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# Calcium and Magnesium Released from Residues in an Integrated Crop-Livestock System under Different Grazing Intensities

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**ABSTRACT:** Under integrated crop-livestock production systems (ICLS), plant and animal residues are important nutrient stocks for plant growth. Grazing management, by affecting the numbers of both plants and animals and the quality of residues, will influence nutrient release rates. The objective of this study was to evaluate the impact of grazing intensity on Ca and Mg release from pasture, dung, and soybean residues in a long-term no-till integrated soybean-cattle system. The experiment was established in May 2001 in a *Latossolo Vermelho Distroférrico* (Rhodic Hapludox). Treatments were a gradient of grazing intensity, determined by managing a black oat + Italian ryegrass pasture at 10, 20, 30, and 40 cm grazing height and no-grazing (NG), followed by soybean cropping. Ca and Mg release rates were determined in two entire cycles (2009/11). Moderate grazing (20 and 30 cm sward height) led to greater Ca and Mg release rates from pasture and dung residues, with low average half-life values (13 and 3 days for Ca and 16 and 6 days for Mg for pasture and dung, respectively). Grazing compared with NG resulted in greater Ca and Mg release from pasture and dung residues. Grazing intensity did not affect Ca and Mg release rates or amounts from soybean residues, but Ca and Mg release rates were greater from soybean leaves than from stems. Although moderate grazing intensities produce higher quality residues and higher calcium and magnesium release rates, a higher total nutrient amount is released by light grazing intensity and no-grazing, determined by higher residue production. Grazing intensity is, then, important for nutrient dynamics in the soil-plant-animal continuum.

**Keywords:** mixed pasture, animal residue, half-life time, nutrient cycling.

## INTRODUCTION

Due to their basic nature, exchangeable calcium (Ca) and magnesium (Mg) are highly related to soil acidity, and are deficient in tropical and subtropical regions (Bohn et al., 2001). These deficiencies are usually corrected by applying dolomitic limestone, used to neutralize soil acidity. In general, these nutrients have been overlooked (Havlin et al., 2005), and little concern has been given to their efficiency in food production systems.

The more production intensive to supply global food demand has led to an unbridled use of inputs, affecting global nutrient budgets. As an example, incentives for purchasing N fertilizers in China has led to severe soil acidification and exchangeable Ca and Mg losses (Guo et al., 2010). Regarding such concerns, Adomaitis et al. (2013) highlighted in a long-term trial in a sandy soil that greater fertilization to achieve high cash crop yields resulted in high Ca and Mg losses, 360 and 67 kg $ha^{-1}$ $yr^{-1}$, respectively, mostly (60 %) during the winter, when the soil remains under fallow conditions. Such a response leads to the importance for more efficient plant nutrient cycling through summer and winter crop rotation and/or succession and highlights how relatively simple management practices – such as cover crops and pasture grazing – can contribute to greater nutrient-use efficiency, which is indispensable for fulfilling agronomical and environmental demands (Jarvis et al., 1995).

Thus, to achieve sustainable agroecosystems, adequate management strategies are necessary (Lal, 2009; Powlson et al., 2011). Integrated crop-livestock systems (ICLS) can improve food production efficiency and environmental quality, enhancing nutrient cycling of plant and animal residues (Haynes and Williams, 1993; Tracy and Zhang, 2008; Tracy and Davis, 2009). Under ICLS, plant and animal residue decomposition releases significant amounts of Ca and Mg throughout the growing season that are not accounted for in soil analysis.

Recently, in subtropical regions, approaches regarding secondary macronutrient cycling under no-till conditions have been carried out (Torres et al., 2008; Bernardes et al., 2010; Heinz et al., 2011; Soratto et al., 2012). However, investigations are lacking under ICLS conditions, in which animal grazing acts as a catalyzer, modifying and accelerating nutrient flow by ingestion of nutrients through plant biomass, returning 70 to 95 % of these nutrients to the soil as urine and dung (Russelle, 1997). This process is continuous, and its magnitude and direction depend on grazing intensity, which promotes changes in the dynamics of black oat and ryegrass tillers, as described by Kunrath et al. (2015) in the same experiment.

Nutrient transfer from forages to animal, and from them to the soil as excreta, increases with increased stocking rate, but with a lower stocking rate, a higher amount of grass residues remain on the soil surface and there is a lower return from animal excreta because of decreased grazing intensity. Ca and Mg cycling of soybean residues will depend on the grazing effect on soybean growth and development.

