Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 30 January 2025
https://doi.org/10.14295/CS.v16.4297

Decomposition and nutrient release from shoot of legumes cover crops

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Abstract

The cover crops can reduce soil exposure and erosion while enhancing nutrient cycling for crops. Effective implementation requires understanding how cover crops decompose and release nutrients to align with crop demand. This research assessed the decomposition rates and nutrient release of various legume residues commonly used as green manure or cover crops in agricultural systems. The study took place in a nutrient-deficient Red-Yellow Ultisol, using a split-plot design with different legume cover crop species: *Crotalaria juncea, Crotalaria spectabilis, Cajanus cajan, Cajanus cajan (L.) Millsp), Dolichos lablab, Canavalia ensiformis and Mucuna aterrima* as the main plots and six evaluation periods: 0, 30, 60, 90, 120, and 150 days after incorporation (DAI) as the subplots. Initial mass losses were observed in the first 60 days, followed by a slower decline over the study period. The order of nutrient accumulation in biomass was found to be: K > N > P > Ca > Mg. The *Dolichos lablab* species had the slowest decomposition rate, with a half-life of 43 days, while *Cajanus cajan* had the fastest, with a half-life of 65 days. Potassium reached its maximum by 30 DAI, indicating a rapid transfer to the soil. Nitrogen, P, and K contents decreased during different vegetative phases, highlighting the importance of proper timing for legume management. Hemp, *Crotalaria spectabilis*, *Dolichos lablab*, and *Canavalia ensiformis* were suitable for short-cycle vegetables due to rapid nutrient availability. Conversely, *Cajanus* spp., and *Mucuna aterrima* were better for extended soil coverage and slow nutrient release.

Keywords: green manure, mass loss kinetics, nutrient cycling, soil fertility

Introduction

Cover crops constitute a pivotal element in bolstering the sustainability of agricultural systems, exerting profound impacts on nutrient cycling and soil quality, while also being esteemed for their resilience and minimal demand on soil fertility (Kliemann et al., 2006). Notably, their fast growth rates facilitate substantial biomass accumulation within short timeframes (Weiler et al., 2019). Integrating these species as cover crops alongside primary crops, presents a promising avenue to enhance carbon (C) and nitrogen (N) contents in the soil. The cultivation of cover crops assumes a pivotal role in safeguarding soil integrity against erosive processes (Kliemann et al., 2006; Poffenbarger et al., 2015), thereby mitigating surface run-off and enhancing water infiltration (Weiler et al., 2019).

Understanding the dynamics of decomposition and nutrient release stands as a critical determinant in cover crop selection, enabling efficient planning and optimal technological utilization (Drost et al., 2020; Xavier et al., 2017). By comprehending the intricate processes governing decomposition, including the quality of the organic substrate, nutrient composition, climatic parameters, and microbial interactions, researchers can better select agricultural practices for enhanced sustainability and yield (Cobo et al., 2002).

In the Brazilian agricultural research landscape, there exists a dedicated initiative to scrutinize the decomposition kinetics and nutrient fluxes inherent to a range of cover crop species, including *Crotalaria juncea* (Sunn hemp), *Crotalaria spectabilis* (Spectabilis), *Cajanus cajan* (Pigeon arbore), *Cajanus cajan* (L.) Millsp) (Pigeon forage), *Dolichos lablab* (Lab Lab), *Canavalia ensiformis* (Jack bean), and *Mucuna aterrima* (Mucuna), within heterogeneous agricultural terrains (Xavier et al., 2017). This focus emphasizes the imperative for

Received: 26 May 2024
Accepted: 09 July 2024

tailored investigations into the degradation mechanisms and consequent nutrient liberation across varied agroecosystems. The breakdown of plant residues assumes paramount importance in orchestrating nutrient cycling dynamics and regulating energy fluxes within ecosystems (Palosuo et al., 2021). The speed at which the large volume of plant residue mass is reduced is carefully influenced by abiotic and biotic factors (Kooch et al., 2019), illustrating the interaction that governs the decomposition processes essential for nutrient cycling, dynamics of ecosystems and how we can manage them sustainably.

This study aims to investigate the decomposition patterns and nutrient release dynamics of leguminous cover crops, contributing to the existing body of knowledge on sustainable agricultural practices. By elucidating the intricate relationships between cover crop residues, soil microbial communities, and nutrient availability, this research seeks to provide valuable insights for optimizing cover crop management strategies in tropical agricultural systems. Through a comprehensive understanding of decomposition processes, farmers can make informed decisions regarding cover crop selection and cultivation practices, thereby promoting soil health, enhancing nutrient cycling, and ensuring the long-term sustainability of agricultural ecosystems.

Materials and Methods

Site Description

The study was conducted in an area located at the experimental station of the Federal University of Alagoas, Campus Arapiraca (9°41'57"S, 36°41'10"W, 321 m a.s.l.). According to the classification of Köppen, the climate of the region is a tropical 'As' with winter rains (April-August) and summer drought (September-March) with average annual rainfall of 854 mm (Xavier & Dornellas, 2010); minimum and maximum temperature of 21.4 and 28.3 °C, respectively. Rainfall and air temperature during the experimental period are presented in the **Figure 1**.

The local soil is classified as dystrophic Red-Yellow Ultisol (Soil Survey Staff, 2014). The soil samples from 0-20 cm layer were collected for chemical and texture analysis (**Table 1**).

