Chapter 17
Leaf Litter Decomposition and Nutrient Release Under Nitrogen, Phosphorus and Nitrogen Plus Phosphorus Additions in a Savanna in Central Brazil

Tamiel K. B. Jacobson and Mercedes M. C. Bustamante

Abstract The aim of this study was to determine leaf decomposition rates and nutrient release in a cerrado *sensu stricto* under nitrogen (N), phosphorus (P) and N plus P additions. The experiment was carried out in an area located in the Ecological Reserve of the Instituto Brasileiro de Geografia e Estatística, near Brasília (15° 56' S, 47° 53' W). Between 1998 and 2006, 100 kg ha^{-1} year^{-1} of N (N treatment), P (P treatment) and N plus P (NP treatment) were applied to 16 225 m^2 plots, arranged in a completely randomized design. Litterfall was collected at the end of dry season (September 2006) and oven dried (60 °C) for 72 h. Litter bags with 10 g of leaf litter were incubated in situ for 453 days to determine decomposition rate. Nitrogen and P concentrations and mass loss were measured during the incubation process. Decomposition rates of leaf litter in N plots did not differ in relation to those in control plots. Leaf litter decomposition rates increased in P ($+18.6\%$) and NP ($+27.4\%$) plots, where there was a greater N (in NP plots) and P (in P and NP plots) initial concentration in litter relative to the control plots ($p < 0.05$). Leaf litter in the N treatment had the highest N mass loss, and together with NP treatment, the smallest P mass loss. Nitrogen addition increased N mass loss, while the combined addition of N and P resulted in an immobilization of N in leaf litter. When the nutrients are supplied separately, there is greater mass loss of N with N addition, and greater mass loss of P with P addition compared to that observed when N and P are supplied together. The results indicate that if the availability of P is not increased proportionally to the availability of N, the losses of N are intensified during the decomposition process.

Keywords Biogeochemical cycling • Cerrado • Nutrient limitation • Woody plants

T. K. B. Jacobson (✉)
Faculdade UnB Planaltina, Universidade de Brasília, LEdoC. Área Universitária n.1,
Vila Nossa Senhora de Fátima, 73300-000, Planaltina,
Distrito Federal, Brazil
e-mail: tamiel@unb.br

M. M. C. Bustamante
Departamento de Ecologia, Universidade de Brasília, Brasília-DF, 70919-970, Brazil
e-mail: mercedes@unb.br

17.1   Introduction

Ecosystem function is defined primarily by organic matter production, accumulation and decomposition. Nutrient cycling is one of the most important functions in the organization and maintenance of an ecosystem and include inputs (atmospheric deposition, biological fixation, rock weathering) and outputs (runoff, runoff water from rivers, leaching and gas losses). Nutrient transfer between plant and soil represents a key factor in ecosystem functioning and organization (Attwill and Adams 1993). Shifts in global biogeochemical cycles, due to human disturbance of environments, can affect biotic interactions and resource availability patterns in a range of different ecosystems (Vitousek 1997; Bobbink et al. 2010). Anthropogenic introduction of nutrients has amplified global nitrogen (N) and phosphorus (P) cycles by 100 and 400 % respectively, since the industrial revolution (Falkowski et al. 2000). Particularly in tropical systems, N cycling had been modified through urbanization and agricultural intensification (Filoso et al. 2006). In this way, cattle ranching expansion and mechanized agriculture since the 1970s has led to large conversion of Cerrado vegetation (one of world's biodiversity hotspots), with intensive fertilizer addition causing rapid loss of sensitive habitats (Klink and Machado 2005). In the Cerrado ecosystem, the seasonality of water supply and highly weathered soils with low nutrient content have probably acted as selection drivers for species with high nutrient retention. Nutrient storage mechanisms such as leaf scleromorphism, high resorption rates and low decomposition rates are common in Cerrado plant communities (Nardoto et al. 2006). Nutrient cycling, especially of N, has been shown to be conservative in this ecosystem. Changing patterns of rainfall distribution and nutrient pulses can disrupt the supply of and demand for nutrients, resulting in higher losses (Bustamante et al. 2006). In this context, the aim of this study was to determine how nutrient additions (N, P and N plus P) affect leaf litter nutrient concentration, decomposition and nutrient release in a cerrado *sensu stricto* area. We tested the following hypotheses: N and P additions will increase N and P leaf litter concentration, leaf decomposition and N and P mass loss. These changes will be more intense when N and P are supplied together.