Therefore, we expect that there is a kind of compromise within the range of intensive to light or no grazing that would best influence the quantity and quality of plant and animal residue and decomposition kinetics, thereby affecting nutrient availability for the subsequent cash crop. The objective of this study was to evaluate the influence of different grazing intensities on Ca and Mg cycling from pasture and excreta residues during the soybean cropping season in the summer, and from soybean stems and leaves during pasture grazing in the winter in a long-term integrated soybean-beef cattle system under no-till in Southern Brazil.

## MATERIALS AND METHODS

### Experiment characterization and treatments

This experiment was established in May 2001 in the municipality of São Miguel das Missões in the state of Rio Grande do Sul (Brazil) (29° 03′ 10″ S latitude and 53° 50′ 44″ W longitude).

The soil was a clayey *Latossolo Vermelho Distroférrico* (Santos et al., 2013) or a Rhodic Hapludox (Soil Survey Staff, 1999). The climate is subtropical with a warm humid summer (Cfa), according to the Köppen classification. Long-term (30 year) average temperature and annual rainfall are 19 °C and 1,850 mm, respectively (National Institute of Meteorology - Inmet, 2013).

Before establishment of the trial, the area was cultivated under no-tillage for seven years (since 1993) with black oat (*Avena strigosa* L.) during the winter, and soybean (*Glycine max* (L.) Merr.) during the summer. Cattle grazing in the area began in the autumn of 2000 with a black oat + Italian ryegrass (*Lolium multiflorum* L.) mixed pasture, followed by soybean cultivation. In 2001, an integrated production system was initiated with black oat + Italian ryegrass grazing during winter and soybean cropping during summer. Treatments consisted of a gradient of grazing intensity (determined by maintaining pasture sward height at 10, 20, 30, and 40 cm) [G10 - intensive grazing, G20 and G30 - moderate grazing, and G40 - light grazing, plus a no-grazing (NG) control]. Treatments were carried out in a randomized block design with three replicates. Grazing cycles occurred from mid-July to mid-November (average of 110 grazing days). Stocking rates were controlled to maintain the pasture grazing heights through the put-and-take method every two weeks. Continuous grazing cycles began when pasture reached 1,500 kg ha$^{-1}$ of dry matter (DM) (sward height of approximately 25 cm).

Nelore × Angus × Hereford crossbred steers of approximately 10 months of age (at the beginning of the grazing cycle) with initial live weight of 200 ± 13 kg were used. After grazing, the pasture was desiccated with glyphosate and soybean was sown in November/December and harvested in April-May of each year. Soybean cropping followed technical recommendations (Oliveira and Rosa, 2014). After the first grazing cycle, in the autumn of 2001, surface broadcast lime was applied over the whole area at a rate of 4.5 Mg ha$^{-1}$, according to recommendations of the Soil Chemistry and Fertility Commission of the States of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC, 2004). Fertilization consisted of broadcast applications of N on pasture and P and K fertilization in the soybean row, aiming at yields from 4.0 to 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 (CQFS-RS/SC, 2004).

### Evaluation period, sampling, and analyses

Two complete grazing-soybean cropping cycles (2009/11) were evaluated. Each ICLS cycle consisted of winter grazed forage, from May to November, and the summer soybean grain crop, from December to April. Beef cattle stocking rates for this period were 1337, 905, 670, and 356 kg live-weight ha$^{-1}$ for G10, G20, G30, and G40, respectively.

Shoot dry matter (DM) production of grass was evaluated throughout pasture development in five representative areas of 0.25 m$^2$ under exclusion cages. Residual dry matter (RDM) (total aboveground shoot dry matter + litter biomass) was sampled at the end of each grazing and soybean cycle. Pasture RDM was obtained by sampling five representative areas (0.25 m$^2$) per plot. Shoot dry matter was determined after drying the samples at 50 °C until constant weight. To evaluated dung total DM production in each grazing treatment, sampling occurred at the end of August and October each year (2009 and 2010). Ten fresh dung samples were randomly collected in each experimental plot, and the average DM was determined. Total dung DM for each grazing treatment was calculated by multiplying animal dung production (Silva, 2012) by average stocking rates and average dung weights. Soybean leaves and plants (stem and remaining legumes) were sampled at flowering, in ten one-meter rows per plot and oven dried at 50 °C for DM determination. The same procedure was performed for soybean harvest, separately determining stem and legume DM production.

