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Nutrient Cycling of Cover Crops in an Amazonian Ecosystem

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Abstract

Cover crops act to improve the chemical and physical quality of the soil and provide sustainability in agricultural systems. Studying the decomposition of these cover crops is key to understand the process of nutrient cycling in cultivation. The purpose of the study was to assess the decomposition and release of nutrients from cover crops in an Amazonian ecosystem. The experiment was conducted in a commercial guarana plantation area at farm Agropecuária Jayoro in Presidente Figueiredo-AM in two agricultural years (2018 and 2019), with a randomized block experimental design following a 4 × 4 factorial scheme, with four cover species (*Arachis pintoi, Brachiaria ruziziensis*, *Canavalia ensiformis* and *Mucuna deeringiana*) and four assessment periods (0, 60, 120, 180 days). The cover crops showed a high rate of decomposition of residues in the two years assessed. The legumes presented high initial nutrient contents. The release of N, P, Ca, and Mg was slower. K showed a rapid release from the decomposition of the residues of the assessed cover crops.

Keywords: decomposition dynamics, half-life, nutrient content

1. Introduction

Cover crops offer excellent ecosystem benefits and have multifunctional uses in different climatic conditions (Blanco-Canqui et al., 2015). When properly managed, cover plant crops can minimize the effects of soil compaction caused by machinery. Improve soil structural and hydraulic properties (Basche et al., 2016; Chalise et al., 2018; Joyce et al., 2002; McVay et al., 2006), reduce soil temperature (Mitchel & Teel, 1977), increase the activities of microorganisms in the soil (Rouifed et al., 2010), recycle nutrients (Snapp et al., 2005). Minimize the negative effect of cultivation by increasing crop yields, and suppress weed populations when they produce sufficient biomass (Büchi et al., 2018; Lowry & Brainard, 2018; Singh et al., 2020).

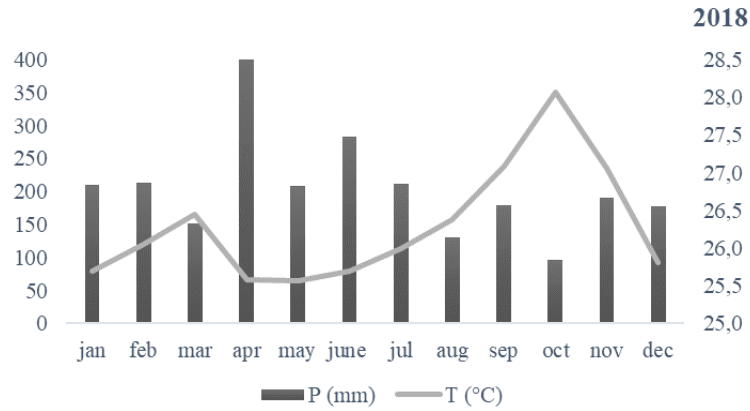
The maintenance of plant residues on the soil and their subsequent decomposition is an important variable in nutrient cycling (Torres et al., 2008). However, depending on the management given to these residues, on the surface or by incorporated them into the soil, when associated with the climatic conditions of the region, will result in different decomposition speeds and nutrient availability.

Among the main species used as cover crops, are grasses and legumes stand out. The grasses provide high phytomass production and legumes have a high potential for fixing atmospheric N. However, other benefits can be attributed to the use of these covers, such as, decreased resistance to root penetration into the soil, due to the pivotal root system of some legumes, and longer periods of straw remaining on the ground, reducing water loss by evaporation and increasing water retention. Besides these benefits, the use of plant covers increases the growth and development of the main crop (Espindola et al., 2006; Ragozo et al., 2006; Perin et al., 2009). In this sense, grasses and legumes can show different behaviors when used as cover, the former tend to show better soil coverage, while the latter tend to show better nutrient cycling (Collier et al., 2018; Pissinati et al., 2018).

