# Carbon and nitrogen cycling in an integrated soybean-beef cattle production system under different grazing intensities

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Abstract – The objective of this work was to evaluate the effect of grazing intensity on the decomposition of cover crop pasture, dung, and soybean residues, as well as the C and N release rates from these residues in a long-term integrated soybean-beef cattle system under no-tillage. The experiment was initiated in 2001, with soybean cultivated in summer and black oat + Italian ryegrass in winter. The treatments consisted of four sward heights (10, 20, 30, and 40 cm), plus an ungrazed area, as the control. In 2009–2011, residues from pasture, dung, and soybean stems and leaves were placed in nylon-mesh litter bags and allowed to decompose for up to 258 days. With increasing grazing intensity, residual dry matter of the pasture decreased and that of dung increased. Pasture and dung lignin concentrations and C release rates were lower with moderate grazing intensity. C and N release rates from soybean residues are not affected by grazing intensity. The moderate grazing intensity produces higher quality residues, both for pasture and dung. Total C and N release is influenced by the greater residual dry matter produced when pastures were either lightly grazed or ungrazed.

Index terms: *Avena strigosa*, *Glycine max*, *Lolium multiflorum*, integrated crop-livestock, nutrient cycling, soil organic matter.

# Ciclagem de carbono e nitrogênio em sistema integrado de produção de soja e bovinos de corte sob diferentes intensidades de pastejo

Resumo – O objetivo deste trabalho foi avaliar o efeito da intensidade de pastejo na decomposição dos resíduos da pastagem utilizada como cultura de cobertura, do esterco e da soja, bem como a liberação de C e N desses resíduos, em um sistema integrado de produção de soja e bovinos de corte, em plantio direto e em longo-prazo. O experimento foi iniciado em 2001, com soja cultivada no verão e aveia-preta + azevém no inverno. Os tratamentos consistiram de quatro alturas de pasto (10, 20, 30 e 40 cm), além de uma área sem pastejo, como controle. Em 2009–2011, resíduos da pastagem, do esterco, e do caule e das folhas de soja foram alocados em sacos de decomposição feitos com malha de nylon e decompostos até 258 dias. Com o aumento da intensidade de pastejo, a matéria seca residual da pastagem diminuiu e a do esterco aumentou. A concentração de lignina e as taxas de liberação de C da pastagem e do esterco foram menores com a intensidade de pastejo moderada. A liberação de C e N do resíduo de soja não é afetada pela intensidade de pastejo. A intensidade moderada de pastejo produz resíduos de maior qualidade, tanto para a pastagem quanto para o esterco. Já a quantidade total de C e N liberada é influenciada pela maior quantidade de matéria seca residual produzida quando a pastagem foi submetida ao pastejo leve ou não foi pastejada.

Termos para indexação: *Avena strigosa*, *Glycine max*, *Lolium multiflorum*, integração lavoura-pecuária, ciclagem de nutrientes, matéria orgânica do solo.

## Introduction

In Brazil, one of the main food-producing countries, studies on nutrient cycling under more complex food production systems, such as integrated crop-livestock systems (ICLS), involving several components (soil, plant, and animals), are still scarce. The importance of researches on the topic goes beyond food-producing issues, reaching economic, social, and environmental aspects (Ryschawy et al., 2012). In this context, ICLS fit well in the modern concept of sustainable agriculture proposed by Doré et al. (2011).

Currently, one of the primary concerns in food production systems is not the lack, but the adequate

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use of nutrient input, in order to achieve greater efficiency and less negative environmental impacts (Powlson et al., 2011). The introduction of animals in integrated production systems modifies fluxes between soil-plant-animal compartments, through nutrient ingestion, consumption, and pasture-structure modification, before the nutrient is returned to the system (Bardgett & Wardle, 2003). Grazing alters the direction, magnitude, and composition of nutrient fluxes, modifying system functioning (Anghinoni et al., 2013). Therefore, pasture management strategies can affect residue amount and quality, and, consequently, residue decomposition and nutrient release rates (Shariff et al., 1994; Dubeux et al., 2006). Considering nutrient losses by the transfer of nutrients from grazing areas, through the deposition of dung and urine (Haynes & Williams, 1993), cycling of plant and animal residues becomes an important source for maintaining soil-plant-atmosphere equilibrium, since it contributes for nutrient supply both for pasture and cash crops (Dubeux et al., 2007).

Nitrogen is bonded to C in organic residues and only becomes available through mechanisms of chemical bond-breaking (mineralization) by microorganisms. Therefore, approaching nutrient supply under long-term ICLS with no-tillage requires understanding C and N dynamics (cycling). This process can become continuous, since sources of nutrients have varying C:N ratios and lignin contents, releasing nutrients at different rates, i.e., days, weeks, or even years. Different defoliation frequencies and intensities, which influence the formation of new tissues, may also affect C and N cycling due to their effects on the biochemical composition of residues (Parsons & Congdon, 2008), N concentrations in the tissues (Liu et al., 2011), and soil microbial population and diversity (Zhou et al., 2010).

Moderate to high grazing intensities increase particulate organic C and N stocks (Assmann et al., 2014a), which are soil components that serve as a vital energy source for soil microorganisms. The hypothesis of the present study is that a moderate grazing management will promote more intense and balanced C and N cycling than heavy grazing or no grazing.

The objective of this work was to evaluate the effect of grazing intensity on the decomposition of cover crop pasture, dung, and soybean residues, as well as the C and N release rates from these residues in a long-term integrated soybean-beef cattle system under no-tillage.

