



Nitrogen fertilization increased grass litter decomposition in a tropical agroforestry system

Maria Karoline de Carvalho Rodrigues de Sousa · Luciano Cavalcante Muniz ·
Valéria Xavier de Oliveira Apolinário · Joaquim Bezerra Costa · Ana María Herrera-Angulo ·
José Carlos Batista Dubeux Jr · Victor Roberto Ribeiro Reis · Thaís Santos Figueiredo ·
Raabe Alves Souza · Erika Gonçalves Corrêa · Janerson José Coelho

Received: 3 October 2023 / Accepted: 6 February 2024
© The Author(s), under exclusive licence to Springer Nature B.V. 2024

Abstract Litter decomposition and livestock excreta are two important sources for replenishing nutrients in the soil of the pastures, and their decomposition rates are affected by their quality, management practices, forage productivity, and biotic and abiotic factors. The objective of this research was to assess the effects of escalating levels of N fertilization (0, 100, 200, and 400 kg N ha⁻¹ yr⁻¹) on litter and fecal decomposition in an agroforestry system comprising palisadegrass [*Urochloa brizantha* (Hochst. Ex A. Rich.) Stapf. cv. Marandu] intercropped with hybrid eucalyptus trees [*Eucalyptus urophylla* × *Eucalyptus tereticornis*], in a two-year field trial. The experiment

was set in a randomized complete block design with four treatments and three repetitions. Litter (0, 4, 8, 16, 32, 64, 128, and 256 days) and cattle excrement samples (0, 4, 8, 16, 32, 64, and 128 days) were incubated on the ground. For forage litter samples, the interaction between N fertilization × year was observed for the decomposition rate (*k*) of DM ($P=0.0014$) and OM ($P=0.0094$). The greatest litter OM disappearance was observed at 400 kg N fertilization ha⁻¹ year⁻¹ (651 g kg⁻¹ DM at 256 days). The interaction between nitrogen fertilizer rate × incubation time, or the isolated effect of the treatment was not observed on fecal decomposition ($P>0.05$). Higher levels of N fertilization associated with the rainy period resulted in faster decomposition of palisadegrass litter, however, it did not show to have a strong influence on the excreta decomposition in this agroforestry system.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10457-024-00968-x>.

M. K. C. R. Sousa · L. C. Muniz · V. X. O. Apolinário ·
V. R. R. Reis · T. S. Figueiredo · R. A. Souza ·
E. G. Corrêa · J. J. Coelho (✉)
Universidade Estadual do Maranhão (UEMA), São Luís,
MA, Brazil
e-mail: janersoncoelhozoo@gmail.com

J. B. Costa
Empresa Brasileira de Pesquisa Agropecuária
(EMBRAPA), Brasília, DF, Brazil

A. M. Herrera-Angulo
Universidad Nacional Experimental del Táchira,
San Cristobal, Táchira, Venezuela

J. C. B. Dubeux Jr
University of Florida, Marianna, FL, USA

Keywords Agrosilvopastoral systems · Forage ·
Fertilization · Nutrient cycling · Trees

Introduction

The climate in the humid tropical regions of Brazil is characterized by constant elevated temperatures of around 30 °C, and precipitations of about 2000 mm⁻¹ year (Oliveira Aparecido et al. 2023). In addition, some of these regions have limiting soil characteristics for agriculture, such as sandy loam

texture, low cation exchange capacity, and reduced nutrient availability, which create many challenges to keeping sustainable agricultural systems (Moura et al. 2010). These problems are mostly associated with the depletion of soil fertility, and the degradation of the physical stability of the soil (Moura et al. 2021). Among the strategies to increase nutrient cycling and availability in sandy loam soils, the use of agrosilvopastoral systems has the potential to increase soil organic matter and keep a constant and diverse litter deposition, which can contribute to increasing the soil carbon stocks, humus formation, and soil stability (Negash and Kanninen 2015; Pardon et al. 2017; Freitas et al. 2020).

Agrosilvopastoral systems combine crops, trees, pasture, and grazing animals in the same area at the same time and/or under succession-rotation-consortium schemes, generating many benefits including diversification of the production and incomes, reduction of inorganic fertilizer inputs, ecosystem services (Pinheiro and Nair 2018; Nair et al. 2021), such as the provision of forage, fuel, fruits, and building material (Albarrán-Portillo et al. 2019; Apolinário et al. 2015; Dubeux and Sollenberger 2020), food for pollinating insects (Dubeux et al. 2017), carbon sequestration (De Stefano and Jacobson 2018), improvement of nutrient cycling (Apolinário et al. 2015, 2016a, b; Herrera et al. 2020). To ensure the economic viability and ecosystem services of the agroecosystems in regions with high rainfall and sandy loam soils, it is essential to improve the root zone environment, nutrient absorption, and to decrease the losses of nutrients in the soil (Moura et al. 2021).

Low N availability in tropical pastures is one of the main limiting factors for increasing forage productivity (Vendramini et al. 2014). In humid tropic conditions, inorganic N use efficiency is generally low, because high temperatures increase ammonia volatilization (Viero et al. 2017), and high precipitation promotes N leaching (Jabloun et al. 2015). Furthermore, in Brazil, inorganic N fertilizers are costly which limits their use in pasture areas (Boddey et al. 2020). The addition of N via litter and animal excreta are important N inputs to the soil system, especially because they generally are slow-release fertilizers reducing nutrient loss compared to inorganic fertilizers (Apolinário et al. 2016b; Dubeux and Sollenberger 2020; Sena et al. 2020). Inorganic

N fertilization inputs can alter plant litter quality, and the content of N deposited via senescent materials (Knorr et al. 2005), nevertheless, this dynamic does not follow a standard pattern and can be different in function of the types of plant species composing the system.

The speed and efficiency of nutrient cycling via excreta are influenced by the type of grazing animals, quality and composition of the forage consumed, stocking rate, excretion frequency, and distribution, among other factors (Hirata et al. 2011; Dubeux and Sollenberger 2020). Non-grazed and senescent parts of the forage plants return nutrients to the soil via litter deposition, and in agrosilvopastoral systems, there is also the contribution of senescent leaves and branches from tree species, forage or non-forage trees (Dubeux and Sollenberger 2020; Sarto et al. 2020). The presence and composition of trees in agrosilvopastoral systems also affect litter quantity and quality (Carvalho et al. 2021; Sari et al. 2022).

The dynamics of litter and animal excreta decomposition in different agrosilvopastoral systems require more information regarding their dynamics, especially under different N fertilization levels which might impact differently litter and excreta quality. In this context, we hypothesized that inorganic N fertilization can influence litter and cattle feces decomposition in an agrosilvopastoral system composed of eucalyptus tree species intercropped with *Urochloa brizantha* (Hochst. Ex A. Rich.) Stapf. (Palisadegrass) cv. Marandu and corn (*Zea mays* L.). The objective of this study was to assess the effect of increasing levels of inorganic N fertilizer applications on the decomposition rates of forage litter and cattle feces in an agroforestry system.

Material and methods

Experimental site, treatments, and experimental design

The experiment was carried out from May 2019 to May 2021, in an Integrated Crop-Livestock-Forestry system (ICLF) area, located in Maranhão State, Brazil, (3°46'9.12" S and 45°30'1.44" W, 33 m a.s.l.). The climate at the site is tropical, according to the Köppen-Geiger classification (Peel et al. 2007), with