For determination of nutrient release, the litterbag decomposition method as proposed by Apolinário et al. (2014), Assmann et al. (2014), and Rezig et al. (2014) was used. Ten twenty-gram samples of pasture residue, dung, and soybean leaves and stems were put inside 2 mm nylon sieve litterbags (0.20 × 0.20 m size). For both seasons evaluated, litterbags with pasture residue and dung were distributed in the experimental area at soybean seeding (12/17/2009 and 11/27/2010), and 10 litterbags with soybean leaves and stems were distributed at pasture seeding (04/30/2010 and 04/19/2011). Pasture and dung litterbags were collected (average of both sampled cycles) at 16, 31, 50, 63, 96, 126, 162, 193, 219, and 253 days, and litterbags with soybean residues were collected at 23, 37, 53, 73, 105, 134, 162, 190, 222, and 258 days after being placed in the experimental area. After collection, the litterbags were dried and weighed and soil was removed from remaining DM, which was subjected to sulfuric digestion and atomic absorption spectrophotometry according to Tedesco et al. (1995).

### Regression models and statistical analysis

Remaining dry matter (RDM) from plant and animal residues and Ca and Mg release rates were estimated by fitting the observed values to nonlinear regression models according to Wieder and Lang (1982). Regression models were as follows:

$$\text{RDM (Ca, Mg)} = A\ e^{-kat} + (100-A) \qquad \text{Eq. 1}$$

$$\text{RDM (Ca, Mg)} = A\ e^{-kat} + (100-A)\ e^{-kbt} \qquad \text{Eq. 2}$$

in which RDM (Ca, Mg) = remaining DM or remaining nutrient percentage over time (t, in days); *ka* and *kb* = decomposition rate constants for DM or nutrient release from the easily decomposable compartment (*A*) and the recalcitrant compartment (*100-A*).

The two models separated RDM or remaining nutrient amounts into two compartments. In the asymptotic model (Equation 1), only RDM and remaining Ca and Mg from the easily decomposable compartment was transformed, decreasing exponentially with time at a constant rate. The RDM from the second compartment is considered recalcitrant, and therefore, does not transform during the sampling period. In the double exponential model (Equation 2), RDM and nutrients from both compartments decrease exponentially, with the easily decomposable compartment transformed at a higher rate than that of the recalcitrant compartment (more difficult to decompose). Selection of which model to use for each treatment was based on best fit from the coefficient of determination ($R^2$). Half-life time ($t^{1/2}$) was determined from RDM or nutrient release rates when 50 % of the compartment was decomposed or nutrient released based on the following equation, according to Paul and Clark (1996):

$$t^{1/2} = 0.693/k(a,b) \qquad \text{Eq. 3}$$

Using the model fitted to remaining nutrients (Ca and Mg), cumulative release over the entire evaluation period was estimated by multiplying Ca and Mg release percentages from each sampling by initial nutrients present within residues. Results from model adjustment variables were subjected to analysis of variance (Anova), and averages were compared by the Tukey test at 5 % probability. Because we evaluated two years, this source of variation was included in Anova, and no differences ($p>0.05$) between them were observed for either C or N cycling.

## RESULTS AND DISCUSSION

Because no differences were observed ($p>0.05$) between the two years of evaluation, results are presented as average values over the two years. Total plant (pasture and soybean) and animal (dung) residue DM production, as well as lignin content, were presented and discussed by Assmann et al. (2015).

Similar effects of grazing intensity were found in Ca and Mg dynamics and in residue concentrations (Table 1). Grazing intensity had no effect on Ca and Mg concentrations in soybean shoots, pasture, or dung residues. Concentration of Ca was lower and concentration of Mg was higher in pasture residues compared with values reported by Borkert et al. (2003) for black oat in southern Brazil. Nutrient concentrations in pasture species can be highly variable, due to different cultivars (Stratton and Sleper, 1979) and within particular cultivars (Crush, 1983). We used mixed black oat and Italian ryegrass to extend the winter grazing period. Few studies have addressed nutrient cycling in mixed pastures, in which interactions between plant species can affect nutrient concentrations (Whitehead, 2000).

Grazing intensity can modify pasture structure (proportion of leaves, stems, and senescent components) (Aguinaga et al., 2008), which could lead to different pasture Ca and Mg tissue concentrations. However, we did not observe such differences in this study. Differences in nutrient distribution between leaves and stems might explain differences in the relative magnitude of Ca and Mg concentration. Evaluating Ca and Mg contents in grasses, Smith and Rominger (1974) verified higher contents in leaves than in stems. However, in another study, leaves contained greater Ca than Mg, while stems had lower Ca than Mg (Laredo and Minson, 1975). Furthermore, in this study, differences in plant (soybean and pasture) Ca and Mg residue concentrations were moderate since grazing affects soil-exchangeable Ca and Mg contents, with lower contents under NG conditions (Martins et al., 2014; Martins et al., 2016). However, soil Ca and Mg contents were greater than the threshold values considered by the CQFS-RS/SC (2004), and, therefore, not likely limiting to plant nutrition.