17.2   Material and Methods

17.2.1   *Study Area and Fertilization Treatments*

This study was carried out in an area located in the Reserva Ecológica do Roncador, Brazilian Institute of Geography and Statistics (RECOR/ IBGE), near Brasília—Federal District, Brazil (15° 56' S, 47° 53' N, average altitude = 1,100 m) in a native cerrado *sensu stricto* area under nutrient additions. The soil is characterized as an Oxisols (Haplustox), which is acidic, with high Al levels and low cation exchange capacity (Haridasan 1994). Total precipitation was 1,667 mm in 2006 and 1,184 mm

in 2007. Air temperature ranged from 10.1 and 31.9 °C during the study period. The vegetation is classified as cerrado *sensu stricto*, which is characterized by a continuous grass layer and a woody layer of trees and shrubs varying in cover from 10–60 %. This is the most common vegetation type of Cerrado region (Eiten 1972). The fertilization experiment began in 1998. The experimental design was completely randomized, with four nutrient addition treatments and four replicates randomly assigned to 16 plots of 225 m², separated by a 10 m buffer area. The treatments were: control (C; without fertilization), +N (single addition of ammonium sulfate $(NH_4)_2SO_4$), +P (single addition of 20 % superphosphate—Ca $(H_2PO_4)_2 + CaSO_4$ $2H_2O$) and +NP (simultaneous addition of ammonium sulphate/20 % superphosphate) applied to the litter layer without incorporation. Between 1998 and 2006, 100 kg ha^{-1} of N, P and N plus P, was applied twice a year (beginning and end of rainy season). The study area was burned accidentally two times, in 1994 (before the beginning of the treatments) and in 2005.

17.2.2 Leaf Litter Decomposition

Leaf litter was collected from the soil surface in the end of the dry season (September 2006) and oven dried at 60 °C for 72 h. Approximately 10 g (10.115 g, *sd* = 0.209) of mixed leaf litter was weighed into each bags (2 mm mesh). In October 2006, litter bags (2 mm; 20 cm × 20 cm) were placed randomly on the litter layer in each plot. A total of 576 litter bags were placed, 36 per plot (144 per treatment). At approximately 60 day intervals, we randomly collected four litter bags per plot (*n* = 16). Initial mass of each litter bag corresponded to time zero (T0). Collection dates were: December (61 days), February 2007 (125 days), April (189 days), June (248 days), August (309 days), October (369 days) and January 2008 (453 days). Litter from the recovered litter bags was oven-dried at 60 °C to constant weight, and ground in a Wiley mill (40 mesh sieve). A simple negative exponential model was used to determine decomposition rate (Olson 1963). We also calculated the half-life (T50 %) (required time for disappearance of 50 % of the litter mass), using the equation ln 2/k, and litter residence time, given by 1/k.

17.2.3 Leaf Litter Nutrient Concentration

Samples (*n* = 4) corresponding to T0 (initial mass, October 2006), T1 (61 days), T4 (248 days) and T7 (483 days) were analyzed for N and P concentrations. Extraction was performed using wet digestion method (nitric, perchloric and sulphuric acid; 10:2:1). Nitrogen was determined by distillation, using the Microkjeldahl method. Phosphorus was determined by colorimetric analysis with ammonium molybdate and ascorbic acid (EMBRAPA 1999). Litter N and P concentrations were used to calculate nutrient release through litter decomposition.

17.2.4   Statistical Analysis

Data were tested for normal distribution using Kolmogorov–Smirnov test. Regression was used to analyze the decomposition data. Decomposition constant (k), % of mass remaining, litter half-life and residence time were compared between treatments using ANOVA and Student-t test ($p<0.05$). Nutrient litter concentrations were compare across the time periods and treatments using repeated measures ANOVA, followed by Bonferroni adjustment for multiple comparisons and Dunnett test ($p<0.05$). The analysis was performed using SPSS 15.0 package for Windows (SPSS Inc. USA).

17.3   Results

After the end of the incubation period, percentage of litter mass remaining was 58.7% (sd=7.82) in control plots, 56.0% (sd=10.88) in N plots, 51.9% (sd=9.11) in P plots and 47.9% (sd=9.12) in NP plots. Leaf litter decomposition rate in N plots did not differ to that in control plots. Rates of mass loss were the same in the control and N plots whereas in the P plots the final mass was significantly less than in control plots. In NP plots, the mass remaining was significantly lower relative to control plots at 125 days, 309 days and 453 days. Litter residence time in control plots was 8.2% higher (2.32 years) than that observed in N plots, but this difference was not significant. Phosphorus and NP plots had significantly lower litter residence time, 18.7% (P) and 27.5% (NP) relative to that observed in control plots (Fig. 17.1).