Experimental design and treatment

The experiment was arranged in a randomized block design with four replications, in split-plot scheme. The plot was composed by seven legumes cover crops: *Crotalaria juncea* (Sunn hemp), *Crotalaria spectabilis* (Spectabilis), *Cajanus cajan* (Pigeon arbore), *Cajanus cajan* (L.) Millsp) (Pigeon forage), *Dolichos lablab* (Lab Lab), *Canavalia ensiformis* (Jack bean) and *Mucuna aterrima* (Mucuna) and subplot consisted of six evaluation time: 0, 30, 60, 90, 120 and 150 days after residue incorporation.

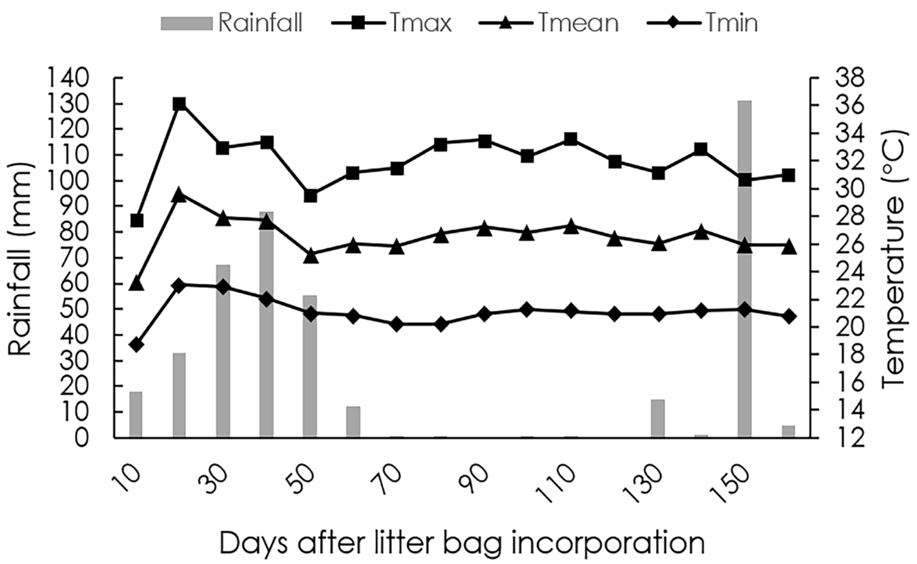

Figure 1. Rainfall and maximum (Tmax), mean (Tmean) and minimum (Tmin) air temperature every ten days during the experimental period

Table 1. Chemical properties and textural fraction in the layer 0-20 cm of the soil in the experimental area

pH	OM	P	K	Ca	Mg	Al	H+Al	Sand	Silt	Clay
H_2O	g dm^{-3}	mg dm^{-3}	--------------cmol$_c$ dm^{-3}--------------					--------g kg^{-1}--------		
5.7	15.0	13.0	0.2	1.4	1.4	0.2	4.0	720	124	156

OM = organic matter (Potassium dichromate); P e K (Mehlich-1); Ca, Mg and Al (KCl); H+Al (Calcium acetate); Sand, silt and clay (Densimeter method) (Teixeira et al., 2017).

Cover crop decomposition and release of nutrients

The shoots of summer cover crop were collected at flowering, dried in a forced-air oven (60 °C), and chopped into pieces of approximately 5 cm. Shoots were placed into litter bags with dimensions of 0.2 × 0.2 m. The amount of dry matter added to the litter bags was 20 g, obeyed the leaf-stem proportion of each species. In each plot, 12 litter bags were randomly distributed (two for each time of evaluation). The litter bags were buried at a 0.20 m depth, simulating incorporation (Weiler et al., 2019).

The percentage of dry mass and remaining nutrients was calculated using the equation:

$$XR(\%) = \frac{Mx}{M_0} \times 100$$

Where: XR is the mass or nutrient remaining, M_x the mass or nutrient at each sampling time and M_0 the initial mass or nutrient content. The decomposition constants were obtained using a first-order exponential decay (Wider & Lang 1982):

$$Y = X_0\, e^{-KT}$$

Where: Y is the dry mass or nutrient remaining at time *t*, X_0 is the initial dry mass or nutrient and the *k*, the decomposition or nutrient release constant.

The half-life ($t_{1/2}$), which expresses the number of days required to decompose half of the initial dry mass or nutrient release was obtained from *k* values from the mathematical model:

$$t_{1/2} = \frac{\ln(2)}{k}$$

The determination of nutrients concentration in plant residue followed the procedure described by Malavolta et al. (1997), in which N was determined by sulfuric digestion followed by distillation and titration by the Kjeldahl method; phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) were determined after digestion in a nitric-perchloric acid solution (5:1). Calcium and Mg concentrations were determined by atomic absorption spectrophotometry, K by flame emission photometry, and P by colorimetric phosphovanadomolybdate method.

Statistical analysis

The cover crop biomass and nutrient release were analyzed by fitting observed data to a single component: negative exponential decay model. Parameter estimates X_0, k and coefficients of determination (R^2), for decay models were generated during the fitting process in the software SigmaPlot.