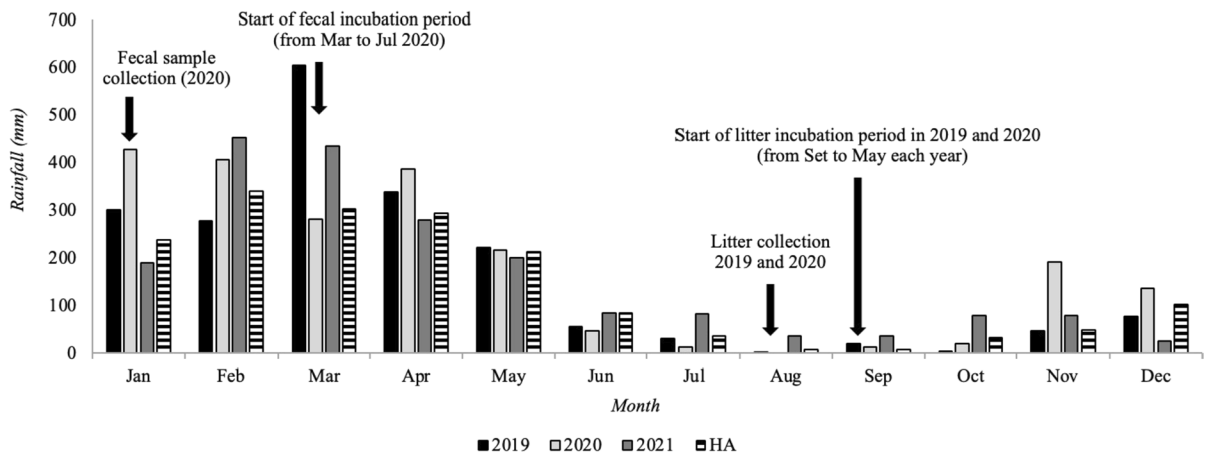


Fig. 1 Monthly rainfall in the experimental area during the research period. HA—historical average (2009–2018)

average annual rainfall and temperature of 2100 mm (Fig. 1) and 27 °C, respectively (Instituto Nacional de Meteorología 2022). The soil at the site is a typical Dystrophic Clay Plinthosol (Araújo et al. 2019), with a sandy-loam texture (sand = 53.3%, silt = 31.3%, and clay = 15.3%). The soil was originally covered by an Ombrophilous Forest vegetation. Before the establishment of the ICLF system in 2016, the area was kept as a pasture of Palisadegrass since 2003, however, it was displaying degradation. Before the initiation of the study, the soil chemical composition (0–20 cm depth) was: soil organic matter (SOM) = 4.0 g kg⁻¹, pH (CaCl) = 4.8; P (Mehlich-I) = 10.7 mg dm⁻³; K⁺ = 0.54 cmol_c dm⁻³; Ca⁺² = 2.13 cmol_c dm⁻³; Mg⁺² = 2.07 cmol_c dm⁻³; Al⁺³ = 0.0 cmol_c dm⁻³; Na⁺ = 0.94 cmol_c dm⁻³; CEC = 7.7 cmol_c dm⁻³, base saturation = 73%.

The experimental area was 3.5 ha. The soil was limed 90 days before corn planting using 1 Mg ha⁻¹ of dolomitic limestone (Relative Power of Total Neutralization-RPTN 80%). We planted a crop-pasture intercropped system with corn (*Zea mays*, hybrid KWS 9304) followed by *Urochloa brizantha* (Hochst. Ex A. Rich.) Stapf. (Palisadegrass) cv. Marandu (Supplemental Figs. 1 and 2). The establishment of the palisadegrass intercropped with corn was carried out simultaneously in November 2015, under a no-tillage system, using 20 and 10 kg ha⁻¹ of corn and grass seeds, respectively, spaced with 0.6 m (within rows) × 0.3 m (between rows). The tree component was composed of a

hybrid eucalyptus (MA-2000 and MA-2001 clones of *Eucalyptus urophylla* × *Eucalyptus tereticornis*). The eucalyptus seedlings were transplanted to the field 70 days after the planting of palisadegrass and corn, the tree seedlings were allocated using the spacings of 3.0 m (between rows) × 2.0 m (within rows) × 28.0 m (between double rows) (Supplemental 1 Fig. 1 and 2).

All pastures (corn crop area) were fertilized using N, P₂O₅, and K₂O, in 2016 and 2017 as follows: during the establishment/planting (16 kg N–120 kg P₂O₅–40 kg K₂O); and at the 4th fully developed leaf of the corn (72 kg N–0 kg P₂O₅–60 kg K₂O), repeating it at the 8th fully developed leaf of the corn. The agroforestry system was fully established in 2017. The experimental design was a randomized complete block design with four treatments and three repetitions. The 12 plots measured 2250 m² each. The treatments corresponded to four levels of N fertilization: 0, 100, 200, and 400 kg N ha⁻¹ year⁻¹; 0 N level was used as the control treatment. Urea (CH₄N₂O) was used as the N source (46.4% N). The application was split-applied in four equal dosages in May, July, August, and September 2019; and in April, May, June, and July 2020.

Pastures were under continuous stocking method using Nellore cattle (*Bos indicus*), these animals had an average initial weight of 262 ± 30 kg, and they were kept using a variable stocking rate (Mott and Lucas 1952). The stocking rate was adjusted every 28 days, to maintain forage allowance of 1 kg DM kg BW⁻¹, according to Sollenberger et al. (2005).

Water and mineral salt were provided ad libitum in each experimental plot.

Litter decomposition

Litter samples of palisadegrass were collected when they were still attached to the plant (senescent tissue), in August 2019, and repeated in the same month in 2020 (Fig. 1). Samples were dried in a forced-air oven at 55 °C to constant weight, and used for incubation. Dried leaves (11.2 g, not ground) were placed in nylon bags with 75- μ m pores measuring 15 \times 30 cm (25 mg DM cm⁻² bag⁻¹), according to the methodology described by Dubeux et al. (2006).

Sixteen nylon bags with dried leaves and sixteen empty bags (control for environmental contamination) were placed on the soil surface in 3-m² exclusion areas in each pasture, in September 2019 (Fig. 1). Two bags with leaves and two empty bags were collected at days 0, 4, 8, 16, 32, 64, 128, and 256 after starting the litter decomposition trial. In the exclusion area, the canopy height was kept in a similar condition to the pasture outside. The bags were covered by palisadegrass litter, simulating the typical condition found in each pasture. Two bags with leaves and two empty ones were separated to be analyzed as the initial (0 days) values (Table 1). The bags (empty and leaf bags) collected at each incubation period were cleaned with a brush and taken to a forced-air oven at 55 °C to constant weight.

Cattle feces decomposition

Bovine feces samples were collected from animals grazing within each pasture immediately after deposition. Special care was taken to avoid soil contamination. These fecal samples were collected in January 2020 (Fig. 1). The samples were dried in a forced-air oven at 55 °C to constant weight, cut into 5 g pieces, and then placed in nylon bags with 75- μ m pores measuring 15 \times 30 cm (25 mg DM cm⁻² bag⁻¹), according to the methodology described by Dubeux Jr. et al. (2006).

Fourteen nylon bags with feces and fourteen empty bags were placed on the soil surface in 3 m² exclusion areas in each pasture. The feces incubation started in March 2020 (Fig. 1) and ended in July 2020. Two bags with feces and two empty bags were collected at days 0, 4, 8, 16, 32, 64, and 128 days after the start of

the feces decomposition trial. The exclusion area in each pasture corresponded to the one used to evaluate litter decomposition. Two bags with feces and two empty bags were separated to be analyzed as the initial values (0 days) (Table 2). The bags (empty and feces bags) collected at each incubation period were cleaned with a brush and taken to a forced-air oven at 55 °C to constant weight.

Chemical analysis

Litter and feces samples from each treatment and time of each experimental plot were ground to pass a 1 mm screen and used for the determination of dry matter (DM), OM (organic matter), N content (Kjeldahl method), and C according to the procedures described by AOAC (2016). Neutral detergent fiber (NDF) was analyzed according to Van Soest and Wine (1967), and acid detergent fiber (ADF) and lignin were according to Van Soest (1973). Results are expressed in terms of OM, to avoid miscalculations due to soil contamination. As the remaining organic matter of the litter at 256 days was considerably very few, we could not analyze the chemical components, those were evaluated until 128 days.

Statistical procedures

Data were analyzed using nonlinear models via PROC NLIN (SAS® OnDemand for Academics) and only the best-fit model was chosen and reported. The single negative exponential model (Wider and Lang 1982) was used to estimate the remaining DM, OM, N, C, and C:N ratio at different times. The model is described by the equation:

$$X = B_0 \times e^{-kt};$$

In which X=corresponds to the proportion of the remaining material; B₀=constant of initial disappearance of DM, OM, N, C and C: N and ratio; k=relative decomposition rate of DM, OM, N, C, and C:N ratio, and t=time in days.

The two-stage linear plateau model described by (McCarty and Rouquette 1977) was used to determine litter N and lignin content. The model is described by the equation:

$$Y_{ijk} = \delta_i + \beta_i(\gamma_i - t_k) + \varepsilon_{ij}t_k \leq \gamma_i, \text{ and } Y_{ijk} = \delta_i + \varepsilon_{ij}t_k > \gamma_i,$$

in which β_i =linear plateau.

The parameters of the model were analyzed using PROC MIXED (SAS® OnDemand for Academics), and when significant ($P < 0.05$), LSMEANS were compared by Tukey's test ($P < 0.05$). N fertilization level, year, and incubation time were considered fixed effects, and the block and their interaction as random effects. The year and its interactions were analyzed as repeated measures. When the interaction was significant, data were analyzed according to Wider and Lang (1982). When differences between treatments were observed, there was a specific equation fit for each treatment. If no differences were observed, there was a single equation to describe the process.