## Materials and Methods

The experiment was established in May 2001 at the Espinilho Farm of Agropecuária Cerro Coroado, located in the municipality of São Miguel das Missões, in the Planalto Médio region of the state of Rio Grande do Sul, Brazil (29°03'10"S, 53°50'44"W). The area, a soft-wavy relief, is characterized by a declivity of 0.02 to 0.10 m m$^{-1}$, and the soil is classified as a clayey Rhodic Hapludox (Oxisol) (Soil Survey Staff, 1999), which is a deep, well-drained and dark-red soil, with: 540, 270, and 190 g kg$^{-1}$ clay, silt, and sand, respectively, in the 0–20 cm soil layer. Concentrations of dithionite-citrate-bicarbonate and ammonium oxalate-soluble iron in the soil were 110.2 and 5.2 g kg$^{-1}$, respectively (Silva Neto et al., 2008). According to these authors, kaolinite and hematite were the predominant minerals in the clay and iron oxide fractions, respectively. The climate is subtropical with a warm and humid summer (Cfa), according to Köppen's classification. Long-term average temperature and annual rainfall are 19ºC and 1,850 mm, respectively, for a period of 30 years (Instituto Nacional de Meteorologia, 2013).

Before trial establishment, the area had been cultivated under no-tillage for 7 years, since 1993, with black oat (*Avena strigosa* Schreb) during winter and soybean [*Glycine max* (L.) Merr.] during summer. Cattle grazing in the area began in the autumn of 2000 in a black oat + Italian ryegrass (*Lolium multiflorum* Lam.) mixed pasture, followed by soybean cropping. In the autumn of 2001, after soybean harvest, the experiment was established by seeding black oat + Italian ryegrass. After soybean harvest, soil was sampled for chemical characterization. The results of soil analysis of the 0 to 20-cm layer, stratified into 5.0-cm layers, indicated values ranging from: 4.9 to 4.6 for pH; 42 to 26 g kg$^{-1}$ for organic matter; 13.4 to 3.7 and 240 to 55 mg kg$^{-1}$ for available P and K (Mehlich 1), respectively; 62 to 40, 22 to 11, and 7.0 to 1.0 mmol$_c$ kg$^{-1}$ for exchangeable Ca, Mg, and Al, respectively; and 48 to 34% and 17 to 4% for base and aluminum saturation, respectively.

The experimental area of 22 ha was split into 15 plots with 0.8 to 3.2 ha for the different treatments: pasture sward heights of 10, 20, 30, and 40 cm (G10, intensive grazing; G20 and G30, moderate grazing; and G40, light grazing), plus an ungrazed area, as the control, distributed in a randomized complete block design with three replicates. The area of each plot is described in detail in Conte et al. (2011). Pasture heights were controlled every 15 days, whereas stocking rates were controlled with the put-and-take method. Continuous stocking was used, and grazing cycles began when pasture reached 1,500 kg ha$^{-1}$ dry matter (DM), i.e., sward height of approximately 25 cm. Grazing cycles were carried out from mid-July to mid-November.

The integrated crop-livestock system consisted of black oat + Italian ryegrass. 'Iapar 61' black oat was sown in rows each year, whereas “common” Italian ryegrass was sown by broadcasting in 2001 and established by natural reseeding in the next years, as a single crop during winter and intercropped with soybean (‘Iguaçu’ in the first three seasons and 'Nidera RR' in the remaining ones) during summer. Male, neutered, Nelore x Angus x Hereford steers (without blood degree definition) of approximately 10 months of age (beginning of grazing cycle) and with initial live weight of 200±13 kg were used. After grazing, pasture was desiccated with glyphosate, and soybean was sown and harvested in April–May of each year. Soybean cropping followed technical recommendations (Oliveira & Rosa, 2014).

After the first grazing cycle, in the autumn of 2001, broadcast lime was applied on soil surface in the whole area at a rate of 4.5 Mg ha$^{-1}$, with a total neutralization relative power of 62%, according to the soil chemistry and fertility commission of the states of Rio Grande do Sul and Santa Catarina, Brazil (Manual de adubação e de calagem para os Estados do Rio Grande do Sul e Santa Catarina, 2004). Fertilization consisted of N broadcast applications on the pasture and of P and K row fertilizations on soybean, in rates aiming yields between 4.0 and 7.0 Mg ha$^{-1}$ for pasture DM in 2009 and 2010 (45 and 90 kg ha$^{-1}$ N, respectively), and of 4.0 Mg ha$^{-1}$ for soybean grains (Manual de adubação e de calagem para os Estados do Rio Grande do Sul e Santa Catarina, 2004).

Nutrient cycling was evaluated from 2009 to 2011 (8 to 10 years after the establishment of the experiment), in two complete grazing-soybean cropping cycles, which started in May with the grazing cycle and ended in April with the cropping cycle, i.e., soybean harvest. Average stocking rates for this period, which comprises two grazing cycles, were: 1,337, 905, 670, and 356 kg ha$^{-1}$ live weight for G10, G20, G30, and G40, respectively.