Knowledge of the dynamics of decomposition and release of essential nutrients in tropical regions can be useful to adjust the rate of release of nutrients contained in cover plants to the period of greatest nutrient demand of the main crop. In addition, can help farmers to grow these plants intercropped or in succession, in order to protect the soil from erosion and save on synthetic fertilizers. Studies related to the decomposition of cover crops in Amazonian ecosystems are still needed. Therefore, our purpose was the assess the decomposition and release of nutrients from the use of cover crops.

2. Materials and Methods

The experiment was conducted at Agropecuary Jayoro, located in Presidente Figueiredo-AM (Latitude: 01°96′04″ S and Longitude: 60°14′37″ W). The average monthly climate data of temperature and rainfall in this study were extracted from the data set belonging to the Agropecuary from the company's weather station (Figure 1).



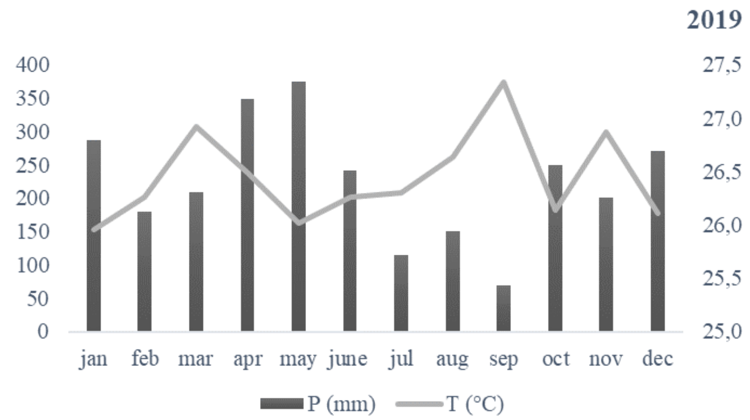


Figure 1. Average rainfall (mm) and average temperature (°C) in the experimental area in the municipality of Presidente Figueiredo (AM), during the conduct of the experiment. Presidente Figueiredo-AM, in 2018 and 2019

The conduct the experiment, a randomized block experimental design was adopted in a 4 × 4 factorial scheme: four cover plant species (*Arachis pintoi, Brachiaria ruziziensis, Canavalia ensiformis* and *Mucuna deeringiana*), and four assessment seasons (0, 60, 120, 180 days), with four repetitions. The experimental units were composed of 15 guarana plants with 5 × 5 spacing; there plants in the central line of the plot were considered useful, totaling 400m^2 of experimental unit.

The cover crops were sown annually at the following densities: *B. ruziziensis*-9 kg ha^{-1}, *C. ensiformis*-135 kg ha^{-1}, *M. deeringiana*-80 kg ha^{-1}. The planting of *B. ruziziensis* was performed by direct sowing in the plot; *C. ensiformis* and *M. deeringiana* were sown 2 cm deep between the rows, with a spacing of 10 cm between each seed, in three rows, with a spacing of 0.50 m between rows. For the sowing of *A. pintoi*, vegetative material (stolons) approximately 30 cm long was used and planted in 10 cm deep pits, at 0.50m spacing between pits and between rows.

To assess the rate of decomposition the method of decomposition bags was used, where after the establishment of the cover crops, in the flowering phase, they were grubbed and the phytomass packed in the litter bags, made of nylon with a 2 mm mesh and dimensions of 0.25 × 0.25 m. The bags were filled with 100 g of fresh plant material from each cover crop. In each plot, 12 bags were distributed, three were collected at 60-day intervals, totaling four collection periods (0; 60; 120; 180 days).

The plant residue samples remaining in the bags, in each collection period, were dried in a forced air oven at 65 °C, until constant weight, prepared for dry matter quantification for analysis of dry matter loss over time and submitted to chemical analysis. For each collection period the nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), contents were determined according to protocols adopted in the Soil Analysis Laboratory in Viçosa, Minas Gerais. N contents were quantified by sulfur digestion, followed by Kjeldahl distillation (Tedesco et al., 1995). P, K, Ca and Mg, were determined according to the procedures described by Bataglia et al. (1983).