Results

Litter decomposition

There was interaction among N fertilization × days of incubation × year on the remaining biomass, OM, C, and C:N ratios (Figs. 2, 3, 4, and 6). For the remaining biomass ($P < 0.0001$; Fig. 2), differences in the function of the level of N fertilization were not observed during Year 1, with the total average amount decomposed ranging from 887 (0 kg N ha⁻¹ year⁻¹) to 937 g DM kg⁻¹ (200 kg N ha⁻¹ year⁻¹). However, in Year 2, differences were observed from day 16 until the end

of the incubation period. The remaining DM from senescent leaves was lower at the fertilization level of 400 kg N ha⁻¹ year⁻¹, with a total disappearance of 858 g DM kg⁻¹, indicating greater decomposition at this level of fertilization. Furthermore, an interaction between N fertilization × year was observed on k ($P = 0.0014$) (decomposition rate); it was higher at the fertilizer level of 400 kg N ha⁻¹ year⁻¹ (0.008770 g g⁻¹ d⁻¹) in the Year 2, and similar in the Year 1 among any N level, 100, 200, and 400 kg N ha⁻¹ year⁻¹ (0.007880, 0.008643, and 0.007580 g g⁻¹ d⁻¹, respectively).

The OM (Fig. 3) and C (Fig. 4) disappearance had a similar pattern of response being affected by the interaction among N fertilization × days of incubation × year ($P < 0.0001$). This resulted in differences between years for the control with no N (0 kg N ha⁻¹ year⁻¹), where the total disappearance of OM (645 and 408 g OM kg DM⁻¹) and C (741 and 597 g C kg OM⁻¹), were greater in the Year 1 compared to the second, respectively. The highest total OM disappearance was recorded at the fertilizer level of 400 kg N ha⁻¹ year⁻¹ (651 g kg⁻¹ DM), and for C at the fertilizer application rates of 200 (822 g kg⁻¹ OM), and 400 kg N ha⁻¹ year⁻¹ (791 g kg⁻¹ OM). However, differences between the incubation years were not observed for OM (2019–2020=660 g kg⁻¹ DM, and 2020–2021=650 g kg⁻¹ DM), and for C (2019–2020=821 g kg⁻¹ OM, and 2020–2021=822 g kg⁻¹ OM).

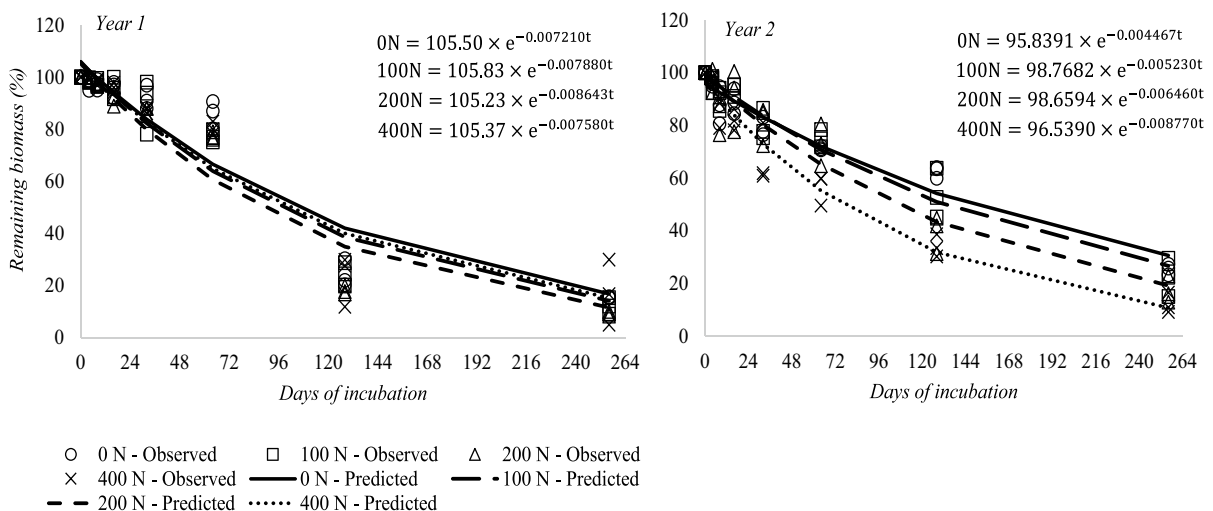


Fig. 2 Remaining biomass from senescent leaves of Palisadegrass after incubation at the soil surface of an agroforestry system, with different levels of N fertilizer

For OM disappearance, an interaction between N fertilization \times incubation year was observed for k ($P=0.0094$), it was higher in Year 2 at the fertilization rate of 400 kg N ha⁻¹ year⁻¹ (0.008990 g g⁻¹ d⁻¹) and at the Year 1 for 100, 200 and 400 kg N ha⁻¹ year⁻¹ (0.008207, 0.008790 and 0.008227 g g⁻¹ d⁻¹, respectively). For C, differences were observed in k between treatments ($P=0.0147$) regardless of the incubation year, with higher averages at 200 (0.01367 g g⁻¹ d⁻¹) and 400 kg N ha⁻¹ year⁻¹ (0.01308 g g⁻¹ d⁻¹). These k values corresponded to the results obtained in the fertilizer application rates with greater disappearance of OM (400 kg N ha⁻¹ year⁻¹) and C (200 kg N ha⁻¹ year⁻¹).

There was less remaining N ($P=0.0027$) in the litter residue in the incubation period of 2020–2021 than in 2019–2020 (Fig. 5), with average disappearance of 340 and 287 g kg⁻¹ OM, respectively. However, no differences were observed for the N decomposition rate between fertilization levels ($P>0.05$). After 128 days of incubation, palisadegrass leaves released 60 and 68% of the N into the soil during the incubation periods 2019–2020 and 2020–2021, respectively.

The C:N ratio was affected by the interaction among N fertilization \times days of incubation \times year ($P<0.0001$) (Fig. 6). There was a greater reduction in C: N values in Year 2 at the fertilizer level of 200 kg N ha⁻¹ year⁻¹, resulting in a lower C:N ratio at the end of the litter decomposition process (25:1). Lesser reduction over the incubation period was observed in the C:N ratio at the fertilizer application rate

of 400 kg N ha⁻¹ year⁻¹ (from 36:1-to-35:1) in the Year 2. Fertilizer application rates of 0 and 100 kg N ha⁻¹ year⁻¹ showed a C:N ratio at 128 days of 45:1 and 37:1, respectively. The fertilizer application rate of 0 kg N ha⁻¹ year⁻¹, had an initial value, for C:N ratio, 55% higher in Year 2 (Table 1) compared to the first ($P=0.0490$). Despite these results, no differences were observed in k for the C:N ratio ($P>0.05$).

There was an interaction between incubation time \times year for ADF content in the remaining litter ($P<0.0001$), which increased from 307 to 410 g kg⁻¹ in 2019–2020, and from 374 to 534 in 2020–2021 (Fig. 7). It stabilized to fit a linear plateau model until 128 days recorded, during both years. Litter ADF content reached a plateau after 39 days in 2019–2020 and after 55 days in 2020–2021.

A single negative exponential model could describe the decay of the litter biomass, OM, C, and N from the senescent leaves of palisadegrass over the incubation time ($P<0.0001$) (Figs. 2, 3, 4, 5). For the C:N ratio, some of the treatments (e.g., 400 kg N ha⁻¹ year⁻¹, in Year 2) could not fit properly a single negative exponential model (Fig. 6). For the variable ADF, the best-fit equation was a positive two-stage linear plateau ($P<0.0001$) (Fig. 7).