Residual dry matter (RDM) (total aboveground shoot dry matter + litter biomass) was sampled at the end of each grazing cycle (before glyphosate application, between October and November of each year) and soybean cycle (between April and May of each year). Pasture RDM was obtained by sampling in five 0.25-m$^2$ representative areas per plot. After drying at 50ºC until constant weight, DM was determined. Total dung DM production in each grazing treatment was obtained at the end of August and October 2009 and 2010. First, ten fresh dungs were randomly sampled in each experimental plot and DM was determined. After average dung DM was obtained for the different treatments, total dung DM for each grazing treatment was calculated by multiplying animal dung production, as in Silva (2012), by average stocking rates and average dung weights. Soybean leaves and plants (stem and remaining legumes) were sampled in 2010 and 2011 during flowering, in ten 1.0-m lines per plot, being oven-dried at 50ºC for DM determination. During soybean harvest, sampling was done in random sites per plot to determine stem and remaining legume DM production.

Twenty-gram samples each of pasture, dung, and soybean leaves and stems were kept in separated 20x20-cm litter bags made of 2.0-mm mesh nylon. For both evaluated seasons, litterbags with pasture residue (green herbage + litter) and dung were sequentially allocated to the experimental area at soybean seeding (12/17/2009 and 11/27/2010), and litter bags with soybean leaves and stems were sequentially allocated to the experimental area at pasture seeding (4/30/2010 and 4/19/2011). To obtain the average of both sampled cycles, litter bags with pasture and dung were sampled at 16, 31, 50, 63, 96, 126, 162, 193, 219, and 253 days, whereas litter bags with soybean leaves and stems were sampled at 23, 37, 53, 73, 105, 134, 162, 190, 222, and 258 days after allocation to the experimental area. After each sampling, litterbags were dried, weighed, and soil was manually removed for DM determination of the remaining material.

To determine nutrients in the remaining residue, the material was ground in a Wiley mill (0.5-mm mesh), and C and N contents were determined with a TruSpec Micro CHNS element analyzer (Leco Corporation, St.

Joseph, MI, USA). The calculation of the remaining DM percentage and of C and N contents was based on total biomass and C and N concentrations at the beginning and at the end of the incubation periods in the field. The percentage of residue decomposition and C and N release rates was calculated as the difference between DM weight and between C and N contents during the incubation periods in the field.

The values obtained for residue DM decomposition and C and N release rates were adjusted with the following nonlinear regression models, according to Wieder & Lang (1982): asymptotic model - RDM (C and N) = A × $e^{-kat}$ + (100 - A); and double exponential model - RDM (C and N) = A × $e^{-kat}$ + (100 - A)$e^{-kbt}$, in which RDM (C and N) is the remaining DM or remaining nutrient percentage along t time (days); and ka and kb are the DM decomposition constants or nutrient release rates from the most decomposable compartment (A) and the most recalcitrant compartment (100 - A), respectively.

According to these two models, residue DM or remaining nutrient amounts could be divided into two compartments. In the asymptotic model, only DM, and remaining C and N from the most decomposable compartment are transformed, decreasing exponentially through time at a constant rate. In the double exponential model, DM and nutrients from both compartments decrease exponentially, with the first fraction transformed into higher rates when compared to the second, which is more recalcitrant, i.e., has a slower decomposition rate. The choice of which model to use was based on the values of the coefficient of determination ($R^2$). Half-life ($t^{1/2}$) was determined from DM decomposition or nutrient release values from each compartment, representing the time necessary for 50% DM from that compartment to decompose or release nutrients. The following formula, described by Paul & Clark (1996), was used: $t^{1/2} = 0.693/k(a,b)$. The adjusted model for the remaining nutrient amounts was used to estimate the accumulative release for the evaluation period by multiplying the C or N release percentages from each sampling (obtained by model adjustment) by the initial amounts. Results from model adjustment variables were subjected to analysis of variance (Anova), and averages were compared by Tukey's test, at 5% probability. Since C and N cycling was evaluated during 2 years, this source of variation was included in Anova and no differences, at 5% probability, were observed between them. Therefore, the results are presented as the average of two years.

## Results and Discussion

Since no differences were observed between the two ICLS cycles, results were presented and discussed considering average values. Grazing sward heights affected pasture residue biomass and dung production (Table 1). Pasture residue decreased from 6.22 to 1.06 Mg $ha^{-1}$ from the ungrazed to the G10 treatment, respectively. However, dung amounts increased with grazing intensity, but with low magnitude, from 0.46 Mg $ha^{-1}$ for G40 to 1.22 Mg $ha^{-1}$ for G10. Soil residue covering (litter and dung) is considered

**Table 1.** Pasture, dung, and soybean (*Glycine max*) residual dry matter, as well as carbon, nitrogen, and lignin initial contents in an integrated soybean-beef cattle system under no-tillage with different grazing intensities, in the municipality of São Miguel das Missões, in the state of Rio Grande do Sul, Brazil(1).