Grazing treatments also did not affect dung Ca or Mg concentrations (Table 1). However, Ca concentrations were lower than in other studies. According to Haynes and Williams (1993), dung Ca concentration ranges from 10 to 25 g $kg^{-1}$. Nutrient concentrations in animal residues are variable, as concentration may differ among animals grazing from the same pasture or from the same animal on different grazing days (Betteridge et al., 1986; Groenwold and Keuning, 1988). Concentration of Mg in dung ranged from 4.3 to 4.8 g $kg^{-1}$ (Table 1). Haynes and Williams (1993) stated that Mg in dung should be between 3.0 and 8.0 g $kg^{-1}$, in agreement with previous findings of 4.5 g $kg^{-1}$ and 3.8 to 5.7 g $kg^{-1}$ (Braz et al., 2002). The Ca:Mg ratio of bovine dung observed by these authors ranged from 1.9 to 3.9, whereas in our study, it was 1.3.

**Table 1.** Calcium and magnesium concentrations from pasture, dung, and soybean residues in an integrated soybean-beef cattle system under no-till with varying grazing intensity (i.e. sward height managed by grazing) (São Miguel das Missões, RS, Brazil)

| Pasture sward height | System residue | | | |
|---|---|---|---|---|
| | Pasture | Dung | Soybean stem | Soybean leaf |
| | Ca (g $kg^{-1}$) | | | |
| 10 cm | 4.1 a | 5.2 a | 8.6 a | 30.9 a |
| 20 cm | 5.3 a | 5.4 a | 9.0 a | 31.2 a |
| 30 cm | 5.0 a | 6.3 a | 8.3 a | 29.6 a |
| 40 cm | 5.3 a | 6.2 a | 9.1 a | 29.7 a |
| NG | 4.9 a | NA | 9.9 a | 29.2 a |
| | Mg (g $kg^{-1}$) | | | |
| 10 cm | 3.4 a | 4.8 a | 9.9 a | 8.1 a |
| 20 cm | 2.9 a | 4.3 a | 9.7 a | 7.9 a |
| 30 cm | 3.3 a | 4.4 a | 10.0 a | 6.7 a |
| 40 cm | 3.4 a | 4.8 a | 9.5 a | 5.8 a |
| NG | 3.2 a | NA | 10.0 a | 6.1 a |

NG: no grazing; NA: not applicable. Within a column and response, values followed by the same letter do not differ by the Tukey test ($p<0.05$).

Although grazing treatments did not affect Ca and Mg concentrations of plant and animal residue (Table 1) and total amount (Table 2) were affected, because the amount of decomposable residues was a function of grazing treatments (Assmann et al., 2015). Thus, the Ca and Mg amounts released from pasture residue and dung were different among the grazing intensities. The quantity of Ca and Mg in pasture residue was greatest in the NG treatment, but this value did not differ from the value in G40, and was followed by G30, G20, and G10. Conversely, the quantity of Ca and Mg in dung increased with greater grazing intensity (G10 > G20 > G30 > G40) (Table 2). The amount of Ca and Mg in soybean residues was not affected by grazing intensity; however, the amount of leaf Ca (73.3 kg $ha^{-1}$) was 2.9 times greater than that of stem Ca (25.0 kg $ha^{-1}$) (Table 2). In contrast, the amount of Mg was lower in leaves (16.7 kg $ha^{-1}$) than in stems (27.3 kg $ha^{-1}$) (Table 2).

Total Ca and Mg amounts to be cycled were related to the intensities of grazing treatments (Table 2) and were determined by total pasture production in the grazing period, since there was no effect on soybean plant residues (Assmann et al., 2015), and no had effect on Ca and Mg concentrations in all residues (Table 1). The discussion below regarding cycling of these nutrients will thus focus on the impacts of grazing intensities on DM production of plant and animal residues.

