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Decomposition of straw resulting from different strategies of recovery of degraded pastures using an integrated crop-livestock system

Decomposição de palhada resultante de diferentes estratégias de recuperação de pastagens degradadas com integração lavoura-pecuária

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Abstract

Several strategies have been used to improve soil fertility using integrated crop-livestock (ICL) systems, and the harvest of the accompanying crop used for silage may have several benefits to the soil depending on the quantity and quality of the remaining litter, providing dry matter (DM) for no-tillage systems and nutrient mineralization for the subsequent crop. The objective of this study is to evaluate the rate of decomposition of macro- and micronutrients of the DM of litter produced in ICL systems at different harvest heights in one year. The study was developed at the Experimental Farm of UNESP in Selvíria, Mato Grosso do Sul, Brazil, in the dry season. The study included five replications in plots of 200 m^2 and was arranged in a completely randomized block design. The following treatments were analyzed: control sample-degraded pasture of signal grass; Marandu grass-pasture renewal from signal grass to Marandu grass; succession 45-planting of sorghum (forage sorghum cv. Volumax) and crop harvest at the height of 45 cm for silage followed by planting of Marandu grass; simultaneous seeding of Marandu grass and sorghum, and crop harvesting for silage at the height of 15 cm (Marandu + sorghum 15) and 45 cm (Marandu + sorghum 45) from the soil surface. After crop harvesting, proportional amounts of green mass remaining from each unit were collected, transferred to nylon bags, and placed in direct contact with the soil of the respective experimental unit. Each bag was opened every 30 days after closure for up to 270 days. In each bag, the DM, and macro- and micronutrients were analyzed, and the percentage of remaining material, daily decomposition rate, and half-life were calculated. The litter of the Marandu + sorghum 45 treatment contained the highest DM, decomposition rate, and nutrient content. The crop succession provided the best condition of the litter, with the highest DM on the soil surface, which improved soil conditions and made the soil less susceptible to degradation.

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Resumo

Tem sido frequente a adoção de estratégias que visem melhorias na fertilidade do solo em sistemas de integração lavoura-pecuária (ILP) e a altura de colheita para ensilagem da cultura acompanhante, pode direcionar diversos benefícios ao solo pela quantidade e qualidade da liteira remanescente, proporcionando massa seca (MS) para o plantio direto e mineralização de nutrientes para a cultura subsequente. Objetivou-se com esse trabalho estudar a dinâmica de decomposição, ao longo de um ano, da MS, macro e micronutrientes de liteiras oriundas de sistemas de ILP com diferentes alturas de colheita. O experimento foi desenvolvido em campo na Fazenda Experimental da UNESP em Selvíria, MS, na condição de sequeiro. O delineamento adotado foi em blocos completos casualizados, com cinco repetições em parcelas de 200 m^2. Os tratamentos corresponderam a Testemunha - pastagem degradada de capim-decumbens; Marandu - renovação da pastagem de capim-decumbens para capim-marandu; Solteiro 45 - capim-marandu semeado em sucessão ao sorgo (Sorgo forrageiro cv. Volumax) solteiro que foi colhido a 45 cm de altura para silagem e; capim-marandu semeado simultaneamente com o sorgo que foi colhido para silagem a 15 (Simultâneo 15) e 45 cm (Simultâneo 45) de altura em relação à superfície do solo. Após a colheita da cultura foram amostradas quantidades proporcionais de massa verde remanescentes de cada unidade experimental que foram acondicionadas dentro de sacos de nylon depositados em contato direto com o solo da respectiva unidade experimental. A abertura de cada saco ocorreu a cada 30 dias até 270 dias após o fechamento. Para cada abertura foram analisados a MS, macro e micronutrientes e calculado o percentual de material remanescente, taxa de decomposição diária e o tempo de meia vida. O tratamento Sucessão 45 foi o que proporcionou a maior massa de liteira, taxa de decomposição e maiores teores de nutrientes na MS. O tratamento com sucessão de cultura proporcionou as melhores condições da liteira, garantindo as melhores condições com maior massa de liteira sobre a superfície do solo, o que garante melhores condições do solo, se tornando menos propenso a degradação.
Palavras-chave: *Urochloa brizantha* cv Marandu. *Urochloa decumbens* cv. Basilisk. Renovação de pastagens. Mineralização. Perda de liteira.