| Pasture sward height (cm) | System residue | | | |
|---|---|---|---|---|
| | Pasture | Dung | Soybean stem | Soybean leaf |
| | Dry matter (Mg $ha^{-1}$) | | | |
| 10 | 1.06±0.12e | 1.22±0.06a | 2.84±0.11a | 2.29±0.16a |
| 20 | 2.50±0.24d | 0.81±0.04b | 2.76±0.09a | 2.30±0.12a |
| 30 | 4.01±0.28c | 0.60±0.04c | 3.10±0.10a | 2.46±0.19a |
| 40 | 5.60±0.23b | 0.46±0.05d | 2.56±0.08a | 2.48±0.19a |
| No grazing | 6.22±0.18a | - | 2.68±0.08a | 2.69±0.09a |
| | Carbon (g $kg^{-1}$) | | | |
| 10 | 422±9a | 357±3a | 531±2a | 478±6a |
| 20 | 443±9a | 412±3a | 531±3a | 479±6a |
| 30 | 469±4a | 431±4a | 531±2a | 479±6a |
| 40 | 463±5a | 411±6a | 531±2a | 480±6a |
| No grazing | 451±7a | - | 530±3a | 479±6a |
| | Nitrogen (g $kg^{-1}$) | | | |
| 10 | 16.4±0.3a | 21.7±0.3a | 15.9±0.3a | 21.6±0.2a |
| 20 | 21.4±0.6a | 25.6±0.5a | 16.7±0.5a | 23.4±0.6a |
| 30 | 20.0±0.4a | 26.4±0.4a | 16.8±0.6a | 22.8±0.5a |
| 40 | 19.6±0.5a | 25.2±0.2a | 16.9±0.6a | 23.3±0.6a |
| No grazing | 18.9±0.4a | - | 16.4±0.4a | 23.0±0.5a |
| | Lignin (%) | | | |
| 10 | 11.2±0.7a | 24.4±1.6a | 11.7±0.4a | 8.8±0.3a |
| 20 | 8.7±0.4b | 17.6±0.9b | 11.5±0.2a | 8.8±0.2a |
| 30 | 9.9±0.3b | 18.8±0.9b | 12.3±0.3a | 8.9±0.4a |
| 40 | 11.7±0.4a | 23.2±0.9a | 11.9±0.2a | 8.8±0.2a |
| No grazing | 12.3±0.9a | - | 11.5±0.1a | 8.0±0.2a |

(1)Means followed by equal letters in the columns do not differ by Tukey's test, at 5% probability. The results are expressed as means±standard error of the mean.

essential for maintaining C and N surpluses (Assmann et al., 2014a). It is important to consider that, for grazed areas, part of the consumed forage nutrients (grazed) returns to the system via dung and urine, being available for subsequent cropping (Haynes & Williams, 1993).

N and lignin contents in dung were greater than those in the pasture (Table 1), which can be explained by the fact that more labile components are broken down in the rumen, going through a concentration process, with a small amount remaining in the animal tissue and the rest being released as dung and urine (Haynes & Williams, 1993). Only lignin contents, in forage and dung, were affected by grazing intensities, with lower values for moderate grazing (G20 and G30). This behavior indicates that, in these intensities, residues have better nutritional quality, with easier (faster) assimilation by animals. Lignin influences negatively residue decomposition rates, both in the soil and in the animal metabolism (Parsons & Congdon, 2008).

Carbon residue mineralization kinetics fits best to the simple exponential model. In this model, only the labile fraction was released during the evaluation period, corresponding to 61–67% pasture, 58–75% dung, 48–49% soybean stems, and 70–73% soybean leaves (Table 2). Differences for this fraction were only observed on pasture residue, with lower values for moderate (G20 and G30) and light (G40) grazing intensities.

Differences in the decomposition rates (ka) were found for pasture and dung residues, with higher rates for G20 and G30, and, consequently, lower $t^{1/2}$. Comparing residue $t^{1/2}$ values, pasture presented lower values (79 to 82 days) than dung (151 to 167 days). Therefore, C-$CO_2$ outputs are likely faster in moderately grazed areas, and the soil remains covered for a longer time in ungrazed ones.

Faster residue decomposition under moderate grazing intensities is a result of morphophysiological modifications due to grazing dynamics under the evaluated stocking rates, which results in constant resprouting, leading to changes in the pasture structure (Lemaire & Chapman, 1996). Plant senescent residues decompose slower than young residues, since older tissues present higher lignin and lower N and soluble sugar contents (Sanaullah et al., 2010). These results corroborate those of Shariff et al. (1994), who observed that moderate grazing intensity (44% shoot removal) resulted in greater decomposition rates, in comparison to ungrazed treatments or intensive grazing (77% shoot removal). The lower dung mineralization rate, when compared to pasture residue, also results from greater lignin proportion (Table 1), a less digestible fibrous material (Haynes & Williams, 1993).

No differences were observed among grazing intensities for C kinetics in the decomposition of soybean stems and leaves (Table 2). For these residues, soybean leaf C-release rates were higher than those of soybean stems. Leaf residues are an easily decomposable material (72%) with an average $t^{1/2}$ of 120 days, contrasting to the 392 days of soybean stems. These differences can be attributed in part to the

**Table 2.** Simple exponential model parameters adjusted to residue carbon release rates, as well as decomposition constants (ka), half-life values, and adjustment ($R^2$) in an integrated soybean-beef cattle system under no-tillage with different grazing intensities, in the municipality of São Miguel das Missões, in the state of Rio Grande do Sul, Brazil(1).

