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# Plant residue quality indices: a methodological approach for evaluating summer cover crops under tropical climates

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22

**ABSTRACT:**

23 The success of conservation agriculture in tropical environments depends on crop rotations that  
24 ensure adequate quantity and quality of phytomass for persistent soil cover. The objective of this  
25 study was to evaluate biomass decomposition and nitrogen (N) release by summer cover crop species,  
26 employing distinct indices to assess their plant residues in terms of accumulated N release (NAR) and  
27 remaining dry matter (RDM). The experiment was conducted on a “Nitossolo Eutrófico” at the “Luiz  
28 de Queiroz” College of Agriculture, in a randomized block design with five treatments and four  
29 replicates. Treatments consisted of plant residues from sunn hemp (*Crotalaria juncea* L.), jack bean  
30 (*Canavalia ensiformis* (L.) DC.), Congo grass (*Urochloa ruziziensis* L.), pearl millet (*Pennisetum*  
31 *glaucum* L.), and maize (*Zea mays* L.). Biomass decomposition and N release were assessed using  
32 nylon litter bags, with samplings conducted at 15, 30, 60, and 90 days after crop termination. The  
33 legume species exhibited the highest N release rates, while among grasses, pearl millet had the highest  
34 NAR and the greatest RDM after 90 days. A significant linear correlation was found between the  
35 Plant Residue Quality Index (PRQI) and the rates of biomass decomposition and N release. At the  
36 same time, the Residual Biomass Quality Index (RBQI) identified tropical forages as more efficient  
37 in balancing NAR and RDM throughout the experimental period. These findings can support cover  
38 crop selection in tropical rotations aiming at synchronized N release and persistent soil cover.

39 **Index terms:** Nitrogen mineralization, Biomass decomposition rate, No-till system, Carbon-to-  
40 nitrogen ratio, Crop rotation

41

**RESUMO:**

42 O sucesso da agricultura conservacionista em ambientes tropicais depende de rotações de  
43 cultura que forneçam fitomassa sobre o solo em quantidade e qualidade suficientes para  
44 assegurar sua cobertura contínua. O objetivo deste estudo foi avaliar a decomposição da  
45 biomassa e a liberação de nitrogênio (N) de espécies de plantas de cobertura de verão,  
46 empregando-se índices distintos para qualificação de seus resíduos vegetais em termos de  
47 liberação cumulativa de N (LCN) e massa seca remanescente (MSR). O experimento foi  
48 conduzido em um Nitossolo Eutrófico na Escola Superior de Agricultura “Luiz de Queiroz”,  
49 em blocos casualizados com cinco tratamentos e quatro repetições. Os tratamentos foram  
50 constituídos de resíduos vegetais de cinco espécies: crotalária-júncea (*Crotalaria juncea* L.),  
51 feijão-de-porco (*Canavalia ensiformis* (L.) DC.), braquiária ruziziensis (*Urochloa ruziziensis*  
52 L.), milheto (*Pennisetum glaucum* L.) e milho (*Zea mays* L.). A decomposição de biomassa e a  
53 liberação de N foram avaliados por meio de sacolas de náilon, com coletas aos 15, 30, 60 e 90  
54 dias após o manejo das espécies. As leguminosas apresentaram as maiores taxas de liberação  
55 de N, enquanto, entre as gramíneas, o milheto apresentou os maiores valores de LCN e de MSR  
56 ao final de 90 dias. Foi observada correlação linear significativa entre o índice de qualidade do  
57 resíduo vegetal (IQRV) e as taxas de decomposição de biomassa e taxa de liberação de N.  
58 Simultaneamente, o índice de qualidade da biomassa residual (IQBR) permitiu distinguir as  
59 forrageiras tropicais como mais eficientes em equilibrar a LCN e a MSR ao longo do período  
60 experimental. Esses resultados podem subsidiar a escolha de plantas de cobertura em rotações  
61 tropicais visando à liberação sincronizada de N e à manutenção da cobertura do solo.

62 **Termos para indexação:** Mineralização de nitrogênio, Taxa de decomposição de biomassa,  
63 Sistema plantio direto, Relação carbono-nitrogênio, Rotação de culturas

## 64 1. INTRODUCTION

65 The success of conservation agriculture in tropical environments depends on crop  
66 rotations that ensure adequate quantity and quality of phytomass for persistent soil cover. High-  
67 quality mulch plays a critical role in reducing water loss through evaporation (Chang et al.,  
68 2023), thereby contributing to the development of production systems more resilient to the  
69 effects of climate change (Souza et al., 2025). From this perspective, the integration of cover  
70 crops (CC) species into rotation systems has been proposed as an effective strategy to achieve  
71 these objectives (Rigon; Franzluebbbers & Calonego, 2020). These plants offer several  
72 advantages, including the diversification of soil microorganisms, nutrient cycling, and the  
73 provision of substantial amounts of nitrogen (N) to cash crops (Hahn et al., 2024).

74 The decomposition and nutrient release from crop residues are regulated by both  
75 intrinsic and extrinsic factors inherent to the plant material. Intrinsic factors include the carbon-  
76 to-nitrogen (C/N) ratio, lignin content, and polyphenol concentration, which directly influence  
77 residue quality (Canalli et al., 2020; Tian, Brussaard & Kang, 1995; Weiler et al., 2022). These  
78 chemical attributes interact with extrinsic factors such as climatic conditions, soil microbial  
79 activity, and the phenological stage at termination (e.g., flowering or grain-filling), collectively  
80 determining decomposition rates, as well as N immobilization and mineralization from plant  
81 residues (Keene et al., 2017; São Miguel et al., 2018). Consequently, litter decomposition  
82 patterns vary among species from different botanical families, such as Fabaceae and Poaceae,  
83 which typically exhibit contrasting effects on soil cover maintenance and N cycling (Chang et  
84 al., 2023; Saadat et al., 2025; Hahn et al., 2024; Kim et al., 2025).

85 Despite the widely recognized benefits of CC, uncertainty remains among technicians  
86 and farmers regarding the most suitable species for rotation systems (Alonso-Ayuso et al.,  
87 2020). Considering the predominant no-tillage production system in the Brazilian Midwest,  
88 based on the succession of soybean (*Glycine max* (L.) Merrill) and maize (*Zea mays* L.), an

89 optimal CC could be characterized by its capacity to produce the highest possible amount of  
90 residual dry matter (RDM) on the soil surface, thereby minimizing water loss through  
91 evaporation, and to release the maximum amount of N, a major yield gap to cash crops (Cassol  
92 et al., 2023; Tittonell & Giller, 2013). In this regard, Souza et al. (2025) emphasize the crucial  
93 role of CC with these characteristics as key components of climate-smart agriculture, essential  
94 for ensuring yield and soil health production systems of the Brazilian “Cerrado”.

95 Similarly, Cassol et al. (2023) proposed a conceptual model for production systems in  
96 southern Brazil, in which elevated values of a residual biomass quality index (RBQI) indicate  
97 CC that achieve an optimal balance between N release and biomass persistence on the soil  
98 surface. Consequently, RBQI could serve as a valuable tool for evaluating the equilibrium in  
99 the provision of these ecosystem services, aiding in the selection of suitable CC for tropical  
100 rotation systems. Additionally, this index may serve for assessing the extent of conservation  
101 practices adopted by farmers in Brazilian “Cerrado” agriculture, encouraging the inclusion of  
102 CC species during the window between the harvest of off-season maize and before soybean  
103 sowing (Possamai et al., 2022; Saadat et al., 2025; Telles et al., 2020).

