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Nitrogen and carbon losses from decomposing litter in natural and agroecosystems of two different climate regions of Brazil

Karina Peña-Peña*, Ulrich Irmler

Christian-Albrechts-Universität Kiel, Institute for Ecosystem Research, Department of Applied Ecology, Olshausenstr. 75, 24118, Kiel, Germany

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ABSTRACT

In the past four decades, Mato Grosso in Central-West Brazil has undergone rapid changes from forested area to pasture and/or cropland. Yet, little is known about how these changes affect litter turnover and nitrogen (N) and carbon (C) cycling. We carried out litter breakdown experiments with litter mesh bags and investigated the effects of five factors on the release of N and C after 20 weeks, i.e. season (rainy, dry), litter quality (local, standard), land-use (forest, pasture, cropland), soil organisms (soil fauna, micro-organisms), and region (savannah climate, Amazon climate). We found that: (1) season had an overall effect on N and C losses by influencing the activity of soil organisms; (2) N and C losses correlated negatively with the initial litter C:N and lignin:N ratio, respectively; (3) N and C losses increased with decreasing human impact on the land-use; (4) soil fauna increased N loss by 35% and C loss by 16%; (5) the effect of the soil fauna on N and C correlated negatively with the initial litter lignin:N ratio; (6) higher N and C losses were observed in South-Amazon systems (except for C losses in the dry season); and (7) soil fauna exclusion resulted in N immobilisation, particularly in the Cerrado. Although the seasonal effect was a major driver of N and C release, our findings indicate that soil organisms are the key to understanding the differences in N and C cycling at regional and land use level.

1. Introduction

The state of Mato Grosso in Brazil is characterised by ongoing land-use change from forest to intensive cropland. In 1970, the expansion of cattle ranching and mechanised agriculture began [1]. By 2007, one-third of the state's native vegetation (33% tropical forests and 38% savannah vegetation) had been converted to pastures or to agricultural land [2]. Nowadays, cattle ranching and annual crop production (mainly soybeans) occupy 25.8 and 13.5 million hectares, respectively [3,4]. Due to economic interests, research in the region largely focused in the development of technologies to improve soil properties for agricultural production [1,5]. New research efforts aimed to understand the extent to which these changes impact the ecosystems and its' processes [2,6–10].

The decomposition of plant residues is an important process in ecosystems involving physical, chemical, and biological processes by which dead plant material is transformed and nutrients are cycled through the environment [11]. Soil fauna contributes as catalysers of both decomposition and nutrient dispersion, while the transformation of nutrients is carried out mainly by soil micro-organisms [12]. Hence, factors affecting microbial growth and activity, such as soil moisture and temperature, are critical for decomposition and nutrient turnover [13]. The chemical composition of the litter, also known as litter quality, differs among plant residues and influences its decay. In most tropical soils, elements, such as nitrogen and phosphorus, act as limiting factors for both plant growth and decomposition. When this occurs, soil micro-organisms will compete against plants and soil fauna for the nutrients, resulting in an accumulation in the microbial biomass [14,15]. Climate, litter quality, and soil organisms have been identified as the main factors controlling decomposition; secondary factors influencing the process include soil physical properties and site-specific parameters [11]. However, the hierarchy of these factors changes depending on the constraints at local level at a particular time [16].

Land-use change is the most evident impact of human activities on ecosystems [17]. It affects litter decay by introducing new plants with different litter quality, shifting soil fauna and microbial communities' structure, altering soil moisture and temperature, and changing physical and chemical properties of the soils through ploughing and the use of chemical inputs [18–20]. These changes can in turn influence carbon cycling, fluxes, stocks, and nutrient cycling in ecosystems, and thus affect gas fluxes and climate change.

The aim of this study was to quantify and compare litter nitrogen (N) and carbon (C) losses in the decomposition among the predominant land-uses (forests, pastures, and croplands) in two different climate

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* Corresponding author.
E-mail address: kpena@ecology.uni-kiel.de (K. Peña-Peña).