   The N concentration in leaf litter significantly increased (+50% in P and +66% in NP plots) during the decomposition process and was significantly higher in N plots (248 days), in NP plots (248 and 453 days) relative to control plots. A higher N (in NP plots) and P (in P and NP plots) initial concentrations in litter were also measured in comparison to control plots (Fig. 17.2).

   Lower N loss was observed in P (−21.4%) and NP (−20.3%) plots while the highest N loss (−38.1%) was observed in N plots. Phosphorus and NP plots had the highest N immobilization rates and also increased P concentrations (+23% P and +70% NP) over the incubation period. These concentrations were significantly higher than those remaining in control plots for all sampling date incubation periods (with the exception of 61 days in the P plots). Higher P mass loss (45.1%), followed by P (35.6%), N and NP plots (both 18.7%) (Fig. 17.3) were measured in control plots during litter decomposition.

17.4   Discussion

Cerrado *sensu stricto* areas are associated with low decomposition rates (Peres et al. 1983). Although environmental characteristics control decomposition rates at the global scale, the initial nutrient content of the litter controls decomposition rates at
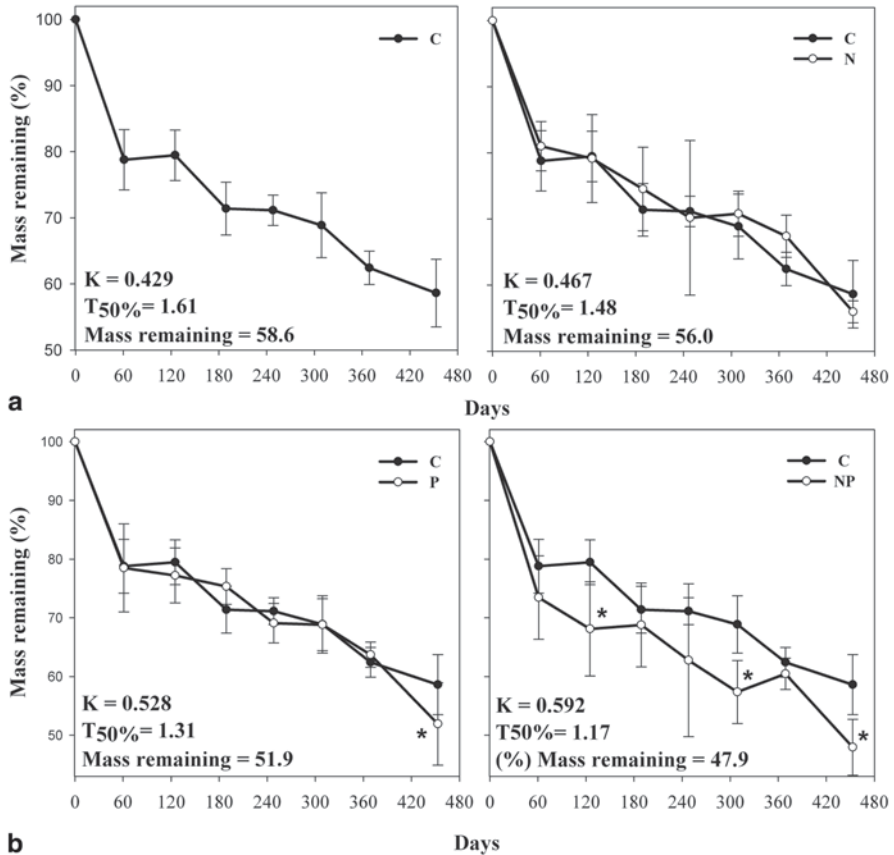
Fig. 17.1 k values, half-life (T 50 %) and % of mass remaining of leaf litter under nitrogen (N), phosphorus (P) and N plus P additions in a savanna in Central Brazil. *Bars* indicate standard deviation. * Indicates significant differences from control (F and t-test, $p < 0.05$). (Reprinted from Jacobson et al. (2011) with permission from Elsevier)