104 However, few studies have assessed the quality of plant residues from CC adapted to  
105 tropical environments. Traditional indices, such as the Plant Residue Quality Index (PRQI)  
106 (Tian, Brussaard & Kang, 1995), were initially developed to link the chemical traits of plant  
107 residues (mainly from agroforestry and forage species) to their decomposition and N release,  
108 but without specific validation for CC. More recently, the Residue Biomass Quality Index  
109 (RBQI) was introduced for evaluating residue quality in winter CC under subtropical climates  
110 (Cassol et al., 2023). Thus, we hypothesized that both indices could also be reliably applied to  
111 summer CC in tropical regions, offering consistent predictions of biomass breakdown and N  
112 release. In this context, the present study aimed to test the applicability of PRQI and RBQI for

113 summer CC species, focusing on: (i) biomass decomposition dynamics, (ii) N release to  
114 subsequent cash crops, and (iii) initial chemical characteristics of the residues.

## 115 **2. MATERIALS AND METHODS**

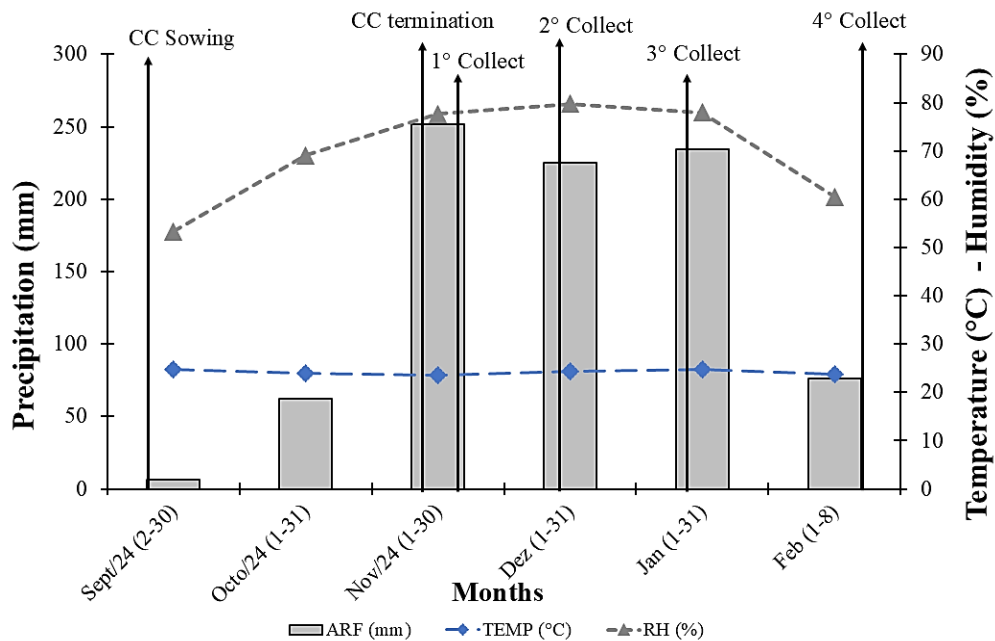
### 116 **2.1 Experimental site and design**

117 This study was conducted between September 2024 and February 2025, in the  
118 experimental area of the Crop Science Department (LPV) at the "Luiz de Queiroz" College of  
119 Agriculture (ESALQ), University of São Paulo (USP), in Piracicaba-SP, Brazil (22° 42' 17.53"  
120 S, 47° 38' 8.33" W, 553 m). The region's climate is classified as tropical (Cwa) according to the  
121 Köppen system, with an average annual precipitation of 1328 mm and a mean temperature of  
122 26.2°C (Alvares et al., 2013). This climate has two distinct seasons: a warm, rainy summer  
123 (October-March) and a cooler, dry winter (April-September). Weather data were recorded by  
124 an automatic station located 1.3 km from the experimental site (Figure 1).

125 The soil was classified as a "Nitossolo Eutrótico Típico de textura argilosa" (Santos et  
126 al., 2018), and its chemical properties were assessed in the 0-0.20 m layer prior to CC sowing,  
127 following the methodology of Raij et al. (2001): Ca = 108.2 mmolC dm<sup>-3</sup>; Mg = 29.4 mmolC  
128 dm<sup>-3</sup>; K = 8.7 mmolC dm<sup>-3</sup>; Al = 0.0 mmolC dm<sup>-3</sup>; H + Al = 24.4 mmolC dm<sup>-3</sup>; P = 16.2 mg  
129 dm<sup>-3</sup>; S = 146 mg dm<sup>-3</sup>; Cu = 5.9 mg dm<sup>-3</sup>; Fe = 22.8 mg dm<sup>-3</sup>; Mn = 15.7 mg dm<sup>-3</sup>; Zn = 2.1  
130 mg dm<sup>-3</sup>; B = 0.36 mg dm<sup>-3</sup>; pH CaCl<sub>2</sub> = 5.45; m = 0.00; MO = 26 mg dm<sup>-3</sup>; CTC = 170.7  
131 mmolC dm<sup>-3</sup>; SB = 146.3 mmolC dm<sup>-3</sup>; V = 86%.

132 The experiment was arranged in a randomized block design with four blocks, each  
133 containing one replicate (litter bag) of five CC species. Residue decomposition and N release  
134 were evaluated at four sampling periods (15, 30, 60, and 90 days after species termination),  
135 totaling 80 experimental units (5 species × 4 blocks × 4 sampling times). To produce the plant

136 residues, all CC species were manually sown (without base fertilizer) on September 2, 2024.  
 137 Sowing densities and row spacings were defined according to Lima-Filho et al. (2023).



138 **Figure 1:** Accumulated rainfall (ARF), mean air temperature (TEMP), and mean relative humidity (RH), recorded  
 139 in the automatic weather station of ESALQ/USP during the experimental period.  
 140

141 The experimental area management included manual weeding up to 30 days after CC  
 142 sowing (DAS), along with supplemental sprinkler irrigation applied exclusively during  
 143 September, in response to low rainfall recorded in that month (Figure 1). Irrigation was  
 144 performed daily for 10 minutes, delivering an estimated water of approximately 0.6 mm per  
 145 event, based on an application rate of 3.6 mm h<sup>-1</sup> for conventional sprinkler systems.

## 146 2.2 Biomass parameters

147 At 68 DAS (November 10, 2024), all CC were terminated with a knife roller and left  
 148 over the soil as mulch. Shoot fresh matter (SFM) was determined by collecting five 0.25 m<sup>2</sup>  
 149 samples per specie and weighing them in the field. Samples were then oven-dried at 65°C for  
 150 72 h to obtain shoot dry matter (SDM). The initial chemical composition of the CC was  
 151 analyzed descriptively after grinding the material (0.5 mm sieve), using a representative mixture  
 152 of stems, leaves, and flowers in the same field proportions produced by the species (Table 1).