The exponential model, described by Thomas & Asakawa (1993), measured the rate of decomposition of plants tissues:

$$X = X_0e^{-kt} \tag{1}$$

where, X is the amount of remaining dry matter (kg/ha^{-1}) existing at time t, in days; X_0 is the potentially decomposable dry matter fraction and k is the tissue decomposition constant (g/g^{-1}/day). In the equation of the constant of decomposition (k) the neperian logarithm (ln) was applied:

$$k = \ln(X/X_0)/t \tag{2}$$

With the obtained value of k the half-life ($T^{½}$) of the remaining dry matter of the cover crops was calculated, that is, the time required for 50% of the dry matter to be decomposed. For this the equation $T^{½} = \ln(2)/k$ was used, where, ln(2) = 0.693 and $T^{½} = 0.693/k$.

For statistical analysis, the Sisvar software (Ferreira, 2011) was used, and the data were submitted to analysis of variance (ANOVA), using the F test at 5% significance level. Comparisons between the factorial and additional treatments were analyzed by the Tukey test at 5% probability level. Significant interactions were submitted to regression analysis, adopting the linear and quadratic models. For selection equation selection, the significance of the F test, the value of the coefficient of determination and the equation with the best fit to the data were considered.

3. Results

The analysis of variance showed significant effects of covers and periods evaluated on the variables nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) in the two experimental years. In the interaction cover crops × periods, only P, K and Ca showed significance in 2018. In 2019 the interaction was significant only for K and Ca (Table 1).

Table 1. Summary of Anova for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) of four cover species, in four evaluation periods, in guaraná plantation Presidente Figueiredo, AM, 2018 and 2019

FV	DF	QM				
		N	P	K	Ca	Mg
			2018			
Cover crops	3	468.7593*	20.7589*	3.1934*	1981.7801*	4.4764*
Evaluation period	3	176.0880*	2.6880*	130.7280*	121.6268*	17.414*
Blocks	3	1.0897^{ns}	0.0964^{ns}	0.5230^{ns}	3.3380^{ns}	0.0993^{ns}
Cover crops × Periods	9	4.7489^{ns}	0.6857*	2.2657*	25.2872*	0.1251^{ns}
Residue	45	3.9987	0.0704	0.3599	3.4164	0.2539
C.V. (%)		7.07	10.62	16.47	12.20	14.49
			2019			
Cover crops	3	166.3855*	4.2026*	8.4700^{ns}	792.0906*	19.1172*
Evaluation period	3	119.0484*	2.1639*	381.2433*	220.3252*	11.0868*
Blocks	3	4.6526^{ns}	0.2493^{ns}	0.4033^{ns}	19.6260^{ns}	0.6168^{ns}
Cover crops × Periods	9	17.7766^{ns}	0.0996^{ns}	7.9077*	27.7363^{ns}	1.6240*
Residue	45	13.8732	0.1426	2.1082	8.1569	0.2147
C.V. (%)		13.20	19.00	26.22	21.99	14.11

Note. *: significant at 5%; ^{ns}: not significant by the F test. C.V.: Coefficient of variation.

3.1 Initial Nutrient Content

As for the initial nutrient contents assessed in the dry matter of cover plants during the two agricultural years, *C. ensiformis* showed high of N, P and K contents and *A. pintoi* high Mg contents in 2018. In 2019 *A. pintoi*, *C. ensiformis* and *M. deeringiana* stood out with high N contents. *B. ruziziensis* showed low contents of the nutrients assessed in both years (Table 2). High Ca contents were observed in *C. ensiformis*, differing from the other cover crops in 2018 and 2019 (Table 2).