| Pasture sward height (cm) | Compartment A (%) | ka (per day) | Half-life (days) | $R^2$ |
|---|---|---|---|---|
| | | Pasture | | |
| 10 | 65±11a | 0.0059±0.0015b | 117±25 | 0.93 |
| 20 | 60±3b | 0.0084±0.0011a | 82±12 | 0.95 |
| 30 | 61±2b | 0.0088±0.0011a | 79±11 | 0.92 |
| 40 | 62±12b | 0.0063±0.0015b | 110±26 | 0.97 |
| No grazing | 67±10a | 0.0050±0.0012c | 138±28 | 0.92 |
| | | Dung | | |
| 10 | 68±6a | 0.0031±0.0001b | 226±6 | 0.96 |
| 20 | 71±14a | 0.0046±0.0002a | 151±6 | 0.90 |
| 30 | 58±11a | 0.0042±0.0002a | 167±6 | 0.92 |
| 40 | 75±10a | 0.0032±0.0001b | 216±5 | 0.98 |
| | | Soybean stem | | |
| 10 | 49±4a | 0.0017±0.0002a | 397±37 | 0.95 |
| 20 | 48±4a | 0.0018±0.0002a | 389±38 | 0.95 |
| 30 | 48±4a | 0.0018±0.0002a | 390±38 | 0.96 |
| 40 | 48±3a | 0.0018±0.0002a | 394±38 | 0.95 |
| No grazing | 48±4a | 0.0018±0.0002a | 390±42 | 0.95 |
| | | Soybean leaf | | |
| 10 | 73±2a | 0.0056±0.0003a | 124±6 | 0.94 |
| 20 | 72±3a | 0.0056±0.0004a | 123±8 | 0.96 |
| 30 | 71±4a | 0.0059±0.0006a | 117±10 | 0.96 |
| 40 | 70±4a | 0.0061±0.0006a | 114±10 | 0.95 |
| No grazing | 73±3a | 0.0056±0.0005a | 123±10 | 0.95 |

(1)Means followed by equal letters in the columns do not differ by Tukey's test, at 5% probability. The results are expressed as means±standard error of the mean.

structural composition of stems and leaves, with lignin contents of 11 and 8%, respectively (Table 1). Padovan et al. (2006) reported lower $t^{1/2}$ of 43 days in soybean plants sampled 115 days after emergence. According to these authors, the early development stage of soybean explains these lower values.

From the adjusted models, the amounts of C released were estimated through time required to achieve residue decomposition (Figure 1). In the decomposition of plant residues, an amount of C is lost as $CO_2$, but a significant amount of released C contributes to soil organic matter formation, being the main process responsible for the incorporation of C in the soil (Cotrufo et al., 2013). Total C release from pasture residue (Figure 1 A) increased with remaining residue amounts (Table 1) along time, with greater values for the ungrazed and G40 treatments, followed by G30>G20>G10, with an accumulated release at 253 days, ranging from 300 to 2,200 kg ha$^{-1}$. Schuman et al. (1999) also observed greater variation in C release, in a mixed pasture system (55% winter species and 23% summer species), of 1.62, 1.28, and 0.75 Mg ha$^{-1}$ C for ungrazed, lightly grazed, and heavily grazed areas, respectively. Carbon released from dung presented an inverse behavior to grazing treatments when compared to pasture residues (Figure 1 B). Highest release was found for the intensive grazing system (G10), followed by G20, G30, and G40, which did not differ from each other. Higher C release from dung in the most intensive grazing system results from higher stocking rates. Accumulated C release from pasture and dung (Figure 1 C), even though responding differently to grazing intensities (Figure 1 A and B), is mainly determined by the amount of pasture residue, in which the ungrazed treatment = G40>G30>G20>G10.

No differences were found among grazing treatments regarding C released from soybean residue (Figures 1 D, E, F), which leads to lower stable organic matter formation, especially under high-intensity grazing systems (G10), as observed after 10 years of trial establishment (Assmann et al., 2014a). Carbon release was greater in soybean leaves, being approximately double the value of stem C release, reaching a total amount of 300 kg ha$^{-1}$.

The kinetics of N release from soybean and pasture residues fits best to the simple exponential model, whereas a double exponential model presented best fit for dung (Table 3). Although it was not the object of the statistical analysis between residues, the low values of the labile N fraction in dung, except for the intensive grazing system (G10), deserve attention. This fraction (labile) was greater in soybean residues, with higher values for stems (82%) than for leaves (75%). Differences in this fraction due to grazing intensities were observed for dung and pasture residues, with lower values for moderate (G20 and G30) and light (G40) grazing intensities. While evaluating decomposition rates of cover crops in Southern Brazil, Aita & Giacomini (2003) stated that approximately 80% N remained in oat (*Avena sativa* L.) residues 15 days after these were allocated to the field. However, Brunetto et al. (2011) reported that 80% N from ryegrass residue was released in 16 weeks, a greater fraction than the values found in the present study, which averaged 40%.

The greatest N release rates (ka) from pasture were observed under moderate (G20 and G30) and light (G40) grazing intensities, with $t^{1/2}$ values of 39 and 55 days, contrasting with no grazing and intensive grazing (G10) systems, with $t^{1/2}$ values of 82 and 128 days. Assmann et al. (2014b) found similar results in a wheat (*Triticum aestivum* L.) grazing system, with half-life values of 105 days and labile fraction of 76% under an ICLS with similar soil and weather conditions. Moderate grazing also accelerated N decomposition and release rates in ryegrass pasture (Semmartin et al., 2008), which can be explained by the constant resprouting that leads to higher tillering with younger leaves and stems.