153 Carbon content was standardized at 40% of dry matter, an average value well supported  
 154 in the literature for its consistency and broad applicability to tropical grasses and legumes used  
 155 as green manure (Lovato et al., 2004; Medina et al., 2013; Palm et al., 2001). Total soluble  
 156 polyphenols were determined using the Folin-Denis method (Anderson & Ingram, 1996; Gama-  
 157 Rodrigues et al., 2007), while lignin content was analyzed following the sequential procedure  
 158 described by Van Soest, Robertson, & Lewis (1991). N determination was performed according  
 159 to the methodology proposed by Tedesco et al. (1995).

160 **Table 1:** Average ( $n = 5$ ) of biomass production of cover crops terminate at the flowering and vegetative stages  
 161 (68 DAS) and initial chemical characteristics of the plant residues. Piracicaba-SP, Brazil.

Species	Shoot matter				Chemical characteristics		
	FM	DM	C	N	C/N	LIG	POL
	----- (Mg ha <sup>-1</sup> ) -----			kg ha <sup>-1</sup>	---	----- (%) -----	
<i>Pennisetum glaucum</i> **	43.0	14.1	5.6	217.0	25.9	4.8	0.4
<i>Urochloa ruziziensis</i> *	27.8	9.8	3.9	138.7	28.3	2.4	1.2
<i>Crotalaria juncea</i> **	32.5	8.5	3.4	245.4	13.9	3.5	0.6
<i>Zea mays</i> *	16.1	4.9	2.0	61.8	32.3	7.6	0.3
<i>Canavalia ensiformis</i> *	14.4	2.8	1.1	104.8	10.8	2.7	2.1

162 FM: Fresh matter; DM: Dry matter; C: Carbon; N: Nitrogen; C/N: Carbon/Nitrogen ratio; LIG: Lignin; POL: Total  
 163 soluble polyphenols; (\*) Species terminated at the vegetative and (\*\*) at the flowering stage. Values in this table  
 164 represent total field biomass and N content, which differ from day 0 litter bag values due to the use of smaller,  
 165 standardized, and proportionally scaled subsamples following the litter bag methodology.

166 The decomposition and N release from the CC plant residues were evaluated using the  
 167 litter bag method, as outlined by Keuskamp et al. (2013) and Cassol et al. (2023). Nylon litter  
 168 bags with a mesh size of 4 mm and dimensions of 16×20 cm (0.032 m<sup>2</sup>) were used, permitting  
 169 the passage of microorganisms, worms and other invertebrates. The initial fresh matter (IFM)  
 170 placed in the litter bags was proportional to the SFM of each species, aiming to evaluate the  
 171 quantity and quality of the CC residues produced for lasting soil cover and N release (Eq. 1).

$$172 \quad IFM \left( \frac{SFM}{\text{"litter bag"}} \right) = (SFM \text{ kg ha}^{-1} / 10,000 \text{ m}^2) \times 0,032 \text{ m}^2 \quad (1)$$

173 It is known that pre-drying plant residues before decomposition experiments can alter  
 174 decomposition rates and delay N release during the initial evaluation period (Doneda et al.,  
 175 2012; Thapa et al., 2022). To mitigate this effect, the equivalent dry matter (EDM) of each

176 species' IFM was determined by drying four samples at 65 °C for 72 hours, with subsequent N  
 177 content (ENC) calculated by Tedesco et al. (1995). Additionally, following the approach  
 178 adopted by Saadat et al. (2025), fresh plant residues were directly placed in nylon mesh litter  
 179 bags to better simulate field conditions. To further enhance representativeness, the same fresh  
 180 proportions of leaves, stems, flowers, and branches observed in the field were maintained and  
 181 conditioned within the litter bags, as recommended by Mangaravite et al. (2023).

182 Thus, immediately after the CC termination, litter bags containing the fresh plant  
 183 residues were evenly distributed across the soil surface within the four experimental blocks.  
 184 The collection times were set at 15, 30, 60 and 90 days after CC termination (DAT), with four  
 185 bags per species retrieved at each interval. The evaluation period was based on previous studies,  
 186 which employed durations of 90 to 120 days (Sodré-Filho et al., 2024; Torres et al., 2021; Thapa  
 187 et al., 2022). Decomposition degree days (DDD) were calculated according to Singh et al.  
 188 (2020), to normalize time based on daily air temperature (Eq. 2):

$$189 \quad DDD = [(T_{max} + T_{min})/2] - T_{base} \quad (2)$$

190 where Tmax and Tmin are daily maximum and minimum air temperature, respectively, and  
 191 Tbase is the base temperature according to McMaster & Wilhelm (1997). For days when Tmax  
 192 or Tmin air temperature was less than Tbase, the Tmax or Tmin was equal to Tbase. For days  
 193 when Tmax was greater than 30°C, it was used the value of 30°C.

194 After retrieval, the bag contents were manually sorted to remove soil particles and  
 195 organisms, then dried in an oven at 65°C until reaching a constant mass to obtain the RDM.  
 196 The decomposition rate (K) and nitrogen release rate (KN) of the CC plant residues were  
 197 calculated from the values of RDM and remaining nitrogen content (RN) obtained at each  
 198 collection period, which were adjusted to the exponential model (Eq. 3) proposed by Thomas  
 199 & Asakawa (1993), using the Sigma Plot<sup>®</sup> Software (version 2014).

$$200 \quad x_t = x_0 \cdot e^{-kt} \quad (3)$$

201 where:  $x_t$  = dry biomass (g) or nitrogen content ( $\text{g kg}^{-1}$ ) of the plant residue remaining on the  
 202 soil surface after  $t$  days;  $x_0$  = dry biomass (g) or nitrogen content ( $\text{g kg}^{-1}$ ) of the plant residue  
 203 packed inside the litter bag on day zero;  $t$  = time in days and  $K$  = decomposition rate or nitrogen  
 204 release rate ( $K_N$ ). The half-life of CC residues, indicating the time required for half of the initial  
 205 material to decompose and release half of the initial N content, was calculated using the  
 206 decomposition ( $K$ ) and nitrogen release ( $K_N$ ) rates (Eq. 4).

$$207 \quad T_{1/2} \text{ and } N_{1/2} = \ln(2)/kt \quad (4)$$

208 where:  $T_{1/2}$  = plant residue half-life;  $N_{1/2}$  = nitrogen release half-life;  $t$  = time in days;  $K$  =  
 209 biomass decomposition rate or nitrogen release rate ( $K_N$ ) obtained from fitting the non-linear  
 210 model. The nitrogen accumulated release (NAR), in  $\text{Kg ha}^{-1}$ , was measured according to  
 211 Doneda et al. (2012), by analyzing the content of this nutrient in the initial dry matter contained  
 212 in the litter bags and on each collection date. The methodology for determining the N content  
 213 in the plant residues was also carried out according to Tedesco et al. (1995).