Introduction

Cattle breeding has improved in the past decades in Brazil by opening new cultivation areas as a result of the migration of livestock from the south and southeast to the midwest and northern regions of Brazil and not by increasing the efficiency of productivity (BRANDÃO et al., 2006). The factors that promoted livestock migration included the increase in the degradation of pastures and the low price of Cerrado lands, which made opening new cultivation areas more feasible than recovering existing areas. However, limited soil fertility combined with poor pasture management in new cultivation areas has led to an expansion of degraded pasture areas. The Cerrado biome occupies an area of 203.6 million ha, corresponding to 22% of the Brazilian territory. At present, 30 million ha of the Cerrado is occupied by grazing areas with an advanced stage of degradation (MACEDO, 2009).

The use of the integrated crop-livestock (ICL) system as a strategy for recovery of pastures becomes a feasible strategy for restoring soil fertility and increasing productivity in degraded areas. The use of pastures and their integration with crops increases livestock productivity and improves the soil, which promotes crop development in subsequent years (BALBINOT JÚNIOR et al., 2009), either by the action of the remaining fertilizer or decomposition of crop residues (litter) deposited in the soil.

Litter is essential for improving the chemical, physical, and biological characteristics of the soil by increasing organic matter (OM) as well as the moisture retention capacity and activity of soil microbiota (KRUTZMANN et al., 2013). The amount of litter available after crop harvesting using the ICL system for silage production can be modified by the harvest height. Despite the decrease in the amount of DM by cutting crops at elevated heights, the benefits obtained by improving silage quality include increased animal production. In this respect, a previous study revealed a 12% increase in milk yield when corn cutting height for silage was increased from 0.15 to 0.45 m from soil level (LAUER, 1998). In contrast, the elevation of the cutting height may cause litter accumulation and consequently increase the OM content and nutrient cycling. Therefore, the objective of this study is to evaluate the dynamics of decomposition of DM in one year, and the cycling of macro- and micronutrients in the litter produced in ICL systems at different harvest heights.

Materials and Methods

Study site and experimental design

The study was carried out at the Teaching, Research, and Extension Farm of the Department of Engineering of Ilha Solteira, at the Júlio de Mesquita Filho State University (Universidade Estadual Paulista “Júlio de Mesquita Filho”-UNESP), located in Selvíria, Mato Grosso do Sul, Brazil, in the dry season in the Cerrado of low altitude (20° 22’S and 51° 22’W, altitude of 335 m). The local soil was classified as Red Yellow Latosol (SANTOS et al., 2013) and was used for animal grazing approximately 25 years ago, without any history of the application of soil correctives and fertilizers. According to Köppen classification, the climate type of the study region is Aw (tropical humid), with a rainy season in summer and a dry season in winter, mean annual temperature of 24.5 °C, and annual cumulative rainfall of 1,232 mm.

In the study period, air temperature data were recorded daily (November 21, 2013, to March 22, 2014) by an automated weather station located in Selvíria. The total precipitation in the study period was 788.9 mm, recorded daily by a rain gauge located near the experimental area. The mean air temperature and relative humidity were 27.3 °C and 76.2%, respectively.

The study included five replications and was arranged in a completely randomized block design. The treatments corresponded to different strategies of renewal of pasture lands of *Urochloa decumbens* cv. Basilisk (signal grass) to *Urochloa brizantha* cv. Marandu (Marandu grass) in the presence or absence of forage sorghum cv. Volumax [*Sorghum bicolor* (L.) Moench] as the accompanying crop. The sampled areas included a degraded pasture of signal grass (control); conventional method of renewal to Marandu grass (Marandu); seeding of Marandu grass after sorghum and crop harvesting for silage at the height of 45 cm from the soil surface (succession 45); simultaneous seeding of Marandu grass and sorghum, and crop harvesting for silage at the height of 15 cm (Marandu + sorghum 15) and 45 cm (Marandu + sorghum 45) from the soil surface, totaling 25 units of 10 x 20 m.

Before the experiments, soil samples were collected at depths of 0 to 20 cm to analyze the chemical attributes of the soil (RAIJ et al., 2001). After sampling, the samples were air-dried, homogenized, and sieved (2 mm) to obtain the air-dried fine earth and evaluate soil fertility, as described by Raij et al. (2001).