N release rates from dung were greater than those from pasture residues (Table 3), with both compartments decreasing exponentially (ka and kb) and the labile fraction (A) releasing N in greater rates, in comparison to the more recalcitrant fraction (less decomposable) (100 - A). Overall, N release was faster under moderate grazing conditions (G20 and G30), with lower $t^{1/2}$ in both compartments (labile and recalcitrant), when compared to the ungrazed and intensively grazed (G10) treatments. The greater N proportion in the more decomposable compartment (61%) in G10 can result from greater animal ingestion of new leaves, with higher digestibility and lower C:N ratios. However, according to Haynes & Williams (1993), forage passage through the cattle digestive system is faster under moderate grazing intensities (G20 and G30) due to the lower lignin contents,

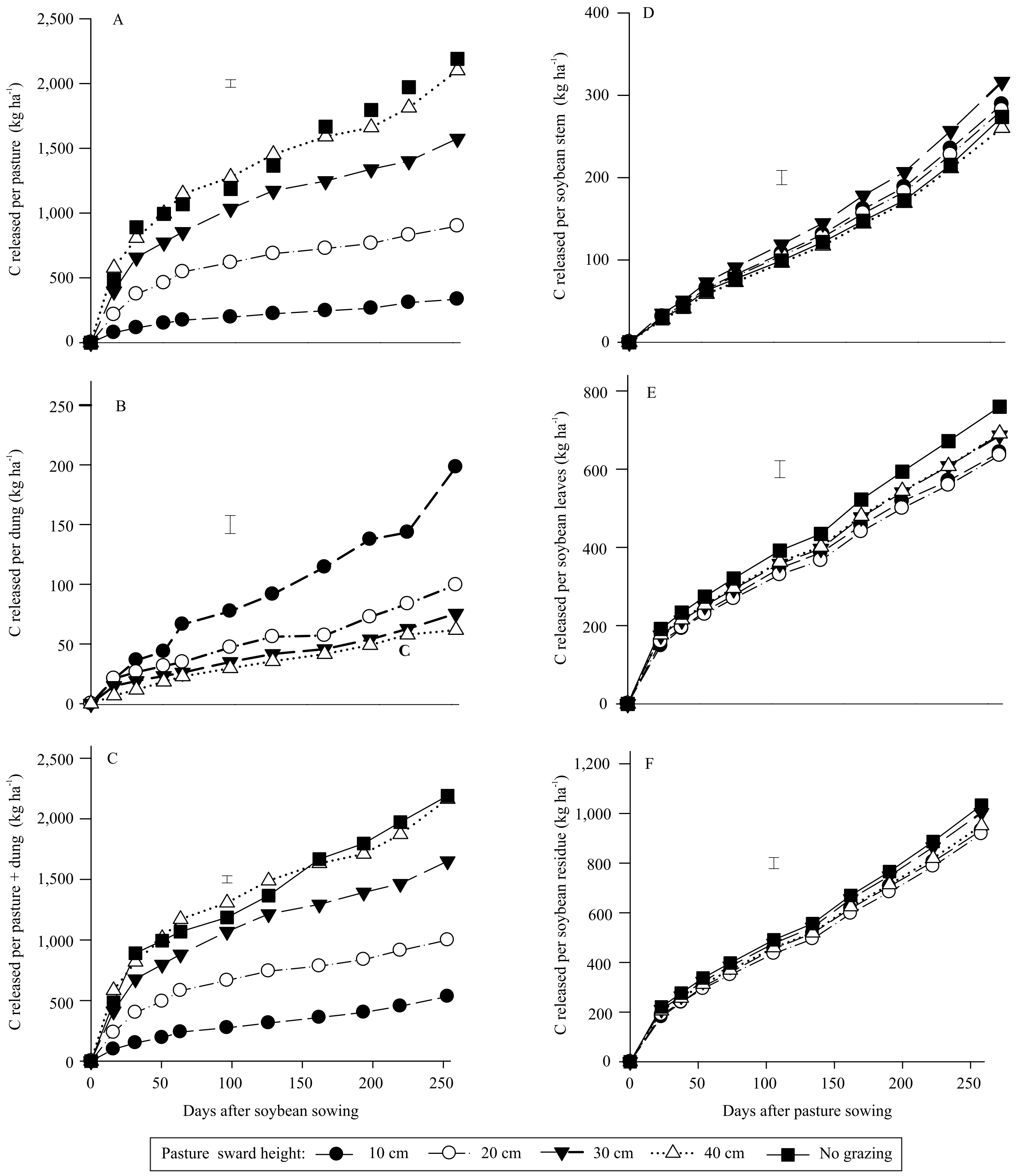

**Figure 1.** Carbon released from pasture (A) and dung (B), as well as accumulated release from pasture and dung (C), soybean stems (D), soybean leaves (E), and soybean residue (stem + leaves) (F) in an integrated soybean-beef cattle system under no-tillage with different grazing intensities, in the municipality of São Miguel das Missões, in the state of Rio Grande do Sul, Brazil. The bars indicate Tukey's least significant difference test, at 5% probability.

resulting in faster N release from dung in comparison to other grazing intensities and to no grazing.

According to Soussana & Lemaire (2014), N cycling is coupled to C cycling from plant growth until decomposition, and grazing management strongly affects both cycles, influencing microorganism capacity and dynamics on capturing and recycling N. Under ICLS conditions, cycling is modified by C dynamics and the decoupling effect. Decoupling occurs through grazing, by forage consumption and the accumulation of a small proportion of C and N in the animal organism (tissue), with the remainder being returned, separately, to the pasture. Carbon returns mostly via dung, whereas N returns mainly as urine (60 and 70%). Therefore, increasing grazing intensity will increase C and N decoupling, affecting ICLS cycling dynamics.

The release rate from soybean residue was not affected by grazing intensities (Table 3). However, this rate was faster than C decomposition rates, due to N demand for microbial growth. Fast N release, especially from soybean leaves, is attributed to the removal of the water-soluble fraction by rain and the easily-decomposable fraction by microorganisms (low C:N ratio), even when residues remain on soil surface (Padovan et al,. 2006). Lower N release from soybean stems (higher $t^{1/2}$) results from higher lignin contents (11%), when compared to leaves (8%) (Table 1). Lignin in plant tissue disfavors decomposition and, therefore, N release (Palm & Sanchez, 1991).