Feces decomposition

The interaction between nitrogen fertilizer rate \times incubation time, or the isolated effect of the treatment

Table 1 Litter chemical composition before incubation in 2019 and 2020

Variable	2019–2020				2020–2021			
	N fertilization				N fertilization			
	0	100	200	400	0	100	200	400
	kg N ha ⁻¹ year ⁻¹				kg N ha ⁻¹ year ⁻¹			
DM (g kg ⁻¹ IM)	978.1	977.1	976.3	972.8	905.9	908.1	907.1	906.6
OM (g kg ⁻¹ DM)	914.6	898.7	901.8	921.6	874.3	866.2	877.6	892.5
	g kg ⁻¹ OM							
C	395.5	397.7	400.9	416.0	424.0	443.4	444.5	422.4
N	12.0	12.1	12.3	11.9	8.3	10.5	9.2	12.5
ADF	298.9	285.0	279.5	295.9	328.7	331.2	395.8	382.8
C:N ratio*	33:1 Ba	33:1 Aa	33:1 Ba	35:1 Aa	51:1 Aa	42:1 Ab	48:1 Aa	34:1 Ab

IM incubated material, DM dry matter, OM organic matter, C carbon, N nitrogen, ADF acid detergent fiber

*N fertilization \times incubation period interaction. Similar lowercase letters within N fertilization in each year, and uppercase for the incubation period, do not differ significantly ($P>0.05$)

was not observed regarding fecal decomposition ($P > 0.05$) (Fig. 8). The C decay rates in fecal samples collected during the 2019–2020 incubation period, differed significantly between fertilizer application rates ($P = 0.0415$). Lower and higher k occurred at fertilizer application rates of 0 ($0.004027 \text{ g g}^{-1} \text{ d}^{-1}$) and $400 \text{ kg N ha}^{-1} \text{ year}^{-1}$ ($0.008743 \text{ g g}^{-1} \text{ d}^{-1}$), with the disappearance of C by the end of the fecal decomposition process of 325 and $413 \text{ g kg}^{-1} \text{ OM}$ ($P > 0.05$), respectively. Organic matter, N, NDF, ADF, and C:N ratio decay rates did not differ significantly ($P > 0.05$). For ADF content, a linear plateau was reached after 9 days of incubation (Fig. 8), regardless of the fertilizer application rate and differences observed between treatments for the initial ADF values (Table 2). The variables were plotted in a single negative exponential model, only ADF showed a two-stage linear plateau (Fig. 8).

Discussion

Litter decomposition

The increases in the decomposition rate of senescent leaves of palisadegrass were favored when N fertilizer was applied. Previous research also showed that increasing N content in litter through fertilizer application has the potential to increase the decomposition rates of tropical grasses. Apolinário et al. (2014) reported that using $300 \text{ kg of N per ha}^{-1} \text{ year}^{-1}$ increased signalgrass decomposition compared to $0 \text{ kg of N ha}^{-1} \text{ year}^{-1}$, where the relative decomposition rate (k) was 4.47 and $3.29 \text{ mg g}^{-1} \text{ d}^{-1}$, respectively. Evaluating the effects of N fertilization on litter decomposition of Tifton 85 bermudagrass [*Cynodon dactylon* (L.) Pers. \times *Cynodon transvaalensis* Burt Davy], Liu et al. (2011) reported increases of over 30% in terms of litter disappearance when increasing the fertilizer dosage from 50 to $250 \text{ kg N ha}^{-1} \text{ year}^{-1}$. These findings are in alignment with what was observed in our present study, especially at higher fertilization rates of $400 \text{ kg N ha}^{-1} \text{ year}^{-1}$.

Greater biomass disappearance in the incubation period 2020–2021 was possibly due to greater rainfall that occurred in Year 2 (Fig. 1), especially in the first 4 months after incubation, compared to Year 1 (358.5 e 147.6 mm , respectively). Under humid

Table 2 Cattle feces chemical composition before incubation trial

Variable	Nitrogen fertilization			
	0	100	200	400
	$\text{kg N ha}^{-1} \text{ year}^{-1}$			
OM ($\text{g kg}^{-1} \text{ DM}$)	789.9	743.1	800.5	779.4
	$\text{g kg}^{-1} \text{ OM}$			
C	394.7	438.1	425.0	535.6
N	14.5	10.5	10.3	13.2
NDF	328.4	273.9	333.3	374.6
ADF*	176.6 b	198.4 ab	303.3 a	294.0 a
C:N ratio	27:1	42:1	41:1	41:1

DM dry matter, OM organic matter, C carbon, N nitrogen, ADF acid detergent fiber

*Same lowercase letters at row, do not differ significantly ($P > 0.05$)

environments or during rainy periods, microbial activity can be stimulated contributing to increasing decomposition rates (Suseela et al. 2013). There are several soil microbial groups directly involved in the process of litter decay including fungi and bacteria (Krishna and Mohan 2017; Bani et al. 2018). Several soil microbes such as saprophytes fungi can secrete a sort of exoenzymes with a cellulolytic activity, which accelerates the decay of fiber compounds (Francioli et al. 2021; Li et al. 2022). Also, it should be considered the role of the micro, meso, and macrofauna in the process of litter decay (Krishna and Mohan 2017); this is a specific limitation when considering incubation bag trials, as some of these organisms possibly cannot access the material inside the bags.

Beyond the effects of the rainfall on the decomposition rates, other factors such as the microclimate conditions generated by the trees (Olival et al. 2021) and the quality of the litter deposited (Silva et al. 2013) in each year of the trial, probably influenced the results observed. However, other factors could have affected these results, such as the initial quality of the incubated material (Bohara et al. 2019; Waring 2012). According to Dubeux and Sollenberger (2020), a high C:N ratio (generally between 50 and 100 in plants with C_4 metabolism) is one of the conditions that can increase the immobilization of nutrients in the organic material under decomposition. Probably, through the incubation period, the increase

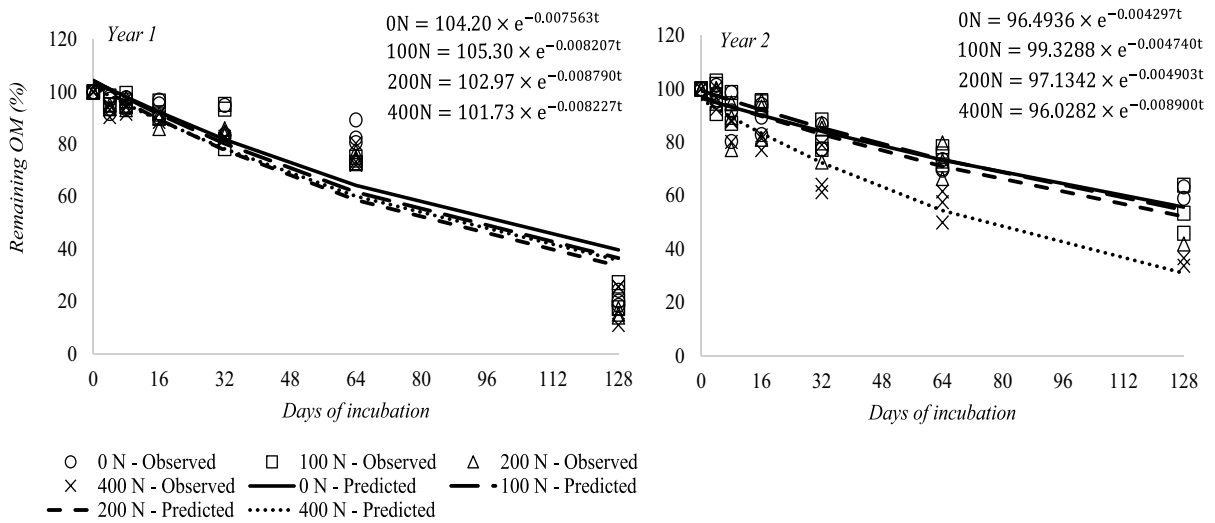


Fig. 3 OM disappearance from senescent leaves of Palisadegrass after incubation at the soil surface of an agroforestry system, with different levels of N fertilizer

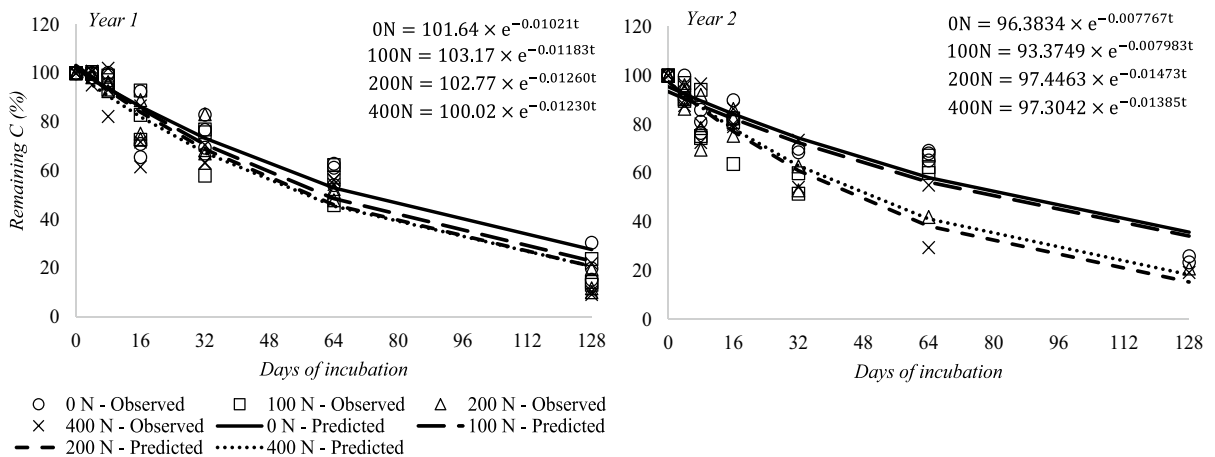


Fig. 4 Remaining C from senescent leaves of Palisadegrass after incubation at the soil surface of an agroforestry system, with different levels of N fertilizer

in N content in some of the treatments reduced the C:N ratio below 30:1, favoring the release of nutrients. According to Silva et al. (2015), N fertilization generally reduces the litter C:N ratio and can lead to faster decomposition rates. Furthermore, C content does not vary widely in plants (Silva et al. 2012).