Results and Discussion

It was observed significant mass losses during the initial phase, notably within the first 60 days, followed by a gradual decline over the observation period (**Figure 2**). In conventional cropping systems, characterized by conditions unfavorable to quality decomposition, major losses primarily stemmed from easily decomposable compounds immediately after biomass incorporation into the soil.This fast early-stage mass loss aligns consistently with existing literature and is typically attributed to the breakdown of soluble carbohydrates and nutrients (Thapa et al., 2022). Processes driving this phenomenon include photo-oxidation, microbial activity, and fragmentation by macro and mesofauna, as well as rainfall events during this period.

The legume species exhibited distinct characteristics for dry mass, with *Canavalia ensiformis* demonstrating X_0 of 89.46%, k of 0.0151 g g^{-1}, and $t_{1/2}$ of 46 days, indicating a moderate decomposition rate (Table 2). With a relatively low percentage remaining at 150 days (9.3%), it is suggested a swift decomposition of *Canavalia ensiformis* shoot, likely facilitating efficient nutrient release into the soil (Barros et al., 2020). *Dolichos lablab* species, with X_0 of 91.73%, k of 0.0161 g g^{-1}, and $t_{1/2}$ of 43 days, demonstrated a slightly higher decomposition rate compared to *Canavalia ensiformis*, with a lower percentage remaining - RM_{150} (8.2%) (**Table 2**), suggesting faster decomposition and potentially more effective nutrient release (Perin et al., 2010).

Mucuna aterrima and *Cajanus cajan* exhibited longer half-lives (Table 2), indicating slower decomposition rates for their shoot biomass. Despite this, both species demonstrated high coefficients of determination (0.91*** and 0.94***, respectively; Table 2), suggesting a strong correlation between initial mass (X_0) and remaining mass after 150 days (RM_{150}).

Crotalaria spectabilis and *Crotalaria juncea* showed similar decomposition rates and percentages of remaining mass (8 to 11%) at 150 days, indicating moderate to fast decomposition (Singh et al., 2020). The slower mass loss phase over time is likely due to the proportional increase of recalcitrant compounds such as lignin and polyphenols, which tend to reduce decomposition rates (Moreira & Siqueira 2006). These findings suggest that *Mucuna aterrima* and *Cajanus* spp. are suitable for semi-arid conditions, as they produce high dry mass and have longer half-lives, thus providing substantial amounts of senescent material for soil protection (Freitas et al., 2019; Xavier et al., 2017).

Significant differences in nutrient release during the decomposition of legume aerial residues were observed (P = 0.05). *Canavalia ensiformis* exhibited moderate decomposition, fast N into the soil, with N release values of 43.6, 63.7, 76.6, 85 and 90,3 % at 30, 60,

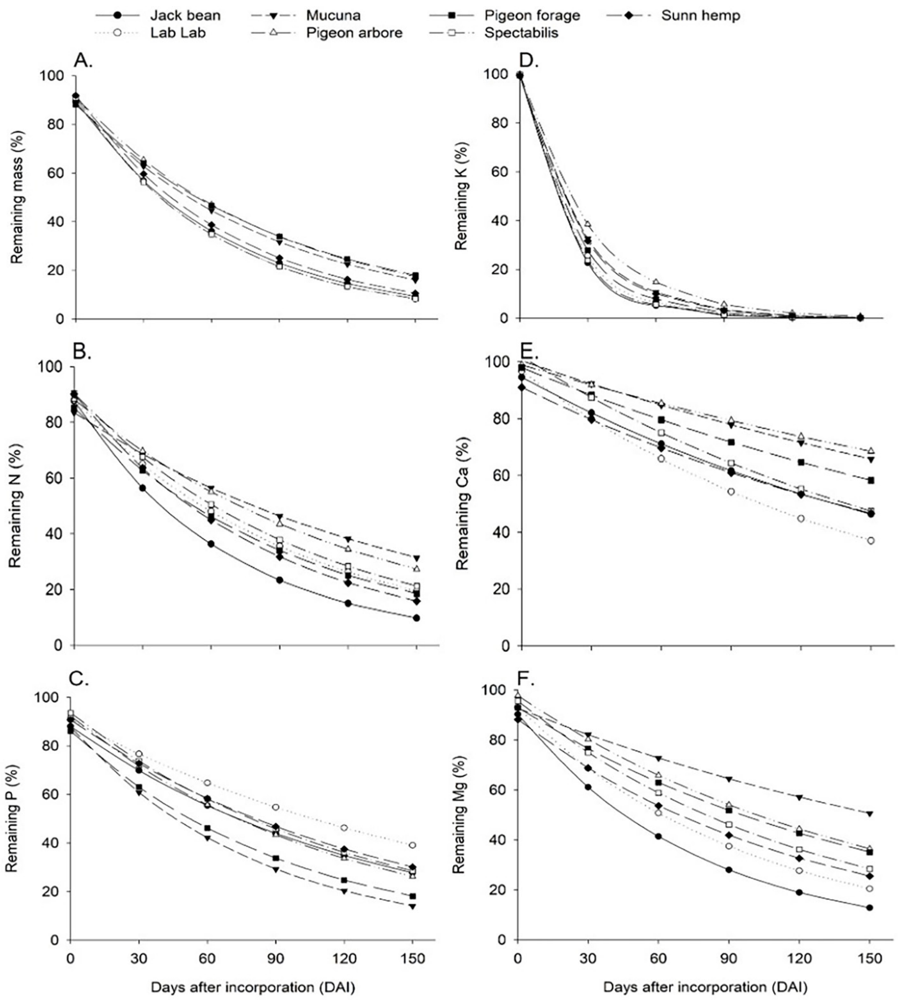

Figure 2. Dry mass and nutrient remaining during the decomposition of aboveground part residues of legumes cover crop