As observed for C cycling (Table 2 and Figure 1), N release from pasture (Figure 2 A) and dung residues (Figure 2 B) depends on residue production (Table 1), being greater for the ungrazed and G40 treatments. For dung, as observed for C, G10 leads to a greater N release, followed by G20, G30, and G40. Since dung N release is a slow process, a fraction can go through recycling during a grazing cycle, considering most of this grazed nutrient returns mainly as urine (Haynes & Williams, 1993).

**Table 3.** Simple and double exponential model parameters adjusted to residue nitrogen release rates, as well as decomposition constants (ka and kb), half-life values, and adjustment ($R^2$) in an integrated soybean-beef cattle system under no-tillage with different grazing intensities, in the municipality of São Miguel das Missões, in the state of Rio Grande do Sul, Brazil⁽¹⁾.

| Pasture sward height (cm) | Compartment A (%) | ka (per day) | kb (per day) | Half-life (days) | | $R^2$ |
|---|---|---|---|---|---|---|
| | | | | A | (100 - A) | |
| | | | Pasture | | | |
| 10 | 72±4a | 0.0054±0.0001d | - | 128±10 | - | 0.94 |
| 20 | 64±1b | 0.0179±0.0012a | - | 39±3 | - | 0.94 |
| 30 | 57±1c | 0.0132±0.0003b | - | 53±1 | - | 0.97 |
| 40 | 51±1d | 0.0125±0.0013b | - | 55±7 | - | 0.95 |
| No grazing | 68±3a | 0.0084±0.0008c | - | 82±9 | - | 0.94 |
| | | | Dung | | | |
| 10 | 61±6a | 0.0090±0.0013d | 0.0014±0.0001d | 77±12 | 485±27 | 0.97 |
| 20 | 14±1bc | 0.0944±0.0121a | 0.0027±0.0001a | 7±1 | 255±6 | 0.99 |
| 30 | 10±1c | 0.0606±0.0054b | 0.0015±0.0001c | 11±1 | 453±11 | 0.96 |
| 40 | 20±1b | 0.0346±0.0028c | 0.0017±0.0001b | 20±1 | 409±15 | 0.98 |
| | | | Soybean stem | | | |
| 10 | 82±3a | 0.0054±0.0006a | - | 127±12 | - | 0.98 |
| 20 | 83±3a | 0.0053±0.0006a | - | 130±15 | - | 0.94 |
| 30 | 82±4a | 0.0058±0.0011a | - | 120±19 | - | 0.97 |
| 40 | 82±5a | 0.0055±0.0009a | - | 125±19 | - | 0.95 |
| No grazing | 83±3a | 0.0053±0.0006a | - | 130±14 | - | 0.97 |
| | | | Soybean leaf | | | |
| 10 | 75±1a | 0.0106±0.0002a | - | 66±1 | - | 0.99 |
| 20 | 74±1a | 0.0106±0.0003a | - | 65±2 | - | 0.99 |
| 30 | 75±1a | 0.0097±0.0005a | - | 71±4 | - | 0.98 |
| 40 | 74±1a | 0.0104±0.0004a | - | 67±3 | - | 0.98 |
| No grazing | 75±1a | 0.0099±0.0004a | - | 70±3 | - | 0.98 |

⁽¹⁾Means followed by equal letters in the columns do not differ by Tukey's test, at 5% probability. The results are expressed as means±standard error of the mean.