The results of the chemical analyses performed before the experiments indicated P-resin and $S\text{-}SO_4$ of 5 and 3 mg dm^{-3}, respectively, OM of 20 g dm^{-3}, pH of 4.5 ($CaCl_2$), levels of K, Ca, Mg, H+Al, Al, SB, and CTC of 1, 4, 6, 36, 19, 11, and 47 $mmol_c$ dm^{-3}, respectively, and base saturation of 23% (V). The level of the micronutrients B, Cu, Fe, Mn, and Zn was 0.19, 2.70, 29.00, 10.80, and 0.10 mg dm^{-3}, respectively. The amount of clay, silt, and total sand was 248, 64, and 689 g kg^{-1}, respectively. Based on the soil analysis and with the objective of increasing V to 60% for sorghum (RIBEIRO et al., 1999), 2.2 t ha^{-1} of dolomitic limestone (PRNT = 80%) were distributed in the study area and were incorporated after each application.

For the treatment of areas in which sorghum was grown (succession 45), sowing occurred in rows spaced at 0.45 m to produce a final yield of 130,000 plants ha^{-1}. The seeds were sown at a depth of 0.04 m concomitantly with fertilization at planting. In the simultaneous cultivation systems, Marandu grass was sown between the sorghum rows, maintaining a distance of 0.22 m between rows, at a depth of 0.04 m, using 7 kg of pure and viable seeds per hectare on November 22, 2013.

Nitrogen fertilization was performed on December 14, 2013, using urea, when the sorghum plants had approximately four expanded leaves, using 100 kg ha^{-1} of N for succession 45, Marandu + sorghum 15, and Marandu + sorghum 45. Sorghum crops were harvested on April 1, 2014, when the grains reached the farinaceous stage. The plants were cut using a single-row forage harvester at the height of 0.15 m or 0.45 m from the soil.

Litter decomposition

After harvesting, proportional amounts of green mass were collected from each experimental unit. The samples were transferred to nylon litter bags (30 x 20 cm) and placed in direct contact with the soil of the respective experimental unit. Each bag was opened at 30, 60, 90, 120, 150, 180, 210, 240, and 270 days after closure to evaluate litter decomposition by measuring the remaining DM inside the bags. For analysis of micro- and macronutrients, the litter composition was analyzed at the start of the experiment and after 270 days, litter was ground to 1 mm and its levels of N, P, K, Ca, S, B, Cu, Mn, and Zn were analyzed. The percentage of remaining litter was calculated using the equation:

% remaining = (final mass/initial mass) x 100

The decomposition rate was calculated using the equation:

Decomposition rate (%) = 100 - % remaining

The first-order exponential equation (MANCILLA-LEYTÓN et al., 2013) was used to calculate the daily decomposition rate k (kg kg^{-1} day^{-1}), and the decomposition constant in the study period divided by the total number of days (270 days) yielded the daily constant:

$$C= C_0 e^{-k t}$$

$$k = - (\ln(C) + C_0) / t$$

where:

C is the final biomass (at the end of 270 days);

C_0 is the initial biomass;

t is the total incubation period (270 days);

k is the decomposition constant

The half-life ($t_{1/2}$) of the litter was calculated according to Rezende et al. (1999) and was considered the period necessary to decompose half of the incubated biomass ($t_{0.5}$ g g^{-1}), according to the equation: $T_{1/2} = \ln(2) / K$.

Statistical analysis

Litter DM mineral content was determined using repeated-measures ANOVA with the Tukey-Kramer test at a significance level of 0.05. The analyzed treatments were three pasture management strategies (succession 45, Marandu + sorghum 15, and Marandu + sorghum 45) and two study periods (baseline and final).

A total of 270 days of incubation in the field was considered for the variables related to litter decomposition. In this case, a randomized complete block design (five treatments with five replicates, totaling 25 experimental units) was used. The means were evaluated in SAS statistical software using Tukey's test at $p<0.05$.