**Table 2.** Total amounts of calcium and magnesium and amounts in compartments to be cycled, and fraction released in 120 days in an integrated soybean-beef cattle system under no-till at different grazing intensities (i.e., sward height managed by grazing) (São Miguel das Missões, RS, Brazil)

| Phase of the integrated system | Compartment | Pasture sward height | | | | No grazing |
|---|---|---|---|---|---|---|
| | | 10 cm | 20 cm | 30 cm | 40 cm | |
| | | | | Ca (kg $ha^{-1}$) | | |
| Livestock | Pasture residue | 4.2 d | 13.2 c | 20.0 b | 29.7 a | 30.2 a |
| | Dung residue | 6.4 a | 4.3 b | 3.9 c | 2.9 d | - |
| | Urine and/or litter[(1)(2)] | 0.1 d | 3.6 b | 3.9 b | 9.2 a | 1.5 c |
| | Cattle beef[(3)] | 6.3 a | 5.7 a | 4.9 b | 2.6 c | - |
| | Total | 17.0 d | 26.8 c | 32.7 b | 42.4 a | 24.2 c |
| | Released in 120 days[(4)] | 8.3 d | 13.4 c | 16.8 b | 21.4 a | 16.0 b |
| Crop | Soybean stems | 24.5 a | 24.9 a | 25.8 a | 23.3 a | 26.7 a |
| | Soybean leaves | 70.6 a | 71.7 a | 72.2 a | 73.7 a | 78.4 a |
| | Total | 95.1 a | 96.6 a | 98.0 a | 97.0 a | 105.1 a |
| | Released in 120 days | 49.4 b | 55.0 b | 54.9 b | 51.4 b | 64.1 a |
| Total | | 112.1 d | 123.4 c | 130.7 ab | 139.4 a | 127.8 b |
| | | | | Mg (kg $ha^{-1}$) | | |
| Livestock | Pasture residue | 3.6 d | 7.1 c | 13.3 b | 19.0 a | 19.7 a |
| | Dung residue | 5.8 a | 3.5 b | 2.7 c | 2.2 d | - |
| | Urine and/or litter[(1)(2)] | 5.0 ab | 4.0 b | 5.6 a | 5.9 a | 1.2 c |
| | Cattle beef[(5)] | 0.2 a | 0.2 a | 0.1 a | 0.1 a | - |
| | Total | 14.6 c | 14.8 c | 21.7 b | 27.2 a | 20.9 b |
| | Released in 120 days[(4)] | 3.7 d | 7.1 c | 10.1 ab | 12.4 a | 9.5 b |
| Crop | Soybean stems | 27.9 a | 26.8 a | 30.9 a | 24.2 a | 26.8 a |
| | Soybean leaves | 18.3 a | 18.1 a | 16.5 a | 14.4 a | 16.3 a |
| | Total | 46.2 a | 44.9 a | 47.4 a | 36.6 a | 43.1 a |
| | Released in 120 days | 24.0 a | 25.1 a | 25.1 a | 20.1 a | 22.0 a |
| Total | | 60.0 b | 59.5 b | 69.0 a | 63.8 ab | 61.7 b |

[(1)] By difference from total minus residues of fresh grass, dung, and removal in cattle beef. [(2)] Litter: senescent grass. [(3)] By considering the export of 1.50 kg of Ca by 100 kg of beef cattle live weight gain [according to McDonald et al. (1995)]. [(4)] By pasture and dung residues. [(5)] By considering the exportation of 0.04 kg of Mg by 100 kg of beef cattle gain live weight [according to McDonald et al. (1995)]. Within a line and response, values followed by the same letter in lines do not differ by the Tukey test ($p<0.05$).

Total amounts for both nutrients were greater at moderate (G30) and light (G40) grazing intensities and lower at more intensive (G10 and G20) grazing intensities compared to the no-grazing treatment (NG) (Table 2). They are related to total pasture growth, which was 4.1, 5.1, 6.5, 8.0, and 6.2 Mg DM $ha^{-1}$ for G10, G20, G30, G40, and NG, respectively. Grazing intensity affects the growth and structural characteristics of both black oat and Italian ryegrass, and can be explained by tillering development dynamics, as described by Aguinaga et al. (2008) and Kunrath et al. (2015). In moderate (G30) and light (G40) grazing intensities, there are adequate conditions for continuous tiller renovation, decreasing their medium age and increasing renewal rates and leaf growth, resulting in higher grass production. Otherwise, according to Kunrath et al. (2015), the tiller populations of both species decrease due to intensive grazing or to overshading and rapidly enter into a reproductive phase under NG.