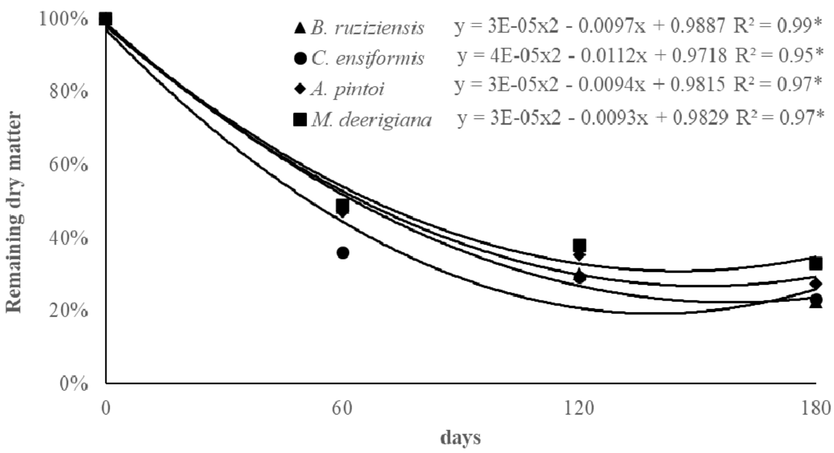
Table 2. Initial nutrient content of N, P, K, and Mg in the phytomass of the aerial part of cover plants in guaraná planting. Presidente Figueiredo, AM, 2018 and 2019

Cover crops	2018				
	N	P	K	Ca	Mg
	g kg^{-1}				
Arachis pintoi	27.17 b	1.97 b	3.75 a	13.75 b	4.65 a
Brachiaria ruziziensis	21.07 c	1.89 b	3.08 b	4.45 d	2.91 c
Canavalia ensiformis	32.01 a	4.20 a	3.77 a	30.76 a	4.07 b
Mucuna deeringiana	32.84 a	1.91 b	3.98 a	11.51 c	3.02 cb
C.V. (%)	7.07	10.62	16.47	12.20	14.49
	2019				
Arachis pintoi	28.46 a	0.17 c	5.00 b	16.41 b	4.90 a
Brachiaria ruziziensis	19.23 b	0.18 cb	5.75 ba	4.95 d	2.53 b
Canavalia ensiformis	28.36 a	0.28 a	4.92 b	20.84 a	2.91 b
Mucuna deeringiana	31.09 a	0.21 b	6.47 a	9.74 c	2.78 b
C.V. (%)	13.20	19.00	26.22	21.99	14.11

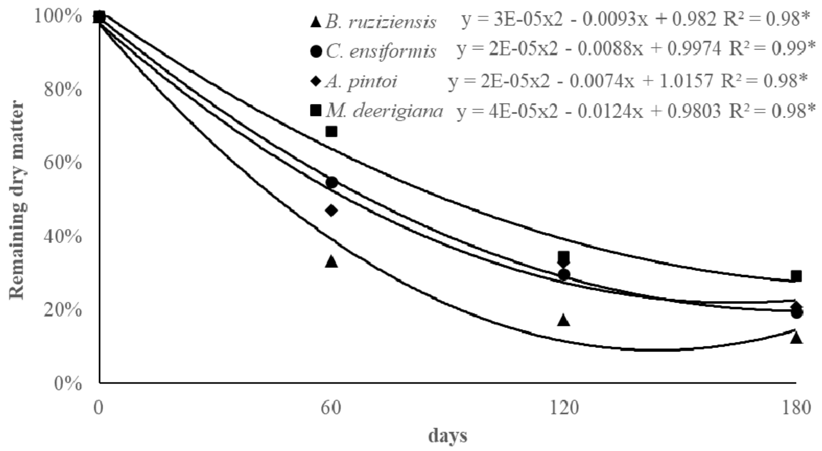
*Note.** Means followed by the same letter in the columns, do not differ by Tukey's test at 5% probability.