the ecosystem scale (Zhang et al. 2008). As expected, higher initial N and P concentrations in litter from the NP plots and higher initial P concentrations in litter from P plots increased decomposition rates. If nutrients (especially N and P) are more readily available, decomposers use less energy in nutrient acquisition, leaving more to invest in enzymes that degrade cellulose, hemicellulose and lignin (Weedon et al. 2009). At the global scale, N addition has had no significant influence on litter mass loss compared with other nutrients (Knor et al. 2005). However, Hobbie (2008) suggested that N addition increases C retention, since decomposition rates in grassland, coniferous forest and oak forest on sandy weathered soils were lowered by N addition. By contrast decomposition rates in tropical rain forest appear insensitive to P additions (Cleveland et al. 2006) although, decomposition rates in Australian Eucalyptus forest were increased by P addition (O'Connell 1994). In combination
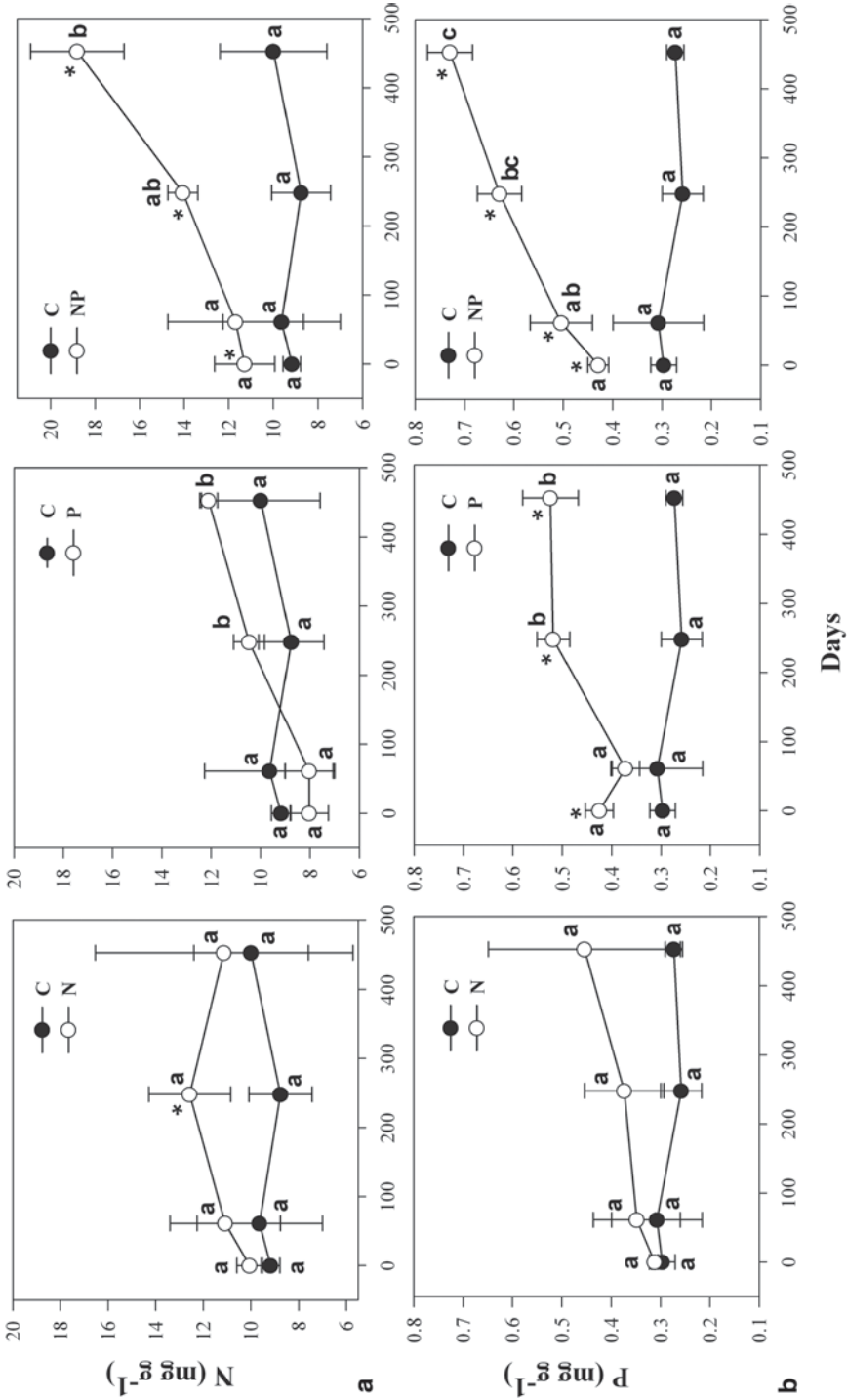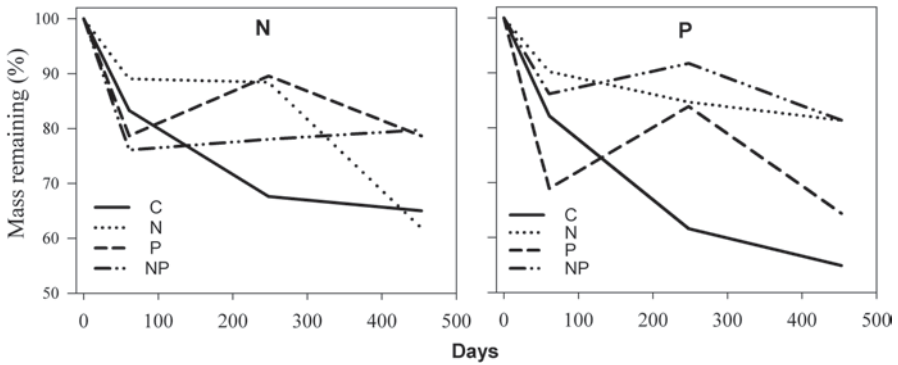
Fig. 17.3 Nitrogen and phosphorus mass remaining (%) during decomposition process. (Reprinted from Jacobson et al. (2011) with permission from Elsevier)