Total Ca and Mg to be cycled decreased with grazing intensity (Table 2), in spite of the increase in these nutrients in dung, since there was no difference in the content of these nutrients in soybean residues (leaves and stems) among grazing treatments. The total amount of Ca cycled in one beef cattle-soybean cycle is high (from 112.1 to 139.4 kg $ha^{-1}$), with differences among grazing intensities in the livestock phase and no difference in the crop phase (average of 98.4 kg $ha^{-1}$) (Table 2). The same response was observed in Mg (Table 2) but at lower amounts: totals ranging from 59.5 to 69.0 kg $ha^{-1}$, with differences among grazing treatments in the livestock phase and without a difference in the crop phase, with an average of 43.6 kg $ha^{-1}$. The amounts of Ca released by pasture residues in a soybean growing season (120 days) varied, with the lowest and highest values found in G10 and G40, respectively (Table 2). On soybean residues was released on average 55.0 kg $ha^{-1}$ of Ca and 23.3 kg $ha^{-1}$ of Mg for pasture. As the average Ca and Mg exported in soybean grain is low, only 7.0 kg $ha^{-1}$ $yr^{-1}$ under normal rainfall conditions (Martins et al., 2014), the most Ca and Mg taken up returns through the decomposition processes of soybean leaves and stems.

Calcium and Mg budgets were calculated at the end of nine years of the study, resulting in budgets of -393, +241, and -1,361 kg $ha^{-1}$ of Ca and +84, +207, and -223 kg $ha^{-1}$ of Mg for G10, G20, and NG, respectively, with the highest non-productive losses for the NG treatment (approximately 272 and 140 kg $ha^{-1}$ $yr^{-1}$ for Ca and Mg, respectively) (Martins et al., 2014). Thus, although the quantities of Ca and Mg cycled were greater under NG than in G20 and G10 (Table 2), this difference does not necessarily maintain greater quantity in the overall soil-animal-plant system. This probably occurs because the current approach did not consider an important component in understanding nutrient cycling in ICLS: the roots. In this protocol, pasture root production is higher under grazed conditions than in NG areas (Souza et al., 2008). Therefore, root nutrient cycling will be an important theme for further studies, especially under grazed conditions, and roots seem to accelerate the cycling process through a synergism between root growth and partial leaf thinning by grazing (Moraes et al., 2014), resulting in continuous growth and a more dynamic source-sink relationship. Another component, bovine urine, was not directly measured in our study (Table 2). This component is especially important for Mg, which can reach 30 % of total excreta (Safley et al., 1984). According to Haynes and Williams (1993), on average, this proportion is 88 % in dung and 22 % in urine.

Grazing treatments also affected the release kinetics of pasture and dung Ca and Mg (Table 3), measured by residue release rates ($p<0.05$), according to the double exponential model. Thus, nutrients from the labile and recalcitrant fractions decreased exponentially at constant rates (*ka* and *kb*), with the labile fraction (*A*) being transformed at a faster rate than that of the recalcitrant fraction (*100-A*). Grazing intensity did not affect ($p>0.05$) the distribution between labile and recalcitrant fractions for either Ca or Mg [Ca was 39 and 36 % and Mg was 21 and 23 % in the labile and recalcitrant fractions, respectively (Table 3)].

**Table 3.** Parameters of single and double exponential models fitted to calcium and magnesium residue release rates, calculated half-life values ($t^{1/2}$), and correlation coefficient ($R^2$) in an integrated soybean-beef cattle system under no-till with varying grazing intensities (i.e., sward height managed by grazing) (São Miguel das Missões, RS, Brazil)