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regions with pronounced dry and rainy season in Central Brazil. The following questions should be answered: (1) How do N and C losses differ between the two regions regarding the decomposition process? (2) Which roles do land-use and litter quality play in the process? (3) Do seasons have different impacts on the breakdown process in the two regions? (4) What roles do soil fauna vs. micro-organisms have in the N and C releases?

2. Sites and methods

2.1. Study area and sites

The study was conducted in two rural regions in the state of Mato Grosso in Central-West Brazil. The Cerrado region was located in the south-eastern part of the state in the municipalities of *Campo Verde* (15° 32′ S, 55° 9′ W; 625–794 m elevation) and *Primavera do Leste* (15° 32′ S, 54° 15′ W; 585–665 m elevation). The natural vegetation is defined as *Cerrado* (savannah-like vegetation) and includes forest and grassland formations. The South-Amazon region was located in the northern part of the state, in the municipality of *Santa Carmem* (12° 1′ S, 55° 16′ W; 333–385 m elevation), approximately 30 km southeast of the city of Sinop. The natural vegetation is defined as transitional zone between the *Cerrado* and Amazonian rainforests, and is characterised by seasonal and ombrophilous forests [21].

Both regions have a seasonal tropical climate (*Aw*) according to Köppen, but winter droughts are more pronounced in the Cerrado than in the South-Amazon region [22]. The dry season extended from May to October. Approximately 80% of the annual rainfall was determined in the rainy season from November to April. Mean temperature and total rainfall during the experiments were as follows: 25.6 °C and 326.8 mm for the dry season, 24.8 °C and 2025.6 mm for the rainy season in the South-Amazon region; 23.3 °C and 355.4 mm for the dry season, 23.3 °C and 1190.2 mm for the rainy season in the Cerrado region [23,24].

Three farms with three land-use system each, native vegetation (tropical forest or *Cerrado* forest), pasture, and soybean cropland, were selected in every region. The area of the sites varied from 15 to 4000 ha. The distances between farms within each region ranged between 30 and 100 km. The agricultural land-use systems were developed on forest sites cleared in the 1980s and planted with African grasses (mainly *Brachiaria*) for cattle pasture. Later, pastures were partly converted to croplands. Forests were still part of the farm areas in order to maintain reserves of native vegetation.

Soils in both regions were very similar and classified as Red-Yellow Latosols (Oxisols, USDA; Ferralsols, WRB) [25]. In general, the soils are deeply weathered, well-drained, acid, and nutrient poor (Table 1). P contents were higher in croplands than in other land-use systems due to fertilisation, particularly in the Cerrado region. During the dry season, forest soils in the Cerrado region were drier than at the other sites. These had also higher sand content, acidity, Al concentrations, and C:N ratios. For the soil analysis, two replicate soil samples (5 cm depth) were collected from each plot using cylinder samplers ($n = 144$; 36 plots x 2 regions x 2 replicates). Samples were pooled for each land-use and region ($n = 24$). Soil bulk density was determined by the core method. Total carbon and nitrogen were measured in an elemental analyser (Euro EA3000, Italy). The soil moisture content was measured in each plot and at each litterbag retrieval date using a calibrated sensor with 16 cm rods (Trime-Pico 64, Trime-HD, IMKO GmbH, Germany). A measurement consisted of the mean of three replicate measurements at random points within each plot. All measurements from every plot within replicate sites were averaged separately for a particular land-use, season, and region ($n = 72$; 4 plots × 3 farms × 6 dates: $t0$ – $t5$).

2.2. Experimental design, litter collection, and litter analysis

Litter mesh bags were used to determine the litter breakdown. The design included five factors: two seasons (rainy and dry), two litter types (local and standard), two mesh sizes (fine and coarse), two regions (South-Amazon and Cerrado), and three land-use types (forest, pasture, and cropland) each with three farms. Decomposition experiments were conducted during each season separately from 2012 to 2013 (Cerrado) and from 2013 to 2014 (South-Amazon). May to October represented the dry season, while November to April represented the rainy season. In each region, four replicate 5 × 5 m plots were selected within each of the three replicate sites of each land-use type (in each region: $n = 36$; 4 plots x 3 land-use types x 3 farms). Plots within a site were 20 m away from the margin of the land-use system and had a minimum distance of 50 m from each other.