### 214 **2.3 Calculation of plant residue quality indices**

215 Two methodologies were used to determine the quality of the summer CC plant residues.  
 216 The approach proposed by Cassol et al. (2023) relies on the Residual Biomass Quality Index  
 217 (RBQI), a tool based on the Remaining Dry Mass Index (RDMI) on the soil surface and the  
 218 Nitrogen Release Index (NRI) after the species have been managed for some period. In this  
 219 way, RBQI values classify the quality of CC residues on a scale ranging from 0 to 1, where a  
 220 higher value corresponds to a better balance between two ecosystemic services: N release and  
 221 the permanence of crop residues on the soil surface (Eq. 5).

$$222 \quad RBQI = RDMI \times NRI \quad (5)$$

223 To obtain the RDMI, the highest RDM value among the CC evaluated was set at 100%,  
 224 as the ideal condition of soil coverage by the crop residues at the end of the 90-day evaluation.  
 225 Similarly, NRI was determined based on the highest NAR value among the CC evaluated, which  
 226 was defined as 100%, representing the ideal condition of N release by the crop residues at the  
 227 end of the evaluation period. To compare the results obtained in determining RBQI, the index  
 228 proposed by Tian, Brussaard & Kang (1995) was also analyzed descriptively (Eq. 6).

$$229 \quad PRQI = \left[ 1 / \left( a \times \frac{C}{N} + b \times Lignin + c \times Polyphenols \right) \times 100 \right] \quad (6)$$

230 where: PRQI = Plant Residue Quality Index; a (0.423), b (0.439), and c (0.138) are coefficients  
 231 representing the relative contribution of the C/N ratio, lignin content (%), and polyphenol  
 232 concentration (%) to the quality of the plant residues, respectively.

## 233 2.4 Statistical analyses

234 To meet the assumptions for analysis of variance (ANOVA), the dataset were first tested  
 235 for residue normality (Shapiro-Wilk and Lilliefors tests) and homogeneity of variances  
 236 (Bartlett's test), both at 5% significance ( $p > 0.05$ ). When necessary, data were transformed  
 237 using the square root method ( $\sqrt{x}$ ) to meet these assumptions. ANOVA was then performed,  
 238 followed by Tukey's test at 5% to compare treatment means at each sampling period (15, 30,  
 239 60, and 90 days). Decomposition and N release dynamics over time were evaluated using  
 240 exponential regression analyses based on five time points, including day 0. Linear regression  
 241 analysis was also applied to assess the relationships between the Plant Residue Quality Index  
 242 (PRQI) and the kinetic parameters K and  $K_N$ . Statistical analyses were performed in Assistat®  
 243 Software (v. 7.7), while regression models were fitted in SigmaPlot® (v. 2014). Ultimately,  
 244 effect size ( $\eta^2$ ) was calculated to support  $p$ -value interpretation (Cohen, 1988).

245

246

247 **3. RESULTS AND DISCUSSION**248 **3.1 Cover crops residual dry matter and decomposition**

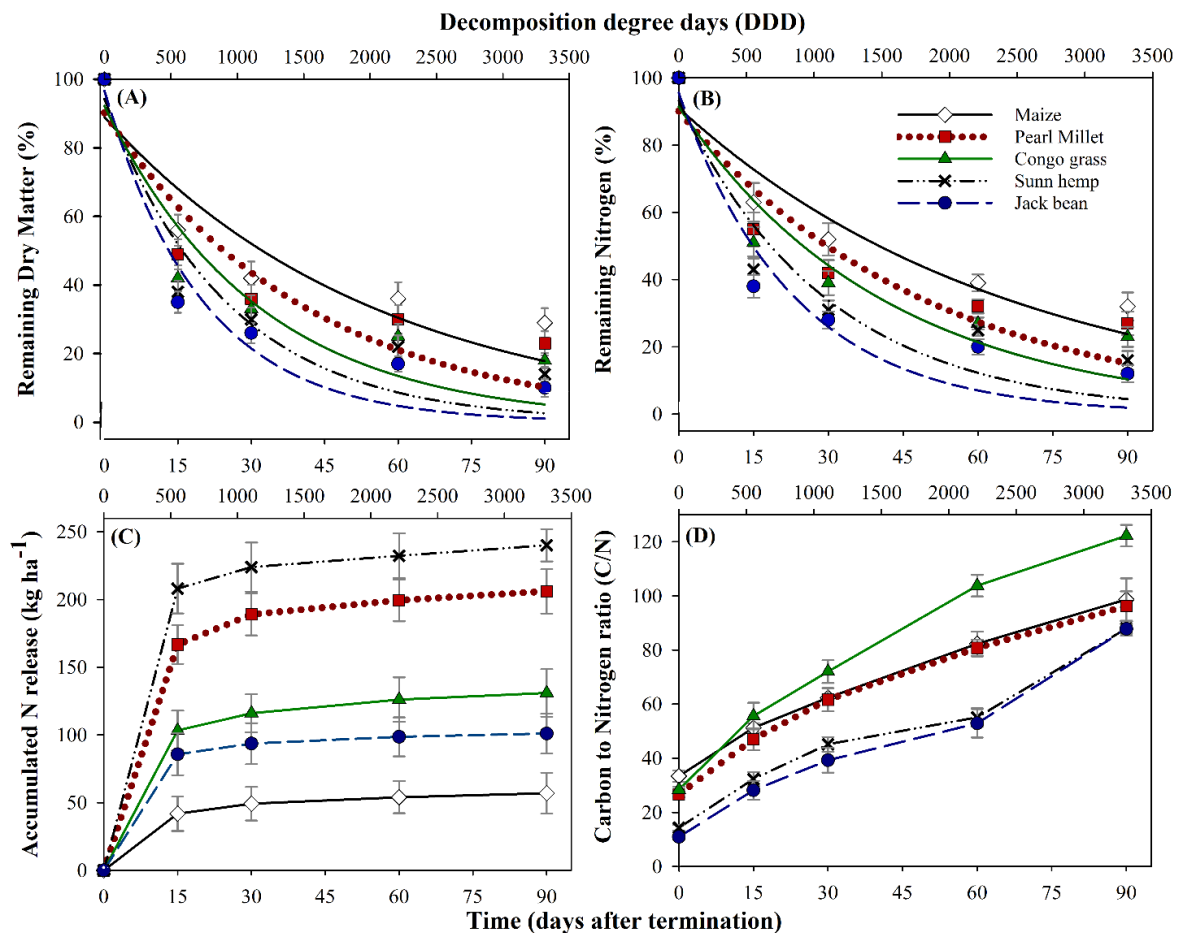
249 Dry matter (DM) loss over time differed significantly among treatments ( $p < 0.01$ ), both  
 250 in absolute values ( $\text{Mg ha}^{-1}$ ) and percentages, indicating distinct decomposition dynamics  
 251 among the evaluated species (Table 2). The only exception was the percentage of remaining dry  
 252 matter (RDM) 30 days after management, which did not exhibit any difference. For instance,  
 253 15 days after CC termination, jack bean ( $1.20 \text{ Mg ha}^{-1}$ ) and sunn hemp ( $2.97 \text{ Mg ha}^{-1}$ ) exhibited  
 254 lower RDM compared to Congo grass ( $4.84 \text{ Mg ha}^{-1}$ ) and pearl millet ( $5.94 \text{ Mg ha}^{-1}$ ). Thus, by  
 255 the end of 30 days, only pearl millet maintained soil cover above  $4.00 \text{ Mg ha}^{-1}$ , a level of mulch  
 256 considered effective for erosion control (Campos et al., 2011; Machado et al., 2001).

257 **Table 2:** Mean values ( $n = 4$ ) of remaining dry matter (RDM) from the decomposition of summer cover crop plant  
 258 residues at each sampling period. Piracicaba-SP, Brazil.