Results and Discussion

There was no significant difference (p=0.54) in the N contents in the litter DM, with a mean of 3.69 g of N per kg of DM (Table 1). The N levels in the litter of treatments Marandu + sorghum 15, Marandu + sorghum 45, and succession 45 were 0.38%, 0.35%, and 0.37%, respectively, which are considered low compared with other forage grasses, including the Tanzania grass (*Megathyrsus maximus* cv Tanzania), for which the mean N values were of 0.96% in grass litter receiving 75 kg of N ha^{-1} $year^{-1}$ (IWAMOTO, 2013). Santos (2014) found that the mean N content in the litter of Mombasa grass (*Megathyrsus maximus* cv Mombaça) managed in full sun with 100 kg of N ha^{-1} $year^{-1}$ was 2.12%.

For most minerals (P, Ca, B, Cu, Mn, and Z), the treatment with the highest N levels in the litter was succession 45 (Table 1), which may be because the planting of sorghum with later planting of Marandu grass increased the availability of nutrients to the plants compared with the sorghum + Marandu strategies.

Table 1. Mineral contents in the litter dry matter according to the treatments at baseline and the end of the study period.

Variables	Unit	Treatments[1] Marandu grass + sorghum 15	Treatments[1] Marandu grass + sorghum 45	Treatments[1] Succession 45	Period Baseline	Period Final	Mean
Nitrogen	$g.kg^{-1}$	3.81	3.51	3.77	3.19 B	4.20 A	3.69
Phosphorus	$g.kg^{-1}$	0.27 b	0.29 b	0.41 a	0.23 B	0.41 A	0.32
Potassium	$g.kg^{-1}$	1.89	1.51	3.06	3.75 A	0.55 B	2.15
Calcium	$g.kg^{-1}$	1.35 b	1.51 b	1.95 a	1.35 B	1.85 A	1.60
Sulfur	$g.kg^{-1}$	1.64 b	2.33 a	1.86 b	0.71 B	3.18 A	1.94
Boron	$mg.kg^{-1}$	23.04 b	30.87 ab	38.90 a	22.93 B	38.93 A	30.93
Copper	$mg.kg^{-1}$	58.40 ab	49.59 b	71.40 a	65.66 A	53.93 B	59.80
Iron	$g.kg^{-1}$	4.07	6.09	3.88	0.91 B	8.45 A	4.68
Manganese	$mg.kg^{-1}$	64.70 b	98.95 a	95.78 a	68.13 B	104.82 A	86.48
Zinc	$mg.kg^{-1}$	340.40 b	225.55 c	388.60 a	390.27 A	246.10 B	318.18

[1]Marandu + sorghum15: simultaneous planting of sorghum and Marandu grass at the height of 15 cm; Marandu + sorghum 45: simultaneous planting of sorghum and Marandu grass at the height of 45 cm; succession 45: planting of sorghum alone and harvest at the height of 45 cm and later planting of Marandu grass.

There was a significant difference (p=0.03) in the litter composition between baseline and the final measurement (Table 2). There was an increase in the content of N, P, Ca, S, B, Fe, and Mn of 24.04%, 43.90%, 27.03%, 77.67%, 41.10%, 89.23%, and 35.00%, respectively, at the end of the study period (Table 1). This result may be related to the type of material in the litter and the decomposition process because the chemical nature of the decomposition material changes over time, especially the amount of carbon and lignin (WEDDERBURN; CARTER, 1999), with an increase in the amount of lignin during litter decomposition, and the consequent decrease in the amount of nutrients returning to the soil (SANTOS, 2014).

Table 2. Level of significance and standard error for nutrient contents in the litter.

Variables	Level of significance		Standard error	
	Treatment	Duration	Treatment	Duration
Nitrogen	0.540[ns]	0.030	0.280	0.347
Phosphorus	0.004	0.001	0.032	0.026
Potassium	0.130[ns]	0.002	0.708	0.507
Calcium	0.001	0.005	0.110	0.123
Sulfur	0.020	0.001	0.188	0.315
Boron	0.132[ns]	0.055	6.910	6.730
Copper	0.070	0.050	8.090	4.910
Iron	0.290[ns]	0.001	1.450	1.150
Manganese	0.060	0.001	13.170	6.830
Zinc	0.001	0.001	9.740	10.080

ns: not significant.

