settings after the assisted reforestation was implemented. Other nutrients showed values within expected ranges and pointed out that the studied forests are the product of a series of appropriate technical decisions that have allowed the system to develop that way it did.

Keywords: climate change, forest conservation, management, resilience, tropical.

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Introduction

In the context of climate change, nutrient cycling assessments are critical to evaluate the effect of global changes on energy fluxes within biological systems (Johnson and Turner, 2019). Such quantifications are highly relevant for the determination of the opportunities for functional adaptation (Malhi et al., 2020). Nutrient deviations from recorded values are useful to determine the resilience and entropic modulation of biosystems and are relevant for conservation targets. However, for empiric purposes, a local baseline of nutrient cycling is necessary for comparison and contrasting purposes and quantifications should be constructed specifically for each location of interest.

In Costa Rica, most basic evaluations of nutrient cycling within forests were carried out decades ago, mainly in privately protected lands, with the idea of understanding ecosystem functioning (e.g., Jordan and Herrera, 1981; Vitousek, 1984). In recent years, researchers have taken a modern approach by quantifying nutrient cycling in the framework of response and resilience of forests to climate change (e.g., Lanuza et al., 2018; Rivero-Villar et al., 2021). However, the conceptualization of most such studies as long-term assessments is rare because most researchers focusing on these issues are not based in the country.

In this manner, long-term studies on nutrient cycling as a proxy for ecosystem resilience represent a real opportunity for local researchers to contribute to the evaluation of climate change effect on global ecosystems (see Lindenmayer et al., 2012). However, the determination of study locations with long-term planification of land use and flexibility for ecological research can be challenging. In this context, early successional forest patches within mixed used landscapes are fantastic systems for functional ecological assessments since they are the most common ecological situation (Arroyo Rodríguez et al., 2020).

The "Finca Experimental Interdisciplinaria de Modelos Agroecológicos" in Turrialba, Costa Rica is an example of the latter and thus a great location for long-term functional studies. This integrated experimental station, is in government-owned lands, has long-term conservation goals and already counts on a basic characterization of biosystems (Mora-Chacón et al., 2019; Quesada-Chacón et al., 2020). Given those precedents, the aim of the present investigation is to contribute to the functional characterization of its successional forests by focusing on nutrient cycling dynamics as a strategy to develop long term functional data for climate change research. This study is therefore, a very important contribution to the monitoring of succession in tropical areas for conservation and management purposes and represents a complement to the previously published data about the forest characteristics of the selected location.

Materials and Methods

This project was carried out between 2018-2020 in the Finca Experimental Interdisciplinaria de Modelos Agroecológicos (abbreviated as FEIMA), located in the vicinity of the La Angostura Hydroelectrical Project in Turrialba, Costa Rica. This research station contains a 28 hectare early successional (~30 years) forest fragment with three different sections determined on plant composition. The common *Erythrina poeppigiana* (Walp.) O.F. Cook dominates the canopy of the entire fragment, but the northeastern section (B1 herein) is codominated by *Eucalyptus deglupta* Blume and is located in the lowest elevations. The central section is codominated by *Abarema idiopoda* (S.F. Blake) Barneby y J.W. Grimes and it is located in the highest lands (B2) and the southwestern section by *Enterolobium cyclocarpum* (Jacq.) Griseb and borders agricultural lands (B3). Based on in situ generated data for the study period, the average temperature was 21.9±0.7°C with an average humidity of 88.6±1.5%, and the accumulated yearly precipitation was about 2700 mm.

Six trees were randomly selected in one 200 m2 study location within each of the three forest sections, and their diameter at breast height was measured by triplicate using a diametric tape, every three months, between January 2019 and April 2020. These data were used to calculate the average diametric growth rate of trees in the study area (average diametric growth/period) and later used to calculate a gross rate of carbon accumulation per hectare per year in FEIMA by calculating the added volume of carbon (via biomass) each year. For the latter, an average tree height of 20.83 m (from Quesada-Chacón et al., 2020) and the assumption of a simple cylindrical trunk shape as well as values of 0.5 g/cm3 for wood density and 45% of carbon in the biomass were used. Also, a ratio of 1.32 to 1.00 of carbon biomass between aerial and underground parts was used based on average values from the IPCC. With this calculation it is possible to have an idea of a value of accumulated carbon per year only by means of the observed tree growth using diametric changes over time.