Therefore, although the N inputs were contrasting, the returns through the litter were not different, as observed by Jaramillo et al. (2021) in bahiagrass pastures. According to Longhini et al. (2021), the average litter deposition of palisadegrass, with and without N

fertilization ($150 \text{ kg N ha}^{-1} \text{ year}^{-1}$), was 16 and 21 $\text{kg OM ha}^{-1} \text{ day}^{-1}$, respectively. Considering this, and the initial average content between the fertilizer application rates for each year (Table 1), the N deposited could be between 194 and 254 and 162 and 212 $\text{g N ha}^{-1} \text{ day}^{-1}$ for the 2019–2020 and 2020–2021 incubation periods, a significant N return to the soil over the year, between 60 and 90 $\text{kg N ha}^{-1} \text{ year}^{-1}$. Nevertheless, it should be considered that these estimations are influenced by the model chosen to describe litter decay. The single negative exponential model used is

Fig. 5 Remaining N from senescent leaves of Palisadegrass after incubation at the soil surface of an agroforestry system, with different levels of N fertilizer

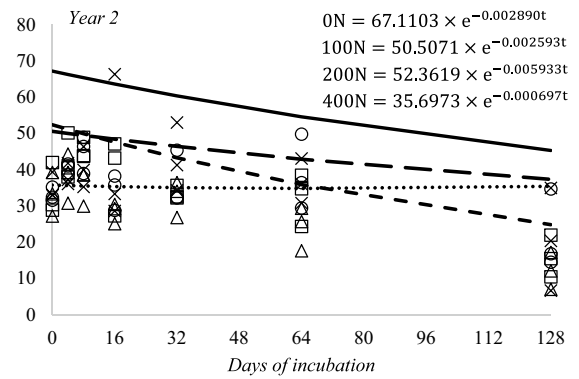
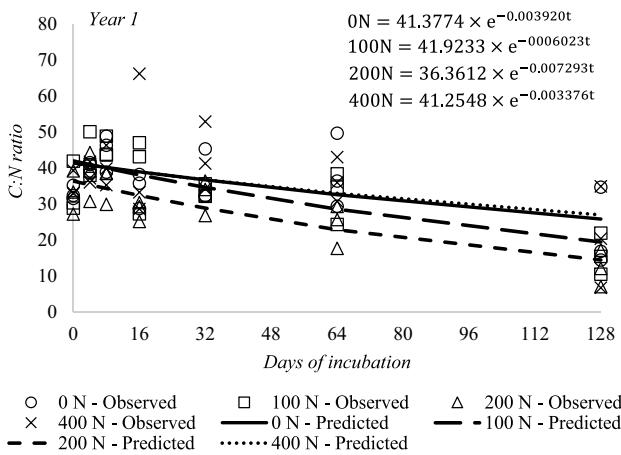
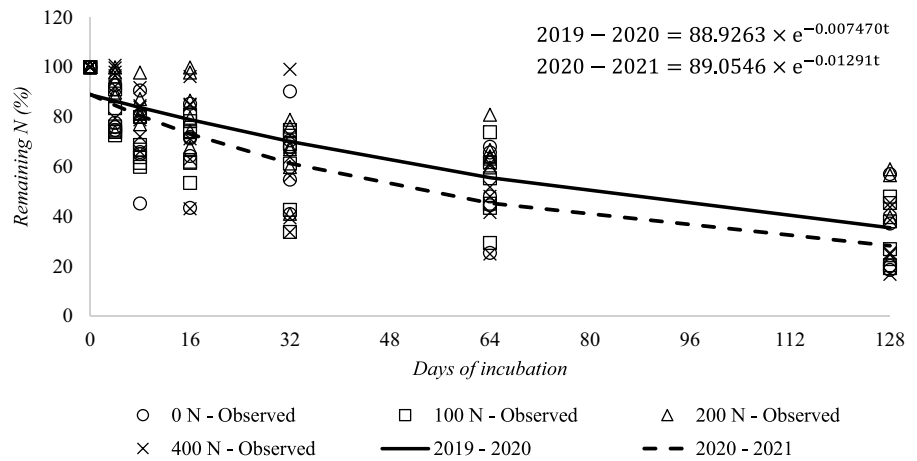
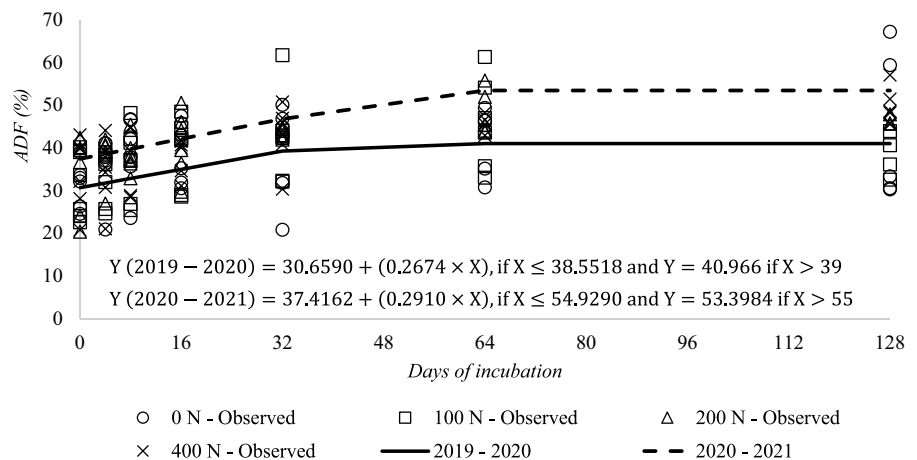


Fig. 6 Carbon: nitrogen ratio from senescent leaves of Palisadegrass after incubation at the soil surface of an agroforestry system, with different levels of N fertilizer

Fig. 7 Acid detergent fiber content of Palisadegrass senescent leaves, after incubation at the soil surface of an agroforestry system, with different levels of N fertilizer