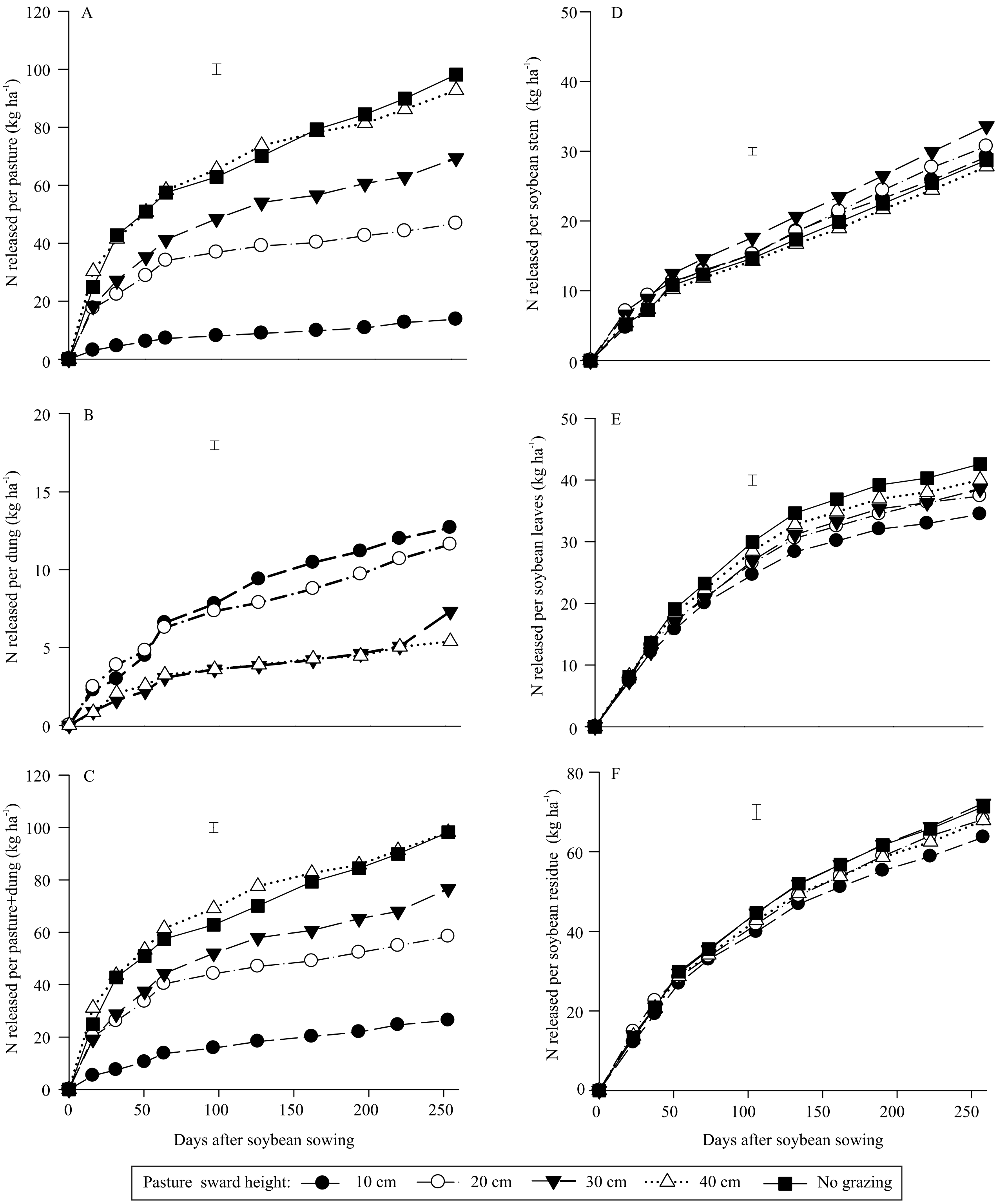

**Figure 2.** Nitrogen released from pasture (A) and dung (B), as well as accumulated release from pasture and dung (C), soybean stems (D), soybean leaves (E), and soybean residue (stem + leaves) (F), in an integrated soybean-beef cattle system under no-tillage with different grazing intensities, in the municipality of São Miguel das Missões, in the state of Rio Grande do Sul, Brazil. The bars indicate Tukey's least significant difference test, at a 5% probability.

Pasture N release (Figure 2 A) was greater in the ungrazed and lightly grazed treatments (G40), followed, in decreasing order, by the moderately grazed (G30 and G20) and intensively grazed (G10) treatments, which released 43, 43, 29, 26, and 8.0 kg ha$^{-1}$, respectively, at soybean seeding (30 days). Throughout the soybean cycle (150 days), the amount of N available from pasture residues was 80, 74, 56, 41, and 10 kg ha$^{-1}$ for the ungrazed, G40, G30, G20, and G10 treatments.

Nitrogen cycling (release) from soybean residues was not influenced ($p>0.05$) by grazing intensities (Figure 2 D, E, and F). N cycling in soybean for subsequent grazing (pasture) is important under ICLS, even though soybean demand for N is low due to the symbiotic fixation process (Paul & Clark, 1996). Therefore, at 150 days (120 average grazing days), the amount (29 kg ha$^{-1}$ N) released from soybean leaf residues was greater than that from soybean stems (17 kg ha$^{-1}$), resulting, in average, in 46 kg ha$^{-1}$ N released gradually from pasture. Soybean residues do not release enough N to maintain high black oat + Italian ryegrass DM production, which demands more than 200 kg ha$^{-1}$ N for DM production, around 7.0 Mg ha$^{-1}$ under ICLS (Assmann et al., 2004). Despite N cycling not supplying enough N amounts for the system, it maintains soil biological activity, enabling greenhouse gas sequestration and decreasing fertilizer demand, which aids ICLS to achieve equilibrium under long-term conditions.

Therefore, residue cycling in long-term, well-managed ICLS (moderate grazing intensity) under no-tillage leads to more intense N fluxes (around 130 kg ha$^{-1}$ per year, for the evaluated period), and to higher C sequestration and nutrient release, becoming a less input-dependent food production system. Production systems with these characteristics are becoming more valuable among society and fomentation institutions (Food and Agriculture Organization of the United Nations, 2010). In the present work, the moderate grazing intensity (pasture sward height of 20–30 cm) produced higher quality cover crop and dung residues, but total C and N release was determined by the greater residual dry matter produced when cover crops were either lightly grazed (sward height of 40 cm) or ungrazed. This shows both positive and negative impacts of grazing winter cover crop pastures on C and N dynamics, such that nutrient cycling can be manipulated to either temporarily sequester nutrients or rapidly release them.

## Conclusions

1. C and N release rates from pasture and dung are greater in soybean-beef cattle integration under moderate grazing when compared to lightly grazed, intensively grazed, and ungrazed areas.
2. C and N release rates from soybean residues (leaves and stems) are not affected by grazing intensity.
3. Greater residual dry matter ultimately determines total C and N release, whereas the quality of limited residual dry matter can be altered by grazing intensity.
4. Grazing intensity affects N fluxes in the soil-plant-atmosphere system, ranging from ~30 kg ha$^{-1}$ for intensive grazing to 100 kg ha$^{-1}$ for lightly grazed and ungrazed areas.

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