Similarly, in the same locations, three 1x1 m "litterfall beds" constructed with PVC tubes and nylon mesh were positioned at 60 cm from the ground in order to quantify litterfall and nutrient input into the soil. These beds were deployed in the field in February 2019 and studied periodically until June 2020 by collecting all the plant material deposited in them during each checkup, every 10-12 weeks. Such material was taken to the laboratory, dried at 40°C for 48 hours, and weighted. After that, a determination of the content of carbon, nitrogen, phosphorus, calcium, magnesium, potassium, sulfur, iron, copper, zinc, manganese, and boron was performed in the Soil and Foliage Laboratory of the Agronomical Research Center (CIA) of the University of Costa Rica.

With those data, a calculation of the annual fluxes of biomass and each of the quantified elements was carried out and the average for the three study locations was used as the final value for the entire forest under investigation. For this, all values of quantified elements were transformed into kg/hectare using the original 1m2 litterfall bed area for the initial spatial determinations. Since several values were obtained during every period of litterfall recollection, the temporal scale was incorporated as well, and the values were communicated in kg/ hectare year.

Results and Discussion

The average tree growth rate during the period of 16 months when measurements were obtained was 10.16 mm in diameter. Such value indicated that trees in FEIMA grew at an average of 0.59 mm/month or about 7.62 mm/year. This value corresponded to the middle section of the 0.35-13.41 mm/year range described by Lieberman et al. (1985) for tropical wet forests in Costa Rica. The average tree diameter measured in FEIMA was 28.37±16.54 cm with a range between 15.61-81.56 cm showing that tree growth, based on diametric classes, was medium high for Costa Rica using the estimations of Clark and Clark (1994).

In the quantification provided in the present study it was observed that the tree growth rate in the studied location is associated with values in the middle range for tropical forests (based on Lieberman et al., 1985) suggesting that the dynamics shaping the forest in FEIMA have allowed this system to grow successfully after the reforestation of the original lands took place about 33 years ago (based on the date from Consejo Universitario, 2009, p. 46-47). Those processes have enabled a great rate of carbon accumulation with a calculated value of about 2200 kg of carbon/hectare year for the combined aerial and underground biomass. Such value only corresponds to the added biomass based on the diametric growth rate calculations.

With this value, FEIMA would have accumulated about 72 600 kg of carbon/hectare after the reforestation of these lands took place (assuming a linear and stable relationship over time), but only about 48 200 kg/hectare are currently observed (from the aerial biomass carbon stock calculation in Quesada-Chacón et al., 2020). This result implies that carbon accumulation performed by plants with shorter life cycles than the trees present in the forest is significant in this system. As expected, a large number of non-woody plants grow in annual cycles in this location and contribute to the accumulation of temporary biomass. Since the carbon accumulated in most of these plants ends up enriching the soil cyclically, it is expected to observe higher soil carbon values in the forest than in non-forested areas. Mora Chacón et al. (2019) precisely recorded this difference with a 22% increase in carbon soil in the forested area of FEIMA versus non-forested areas.

The aerial biomass accumulation in the studied system was associated with an average movement of 434 kg/hectare year only from the litterfall input, although the range calculated using the data from the litterfall beds ranged from 276-677 kg/hectare year (see Table 1). Similarly, the flux of nitrogen in the system oscillated between 23-33 kg/hectare year with an average value of about 28 kg/hectare year. Based on the work of Lanuza et al. (2018) and Xu et al. (2005) the carbon flux, in the form of litterfall, observed in FEIMA, corresponded to values that are observed in recovered areas under management or in systems in the process of recovery, exactly the situation of the studied forest patch. Similarly, the flux of nitrogen in FEIMA corresponded to the high end of the reported range of 8.5-36.1 kg/hectare year observed by Correa et al. (2002) in Colombia. Much higher values have been communicated in Brazil (de Oliveira, 2008) for 25-year-old successional forests, but nutrient flux determinations and data collection vary among studies and comparisons can be difficult in some cases. Despite that, litterfall quantifications are always useful for monitoring purposes in stable locations (Sayer and Tanner, 2010).