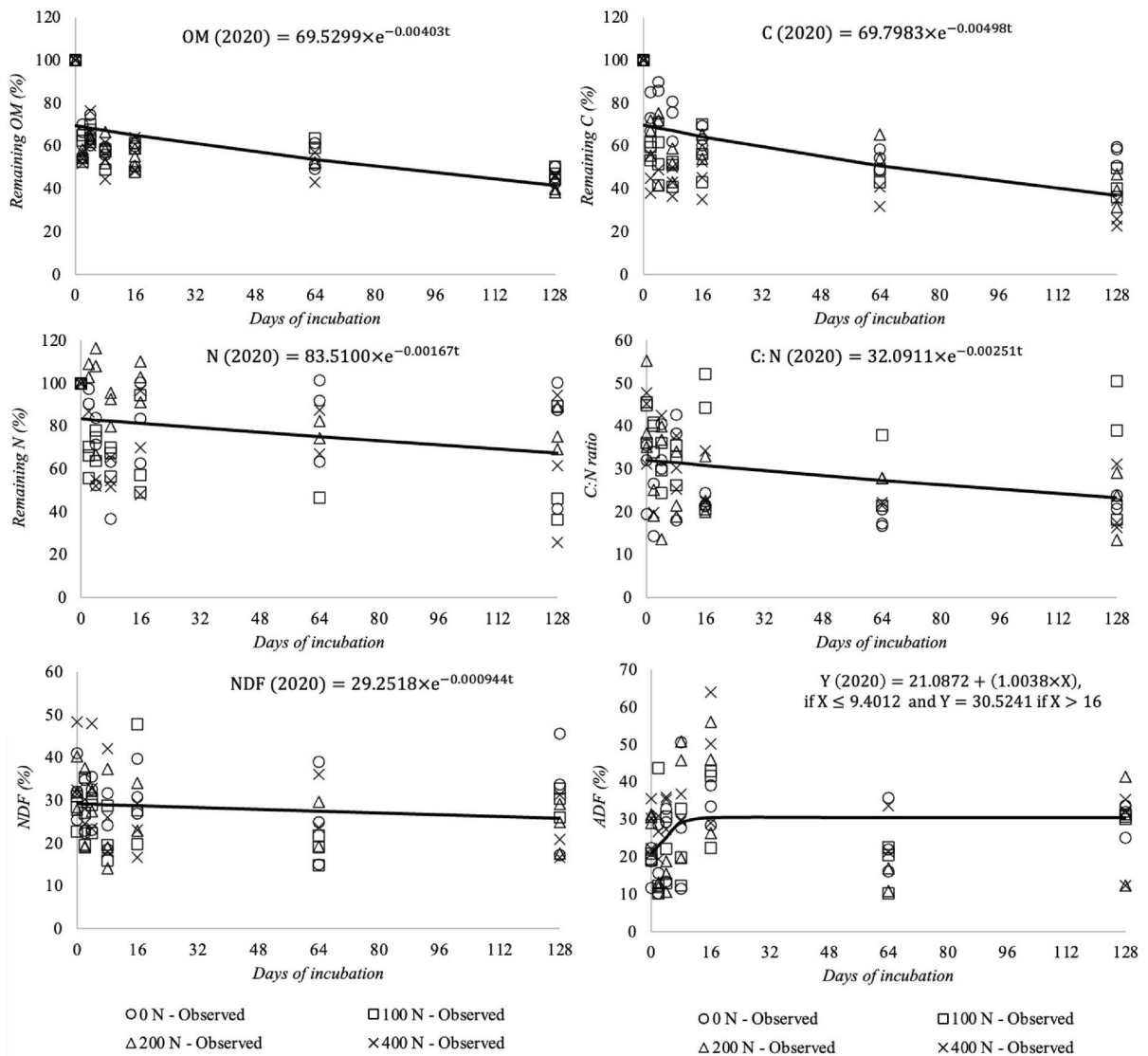


Fig. 8 Remaining OM, C, N, C:N ratio and, NDF and ADF content in incubated feces collected from cattle grazing Palisadegrass in agrosilvopastoral systems, with different levels of N fertilizer

very useful for a general and simplified verification of the effects of different treatments. However, other factors may interfere with the decay rate over time, especially the proportion of easily digestible compounds (e.g. simple sugar, protein) and more recalcitrant materials (e.g., cellulose and lignin), which can be deepened using decaying models such as double exponential (Wider and Lang 1982).

Palisadegrass may have a C:N ratio that favored the OM and C remained after 128 days of incubation. It is known that lesser N availability to microorganisms,

and a high C:N ratio may limit the decomposition process (Apolinário et al. 2014; Maluf et al. 2015). On the other hand, according to Liu et al. (2011), increasing N fertilization could result in an increase in N immobilization in plant litter. These authors concluded that the amount of exogenous N appeared to be the key factor controlling N immobilization. Therefore, both immobilization and N mineralization are possible responses to N fertilization (Liu et al. 2011). According to Pulrolnik et al. (2009), the litter deposited by the *Eucalyptus* tree is characterized

by adding large amounts of C and by a slow decomposition as a consequence of the high C:N ratio, and high content of recalcitrant materials. Demessie et al. (2012) reported annual litter production of different *Eucalyptus* species in Ethiopia ranging from 9 to 12 Mg ha⁻¹ year⁻¹, under pure stands. In Brazil, Vargas et al. (2019) reported litter fall from Eucalyptus trees ranging from 2.8 to 3.5 Mg ha⁻¹ year⁻¹, with the leaves contributing with around 50% of the senescent material collected. It is possible that the soil conditions in the integrated system evaluated, regardless of fertilizer application rates, were influenced by organic matter from the decomposition of the senescent leaves from the Eucalyptus trees.

The ADF content in litter increased over time during the two years. In Year 1, the lower initial C:N ratio in the incubated material compared to Year 2 (Table 1), possibly contributed to the content of recalcitrant compounds such as lignin. Lignin may limit the rate of microbial activity, thereby reducing degradation rates (Manzoni et al. 2012; Suseela et al. 2013). According to Colburn and Evans (1967), lignin is contained in the ADF and may reach up to 11% in the chemical composition of grasses. In Year 2, despite having reached the plateau in a longer period, the ADF contents were higher throughout the incubation period. Possibly this has contributed to the results observed in terms of the remaining N in that year (Fig. 5), regardless of fertilizer application rates. Although the content of lignin and insoluble N in acid detergent were not evaluated in the current research, they are factors that could have influenced these results (Apolinário et al. 2014; Herrera et al. 2020; Jaramillo et al. 2021).

Feces decomposition

There was no effect of the level of N fertilizer over the decomposition of the cattle dung. Despite these results, according to Homem et al. (2021), the application of N fertilizers can contribute to a positive balance of N cycling, increasing the total N recycled through both litter and livestock excreta, and improving the productivity and sustainability of the grazing systems. Eventually, several factors could influence a hypothetical direct relationship between soil N fertilization level and the decomposition rate of cattle feces. Possibly, the most influential factors would be associated with the amount and quality

of the N consumed via forage, which could vary as a function of the parts of the forage consumed and their maturity stage (Temu et al. 2014; Mganga et al. 2021). It is proven that supplementation using N-rich feedstuff increases N excretion in cattle feces (Van Vliet et al. 2007; Jost et al. 2013).

Ruminants return most of the nutrients they consume (80–90%) to the system in the form of excreta (urine and feces) (Dubeux et al. 2007). In systems with greater grazing pressure, the N return via excreta might be greater than via litter. Urine excretion also has a great impact on returning N to the system, Garcia et al. (2021) reported that the amount of urine excreted daily could range from 16 to 48 L ha⁻¹ day⁻¹ in adult cattle, with N concentration varying from 3 to 4.4 g kg⁻¹. In the ICLF system, the presence of the trees must be considered as a factor that could drive the predominance of excreta (feces and urine) deposition, as the animals tend to spend substantial time near shaded areas (Cavernalli et al. 2020).

N fertilizer application is one of the management strategies recommended to improve nutrient cycling (Dubeux and Sollenberger 2020). According to Lima et al. (2016), fecal decomposition rates are a function of the time required for the complete decomposition and disappearance of manure blocks, which varies due to environmental conditions, management, animal species, and diet. Furthermore, N in livestock excreta has several fates, including immobilization by soil microbes, plant uptake, volatilization, denitrification, leaching, and runoff (Dubeux and Sollenberger 2020).

Conclusions

The association with greater N fertilization and higher rainfall contributed to faster decomposition of Palisadegrass senescent leaves. Faster decay rates result in a greater release of nutrients to the soil through the OM incorporated, enhancing nutrient cycling. Differing environmental conditions during different years or the presence of carryover effects from treatments applied in a previous year affected residual biomass, OM, C, C/N ratio, and ADF content of Palisadegrass senescent leaves, reinforcing the need for long-term nutrient cycling trials in tropical pastures.

N mineralization could not be explained by the differences in N fertilization levels. Other factors such as the litter deposited by Eucalyptus trees possibly generated changes in soil organic matter, which is necessary to be evaluated in these integrated systems. N fertilizer application on Palisadegrass did not contribute to the decomposition of excreta in agroforestry systems under the current conditions, however, several factors including grazing management, supplementation, type of cattle, and biotic and abiotic factors would influence this response. It should be considered the complex set of pathways from adding N to the pasture until it increases N in the forage and then increasing N content in feces and affecting the decomposition rate.

Further studies are required to evaluate the long-term nutrient return via excreta, including both feces and urine, especially considering the variations in the types of agroforestry system, their management, and environmental factors.

Acknowledgements Universidade Estadual do Maranhão (UEMA), Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA) (000957/2019), Fundação de Estudos Agrários Luiz de Queiroz (FEALQ), Banco da Amazônia (BASA) and the ICLF Network Association. Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (scholarship 300634/2023-4), and Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA) (PDCTR-08834/22).