| Pasture sward height | Compartment A | ka | kb | $t^{1/2}$ | | $R^2$ |
|---|---|---|---|---|---|---|
| | | | | A | (100-A) | |
| | % | —— $day^{-1}$ —— | | ——— day ——— | | |
| | | | Calcium | | | |
| | | | Pasture | | | |
| 10 | 44 a | 0.0320 b | 0.0026 c | 22 | 270 | 0.99 |
| 20 | 41 a | 0.0534 a | 0.0050 a | 13 | 138 | 0.99 |
| 30 | 37 a | 0.0553 a | 0.0043 b | 13 | 161 | 0.99 |
| 40 | 39 a | 0.0388 b | 0.0026 c | 18 | 266 | 0.99 |
| NG | 36 a | 0.0339 b | 0.0021 d | 20 | 326 | 0.99 |
| | | | Dung | | | |
| 10 | 22 a | 0.0768 b | 0.0044 b | 9 | 156 | 0.99 |
| 20 | 20 a | 0.2231 a | 0.0066 a | 3 | 104 | 0.99 |
| 30 | 20 a | 0.2473 a | 0.0064 a | 3 | 108 | 0.99 |
| 40 | 20 a | 0.0741 b | 0.0043 b | 9 | 162 | 0.99 |
| | | | Soybean stem | | | |
| 10 | 58 a | 0.0118 a | | 59 | | 0.99 |
| 20 | 59 a | 0.0119 a | | 58 | | 0.99 |
| 30 | 59 a | 0.0114 a | | 61 | | 0.99 |
| 40 | 61 a | 0.0115 a | | 60 | | 0.99 |
| NG | 58 a | 0.0118 a | | 59 | | 0.99 |
| | | | Soybean leaf | | | |
| 10 | 49 a | 0.0303 a | 0.0018 a | 23 | 385 | 0.99 |
| 20 | 46 a | 0.0312 a | 0.0018 a | 22 | 390 | 0.99 |
| 30 | 46 a | 0.0317 a | 0.0018 a | 22 | 394 | 0.99 |
| 40 | 46 a | 0.0312 a | 0.0017 a | 22 | 411 | 0.99 |
| NG | 47 a | 0.0313 a | 0.0017 a | 22 | 406 | 0.99 |
| | | | Magnesium | | | |
| | | | Pasture | | | |
| 10 | 36 a | 0.0229 c | 0.0016 c | 30 | 446 | 0.99 |
| 20 | 36 a | 0.0442 a | 0.0029 a | 16 | 243 | 0.99 |
| 30 | 36 a | 0.0438 a | 0.0027 a | 16 | 257 | 0.99 |
| 40 | 34 a | 0.0295 b | 0.0022 b | 23 | 312 | 0.99 |
| NG | 36 a | 0.0230 c | 0.0018 c | 30 | 384 | 0.99 |
| | | | Dung | | | |
| 10 | 23 a | 0.0615 b | 0.0029 b | 11 | 237 | 0.99 |
| 20 | 22 a | 0.1237 a | 0.0036 a | 6 | 190 | 0.99 |
| 30 | 22 a | 0.1129 a | 0.0036 a | 6 | 195 | 0.99 |
| 40 | 23 a | 0.0600 b | 0.0029 b | 12 | 238 | 0.99 |
| | | | Soybean stem | | | |
| 10 | 61 a | 0.0107 a | | 65 | | 0.99 |
| 20 | 60 a | 0.0107 a | | 65 | | 0.99 |
| 30 | 61 a | 0.0106 a | | 65 | | 0.99 |
| 40 | 60 a | 0.0107 a | | 65 | | 0.99 |
| NG | 60 a | 0.0107 a | | 65 | | 0.99 |
| | | | Soybean leaf | | | |
| 10 | 58 a | 0.0274 a | 0.0014 a | 25 | 496 | 0.99 |
| 20 | 58 a | 0.0270 a | 0.0014 a | 26 | 483 | 0.99 |
| 30 | 57 a | 0.0260 a | 0.0014 a | 27 | 482 | 0.99 |
| 40 | 58 a | 0.0274 a | 0.0014 a | 25 | 491 | 0.99 |
| NG | 59 a | 0.0253 a | 0.0014 a | 27 | 494 | 0.99 |

NG: no grazing. Within a column and response, values followed by the same letter do not differ by the Tukey test ($p<0.05$).

Moderate grazing intensity (G20 and G30) resulted in greater pasture Ca release rates (Table 3) than for extremes in grazing intensity, for both labile and recalcitrant fractions. The half-life time of Ca in pasture residues was considerably shorter with moderate grazing than at high and low grazing intensities (i.e., approximately 33 % lower in the labile fraction and 50 % lower in the recalcitrant fraction) (Table 3). A similar response was observed for Mg release rates (Table 3).

With different grazing periods of dual-purpose (grain and grazing) wheat, Assmann et al. (2014) observed Ca release rates similar to our study. The stocking rate and grazing period in that study were similar to those under moderate grazing in our research, resulting in a similar half-life time of Ca in the labile fraction of 13-16 days. Under no-grazing conditions, the Ca release rate from the labile fraction was greater in Assmann et al. (2014) than in our study, with a half-life time of 27 days. Agreement between studies is explained by similar soil type, management practices, and weather conditions (long-term no-tillage system under an Oxisol in a subtropical climate), reinforcing the importance of specific soil, weather, and management system interactions and the impact of nutrient cycling on food production. In a tropical long-term (20 year) tilled experiment, Ca and Mg release rates from black oat residues resulted in half-life time values of 33 and 14 days, respectively (Torres et al., 2008).