Senescent local litter was collected from each land-use: mixed leaf-litter from the forests, *Brachiaria*-grass leaf and stem litter from the pastures, and soybean residues (*Glycine* max L.) from the croplands. Fresh forest leaf litter, without signs of advance decomposition, was collected in nets and from the forest floor at each farm and pooled for each season and region. Maize blade and husk leaf litter (*Zea mays* L.) were collected from standing senescent plants. Maize was used as standard material to separate the regional and land-use effects from the other environmental impacts. To reduce variability, grass, soybean, and maize litter were collected from a single farm in the Cerrado region. The collected litter was oven-dried (24 h, 60 °C) and kept in a dry place

Table 1
Mean values (± standard deviation) of soil parameters (upper 5-cm) in forests, pastures, and croplands in the Cerrado and South-Amazon study regions in the state of Mato Grosso, Brazil.

Soil parameter	Forest		Pasture		Cropland	
	Cerrado	S-Amazon	Cerrado	S-Amazon	Cerrado	S-Amazon
Clay (%)	26.3 ± 17.2	nd	40.5 ± 18.7	nd	48.8 ± 11.8	nd
Silt (%)	5.9 ± 4.3	nd	6.5 ± 2.6	nd	6.6 ± 3.4	nd
Sand (%)	67.8 ± 19.0	nd	53.0 ± 17.2	nd	44.6 ± 13.6	nd
Bulk density (g cm^{-3})	1.2 ± 0.3	nd	1.1 ± 0.1	nd	1.0 ± 0.1	nd
Soil moisture (dry)	9.4 ± 6.2	22.5 ± 3.1	17.5 ± 11.2	20.5 ± 9.0	21.2 ± 10.8	19.5 ± 9.2
Soil moisture (rainy)	27.1 ± 3.3	28.3 ± 3.4	32.3 ± 3.4	30.1 ± 4.2	33.3 ± 2.9	32.2 ± 3.4
pH ($CaCl_2$)	3.7 ± 0.4	4.8 ± 0.9	4.6 ± 0.4	4.6 ± 0.7	5.1 ± 0.5	4.9 ± 0.9
P (mg kg^{-1})	1.5 ± 0.8	2.5 ± 1.3	1.8 ± 0.9	3.7 ± 5.3	21.2 ± 13.7	8.3 ± 7.4
Ca + Mg ($cmol_c$ kg^{-1})	4.2 ± 1.4	3.0 ± 1.8	3.1 ± 1.4	3.0 ± 1.2	3.5 ± 1.4	4.2 ± 1.9
Al ($cmol_c$ kg^{-1})	1.0 ± 0.3	0.5 ± 0.4	0.1 ± 0.1	0.5 ± 0.3	0.1 ± 0.1	0.3 ± 0.3
CEC ($cmol_c$ kg^{-1})	5.0 ± 1.5	7.1 ± 2.2	4.9 ± 1.5	5.8 ± 1.7	6.0 ± 1.1	7.3 ± 1.7
Base saturation (%)	16.3 ± 5.0	47.6 ± 24.3	38.6 ± 16.4	58.2 ± 21.8	43.6 ± 11.7	60.3 ± 21.5
C_{tot} (%)	2.7 ± 1.1	3.5 ± 1.1	3.0 ± 0.6	2.5 ± 0.8	2.9 ± 0.6	3.3 ± 1.1
N_{tot} (%)	0.14 ± 0.06	0.24 ± 0.07	0.17 ± 0.02	0.17 ± 0.05	0.19 ± 0.04	0.23 ± 0.07
C:N ratio	19.2 ± 2.7	14.7 ± 1.1	17.5 ± 2.1	14.6 ± 1.3	15.2 ± 1.0	14.0 ± 0.8

nd: not determined; CEC: cation exchange capacity at pH 7; C_{tot}: total carbon; N_{tot}: total nitrogen; unpublished data of O. Weber except bulk density, soil moisture, C_{tot}, N_{tot}, and C:N ratio measured by authors.