3.2 Decomposition Rate and Nutrient Release

The equation parameters for decomposition rates and nutrient release are shown in Table 3. The decomposition rate showed a similar pattern in 2018 and 2019, where dry matter decreased over time, fitting quadratic model (Figure 2). The results for the residue decomposition constants show that *B. ruziziensis* and *C. ensiformis* showed the shortest half-life times ($T^{½}$) in the two Years assessed (Table 3).



(a)



(b)

Figure 2. Remaining dry matter of cover plants in guaraná planting, in the four four assessment in 2018 (a) and 2019 (b). Presidente Figueiredo-AM. *significant ($p < 0.05$)

A. pintoi showed the lowest half-life ($T^{1/2}$) for N in the 2018. The $T^{1/2}$ for N was higher in 2019 in *M. deeringiana* residues (Table 3).

For the remaining P content, regression, the regression analysis was significant for *B. ruziziensis*, *C. ensiformis* and *M. deeringiana* in 2018 (Figure 4a). In 2019, no significant interaction between factors occurred for remaining P content (Table 1).

As for the behavior of remaining K in 2018 and 2019 over the periods, the cover species showed fits of the data to the quadratic function, with marked initial release and subsequent reduction (Figure 3). In 2019, the regression was not significant for *M. deeringiana* (Figure 3b). The $T^{1/2}$ of K was higher in *B. ruziziensis* residues in 2018 and *C. ensiformis* in 2019 and lower in *M. deeringiana* in 2018 and *A. pintoi* in 2019 (Table 3).

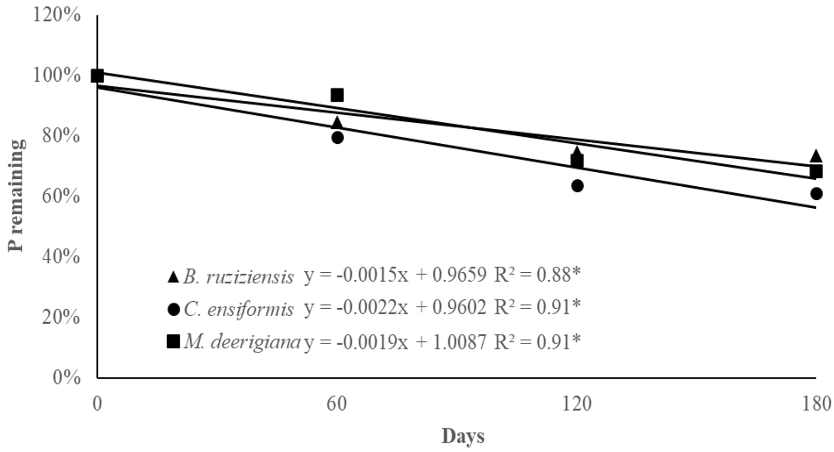
Table 3. Decomposition constant (k) and half-life time ($T^{½}$) relative to decomposition rates and nutrient release of cover plants residues, in guaraná plantation in 2018 and 2019. Presidente Figueiredo-AM

Cover crops	Variable	2018			2019		
		k (g day^{-1})	$T^{½}$ (days)	r^{2*}	k (g day^{-1})	$T^{½}$ (days)	r^{2*}
Arachis pintoi	DM	0.0072	97	0.95	0.0087	79	0.98
	N	0.0018	368	0.99	0.0021	323	0.90
	K	0.0073	93	0.96	0.0128	54	0.99
	Mg	-	-	-	0.0073	95	0.96
Brachiaria ruziziensis	DM	0.0083	84	0.99	0.0115	60	0.98
	N	0.0017	391	0.99	0.0017	419	0.90
	P	0.0017	407	0.88	-	-	-
	K	0.0073	94	0.88	0.0119	58	0.1
	Mg	-	-	-	0.0039	178	0.93
Canavalia ensiformis	DM	0.0081	85	0.95	0.0090	76	0.99
	N	0.0016	430	0.99	0.0019	371	0.90
	P	0.0021	253	091	-	-	-
	K	0.0080	85	0.98	0.0111	62	0.96
	Ca	0.0024	294	0.98	-	-	-
	Mg	-	-	-	0.0032	95	0.86
Mucuna deeringiana	DM	0.0061	113	0.97	0.0068	101	0.98
	N	0.0015	457	0.99	0.0022	320	0.90
	P	0.0021	329	0.91	-	-	-
	K	0.0099	69	0.91	-	-	-
	Ca	0.0045	152	0.89	-	-	-
	Mg	-	-	-	0.0035	197	0.99