Table 2. Model parameters fit to the measured values of remaining dry mass, nutrient, half-life, and R^2 in each treatment

Species	X_0(%)	k(g g^{-1})	$t_{1/2}$ (day)	R^2	RM_{150}%	X(%)	k(g g^{-1})	$t_{1/2}$ (day)	R^2	RM_{150}%
			Dry mass					Nitrogen		
Canavalia ensiformis	89,46	0.0151	46	0.88	9,3	87,72	0.0147	47	0.84	9,7
Dolichos lablab	91,73	0.0161	43	0.90	8,2	88,08	0.0101	69	0.91	19,1
Mucuna aterrima	88,37	0.0114	61	0.91	16,0	83,51	0.0065	106	0.87	31,5
Cajanus cajan	91,08	0.0110	63	0.94	17,5	88,29	0.0078	88	0.94	27,4
Cajanus cajan (L.) (Millsp)	88,15	0.0106	65	0.91	18,0	85,26	0.0102	68	0.88	19,1
Crotalaria spectabilis	90,89	0.0160	44	0.89	8,2	90,38	0.0097	72	0.92	21,1
Crotalaria juncea	91,83	0.0144	48	0.93	10,6	90,12	0.0116	60	0.91	15,8
			Phosphorus					Potassium		
Canavalia ensiformis	88,03	0.0077	90	0.93	27,7	99,80	0.0494	14	0.97	0
Dolichos lablab	90,76	0.0056	123	0.90	39,2	99,73	0.0453	15	0.99	0
Mucuna aterrima	87,71	0.0122	57	0.87	14,1	99,08	0.0370	19	0.96	0
Cajanus cajan	92,28	0.0084	82	0.93	26,2	100,0	0.0318	22	0.91	0
Cajanus cajan (L.) (Millsp)	86,14	0.0104	67	0.87	18,1	99,42	0.0423	16	0.98	0
Crotalaria spectabilis	93,60	0.0079	87	0.92	28,6	99,88	0.0479	14	0.98	0
Crotalaria juncea	90,69	0.0074	94	0.93	29,9	99,45	0.0381	18	0.98	0
			Calcium					Magnesium		
Canavalia ensiformis	94,60	0.0048	146	0.96	46,0	90,25	0.0130	53	0.88	12,8
Dolichos lablab	99,72	0.0064	108	0.96	38,2	92,95	0.0101	69	0.92	20,4
Mucuna aterrima	100,4	0.0028	246	0.98	66,0	92,66	0.0040	172	0.96	50,9
Cajanus cajan	98,91	0.0025	283	0.96	68,0	97,70	0.0066	105	0.93	36,3
Cajanus cajan (L.) (Millsp)	97,96	0.0035	200	0.97	57,9	92,99	0.0065	107	0.93	35,1
Crotalaria spectabilis	101,9	0.0051	136	0.92	47,4	95,59	0.0081	86	0.86	28,4
Crotalaria juncea	91,03	0.0045	156	0.95	46,3	88,17	0.0083	84	0.93	25,4

X_0 (%) Initial mass; k (g g^{-1}) decomposition rate; $t_{1/2}$ (day) half-life time; R^2 coefficient of determination and RM_{150} = percentage of mass or nutrient remaining at 150 days after litter bags incorporation.

90, 120 and 150 DAI, respectively. *Mucuna aterrima*, with the lowest initial mass (83.51%) and a lower decay rate constant (0.0065), showed slower decomposition due to its more resistant chemical composition, resulting in long-term N release. The N release values for *Mucuna aterrima* were 31.3, 43,5, 53,5, 61,7 and 68,5% at 30, 60, 90, 120 and 150 DAI, respectively. *Dolichos lablab*, despite its slower decomposition, potentially releases N more consistently over time, with N release values of 34,9, 51,9, 64,5, 73,8 and 80,6% at 30, 60, 90, 120 and 150 DAI, respectively. *Cajanus cajan* and *Crotalaria spectabilis* demonstrated moderate to fast decomposition with significant N release (Castellano-Hinojosa et al., 2021). The high N remnants from these legumes can aid in biological fixation, which is crucial for soil conditioner management strategies (Mendonça et al., 2017). Faster decomposing legumes like *Canavalia ensiformis* and *Dolichos lablab* can quickly release N into the soil, benefiting subsequent crops, while slower decomposers like *Mucuna aterrima* provide a steadier N supply over time (Mendonça et al., 2017; Paulino et al., 2009). These differences in legume decomposition directly impact N availability to cultivated plants, influencing agricultural system productivity and sustainability (Liebman et al., 2018). The introduction of legumes in green manure crops is particularly important in initially N-poor tropical soils (Schiavinatti et al., 2011; Teodoro et al., 2011).

The phosphorus (P) release showed behavior opposite to the decomposition of the residues. *Dolichos lablab* exhibited greater mass loss kinetics, but had relatively lower P release, suggesting a faster decomposition rate but less consistent P release over time. The opposite occurred for Mucuna aterrima.