N and P additions produced synergistic positive effects on decomposition rates in Hawaiian rainforests (Allison and Vitousek 2004). These results indicate that decomposition responses, like most ecosystem responses to elevated N deposition, are preconditioned by the balance in N and P availability.

In our study, P addition (single or combined) increased decomposition rates, while N alone, despite increasing the initial N concentration of the litter, only accelerated decomposition when applied with P, indicating P co-limitation. According to Vitousek (2004), long-term fertilization experiments incorporate edaphic and plant chemical modifications. By contrast short-term experiments usually do not reproduce these effects because the communities of plant and soil organisms respond slowly to changes in nutrient availability. This can be verified when we compare our results with initial results from the same experimental area (Kozovits et al. 2007). Nine years after the first fertilization, control litter half-life (1.6 years) has not been modified. Decomposition rates in the NP plots are still significantly lower than those observed in the control, but with the effects are decreasing (−42% in 1999 down to −27.4% in 2007). Decomposition rates in the N plots increased 21.8% over those observed by Kozovits et al. (2007). However, in the P plots decomposition rates were significantly increased, whereas in the early years of fertilization no effect of P had been seen. Nitrogen addition promoted greater N mass loss, while the combined P addition promoted P immobilization in litter. Nitrogen addition did not lead to N conservation in the litter in contrast to NP addition. Nitrogen mass loss increased by 9% in N addition treatment while P and NP addition immobilized N in litter, decreasing, respectively, 39 and 42% N mass loss. This may be due to nutritional limitation of the decomposer community, which immobilizes nutrients in litter in response to increased micro-organism activity (Allison and Vitousek 2004).

Fig. 17.2 Nitrogen (**a**) and phosphorus (**b**) concentration (mg.g^{-1}) in leaf litter during the decomposition process. *Bars* indicate standard deviation. * Indicates significant differences with control (Dunnett, $p < 0.05$). Different letters indicate differences during litter incubation process (Bonferroni, $p < 0.05$). (Reprinted from Jacobson et al. (2011) with permission from Elsevier)

Nitrogen and P litter retention patterns in fertilized plots indicate that the decomposer community appears to be limited by these nutrients. High N mass loss in N plots litter may be due to the fact that C microbial biomass limitation was reached earlier that N limitation. The initial immobilization of N seems to have been reversed due to rapid microbial turnover in response to increased N availability, as observed by Fisk and Fahey (2001). All treatments showed P immobilization relative to control plots, N addition with and without P (NP and N) reduced P loss ~58 but P alone (P) only reduced P loss by 21%. Phosphorus fertilization has a major impact on the activity of litter decomposers, in some cases, exceeding N fertilization effects (Hobbie and Vitousek 2004). The results suggest that fertilization increases leaf litter N and P initial content, which results in higher decomposition rates in P and NP plots. Even with an acceleration in decomposition rate of higher nutritional quality material, soil N transfer (except for N plots) and P soil transfer via litter is not increased, indicating that the additional supply of nutrients is immobilized by microbial biomass.

17.5   Conclusions

Fertilization can increases leaf litter N and P concentrations, suggesting the withdrawl of these nutrients prior to litterfall is less efficient. Adding P and especially P+N increased decomposition rates (mass loss) in this ecosystem. The absence of a stimulatory effect of N addition suggests decomposition is limited primarily by P then N. The greater loss of N and P from litter in the N or P treatments provides evidence of this co-limitation. As hypothesized the combined NP addition had the greatest effect on decomposition, and conservation of these nutrients within the ecosystem. Even with an acceleration in decomposition rate of higher nutritional quality material transfers of both N and P remain unaffected indicating increased immobilization of these nutrients within the litter.

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