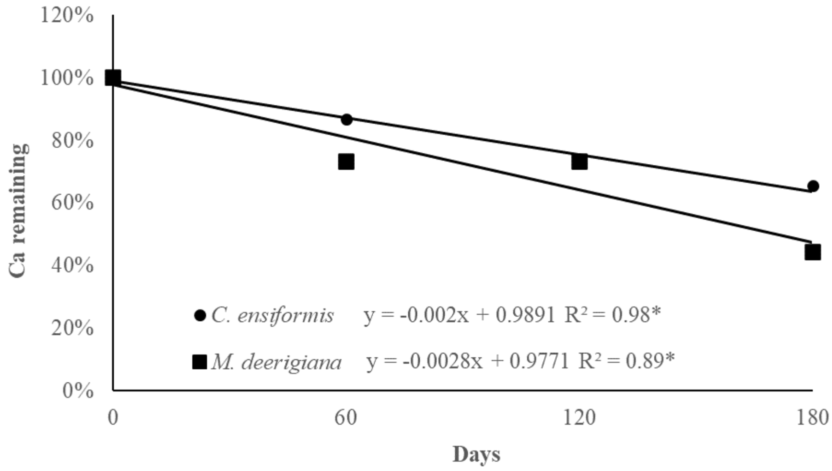
Note. * Significant ($p < 0.05$), k: Decomposition constant, $T^{½}$: Half-life time; r^2: coefficient of determination, DM: Dry matter.

C. ensiformis and *M. deeringiana* showed significant regression, fitting a linear function in relation to the remaining Ca content in 2018 (Figure 4b). At 180 days, the remaining Ca content was 44% for *M. deeringiana* and 65% for *C. ensiformis* (Figure 4b). *M. deeringiana* and *C. ensiformis* showed the highest $T^{½}$ in 2018 (Table 3).

Regarding the remaining Mg content, there was no significant interaction between factors in 2018 (Table 1). In 2019 the data were fitted to a linear model. At 180 days, the remaining Mg content was 27% for *M. deeringiana* (Figure 4c). The lowest $T^{½}$ for Mg was observed in *A. pintoi*, *C. ensiformis*, followed by *B. ruziziensis* and *M. deeringiana* (Table 3).



(a)



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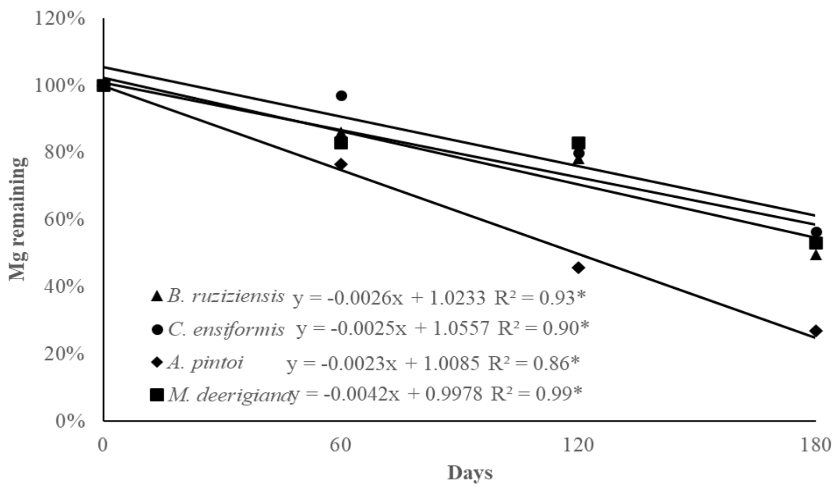