Santos (2014) and Brandt et al. (2007) observed a decrease in the rate of decomposition, which limited the extraction of some nutrients from the litter because of the higher C: N ratio of the material over time. This result is because some nutrients are easily extracted, including K and organic compounds such as carbohydrates, proteins, and peptides, which are quickly released to the soil, increasing the amount of poorly decomposed nutrients in the litter (BERG et al., 1996).

With respect to the rate of decomposition of litter DM over time (Figures 1 and 2), the litter in Marandu grass presented the highest decomposition rate, and more than 70% of the litter was mineralized at the end of the study period. This result is because grass litter has a lower C: N ratio compared to other treatments, which promotes degradation by microorganisms.

Figure 1. Dynamics of loss of litter dry matter over time.

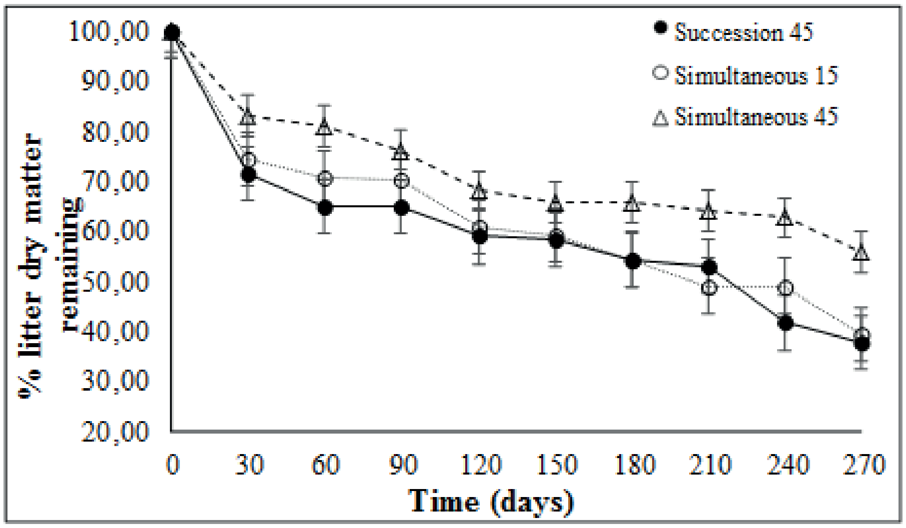
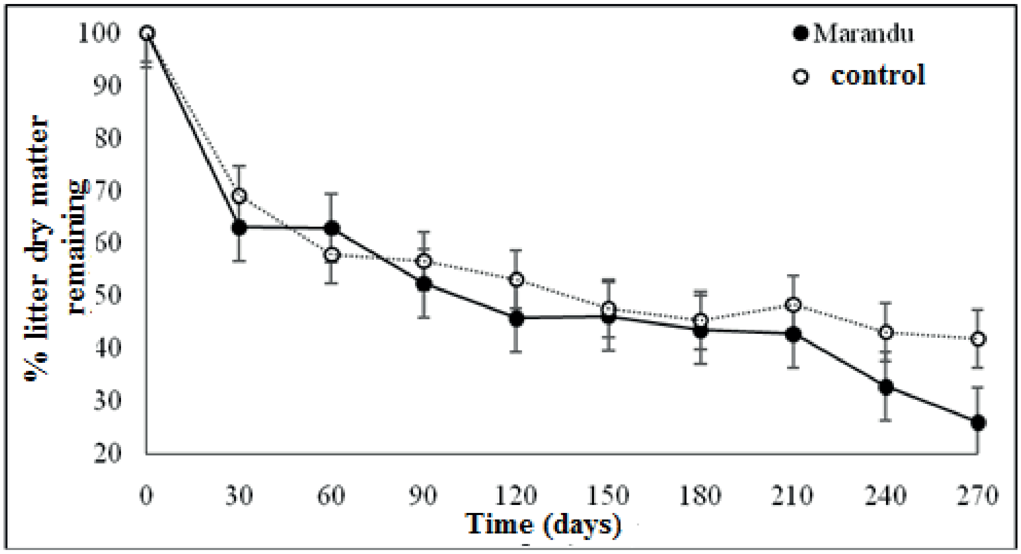


Figure 2. Dynamics of loss of litter dry matter over time.