Dolichos lablab exhibited slower rate (0,0056 g g^{-1}) and $t_{1/2}$ of 123 days (Table 2), but showed potential for P release over time with P release values: 23,3, 35,1, 45,2, 53,7 and 60,8% at 30, 60, 90, 120 and 150 DAI, respectively. On the other hand, Mucuna aterrima presented the highest rate (0.0122 g g^{-1}) and $t_{1/2}$ of 57 days followed by Cajanus cajan (L.) (Millsp). Mucuna aterrima released 39,2, 57,8, 70,7, 79,7 and 85,1% at 30, 60, 90, 120 and 150 DAI, respectively. The other species were similar and presented $t_{1/2}$ of 82 to 94 days.

Varela et al. (2017) reported P release rates similar to those of Mucuna aterrima and Cajanus cajan (L.) (Millsp) for Oat, Rye and Ryegrass. According to the authors the magnitude of P release was affected by the type and amount of residues and by the environmental conditions during the decomposition period, as reflected by the interspecific differences in P release decay constant.

All legumes studied showed complete release of K during decomposition, indicating effective K availability in the soil, which can be strategically utilized in crop rotation programs to replenish this nutrient for subsequent crops (Quadros et al., 2009). The K release dynamics followed a similar decay pattern for all species (Figure 2), which is consistent with $t_{1/2}$ of 14 to 22 DAI (Table 2).

Giacomini et al. (2003) reported that around 70% of the K in the plant tissue of cover crops was soluble in water and with the occurrence of rain after species management, most of this nutrient was released from crop residues into the soil. This must be associated with the fact that K is a nutrient that is not associated with any structural component of the plant tissue, remaining as a free ion within the plant (Carpim et al., 2008).

The Ca release showed an almost linear fit over time and followed the same pattern as mass loss in all species. It was the nutrient with the slowest release from residue. Between 65 and 85% of the Ca remained in the residues at 60 DAI, and on average less than 50% of the total Ca was released during the period evaluated (150 DAI) (Figure 2).

Dolichos lablab demonstrated efficient Ca release, with release values of 17,7, 32,1, 43,9, 53,7 and 61,8% at 30, 60, 90, 120 and 150 DAI, respectively. In contrast, Mucuna aterrima and Cajanus cajan decomposed faster initially, resulting in an intense release of Ca into the soil followed by a gradual decrease (Espindola et al., 2006).

The greater persistence of Ca in the residues is reflected in the longer half-life, which ranged from 136 to 283 days (Table 2), with half-life exceeding 200 days for Cajanus cajan and Mucuna aterrima. The literature reports the greater persistence of Ca in plant residues as it is a structural component of the middle lamella and cell walls of plants and it takes three to six months to release around 50% of the amounts found in the residues (Moradi et al., 2014; Pereira et al., 2016), which is consistent with the results obtained in this study.

Mucuna aterrima exhibited the highest percentage of Mg remnant, while Canavalia ensiformis showed the lowest Mg remnant values (Figure 2), indicating varied potential for Mg recycling among these legumes. These results underscore the significant role of legumes in Mg availability, influencing plant nutrition and the health of agricultural ecosystems (Salmi et al., 2007). Variations in Mg release by legumes are depicted in Table 2. Mucuna aterrima demonstrated a gradual release over time, with a high remaining percentage at 150 days (50.9%). In contrast, species like *Canavalia ensiformis* and *Crotalaria spectabilis* exhibited faster release with smaller remnant percentages. *Canavalia ensiformis* released Mg at values of 38,9, 58,6, 72, 81 and 87,2% at 30, 60, 90, 120