(c)

Figure 4. Remaining P, Ca and Mg content of decomposing cover crops in four assessment periods in 2018 (a) and (b) and 2019 (c). Presidente Figueiredo-AM.* significant ($p < 0.05$)

4. Discussion

4.1 Initial Nutrient Contents

The average initial nutrient contents of the cover plants (Table 2) demonstrate the legumes showed high values of the nutrients evaluated, especially N, when compared to the cover *B. ruziziensis*. According to Roumet et al. (2008), this result may be related to the very nature of the family of legume species that determines, in addition to dry matter production, the fixation and accumulation of N.

The *C. ensiformis* results in relation to P content (Table 2) demonstrate that this species has the potential in the uptake of P from the soil when cultivated as a cover crop in intercropping or succession, where the accumulated nutrient is released from the decomposition. According to Novais et al. (2007), the concentration of P in plants varies from 0.5 to 3.0 g kg^{-1}, and adequate levels for good development are in the range of 1.0 to 1.5 g kg^{-1}.

Horst et al. (2001) studying measures to increase the availability of P to crops through the use of cover crops, among them *C. ensiformes*, concluded that the species can alter the forms of P in the soil, tending towards more soluble forms. The main effect of these changes seems to be related to the recycling of P mobilized in the residue. According to Casali et al. (2011) it is essential to identify plants with greater potential to absorb and cycle P, especially those that can be used as cover crops grown in succession or intercropping in agricultural crops.

Among the legumes, *C. ensiformis* proved efficient in cycling nutrients when high levels of N, P, K and Ca were observed in the dry matter of this cover crop (Table 3). Saminêz et al. (2006), aiming to assess the capacity of extraction of nutrients from the soil by the bean pig (*C. ensiformis*) under organic production system in the summer conditions of the cerrados (savanas), in Brasilia, observed high levels of N, K and Ca. According to Pandovam et al. (2011) these results reinforce the great potential of the bean pig to recycle nutrients and serve as a subsidy for planning the management of plant phytomass, aiming for efficient use for subsequent crops. The high capacity of these covers to accumulate K makes them a good alternative for increasing this element in a system in which species demanding P are cultivated (Oliveira et al., 2007).

As for Mg content, *A. pintoi* showed the highest values. Azevedo (2010), evaluating forage peanut genotypes (*Arachis pintoi*) reports average Mg contents in the phytomass ranging from 4.42 and 9.17 g kg^{-1}. In general, the legume species showed the highest levels of macronutrients evaluated (Table 3) in relation to *B. ruzizienses* (Gramineae). These results are important, since it is expected that the cover plants produce high amounts of dry matter and to cycle nutrients in large quantities.

4.2 Decomposition Rate and Nutrient Release

In 2018 and 2019 the cover plants showed high dry matter losses (Figure 2). These high values at 60 days can be justified by the high rainfall that occurred in the months of May and June, a rainy period in the Amazon region (Figure 1). Studies have proven the influence of rainfall on the speed of decomposition of residues, where it is highlighted that the decomposition increases with increased rainfall and decreases in the dry period of the year (Torres et al., 2008; Boer et al., 2008; Leite et al., 2010; Pacheco et al., 2011).

On average the legumes had 50% of dry matter decomposed in 98 days in 2018 and at 85 days in 2019 (Table 3). The quality of the organic residue presents itself as one of the regulating factors of the decomposition constant and half-life time. Probably, the legume species present in their mineral composition higher amounts of N, when compared to other species studied (Ramos et al., 2018). In agreement with the author, the legume species studied showed high initial nitrogen contents in both experimental years (Table 2).