Author contributions Maria Karoline de Carvalho Rodrigues de Sousa: project administration/data sampling/writing original draft; Luciano Cavalcante Muniz, Valéria Xavier de Oliveira Apolinário, Joaquim Bezerra Costa: Funding acquisition/administration/project manager/Supervision; José Carlos Batista Dubeux Jr, Janerson José Coelho: Writing review; Ana María Herrera-Angulo, statistical analysis. Victor Roberto Ribeiro Reis, Thaís Santos Figueiredo, Raabe Alves Souza, Erika Gonçalves Corrêa: sampling and laboratory analysis.

Data availability The datasets of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they do not have any financial or personal relationships with other people or organizations that could inappropriately influence their work.

References

- Albarrán-Portillo B, García-Martínez A, Ortiz-Rodea A et al (2019) Socioeconomic and productive characteristics of dual purpose farms based on agrosilvopastoral systems in subtropical highlands of central Mexico. *Agrofor Syst* 93:1939–1947. <https://doi.org/10.1007/s10457-018-0299-2>
- AOAC (2016) Official methods of analysis of AOAC International. AOAC International, Rockville, MD
- Apolinário VXO, Dubeux JCB, Mello ACL et al (2014) Litter decomposition of signalgrass grazed with different stocking rates and nitrogen fertilizer levels. *Agron J* 106:622–627. <https://doi.org/10.2134/agronj2013.0496>
- Apolinário VXO, Dubeux JCB, Lira MA et al (2015) Tree legumes provide marketable wood and add nitrogen in warm-climate silvopasture systems. *Agron J* 107:1915–1921. <https://doi.org/10.2134/agronj14.0624>
- Apolinário VXO, Dubeux JCB, Lira MA et al (2016a) Decomposition of arboreal legume fractions in a Silvopastoral system. *Crop Sci* 56:1356–1363. <https://doi.org/10.2135/cropsci2015.09.0588>
- Apolinário VXO, Dubeux JCB, Lira MA et al (2016) Arboreal legume litter nutrient contribution to a tropical silvopasture. *Agron J* 108:2478–2484. <https://doi.org/10.2134/agronj2016.02.0120>
- Araújo EP, Dias LJBS, Catunda, PHA (2019) Relatório Técnico de Pedologia do Zoneamento Ecológico Econômico do Estado do Maranhão (ZEE) - Etapa Bioma Amazônico. São Luís
- Bani A, Pioli S, Ventura M, Panzacchi P, Borruso L, Tognetti R, Brusetti L (2018) The role of microbial community in the decomposition of leaf litter and deadwood. *Appl Soil Ecol* 126:75–84. <https://doi.org/10.1016/j.apsoil.2018.02.017>
- Boddey RM, Casagrande DR, Homem BGC, Alves BJR (2020) Forage legumes in grass pastures in tropical Brazil and likely impacts on greenhouse gas emissions: a review. *Grass Forage Sci* 75:357–371. <https://doi.org/10.1111/gfs.12498>
- Bohara M, Yadav RKP, Dong W et al (2019) Nutrient and isotopic dynamics of litter decomposition from different land uses in naturally restoring Taihang Mountain. *North China Sustain* 11:1752. <https://doi.org/10.3390/su11061752>
- Carnevali RA, de Mello ACT, Coletti AJ, Garcia LF, Xavier DB (2020) Shade controls the ruminating and idleness times of dairy heifers in tropical integrated systems. *Agrofor Syst* 94:779–790. <https://doi.org/10.1007/s10457-019-00448-7>
- Carvalho AF, Fernandes-Filho EI, Daher M et al (2021) Microclimate and soil and water loss in shaded and unshaded agroforestry coffee systems. *Agrofor Syst* 95:119–134. <https://doi.org/10.1007/s10457-020-00567-6>
- Colburn MW, Evans JL (1967) Chemical composition of the cell-wall constituent and acid detergent fiber fractions of forages. *J Dairy Sci* 50:1130–1135. [https://doi.org/10.3168/jds.S0022-0302\(67\)87578-7](https://doi.org/10.3168/jds.S0022-0302(67)87578-7)
- De Stefano A, Jacobson MG (2018) Soil carbon sequestration in agroforestry systems: a meta-analysis. *Agrofor Syst* 92:285–299. <https://doi.org/10.1007/s10457-017-0147-9>

- Demessie A, Singh BR, Lal R, Strand LT (2012) Leaf litter fall and litter decomposition under eucalyptus and coniferous plantations in Gambo district, southern Ethiopia. *Acta Agric Scand, Sec B-Soil Plant Sci* 62:467–476. <https://doi.org/10.1080/09064710.2011.645497>
- Dubeux JCB, Sollenberger LE (2020) Nutrient cycling in grazed pastures. Management strategies for sustainable cattle production in southern Pastures. Elsevier, Netherlands, pp 59–75
- Dubeux JCB, Sollenberger LE, Vendramini JMB et al (2006) Litter mass, deposition rate, and chemical composition in bahiagrass pastures managed at different intensities. *Crop Sci* 46:1299–1304. <https://doi.org/10.2135/cropsci2005.08-0262>
- Dubeux JCB Jr, Sollenberger LE, Mathews BW et al (2007) Nutrient cycling in warm-climate grasslands. *Crop Sci* 47:915–928
- Dubeux Junior JCB, Muir JP, de Apolinário VX, O, et al (2017) Tree legumes: an underexploited resource in warm-climate silvopastures. *Rev Bras Zootec* 46:689–703. <https://doi.org/10.1590/S1806-92902017000800010>
- Francioli D, Van Rijssel SQ, Van Ruijven J, Termorshuizen AJ, Cotton TA, Dumbrell AJ, Mommer L (2021) Plant functional group drives the community structure of saprophytic fungi in a grassland biodiversity experiment. *Plant Soil* 461:91–105. <https://doi.org/10.1007/s11104-020-04454-y>
- Freitas IC, Ribeiro JM, Araújo NCA et al (2020) Agrosilvopastoral systems and well-managed pastures increase soil carbon stocks in the Brazilian Cerrado. *Rangel Ecol Manag* 73:776–785
- García L, Dubeux JCB Jr, Sollenberger LE, Vendramini JM, DiLorenzo N, Santos ERS, Ruiz-Moreno M (2021) Nutrient excretion from cattle grazing nitrogen-fertilized grass or grass–legume pastures. *Agron J* 113:3110–3123. <https://doi.org/10.1002/agj2.20675>
- Herrera AM, de Mello ACL, de Apolinário VX, O, et al (2020) Decomposition of senescent leaves of signalgrass (*Urochloa decumbens* Stapf. R. Webster) and arboreal legumes in silvopastoral systems. *Agrofor Syst* 94:2213–2224. <https://doi.org/10.1007/s10457-020-00542-1>
- Hirata M, Higashiyama M, Hasegawa N (2011) Diurnal pattern of excretion in grazing cattle. *Livest Sci* 142:23–32. <https://doi.org/10.1016/j.livsci.2011.06.015>
- Homem BGC, de Lima IBG, Spasiani PP et al (2021) N-fertiliser application or legume integration enhances N cycling in tropical pastures. *Nutr Cycl Agroecosyst* 121:167–190. <https://doi.org/10.1007/s10705-021-10169-y>
- INMET (2022) Instituto Nacional de Meteorologia (INMET), Brazil. <https://portal.inmet.gov.br/>. Accessed 22 Nov 2022
- Jabloun M, Schelde K, Tao F, Olesen JE (2015) Effect of temperature and precipitation on nitrate leaching from organic cereal cropping systems in Denmark. *Eur J Agron* 62:55–64. <https://doi.org/10.1016/j.eja.2014.09.007>
- Jaramillo DM, Dubeux JCB, Sollenberger L et al (2021) Litter mass, deposition rate, and decomposition in nitrogen-fertilized or grass–legume grazing systems. *Crop Sci* 61:2176–2189. <https://doi.org/10.1002/csc2.20475>
- Jost DI, Aschemann M, Lebzien P, Joergensen RG, Sundrum A (2013) Microbial biomass in faeces of dairy cows affected by a nitrogen deficient diet. *Arch Anim Nutr* 67:104–118. <https://doi.org/10.1080/1745039x.2013.776326>
- Knorr M, Frey SD, Curtis PS (2005) Nitrogen additions and litter decomposition: a meta-analysis. *Ecology* 86(12):3252–3257
- Krishna MP, Mohan M (2017) Litter decomposition in forest ecosystems: a review. *Energy Ecol* 2:236–249. <https://doi.org/10.1007/s40974-017-0064-9>
- Li X, Qu Z, Zhang Y, Ge Y, Sun H (2022) Soil fungal community and potential function in different forest ecosystems. *Diversity* 14:520. <https://doi.org/10.3390/d14070520>
- Lima HNB, Dubeux JC, dos Santos MVF et al (2016) Decomposition of cattle dung on grazed signalgrass (*Brachiaria decumbens* Stapf) pastures in monoculture or intercropped with tree legumes. *African J Range Forage Sci* 33:119–126. <https://doi.org/10.2989/10220119.2016.1158737>
- Liu K, Sollenberger LE, Silveira ML et al (2011) Grazing intensity and nitrogen fertilization affect litter responses in “Tifton 85” bermudagrass pastures: I. mass, deposition rate, and chemical composition. *Agron J* 103:156–162. <https://doi.org/10.2134/agronj2010.0319>
- Longhini VZ, Cardoso AS, Berça AS et al (2021) Nitrogen fertilizer increased litter deposition and litter N in warm-climate grasslands. *Nutr Cycl Agroecosyst* 119:247–258. <https://doi.org/10.1007/s10705-021-10119-8>
- Maluf H, Soares EMB, da Silva IR et al (2015) Nutrient availability and recovery from crop residues in soil with different textures. *Rev Bras Cienc Do Solo* 39:1690–1702
- Manzoni S, Piñeiro G, Jackson RB et al (2012) Analytical models of soil and litter decomposition: solutions for mass loss and time-dependent decay rates. *Soil Biol Biochem* 50:66–76. <https://doi.org/10.1016/j.soilbio.2012.02.029>
- McCarty MM, Rouquette FM (1977) Grazing pressures and animal performance from pearl millet 1. *Agron J* 69:983–987. <https://doi.org/10.2134/agronj1977.00021962006900060020x>
- Mganga KZ, Ndathi AJ, Wambua SM, Bosma L, Kaindi EM, Kioko T, Musimba NK (2021) Forage value of vegetative leaf and stem biomass fractions of selected grasses indigenous to African rangelands. *Anim Prod Sci* 61:1476–1483. <https://doi.org/10.1071/AN19597>
- Mott GO, Lucas HL (1952) The design, conduct, and interpretation of grazing trials on cultivated and improved pastures. In: *International Grassland Congress*. Pennsylvania, pp 1380–1385
- Moura EG, Serpa SS, dos Santos JGD et al (2010) Nutrient use efficiency in alley cropping systems in the Amazonian periphery. *Plant Soil* 335:363–371. <https://doi.org/10.1007/s11104-010-0424-0>
- Moura EG, Sousa RM, Campos LS et al (2021) Could more efficient utilization of ecosystem services improve soil quality indicators to allow sustainable intensification of Amazonian family farming? *Ecol Indic*. <https://doi.org/10.1016/j.ecolind.2021.107723>
- Nair PR, Kumar BM, Nair VD (2021) Classification of agroforestry systems. In: *An introduction to agroforestry: four decades of scientific developments*, pp 29–44. https://doi.org/10.1007/978-3-030-75358-0_3
- Negash M, Kanninen M (2015) Modeling biomass and soil carbon sequestration of indigenous agroforestry