Species	Time (days)				
	0	15	30	60	90
	Percentage (%) of remaining dry matter				
<i>Zea mays</i>	100	55.32 a	41.91	35.20 a	26.55 a
<i>Pennisetum glaucum</i>	100	47.12 b	34.64	28.52 ab	21.70 a
<i>Urochloa ruziziensis</i>	100	42.12 bc	34.72	27.14 ab	20.38 ab
<i>Crotalaria juncea</i>	100	37.57 cd	29.66	21.75 bc	13.84 b
<i>Canavalia ensiformis</i>	100	33.14 d	25.89	17.26 c	12.94 b
CV (%)	--	7.45	21.35	15.43	17.63
<i>p</i> -value	--	< 0.001	0.069 ns	0.003	0.004
$\eta^2$	--	0.89	0.88	0.77	0.77
	Remaining dry matter ( $\text{Mg ha}^{-1}$ )				
<i>Pennisetum glaucum</i>	12.06	5.94 a	4.37 a	3.59 a	2.75 a
<i>Urochloa ruziziensis</i>	11.50	4.84 b	3.90 a	3.12 a	2.34 a
<i>Crotalaria juncea</i>	7.90	2.97 c	2.34 b	1.71 b	1.09 b
<i>Zea mays</i>	4.66	2.57 c	1.95 b	1.64 b	1.25 b
<i>Canavalia ensiformis</i>	3.62	1.20 d	0.93 c	0.62 c	0.46 c
CV (%)	--	8.08	14.19	8.55	9.16
<i>p</i> -value	--	< 0.001	< 0.001	< 0.001	< 0.001
$\eta^2$	--	0.98	0.94	0.93	0.92

259 Means followed by the same letter in the same column do not differ significantly according to Tukey's test at the  
 260 5% significance within the same evaluation period. CV (%): coefficient of variation. *p*-value: probability  
 261 associated with the F-test from ANOVA. ns: not significant according to ANOVA ( $p > 0.05$ ).  $\eta^2$ : effect size,  
 262 indicating the proportion of variance explained by treatments at each sampling time;  $\eta^2$  values > 0.14 represent a  
 263 large treatment effect (Cohen, 1988). Data presented in  $\text{Mg ha}^{-1}$  for 60 and 90 days were transformed using the  
 264 square root method ( $\sqrt{x}$ ) to meet the assumptions of normality and homogeneity of variances.  
 265  
 266

267 Although effect size values remained statistically meaningful throughout the evaluation  
 268 period, indicating a consistent treatment effect ( $\eta^2 > 0.14$ ), their gradual decline over time  
 269 suggests that the initial influence of residue quality on decomposition dynamics became less  
 270 pronounced as the process advanced. This reduction likely reflects the increasing influence of  
 271 environmental factors such as air temperature, relative humidity, and rainfall (Figure 1). Thus,  
 272 the consistently high  $\eta^2$  values also demonstrate the statistical robustness of our data,  
 273 confirming the sensitivity of the experimental design to detect differences among treatments  
 274 despite the relatively limited number of experimental units.



275 **Figure 2:** Percentage of remaining dry matter (A); Percentage of remaining Nitrogen (B); Accumulated Nitrogen  
 276 release (kg ha<sup>-1</sup>); and (C) Evolution of the Carbon/Nitrogen (C/N) ratio (D). Points represent the mean of the four  
 277 blocks ( $n = 4$ ), and vertical bars indicate the standard error of the mean. Superior x-axis indicates the decomposition  
 278 degree days (DDD). Piracicaba-SP, Brazil.

279 Forage grasses consistently exhibited higher RDM values throughout the entire  
 280 experimental period, reinforcing their potential for persistent soil cover. In this regard, 90 days  
 281 after CC termination, Congo grass and pearl millet retained 2.34 Mg ha<sup>-1</sup> and 2.73 Mg ha<sup>-1</sup> of

282 mulch over the soil, respectively. In contrast, the rapid biomass decomposition observed for  
283 legumes (Figure 2A; Table 2) can be attributed to their low initial C/N ratios and inferior lignin  
284 contents (Table 1), corroborating previous studies that identify these factors as critics in  
285 determining the susceptibility to DM loss and N release from CC plant residues (Cotrufo et al.,  
286 2015; Doneda et al., 2012; Thapa et al., 2022; Torres et al., 2021).

287         However, the C/N ratio is a general indicator that represents the total plant biomass,  
288 without distinguishing tissue fractions or organs with different chemical properties (Canalli et  
289 al., 2020; Weiler et al., 2022). Accordingly, as more labile compounds (e.g., sugars and free  
290 amino acids) present in leaves and flowers are decomposed, the C/N ratio tends to increase,  
291 likely due to the relative predominance of recalcitrant components (e.g., lignin, cellulose, and  
292 polyphenols) in stems and branches (Figure 2D). This response may partially explain the  
293 biphasic decomposition and N release dynamics observed in this study (Figure 2C),  
294 characterized by an initial phase of rapid DM and N losses, potentially driven by the C/N ratio  
295 and the presence of labile compounds, followed by a slower phase, possibly influenced by the  
296 effect of recalcitrant molecules (Sodré-Filho et al., 2024; Thapa et al., 2022).

297         Probably, this rapid loss of DM and N within the first 15 days is likely due to the early  
298 termination of CC, conducted during the flowering and vegetative stages (Adetunji et al., 2020).  
299 According to Khatounian (2001), the phenological stage at the time of termination significantly  
300 influences biomass decomposition rates and N release from summer green manure. At this  
301 moment, plants exhibit high levels of free amino acids and soluble compounds in the cellular  
302 vacuole, along with low cellulose and lignin content in stems and leaves, as nutrients have not  
303 yet been translocated to the seeds (Otte et al., 2019; Keene et al., 2017).

304         From this perspective, the overall regression analysis of DM decomposition and N  
305 release for all treatments was significant at the 1% level according to the F-test ( $p < 0.01$ ).  
306 Additionally, the K and  $K_N$  parameters, derived from the exponential regression equations, were

307 statistically significant according to the  $t$ -test ( $p < 0.05$ ). Thus, the corresponding half-live  
 308 values, calculated from  $K$  and  $K_N$ , likely reflect differences in the chemical characteristics and  
 309 the proportion of plant tissues present in the residues of the CC (Table 3).

310 **Table 3:** Exponential regression equations for estimating dry matter decomposition and residual nitrogen over  
 311 time (90 days evaluation period) in residues of summer cover crops species. Piracicaba, SP, Brazil.