B. ruzizienses showed $T^{½}$ lower than the other cover crops assessed in both years, with a high rate of decomposition rate (Table 3). Compared to the other covers, in this species the leaves predominate, which is related to the low lignin content in the material and consequent faster decomposition (Carvalho et al., 2008). Cavalli et al. (2018) studying the decomposition and release of nutrients from crop residues, found that brachiaria showed the highest decomposition rate (85%) compared to the other species evaluated.

When compared to the other legume species the $T^{½}$ of *C. ensiformis* averaged 80 days in the years studied (Table 3). Ramos et al. (2018) verifying the decomposition dynamics and half-life time in different green manure species observed that *Canavalia ensiformis* showed similar half-life time.

According to Torres et al. (2008), it is important to consider when evaluating the decomposition of cover plants, the decomposition of cover plants, the composition of the material and the amount of woody material that will be placed in the bag, this can influence the half-life time of the cover and the nutrient content. Usually, legumes have a larger amount of stem biomass than grasses. Normally, decomposition is controlled by the C/N ratio and the lignin content, as well as by management, which will define the size of the fragments, together with the action of the climate, especially air temperature and precipitation.

As for the release of nutrients from the decomposition of the cover crops, N showed the highest $T^{½}$ for all cover species evaluated (Table 3). According to Calonego et al. (2012), the decomposition process of residues and the release of nitrogen occurs in two phases, the first with the rapid decomposition of structural components of the plant, which easily decompose, and has low C:N ratio; and the second phase is the slow decomposition of more resistant materials, which have higher C:N ratio.

The results report a slow release of P over time. This is related to the high $T^{½}$ values of P. Most of the P in the plant is associated with plant organic components and its release is closely linked to the decomposition process by soil microorganisms (Marschener, 1995). These results demonstrate the need for direct contact of the residues of the cover crops with the soil so that there is a rapid mineralization of these nutrients by the microorganisms.

In all the cover species evaluated, K presented a rapid release in the first 60 days after deposition of the bags (Figure 3). According to Marschner (1995), the speed of release of nutrients from cultural residues during the decomposition process depends on the location and form in which these nutrients are found in the plant tissue.

Other authors also report the ease with which the element K is released during its decomposition (Oliveira et al., 2008; Oliveira, 2010; Teixeira et al., 2011). For Gama Rodrigues (2002) and Costa et al. (2005), these results may be related to the way K is compartmentalized in the plant, since it is not a structural component of any plant compound and mineralization is not a prerequisite for its release.

Ca also showed high values related to $T^{½}$ (Table 3). According to Vitti et al. (2006) these results can be explained by the fact that this element is found in soluble forms in the plant tissue, mainly as part of the medium lamella of the cell wall, which influences its slow release.

$T^{½}$ for Mg (Table 3) coincides with the rapid release of this nutrient from the decomposition of the cover crops (Figure 4c). The participation of Mg in ionic compounds and soluble molecules causes it to be released quickly after the management of the cover crops. However, a portion of it (30%) is a constituent of plant structural compounds, with gradual release during biological decomposition by microorganisms (Crusciol, 2008).

When studying the rate of decomposition and release of nutrients, Gama-Rodrigues et al. (2007) found that the rates of Mg release were higher in bean pig (*C. ensiformis*) compared to forage peanut (*A.s Pintoi*).

Studies related to the decomposition and release of nutrients from cover crops are still insipient in the Amazon region. Understanding these processes is important for agricultural sustainability.

5. Conclusion

The cover crops showed a high rate of decomposition of residues in the two years assessed. The legumes plants (*Arachis pintoi*, *Canavalia ensiformes* and *Mucuna deeringiana*) showed high initial contents of nutrients evaluated and longe half life for decomposition of residues. The release of N, P, Ca and Mg was slower from the decomposition of the residues. K showed a rapid release from the decomposition of the residues of the evaluated cover crops.

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