In this manner, using the values presented herein for comparison, both carbon and nitrogen fluxes calculated in FEIMA seemed "within range" for tropical systems. However, it appears that even though carbon moves at an expected rate for successional forests, nitrogen is moving at comparatively higher rates (based on Correa et al., 2002) indicating that this element is more available for nutrient cycling purposes. Interestingly, nitrogen was observed to be 24% higher in the soils of the FEIMA forests than in non-forested areas in the same location (Mora Chacón et al., 2019), suggesting that some process of nitrification is likely taking place in these areas as well. Given the abundance and patchy dominance of Fabaceae trees in FEIMA (i.e., *Erythrina poeppigiana*, *Abarema idiopoda*, *Entorolobium cyclocarpum*), it would not be surprising to think that those trees, via their symbiotic nitrifying root bacteria, have been largely responsible for increasing the levels of nitrogen in the system (see Gey and Powers, 2013). However, the impact of this nitrification for the recovery of the forest is uncertain. Recent data from tropical forests in Costa Rica indicated that nitrogen fixing trees do not impact the regenerating performance of the system as much as previously expected (Taylor et al., 2017).

All other studied nutrients were quantified at expected values in FEIMA based on the works of Correa et al. (2002) and Lanuza et al. (2018). Interestingly, the distribution of the data in relation with the forest sections varied substantially in some situations. For instance, all nutrient values were higher in the B1 section (the lowest elevations) of the forest than in the other two forest sections. Calcium, phosphorus and sulfur fluxes were, in average, 38% higher in B1 than in B2 or B3. Magnesium and potassium were 177% higher in the same section. These results indicated that nutrient dynamics are highly dependent on the characteristics of the forest, which based on the previous assessments in FEIMA, are likely dependent on the different plant composition of the three forest sections. Both *Erythrina poepiggiana* (Mountain immortelle) and *Castilla elastica* (Panama rubber tree) were highly dominant in FEIMA but occurred in similar frequencies across the three forest sections. However, *Eucalyptus deglupta*, was codominant only in B1 and was not even present in B2 or B3; and the presence of such species had an effect on shorter heights and closer horizontal distances between trees in B1 (Quesada-Chacón et al., 2020). The combination of more trees per area, albeit smaller, and a codominant species with high bark and leaf turnover rates very likely explained the data observed herein.

Table 1. *Annual nutrient fluxes per hectare (in kilograms) for different chemical elements calculated with the data from litterfall beds collected in FEIMA (2019-2020)*

Element cycle rate (kg/hc yr)	**Forest section**			**Average**
	B1	**B2**	**B3**	
Dry Biomass	1490.79	584.18	797.60	957.53
C	676.67	275.96	349.91	434.18
N	33.16	23.32	28.19	28.22
Ca	36.11	14.46	26.45	25.67
P	1.76	0.93	1.53	1.41
Mg	6.65	1.20	2.52	3.46
K	4.03	1.41	2.52	2.65
S	2.42	1.41	2.25	2.03
Fe	2.33	0.17	0.36	0.95
Cu	0.02	0.01	0.01	0.01
Zn	0.04	0.02	0.03	0.03
Mn	0.21	0.09	0.15	0.15
B	0.03	0.01	0.02	0.02

Conclusions

The nutrient dynamics quantified in the early successional forests of FEIMA displayed the positive effect of reforestation in tropical lands. Only after three decades of forest recovery, the effect of the assisted reforestation can be measured in form of effective fluxes of chemical elements. Even though expected differences in those fluxes could be attributed to differences in the composition of dominant trees and associated characteristics, all forest sections were functioning as an integrated system in recovery. Carbon fluxes and accumulation of biomass are important for reducing the impact of carbon emissions and have allowed both the forests and the soils in FEIMA to become, albeit small in scale, carbon sinks in the general area of Turrialba. Nitrogen dynamics likely demonstrated the effect of nitrification via symbiosis and certainly have played a role in the advance of succession in FEIMA. Other nutrients showed values within expected ranges and pointed out that the studied forests were the product of a series of appropriate technical decisions that have allowed the system to develop that way it did.

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