Species	Remaining Dry Matter (RDM)				
	Equation	$K$ day <sup>-1</sup>	$T_{1/2}$ days	$R^2$	$p$ -value ( $K$ )
<i>Canavalia ensiformis</i>	$y = 96.69 e^{-0.0501t}$	0.0501	14	0.92*	0.0279
<i>Crotalaria juncea</i>	$y = 94.31 e^{-0.0398t}$	0.0398	17	0.88*	0.0436
<i>Urochloa ruziziensis</i>	$y = 92.28 e^{-0.0320t}$	0.0320	21	0.84*	0.0489
<i>Pennisetum glaucum</i>	$y = 90.23 e^{-0.242t}$	0.0242	27	0.84*	0.0486
<i>Zea mays</i>	$y = 89.00 e^{-0.0179t}$	0.0179	39	0.83*	0.0448
Species	Remaining Nitrogen (RN)				
	Equation	$K_N$ day <sup>-1</sup>	$N_{1/2}$ days	$R^2$	$p$ -value ( $K_N$ )
<i>Canavalia ensiformis</i>	$y = 95.56 e^{-0.0435t}$	0.0435	16	0.91*	0.0331
<i>Crotalaria juncea</i>	$y = 93.24 e^{-0.0338t}$	0.0338	20	0.88*	0.0415
<i>Urochloa ruziziensis</i>	$y = 91.44 e^{-0.0242t}$	0.0242	28	0.88*	0.0338
<i>Pennisetum glaucum</i>	$y = 90.18 e^{-0.0198t}$	0.0198	35	0.86*	0.0362
<i>Zea mays</i>	$y = 91.06 e^{-0.0149t}$	0.0149	46	0.90*	0.0208

312  $K$ : Biomass decomposition rate;  $T_{1/2}$ : Plant residue half-life;  $K_N$ : Nitrogen release rate;  $N_{1/2}$ : Nitrogen release half-  
 313 life;  $R^2$ : Adjustment coefficient of determination for estimating  $K$  or  $K_N$ ; (\*) Indicates that the overall regression  
 314 model was significant at the 1% level according to the F-test ( $p < 0.01$ );  $p$ -value: Refers to the significance of the  
 315  $K$  or  $K_N$  coefficient, a component of the exponential regression equation, assessed by the  $t$ -test ( $p < 0.05$ ).  
 316

317 For example, jack bean and sunn hemp exhibited the highest  $K$  values (0.0501 and  
 318 0.0398 day<sup>-1</sup>, respectively) and the lowest  $T_{1/2}$  among treatments (14 and 17 days). The  
 319 predominance of leaves and flowers in their residues, rich in labile compounds and nutrients,  
 320 likely favored their rapid decomposition process (Cotrufo et al., 2015; Khatounian, 2001; Otte  
 321 et al., 2019). The evolution of the C/N ratio in Fabaceae species supports this hypothesis (Figure  
 322 2D), as the lower proportion of recalcitrant organs, such as lignified stems with high  
 323 polyphenols content, resulted in lower C/N ratio values over time compared to grasses.

324 This result is consistent with the findings of Calonogo et al. (2012), who also reported  
 325 that the C/N ratios of the legume CC *Dolichos lablab* L. were lower than those observed for  
 326 Poaceae species over a 135-day evaluation period. Therefore, the observed increase in the C/N  
 327 ratio after 30 days (Figure 2D), for all treatments, could be associated with the decomposition

328 of recalcitrant compounds, such as cellulose and hemicellulose, following the final degradation  
329 process of leaves and flowers (as evidenced by visual assessments). Similar findings have been  
330 reported by Weiler et al. (2022), suggesting that the breakdown of cellulose intensifies after the  
331 decomposition of labile compounds. Against this background, the variations in C/N ratios  
332 among CC over time could also be attributed to the higher concentrations of polyphenols and  
333 lignin in Poaceae residues compared to those of Fabaceae species (Table 1)

334 Additionally, despite presenting similar C/N ratios, Congo grass and pearl millet  
335 exhibited markedly different decomposition dynamics. Congo grass decomposed more rapidly,  
336 with a higher K value and shorter half-life (21 days) than pearl millet (28 days). This divergence  
337 suggests that other biochemical traits, such as lignin content, may have exerted a decisive  
338 influence in regulating decomposition rates. These results reinforce that the C/N ratio alone is  
339 not a sufficient predictor of residue degradation, aligning with previous findings that emphasize  
340 the influence of structural compounds like lignin and polyphenols (Singh et al., 2020;  
341 Mangaravite et al., 2023; Thapa et al., 2022; Weiler et al., 2022).

342 Interestingly, these both species exhibited similar PRQI values (Table 5), which,  
343 according to Tian, Brussaard, & Kang (1995), would imply comparable rates of biomass  
344 decomposition and N release. However, the present findings contradict this expectation, as pearl  
345 millet and Congo grass displayed distinct values for both K and  $N_{1/2}$ , indicating clear differences  
346 in DM and N release dynamics. These results suggest that PRQI alone may not fully capture  
347 the complexity of residue decomposition, particularly when factors such as N forms or tissue  
348 compartmentalization play a significant role in regulating mineralization processes.

349 Furthermore, our findings on biomass decomposition rates differ from those reported by  
350 Costa et al. (2016), who observed slower decomposition of *Urochloa* spp. compared to pearl  
351 millet. These discrepancies could be derived from environmental conditions (air temperature  
352 and humidity), differences in the phenological stage at termination, or methodological factors

353 related to the litter bag technique. In this sense, Saadat et al. (2025) highlight that variations in  
354 litter bag preparation (residue particle size, drying methods and amount of residue) can  
355 significantly affect biomass decomposition and N release, influencing microbial activity and  
356 the comparability of results across studies (Keuskamp et al., 2013).

357 The maize crop, in turn, exhibited the lowest decomposition rate and the highest  $T_{1/2}$ .  
358 This response can be attributed to the high initial C/N ratio and lignin content (Table 1), as well  
359 as the greater proportion of recalcitrant fractions compared to labile ones (Chen et al., 2009).  
360 Moreover, it is noteworthy that the half-life values observed in this study were at least twice as  
361 low as those typically reported in rainfed conditions (Hahn et al., 2024; Moreira et al., 2009;  
362 Pacheco et al., 2017). In contrast, our results were more similar to those found by Torres et al.  
363 (2021) under irrigated conditions, suggesting that favorable climatic conditions, particularly  
364 accumulated rainfall, played a crucial role in enhancing microbial activity and thereby  
365 accelerating residue decomposition and N release process.

366 In this sense, the high relative humidity (RH) and frequent rainfall events observed  
367 during the first month of evaluation (November 2024) likely contributed to the accelerated  
368 breakdown of more labile residues (Figure 2). These findings align with Thapa et al. (2022),  
369 who highlighted precipitation and RH as key drivers of residue decomposition. Additionally,  
370 the use of fresh (non-dried) residues in the litter bags could also have contributed to the shorter  
371 half-life values observed in this study, as reported by Saadat et al. (2025).

### 372 **3.2 Cover crops N release**

373 The pattern of remaining N closely mirrored that of DM loss, with significant  
374 differences observed among treatments ( $p < 0.01$ ) (Table 4; Figure 2B). Effect size values ( $\eta^2$ )  
375 reinforced this result, highlighting the strong influence of species-specific residue quality on N  
376 retention. Overall, the consistently elevated  $\eta^2$  values demonstrate the statistical robustness of

377 the data and the adequacy of the experimental design. In this manner, previous studies indicate  
 378 that N release is directly related to plant decomposition, as most nutrients are concentrated in  
 379 leaf tissues for structural and storage functions (Doneda et al., 2012; Varela et al., 2017).

380 **Table 4:** Mean values ( $n = 4$ ) of remaining nitrogen in cover crop plant residues at each sampling period, reflecting  
 381 the dynamics of nitrogen release during decomposition. Piracicaba-SP, Brazil.