The period with the highest litter mineralization was the first 30 days of incubation of the material in the soil (Figures 1, 2, 3, and 4), and this period coincided with the rainy season. Increased soil moisture favors an increase in the population of microorganisms, thus providing a higher rate of decomposition of the litter. Litter mineralization occurs by the transformation of the litter to OM because the microorganisms use OM as a source of nutrients for growth, and the water level has a direct effect on decomposition because the soil moisture affects the population dynamics of these microorganisms (SILVA, et al., 2009; LOPES et al., 2009). The higher decomposition rate of litter at baseline (29.48%, 25.64%, 16.70%, 36.70%, and 30.86% for succession 45, Marandu + sorghum 15, Marandu + sorghum 45, Marandu, and control) in up to 30 days may be because this material has a higher content of soluble components, facilitating the action of microorganisms (SILVA et al., 2009).

Figure 3. Loss of litter dry matter over time.

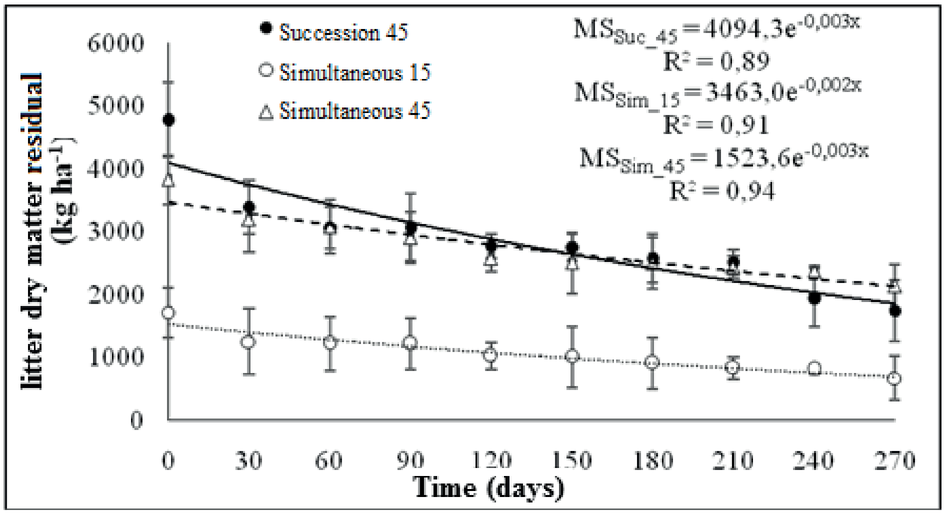
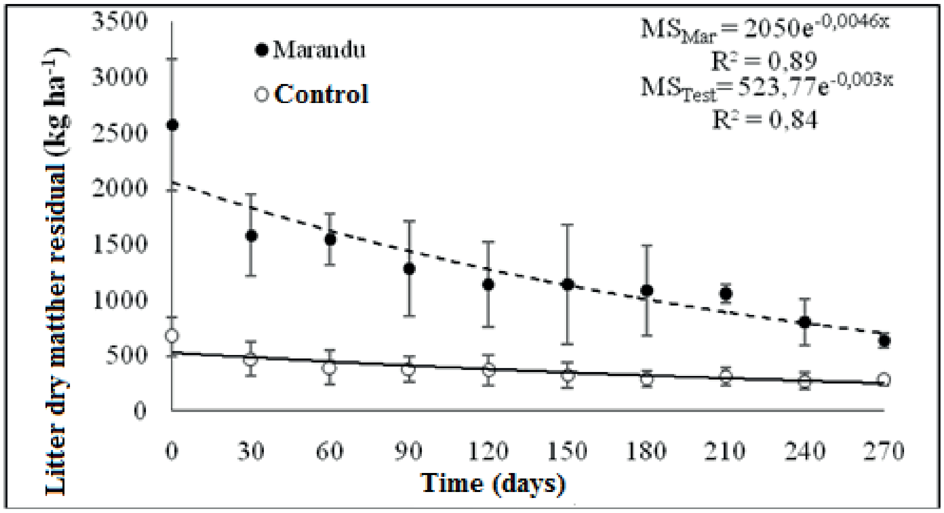


Figure 4. Dynamics of loss of litter dry matter residual over 270 days.