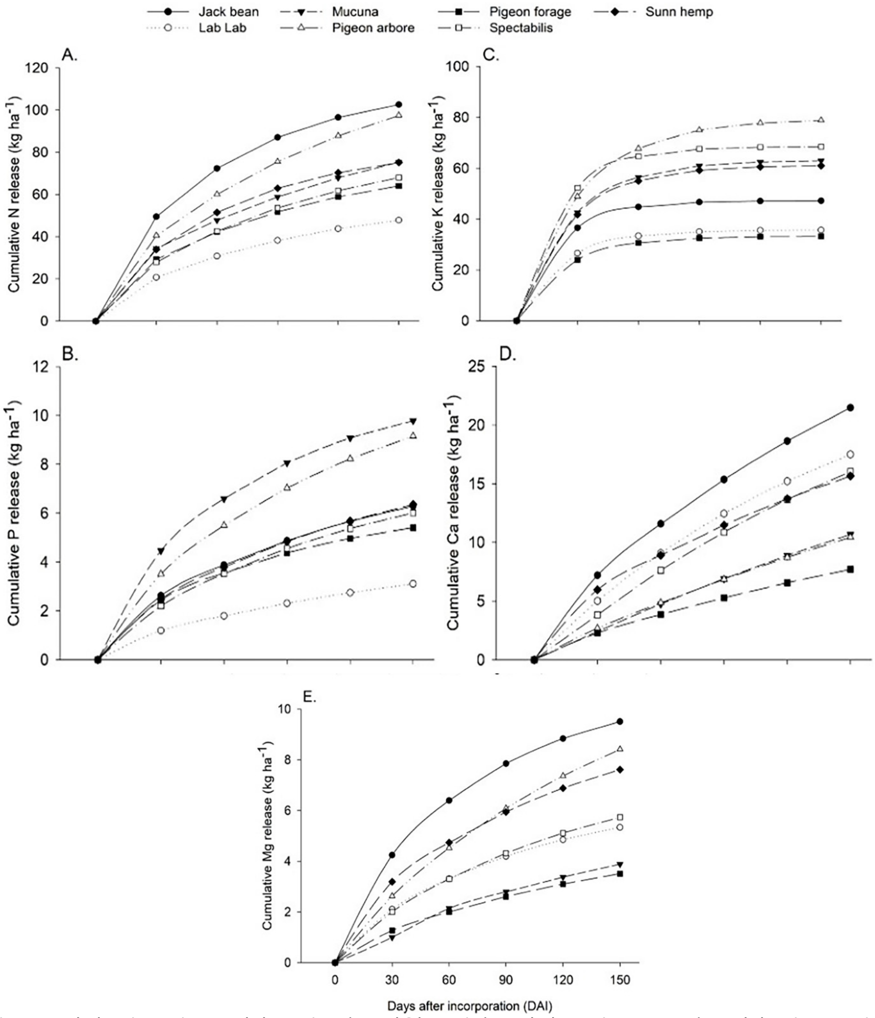

Figure 3. Cumulative nitrogen (A), phosphorus (B), potassium (C), calcium (D) and magnesium (E) release during the decomposition of aboveground part residues of legumes cover crops.

and 150 DAI, respectively. For *Mucuna aterrima* released Mg at values of 17,8, 27,1, 35,4, 42,7 and 49,1 at 30, 60, 90, 120 and 150 DAI, respectively. Legumes play a crucial role in making Mg available in the soil (Cakmak & Marschner, 1992).

In summary, legume cover crops exhibit diverse decomposition rates and nutrient release dynamics, which are crucial for soil fertility and plant nutrition. Understanding these dynamics informs agricultural management strategies aimed at maximizing nutrient availability and sustainability in cropping systems. Continued research is essential for unraveling the complexities of legume decomposition and its implications for soil health and agricultural productivity (Engels et al., 2012; Siddiqui et al., 2013).

The study investigated the cumulative release dynamics of essential nutrients during the decomposition of legume cover crop above-ground residues (**Figure 3**). A detailed analysis of N, P, K, Ca, and Mg cumulative release provided insights into nutrient cycling in the soil. Distinct patterns of nutrient release during legume aboveground part residue decomposition were observed. Nitrogen exhibited gradual and cumulative release over time, emphasizing legume residues significance as N sources for agricultural systems. Similarly, P, Ca, and Mg release occurred progressively, reflecting residue decomposition and nutrient availability to plants. Potassium release reached a plateau after 30 days, uniformly across all residues (Figure 3).

The dynamics of cumulative nutrient release during legume residue decomposition are influenced by various factors, including residue chemical composition, environmental conditions, and soil microbial activity. In general, mass production followed the growth cycle of the species in the region, with greater contribution of biomass and nutrients for those with a shorter vegetative cycle (Varela et al., 2017).

Nitrogen release, for instance, stems from nitrogenous organic compound mineralization in the residues and decomposer microorganism activity (Aulakh et al., 1991; Chinta et al., 2020).

Phosphorus, K, Ca, and Mg release correlate with plant tissue decomposition and inorganic compound solubilization in the residues. *Canavalia* *ensiformis*, with a high decomposition rate (0.0147 g g^{-1}), promotes rapid mineralization and N release during decomposition, consistent with previous findings (Barros et al., 2020; Mangaravite et al., 2023). *Mucuna aterrima* demonstrated a higher P release rate (0.0122 g g^{-1}) among others, gradually releasing it during decomposition due to its residue's richness in organic matter and nutrients (Mangaravite et al., 2023). The plateau in potassium release after 30 days contrasts with other nutrients. Cajanus cajan exhibited the lowest K accumulation potential (Figure 3), suggesting a strategy for returning this nutrient to subsequent crops in rotation programs. Low Ca release rates from plant biomass are common in Fabaceae and other species, which is attributed to Ca presence in the middle lamella of the cell wall, a recalcitrant plant tissue component (Berg & Staaf, 1987; Osono & Takeda, 2004).

The similar dynamics of Mg and K release in the initial 30 days may be linked to ionic form of Mg within plant tissue. Over 70% of Mg diffuses freely in cell suspension or binds to negatively charged components like proteins, similar to the structural role of N in proteins and chlorophyll alongside Mg (Osono & Takeda, 2004).

Understanding nutrient release dynamics during legume residue decomposition is crucial for sustainable soil management practices. This study lays a foundation for future research, advancing knowledge on legume cover crops' role in nutrient cycling and agricultural system sustainability. The study underscores the need to align associated crop nutrient demand phases with cover crop nutrient release rates. Legume use in green manure, especially among the studied species, presents an economically viable alternative to fertilizers, contributing to environmental protection by safeguarding soils against processes like leaching and erosion, which degrade soil quality, particularly in tropical environments.

Conclusion

The legumes evaluated in this study show significant potential for use in crop rotation or as green manure. *Crotalaria juncea*, *Crotalaria spectabilis*, *Dolichos lablab*, and *Canavalia ensiformis* demonstrated high decomposition rates and nutrient release, making them suitable for short-cycle vegetable cultivation due to their fast nutrient availability. In contrast, *Cajanus cajan*, *Cajanus cajan* (L.) (Millsp), and *Mucuna aterrima* are more appropriate for areas needing prolonged soil coverage, offering extended residue persistence and steady nutrient release. These findings underscore the importance of selecting suitable legume species to enhance soil fertility and crop productivity effectively.