Species	Time (days)				
	0	15	30	60	90
	Percentage (%) of Remaining Nitrogen				
<i>Zea mays</i>	100	62.90 a	52.41 a	39.11 a	32.46 a
<i>Pennisetum glaucum</i>	100	54.87 ab	41.88 b	31.98 ab	26.94 b
<i>Urochloa ruziziensis</i>	100	51.79 bc	39.92 bc	27.69 bc	23.56 b
<i>Crotalaria juncea</i>	100	42.88 cd	30.99 cd	25.17 bc	15.71 c
<i>Canavalia ensiformis</i>	100	38.00 d	28.11 d	20.46 c	12.39 c
CV (%)	--	9.11	10.54	7.50	7.71
<i>p</i> -value	--	< 0.001	< 0.001	0.006	< 0.001
$\eta^2$	--	0.65	0.85	0.76	0.96
	Remaining Nitrogen (kg ha <sup>-1</sup> )				
<i>Pennisetum glaucum</i>	216.14	50.59 a	28.17 a	17.80 a	11.35 a
<i>Crotalaria juncea</i>	244.80	36.37 b	20.78 ab	12.43 ab	4.89 c
<i>Urochloa ruziziensis</i>	138.18	35.00 b	22.17 a	12.25 ab	7.65 b
<i>Zea mays</i>	62.12	20.06 c	12.76 bc	8.97 bc	4.98 b
<i>Canavalia ensiformis</i>	103.30	16.84 c	10.30 c	4.14 c	2.11 d
CV (%)	--	7.90	22.09	23.51	16.31
<i>p</i> -value	--	< 0.001	0.002	< 0.001	< 0.001
$\eta^2$	--	0.86	0.79	0.79	0.93

382 Means followed by the same letter in the same column do not differ significantly according to Tukey's test at the  
 383 5% significance within the same evaluation period. CV (%): coefficient of variation. *p*-value: probability  
 384 associated with the F-test from ANOVA.  $\eta^2$ : effect size, indicating the proportion of variance explained by  
 385 treatments at each sampling time;  $\eta^2$  values > 0.14 represent a large treatment effect (Cohen, 1988). Data presented  
 386 in kg ha<sup>-1</sup> for 15 days were transformed using the square root method ( $\sqrt{x}$ ).

387 Nevertheless, the NAR from pearl millet (206 kg ha<sup>-1</sup>) after 90 days was higher than  
 388 that of jack bean (101 kg ha<sup>-1</sup>) and comparable to sunn hemp (Table 5). This result contrasts  
 389 with previous studies reporting that Poaceae species generally release less N than legumes  
 390 (Canalli et al., 2020; 2012; Adetunji et al., 2020). Thus, rather than botanical classification, our  
 391 results suggests that N release dynamics appear to be more strongly influenced by biomass  
 392 production and the phenological stage at termination (Khatounian, 2001; Adetunji et al., 2020).  
 393 Supporting this interpretation, Singh et al. (2020) observed similar NAR patterns, attributing  
 394 the rapid N release within two weeks of termination to elevated air temperatures and humidity

395 during the early decomposition phase, as well as to the early termination management of CC,  
396 which preserved a higher proportion of labile compounds in plant tissues.

397         Thereafter, clear differences were observed among CC species in terms of  $K_N$  and  $N_{1/2}$   
398 (Table 4). Jack bean and Sunn hemp exhibited the fastest N release, with  $K_N$  values of 0.0435  
399 and 0.0338  $\text{day}^{-1}$  and  $N_{1/2}$  of 16 and 20 days, respectively, likely due to their high content of  
400 labile compounds and low initial C/N ratios. Congo grass exhibited intermediate values ( $K_N =$   
401 0.0242  $\text{day}^{-1}$ ;  $N_{1/2} = 28$  days), while pearl millet presented a slightly lower  $K_N$  (0.0198  $\text{day}^{-1}$ )  
402 and higher  $N_{1/2}$  (35 days), probably reflecting its higher lignin content (Table 1). Thus, maize  
403 exhibited the slowest N release among treatments, with the lowest  $K_N$  (0.0149  $\text{day}^{-1}$ ) and the  
404 highest  $N_{1/2}$  (46 days), which can be attributed to the predominance of lignified stems and its  
405 higher initial C/N ratio. These differences are consistent with Weiler et al. (2019), who reported  
406 that higher proportions of recalcitrant compounds delay N mineralization, whereas residues rich  
407 in soluble and easily degradable fractions promote faster nutrient release (Table 1).

408         On the other hand, our findings contrast with those of Nascente et al. (2014), who  
409 reported significantly lower  $N_{1/2}$  values for pearl millet compared to Congo grass and observed  
410 more marked differences in both  $T_{1/2}$  and  $N_{1/2}$  among CC. Nonetheless, our results are consistent  
411 with the well-established hypothesis that tropical legumes tend to release N more rapidly due  
412 to their lower C/N ratios and lignin content, whereas tropical grasses retain more biomass and  
413 thus provide more persistent soil cover (Hahn et al., 2024; Souza et al., 2025; Torres et al.,  
414 2021; Weiler et al., 2019). In addition, the overall performance of each species corroborated the  
415 expected balance between residue decomposition rate and mulch persistence.

### 416 **3.3 Plant residue quality indices**

417         The PRQI calculated using Equation (5) differed among the evaluated species, except  
418 for pearl millet and Congo grass, which showed similar values (Table 5). PRQI values ranged  
419 from 5.87 for maize to 16.44 for jack bean, supporting the assertion by Tian, Brussaard & Kang,

420 (1995) that crop residues tend to have lower PRQI than agroforestry species. Considering  
 421 biomass decomposition and N release, the plant residues of the analyzed species followed a  
 422 descending PRQI order: jack bean > sunn hemp > pearl millet  $\approx$  Congo grass > maize.

423 **Table 5:** Components and results of the indices that evaluate the quality of the plant residues from the summer  
 424 cover crops at the end of 90 days. Piracicaba-SP, Brazil.

Species	NAR	RDM	NRI	RDMI	RBQI	PRQI
	----- (kg ha <sup>-1</sup> ) -----					
<i>Pennisetum glaucum</i>	206	2750	0.86	1.00	0.86	7.60
<i>Urochloa ruziziensis</i>	131	2344	0.55	0.85	0.47	7.57
<i>Crotalaria juncea</i>	240	1094	1.00	0.40	0.40	13.37
<i>Zea mays</i>	57	1250	0.24	0.45	0.11	5.87
<i>Canavalia ensiformis</i>	101	406	0.42	0.15	0.06	16.44
Ideal Cover crop	240	2750	1.00	1.00	1.00	---

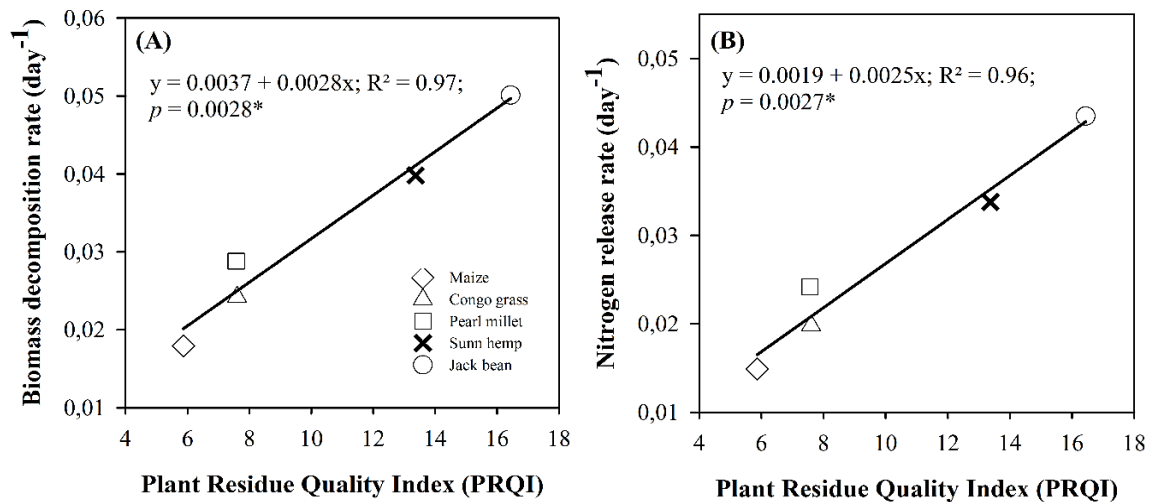
425 NAR: Nitrogen accumulated release; RDM: Remaining dry matter; NIR: Nitrogen release index; RDMI:  
 426 Remaining dry mass index; RBQI: Residual biomass quality index; PRQI: Plant residue quality index.