Moderate grazing intensity also resulted in greater Ca and Mg release rates from dung residues, with half-life time in the labile fraction of 3 and 6 days for Ca and Mg (Table 3), respectively. Average half-life of the recalcitrant fraction was 106 days for Ca, releasing 20 % of this nutrient (Table 3). Under intensive (G10) and light (G40) grazing intensities, average half-life values were 9 and 159 days for the labile and recalcitrant fractions (Table 3), respectively, representing 65 % longer decomposition compared to moderate grazing (G20 and G30). Regarding dung Mg (Table 3), in the labile fraction (22 %), half-life time was 6 days and 192 days for the recalcitrant compartment (78 %) under moderate grazing intensity. For the intensive (G10) and light (G40) grazing intensities, the labile fraction had half-life time of 11 and 12 days, respectively. Highlighting the degradation process in the ruminant digestive system, steers absorb readily available nutrients from the labile fraction of pasture forage, resulting in dung with greater lignified content. This explains the lower quantity of labile Mg in dung compared to that in pasture residues.

Lower pasture and dung residue lignin contents (on average, 9 and 19 %, respectively) (Assmann et al., 2015) help explain the difference between Ca and Mg release kinetics, with faster release and lower half-life time under moderate grazing intensities. Lower pasture lignin content under moderate grazing intensity provides higher quality forage. Aguinaga et al. (2006) reported higher *in vitro* digestibility of organic matter under moderate grazing intensity, resulting in greater dung "quality" and decomposition. According to Semmartin et al. (2004) and Parsons and Congdon (2008), lignin controls decomposition and nutrient release rates in both plant and animal residues. For example, 70 % of Ca in poultry litter (animal residue with high lignin content in the recalcitrant fraction due to wood shavings as bedding) had a half-life of 300 days (Pitta et al., 2012), although the half-life time of Ca in the labile fraction was 13 days.

Grazing intensity did not affect ($p>0.05$) Ca and Mg release rates from soybean leaves and stems (Table 3). Best-fit regressions for these residues were the single-exponential model for stems and the double-exponential model for leaves (Table 3). Soybean leaves had lower lignin content, a lower C:N ratio, and higher N content than stems (Assmann et al., 2015), promoting high microbial activity and degradability.

The release rate of Ca was faster in leaves than in stems (Table 3). The determining feature was the lower half-life time of soybean leaves (22 days) in the labile fraction than in stems (59 days). Based on simultaneous decomposition of both fractions, 60 % of Ca was released from soybean leaves in 119 days (average duration of the grazing season), compared with 45 % from soybean stems. Again, this difference is attributed to lignin content of 11 % in stems compared to 8 % in leaves (Assmann et al., 2015). Among the few studies that have investigated soybean Ca release dynamics, Padovan et al. (2006) observed a half-life of 34 days in soybean plants (leaves + stems) that were harvested at 115 days after emergence. This value is similar to that in our study: an average of 40 days from leaves and stems decomposing simultaneously.

Most Mg of soybean leaves was from the labile fraction (58 %), with a half-life of 26 days; whereas in stems, the proportion in the labile fraction was similar (60 %), but half-life time was higher (65 days) (Table 3). Therefore, during the 120-day grazing period, soybean leaves and stems released 62 and 43 % of Mg available for forage growth. Again, this difference is due to lignin content, which was higher in stems than in leaves (Assmann et al., 2015).

Transition from input-based food-production systems to those that prioritize energy flux and processes leading to a balance of socio-economic and environmental goals is only achievable with an understanding of energy and nutrient fluxes in the soil-plant-animal system. Thus, understanding nutrient cycling and recycling under integrated food-production systems, as conducted in this study, becomes essential for successful transition to a better way. The general lack of information regarding this theme when approaching Ca and Mg highlights the importance of such studies. Relevant nutrient cycling data enable development of future studies to advance our knowledge in an agro-ecological approach. More efficient fertilizer recommendations that synchronize source-sink relationships are expected in such food-production systems. Therefore, the impact of grazing intensity on Ca and Mg release kinetics is an important management consideration to improve ICLS food production systems and maintain equilibrium in Ca and Mg budgets under a soil-plant-animal continuum.

## CONCLUSIONS

Under an integrated soybean-beef cattle system with moderate grazing intensity (20 to 30 cm sward height of black oat+ Italian ryegrass), calcium and magnesium release from plant and animal residues is higher than their release from non-grazed pasture.

Considering only pasture shoot and bovine dung dry matter as pool components of the grazing cycle, amounts of calcium and magnesium released are greater with light grazing intensity (40-cm pasture sward height) and non-grazed pasture.

Release of calcium and magnesium is more rapid from soybean leaves than stems, and cycling amounts are greater than from pasture and dung, though not influenced by grazing intensity.

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