Acknowledgements

The authors are particularly grateful to the company Piraí sementes, for supplying seeds from the cover crops used in this research.

References

Aulakh, M.S., Walters, D.T., Doran, J.W., Francis, D.D., Mosier, A. 1991. Crop residue type and placement effects on denitrification and mineralization. *Soil Science Society of America Journal* 55: 1020–1025.

Barros, V.D.C., Lira Junior, M.A., Fracetto, G.G.M., Ferreira, J.S., Fracetto, F.J.C., Barros, D.J., Silva Júnior, A.F. 2020. Effects of different legume green manures on tropical soil microbiology after corn harvest. *Bragantia* 79: 505–515.

Berg, B., Staaf, H. 1987. Release of plant nutrients from decomposing white birch leaves and scots pine needle litter. *Pedobiologia* 30: 55–63.

Cakmak, I., Marschner, H. 1992. Magnesium deficiency and high light intensity enhance activities of superoxide dismutase, ascorbate peroxidase, and glutathione reductase in bean leaves. *Plant Physiology* 98: 1222–1227.

Carpim, L.K., Assis, R.L., Braz, A.J.B.P., Silva, G.P., Pires, F.R., Pereira, V.C., Gomes, G.V., Silva, A.G. 2008. Liberação de nutrientes pela palhada de milheto em diferentes estádios fenológicos. *Revista Brasileira de Ciência do Solo* 32: 2813-2819.

Castellano-Hinojosa, A., Nevins, C.J., Strauss, S.L. 2021. Influence of cover crops on nitrogen cycling and the soil microbial community. In: Gonzalez-Lopez, J., Gonzalez-Martinez, A. (ed.) *Nitrogen Cycle*. CRC Press, Boca Raton, USA. p. 264–283.

Chinta, Y.D., Uchida, Y., Araki, H. 2020. Availability of nitrogen supply from cover crops during residual decomposition by soil microorganisms and its utilization by lettuce (Lactuca Sativa L.). *Scientia Horticulturae* 270: 109415.

Cobo, J.G., Barrios, E., Kass, D.C.L., Thomas, R.J. 2002. Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. *Plant and Soil* 240: 331–342.

Drost, S.M., Rutgers, M., Wouterse, M., Boer, W., Bodelier, P.L.E. 2020. Decomposition of mixtures of cover crop residues increases microbial functional diversity. *Geoderma* 361: 114060.

Engels, C., Kirkby, E., White, P. 2012. Mineral nutrition, yield and source–sink relationships. In: Marschner, P. (ed.) *Marschner's Mineral Nutrition of Higher Plants*. Academic Press, London, UK. p. 85–133.

Espindola, J.A.A., Guerra, J.G.M., Perin, A., Teixeira, M.G., Almeida, D.L. Urquiaga, S., Busquet, R.N.B. 2006. Banana plants intercropped with perennial herbaceous legumes used as living mulches. *Pesquisa Agropecuaria Brasileira* 41: 415–420.

Freitas, M.S.C., Souto, J.S., Gonçalves, M., Almeida, L.E.S., Salviano, A.M., Giongo, V. 2019. Decomposition and nutrient release of cover crops in mango cultivation in Brazilian Semi-Arid Region. *Revista Brasileira de Ciência do Solo* 43: e0170402.

Giacomini, S.J. Aita, C., Hübner, A.P., Lunkes, A., Guidini, E., Amaral, E.B. 2003. Liberação de fósforo e potássio durante a decomposição de resíduos culturais em plantio direto. *Pesquisa Agropecuária Brasileira* 38: 1097-1104.

Kliemann, H.J., Braz, A.J.P.B., Silveira, P.M. 2006. Taxas de decomposição de resíduos de espécies de cobertura em latossolo vermelho distroférrico. *Pesquisa Agropecuária Tropical* 36: 21–28.

Kooch, Y., Sanji, R., Tabari, M. 2019. The effect of vegetation change in C and N contents in litter and soil organic fractions of a Northern Iran Temperate Forest. *Catena* 178: 32–39.

Liebman, A.M., Grossman, J., Brown, M., Wells, M.S., Reberg-Horton, S.C., Shi, W. 2018. Legume cover crops and tillage impact nitrogen dynamics in organic corn production. *Agronomy Journal* 110: 1046–1057.

Malavolta, E., Vitti, G.C., Oliveira, S.A. 1997. *Avaliação do estado nutricional das plantas: princípios e aplicações*. Potafos, Piracicaba, BR. 319 p.

Mangaravite, J.C.S., Passos, R.R., Andrade, F.V., Silva, V.M., Marin, E.B., Mendonça, E.S. 2023. Decomposition and release of nutrients from species of tropical green manure. *Revista Ceres* 70: 114–124.

Mendonça, E.S., Lima, P.C., Guimarães, G.P., Moura, W.M., Andrade, F.V. 2017. Biological nitrogen fixation by legumes and N uptake by coffee plants. *Revista Brasileira de Ciência do Solo* 41: e0160178.

Moradi, A., Teh, C.B.S., Goh, K.J., Husni, M.H.A., Ishak, C.F. 2014. Decomposition and nutrient release temporal pattern of oil palm residues. *Annals of Applied Biology* 164: 208-219.