Litter decomposition is affected by the quality of the material (C: N ratio in the litter) and rainfall, which is directly related to the rate of litter deposition. In this respect, Lopes et al. (2009) observed that litter deposition was higher in the transition period between the rainy and dry season. With the shortening of the rainy period, the plants drastically reduce perspiration and increase the senescence of the tissues that contribute to the formation of litter. It is evident that litter decomposition accompanies the climate seasonality, and the rate of decomposition of litter is higher in specific periods of the year, as observed in this study, wherein there was a higher rate of decomposition in the period of higher rainfall because the increase in soil moisture favors an increase in the action of microorganisms, increasing litter degradation. Luizão (1982) found that the rate of decomposition was higher in a tropical climate during the rainy season, with an increase of >196% compared to the dry season.

Other factors that affect litter decomposition are soil temperature and aeration, which are essential for the growth of soil microorganisms. The ICL system may have improved the physical and chemical characteristics of the soil because the root system of both crop systems (sorghum and grass), in addition to the cultivation practices performed in some of the studied areas, may have favored the increased activity of soil microorganisms. Furthermore, microclimatic factors affect several physiological processes of plants, including growth rate, tillering, leaf area index, and senescence rate, and also affect litter production (SILVA et al., 2009).

The litter DM was affected (p=0.001) by the adopted ICL system, and succession 45 presented the highest DM (Tables 3 and 4). The treatments with the highest litter DM were those with the highest decomposition rates, and this may be related to the greater participation of grass DM in the litter because grass under development is easily mineralized compared to the DM of straw from sorghum crops considering that sorghum straw is at the end of the reproductive cycle, when most nutrients are lost to the panicle, in contrast to what is observed in grass.

Table 3. Litter dry matter, remaining litter, and rate of litter decomposition over a 270-day period, litter decomposition coefficient, litter half-life, and litter decomposition period using different pasture management strategies.

Variables	Unit	Treatments[1]				
		Marandu + sorghum		Succession 45	Marandu grass	Control sample
		15	45			
Litter dry matter at baseline	$kg.ha^{-1}$	1716.3 d	3815.7 b	4777.7 a	2573.0 c	666.3 e
Remaining litter	%	39.32 ab	55.98 a	37.72 b	26.01 b	41.83 ab
Decomposition rate	%	60.68 ab	44.02 b	62.28 a	73.98 a	58.17 ab
Decomposition coefficient	$kg.kg^{-1}.day^{-1}$	0.0035 ab	0.0022 b	0.0038 ab	0.0052 a	0.0032 b
Half-life of litter	Days	204.2 b	328.2 a	206.4 b	141.0 c	218.6 ab
Lifespan of litter	Days	408.4 b	656.4 a	413.2 b	282.6 c	437.4 ab

[1]Marandu + sorghum 15: simultaneous planting of sorghum and Marandu grass with harvesting at the height of 15 cm; Marandu + sorghum 45: simultaneous planting of sorghum and Marandu grass with harvesting at the height of 45 cm; succession 45: planting of sorghum, harvesting at the height of 45 cm, followed by planting of Marandu grass; Marandu: conventional method of pasture renewal using Marandu grass; control: degraded pasture of signal grass.

The areas with the lowest rate of litter decomposition (p=0.001) were Marandu + sorghum 45 (44.02%) and control (58.17%) (Table 3). These treatments presented the lowest rate of decomposition and disappearance of litter probably because the litter had a higher carbon/nitrogen ratio and higher lignification.

Table 4. Level of significance and coefficient of variation of litter decomposition over a 270-day period.

Variables	p-value	CV
Litter dry matter	0.001	15.86
Remaining litter	0.001	22.40
Decomposition rate	0.001	15.04
Decomposition coefficient	0.002	25.79
Half-life of litter	0.002	26.80
Lifespan of litter	0.002	26.70

There a significant difference in the half-life of litter between treatments (p=0.002), and Marandu grass litter had the smallest decomposition period (141 days) (Table 3). This result is because litter from grasses has a less lignified material and a lower C: N ratio, which promotes litter degradation by microorganisms.

Conclusion

The results of mineral content and litter decomposition indicate that the pasture areas managed with crop succession (sorghum harvested at the height of 45 cm and later planting of Marandu grass) presented the best pasture conditions, with more litter DM covering the soil surface, which improves the physical attributes of the soil, preventing its degradation, and ensures a higher supply of nutrients to the soil throughout the year.

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