- systems using CO2FIX approach. *Agric Ecosyst Environ* 203:147–155
- Olival AA, de Souza SEXF, de Moraes JPG, Campana M (2021) Effect of Amazonian tree species on soil and pasture quality in silvopastoral systems. *Acta Amaz* 51:281–290. <https://doi.org/10.1590/1809-4392202004692>
- Oliveira Aparecido LE, Meneses KC, Lorençone PA, Lorençone JA, Moraes JRSC, Souza Rolim G (2023) Climate classification by Thornthwaite (1948) humidity index in future scenarios for Maranhão State. *Brazil Environ Dev Sustain* 25:855–878. <https://doi.org/10.1007/s10668-021-02082-9>
- Pardon P, Reubens B, Reheul D et al (2017) Trees increase soil organic carbon and nutrient availability in temperate agroforestry systems. *Agric Ecosyst Environ* 247:98–111
- Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Köppen–Geiger climate classification. *Hydrol Earth Syst Sci* 11:1633–1644. <https://doi.org/10.5194/hess-11-1633-2007>
- Pinheiro FM, Nair PKR (2018) Silvopasture in the caatinga biome of Brazil: a review of its ecology, management, and development opportunities. *For Syst* 27:eR01S. <https://doi.org/10.5424/fs/2018271-12267>
- Pulrolnik K, de Barros NF, Silva IR et al (2009) Carbon and nitrogen pools in soil organic matter under eucalypt, pasture and savanna vegetation in Brazil. *Rev Bras Cienc Do Solo* 33:1125–1136. <https://doi.org/10.1590/s0100-06832009000500006>
- Sari RR, Rozendaal DMA, Saputra DD et al (2022) Balancing litterfall and decomposition in cacao agroforestry systems. *Plant Soil* 473:251–271. <https://doi.org/10.1007/s11104-021-05279-z>
- Sarto MVM, Borges WLB, Sarto JRW et al (2020) Soil microbial community and activity in a tropical integrated crop-livestock system. *Appl Soil Ecol* 145:103350. <https://doi.org/10.1016/j.apsoil.2019.08.012>
- Sena VGL, de Moura EG, Macedo VRA et al (2020) Ecosystem services for intensification of agriculture, with emphasis on increased nitrogen ecological use efficiency. *Ecosphere* 11:e03028–e03028. <https://doi.org/10.1002/ecs2.3028>
- Silva HMS, Dubeux JCB, dos Santos MVF et al (2012) Signal grass litter decomposition rate increases with inclusion of calopo. *Crop Sci* 52:1416–1423. <https://doi.org/10.2135/cropsci2011.09.0482>
- Silva AB, Lira MA Jr, Dubeux Jr JCB et al (2013) Soil litter stock and fertility after planting leguminous shrubs and forage trees on degraded signal grass pasture [Fertilidade do solo em pastagem degradada de *Brachiaria decumbens* após implantação de leguminosas arbustivas e arbóreas forrageiras]. *Rev Bras Cienc Do Solo* 37:502–511
- Silva HMS, Dubeux JCB, Silveira ML et al (2015) Stocking rate and nitrogen fertilization affect root decomposition of elephantgrass. *Agron J* 107:1331–1338. <https://doi.org/10.2134/agronj14.0618>
- Sollenberger LE, Moore JE, Allen VG, Pedreira CGS (2005) Reporting forage allowance in grazing experiments. *Crop Sci* 45:896–900. <https://doi.org/10.2135/cropsci2004.0216>
- Suseela V, Tharayil N, Xing B, Dukes JS (2013) Labile compounds in plant litter reduce the sensitivity of decomposition to warming and altered precipitation. *New Phytol* 200:122–133. <https://doi.org/10.1111/nph.12376>
- Temu VW, Rude BJ, Baldwin BS (2014) Nutritive value response of native warm-season forage grasses to harvest intervals and durations in mixed stands. *Plants* 3:266–283. <https://doi.org/10.3390/plants3020266>
- Van Soest PJ (1973) Collaborative study of acid-detergent fiber and lignin. *J AOAC Int* 56:781–784. <https://doi.org/10.1093/jaoac/56.4.781>
- Van Vliet PCJ, Reijs JW, Bloem J, Dijkstra J, De Goede RGM (2007) Effects of cow diet on the microbial community and organic matter and nitrogen content of feces. *J Dairy Sci* 90:5146–5158. <https://doi.org/10.3168/jds.2007-0065>
- Van SPI, Wine RH (1967) Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. *J AOAC Int* 50:50–55. <https://doi.org/10.1093/jaoac/50.1.50>
- Vargas GRD, Marques R, Bianchin JE, Teixeira WWR, Blum H (2019) Biomass deposition and chemical composition of litterfall in clonal eucalyptus plantations. *Floresta e Ambiente* 26:e20170450. <https://doi.org/10.1590/2179-8087.045017>
- Vendramini JMB, Dubeux JCB, Silveira ML (2014) Nutrient cycling in tropical pasture ecosystems. *Rev Bras Cienc Agrar* 9:308–315. <https://doi.org/10.5039/agraria.v9i2a3730>
- Viero F, Menegati GB, Carniel E et al (2017) Urease inhibitor and irrigation management to mitigate ammonia volatilization from urea in no-till corn. *Rev Bras Cienc Do Solo*. <https://doi.org/10.1590/18069657rbcs20160567>
- Waring BG (2012) A meta-analysis of climatic and chemical controls on leaf litter decay rates in tropical forests. *Ecosystems* 15:999–1009. <https://doi.org/10.1007/s10021-012-9561-z>
- Wider RK, Lang GE (1982) A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology* 63:1636–1642. <https://doi.org/10.2307/1940104>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.