Moreira, F.M.S., Siqueira, J.O. 2006. *Microbiologia e bioquímica do solo*. UFLA, Lavras, BR. 729 p.

Osono, T., Takeda, H. 2004. Potassium, calcium, and magnesium dynamics during litter decomposition in a cool Temperate Forest. *Journal of Forest Research* 9: 23–31.

Palosuo, T., Hoffmann, M.P., Rötter, R.P., Lehtonen, H.S. 2021. Sustainable intensification of crop production under alternative future changes in climate and technology: the case of the North Savo Region. *Agricultural Systems* 190: 103135.

Paulino, G.M., Alves, B.J.R., Barroso, D.G., Urquiaga, S., Espindola, J.A.A. 2009. Fixação biológica e transferência de nitrogênio por leguminosas em pomar orgânico de mangueira e gravioleira. *Pesquisa Agropecuária Brasileira* 44: 1598–1607.

Pereira, N.S., Soares, I., Miranda, F.R. 2016. Decomposition and nutrient release of leguminous green manure species in the Jaguaribe-Apodi region, Ceará, Brazil. *Ciência Rural* 46: 970-975.

Perin, A., Santos, R.H.S., Caballero, S.S.U., Guerra, J.G.M., Gusmão, L.A. 2010. Acúmulo e liberação de P, K, Ca e Mg em crotalária e milheto solteiros e consorciados. *Revista Ceres* 57: 274–281.

Poffenbarger, H.J., Mirsky, S.B., Weil, R.R., Kramer, M., Spargo, J.T., Cavigelli, M.A. 2015. Legume proportion, poultry litter, and tillage effects on cover crop decomposition. *Agronomy Journal* 107: 2083–2096.

Quadros, D.A., Iung, M.C., Ferreira, S.M.R., de Freitas, R.J.S. 2009. Composição química de tubérculos de batata para processamento, cultivados sob diferentes doses e fontes de potássio. *Ciência e Tecnologia de Alimentos* 29: 316–323.

Salmi, A.P., Risso, I.A.M., Guerra, J.G.M., Urquiaga, S., Araújo, A.P., Abboud, A.C.S. 2013. Crescimento, acúmulo de nutrientes e fixação biológica de nitrogênio de *Flemingia macrophylla*. *Revista Ceres* 60: 79–85.

Schiavinatti, A.F., Andreotti, M., Benett, C.G.S., Pariz, C.M., Lodo, B.N., Buzetti, S. 2011. Influência de fontes e modos de aplicação de nitrogênio nos componentes da produção e produtividade do milho irrigado no Cerrado. *Bragantia* 70: 925–930.

Siddiqui, M.H., Al-Whaibi, M.H., Sakran, A.M., Ali, H.M., Basalah, M.O., Faisal, M., Alatar, A., Al-Amri, A.A. 2013. Calcium-induced amelioration of boron toxicity in radish. *Journal of Plant Growth Regulation* 32: 61–71.

Singh, G., Dhakal, M., Yang, L., Kaur, G., Williard, K.W.J., Schoonover, J.E., Sadeghpour, A. 2020. Decomposition and nitrogen release of cover crops in reduced- and no-tillage systems. *Agronomy Journal* 112: 3605–3618.

Soil Survey Staff. 2014. Keys to soil taxonomy. USDA, Washington, USA. 360 p.

Teixeira, P.C., Donagemma, G.K., Fontana, A., Teixeira, W.G. 2017. *Manual de métodos de análise de solo*. Embrapa, Brasília, BR. 574 p.

Teodoro, R.B., Oliveira, F.L., Silva, D.M.N., Fávero, C., Quaresma, M.A.L. 2011. Aspectos agronômicos de leguminosas para adubação verde no Cerrado do Alto Vale do Jequitinhonha. *Revista Brasileira de Ciência do Solo* 35: 635–643.

Thapa, R., Tully, K.L., Reberg-Horton, C., Cabrera, M., Davis, B.W., Fleisher, D., Gaskin, J., Hitchcock, R., Poncet, A., Schomberg, H.H., Seehaver, S.A., Timlin, D., Mirsky, S.B. 2022. Cover crop residue decomposition in no-till cropping systems: insights from multi-state on-farm litter bag studies. *Agriculture, Ecosystems & Environment* 326: 107823.

Varela, M.F., Barraco, M., Gili, A., Taboada, M.A., Rubio, G. 2017. Biomass decomposition and phosphorus release from residues of cover crops under no-tillage. *Agronomy Journal* 109: 317–326.

Weiler, D.A., Giacomini, S.J., Aita, C., Schmatz, R., Pilecco, G.E., Chaves, B., Bastos, L.M. 2019. Summer cover crops shoot decomposition and nitrogen release in a no-tilled sandy soil. *Revista Brasileira de Ciência do Solo* 43: e0190027.

Wider, R.K., Lang, G.E. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology* 63: 1636–1642.

Xavier, F.A.S., Oliveira, J.I.A., Silva, M.R. 2017. Decomposition and nutrient release dynamics of shoot phytomass of cover crops in the Recôncavo Baiano. *Revista Brasileira de Ciencia do Solo* 41: e0160103.

Xavier, R.A, Dornellas, P.C. 2010. Análise do comportamento das chuvas no município de Arapiraca, Região Agreste de Alagoas. *Geografia* 14: 49–64.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.