427 These results suggests that biomass decomposition may be sufficiently explained by the  
 428 chemical composition of CC residues, as supported by previous studies (Gama-Rodrigues et  
 429 al., 2007; Pacheco et al., 2017; Thapa et al., 2022; Weiler et al., 2022). Furthermore, the PRQI  
 430 values obtained in this research showed a direct and significant ( $p < 0.01$ ) correlation with the  
 431 parameters K and  $K_N$ , a result also observed by Tian, Brussaard & Kang (1995) when evaluating  
 432 plant residues from other five different species (Figure 3). However, these findings contrast  
 433 with Mandro (2024), who found no significant differences in PRQI values among summer CC,  
 434 likely due to the exclusion of polyphenol concentrations from the index calculation.

435 Nonetheless, further research on plant residue from various CC and diverse climatic  
 436 conditions are necessary to validate the applicability of PRQI, considering different agronomic  
 437 factors. For instance, Tian, Brussaard & Kang (1995) observed a correlation between PRQI and  
 438 key variables such as soil temperature, soil moisture levels, microbial diversity, and the yield  
 439 of maize grown in succession, critical aspects that were not the objective of this study.

440 From this perspective, PRQI stands out as a potential predictive tool for assessing the  
 441 response of CC residues in crop rotation systems. Its direct and significant correlation with the  
 442 parameters K and  $K_N$  allows for an estimation of a species' decomposition rate and nutrient

443 cycling potential even before sowing. This predictive capacity enables informed decision-  
 444 making regarding species selection to align with specific agricultural objectives. For instance,  
 445 in no-tillage systems, species with low PRQI values can enhance soil structure and moisture  
 446 retention, whereas high PRQI species can rapidly supply N to subsequent crops, reducing  
 447 fertilizer dependency (Souza et al., 2025; São Miguel et al., 2018; Tiftonell & Giller, 2013).

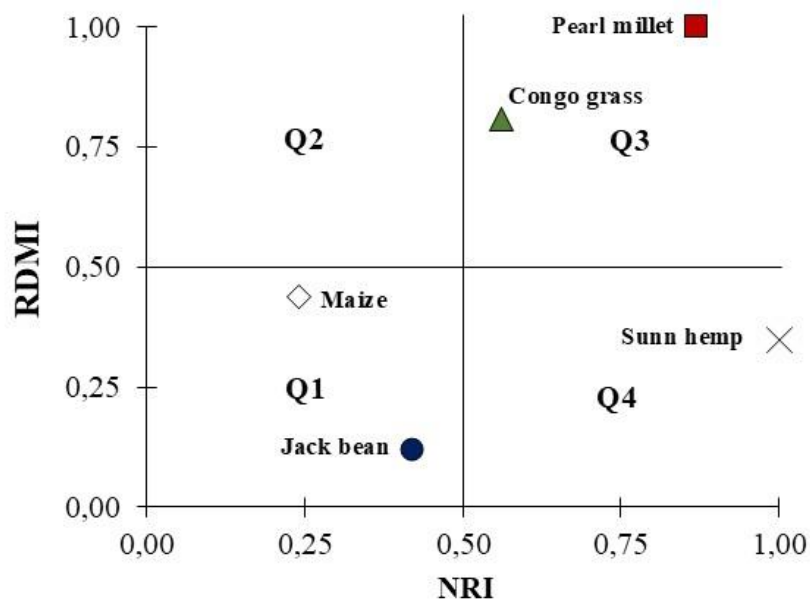


448 **Figure 3:** Linear regression analysis between the Plant Residue Quality Index (PRQI) and (A) biomass  
 449 decomposition rate (K) and (B) nitrogen release rate (K<sub>N</sub>) in residues of the evaluated summer cover crops. (\*)  
 450 indicates statistical significance of the linear regression analysis at the 1% level ( $p < 0.01$ ).

451 Meanwhile, the RBQI represents a theoretical model based on the RDMI and NRI in  
 452 comparison to an ideal species (Cassol et al., 2023). In this regard, sunn hemp and pearl millet  
 453 were identified as the ideal CC for N release (240 kg ha<sup>-1</sup>) and continuous soil cover (2750 kg  
 454 ha<sup>-1</sup>), respectively. Considering the balance between maximum NAR and the highest RDM  
 455 production, the plant residues of the evaluated species followed the descending RBQI order:  
 456 jack bean > maize > sunn hemp > Congo grass > pearl millet (Figure 4).

457 In this study, pearl millet exhibited the highest RBQI (0.86), indicating an optimal  
 458 balance between soil cover maintenance and N release. Congo grass (0.55) and sunn hemp  
 459 (0.40) showed intermediate performance, with Congo grass standing out for its favorable  
 460 combination of residue persistence and N availability. Conversely, maize (0.11) and jack bean

461 (0.06) presented the lowest RBQI values, reflecting either limited N release or rapid biomass  
 462 decomposition, patterns likely driven by differences in chemical composition and C/N ratios.



463 **Figure 4:** Points of intersection of the Remaining Dry Matter Index (RDMI) and Nitrogen Release Index (NRI) of  
 464 the evaluated summer cover crops species. Piracicaba-SP, Brazil.

465 The superior performance of tropical forage species, particularly pearl millet and Congo  
 466 grass can be attributed to their higher DM production and greater concentrations of lignin and  
 467 polyphenols (Table 1), which contributed to longer residue persistence and a more gradual N  
 468 release over the 90-day evaluation period. These findings align with previous studies  
 469 emphasizing the role of forage grasses in improving efficiency of nutrient use, reducing N yield  
 470 gaps, and enhancing soil protection in tropical cropping systems (Baptistella et al., 2020; Batista  
 471 et al., 2024; Souza et al., 2024). Additionally, the higher RBQI values observed for pearl millet  
 472 and Congo grass corroborate the results reported by São Miguel et al. (2018) and Araújo et al.  
 473 (2024), who highlighted the agronomic benefits of these species in tropical crop rotations,  
 474 particularly their contributions to soil cover and nutrient cycling efficiency.

475 Thus, although both PRQI and RBQI aim to evaluate plant residue quality, they appear  
 476 to serve distinct purposes and are grounded in different theoretical approaches. PRQI, based  
 477 exclusively on the chemical composition of plant residues, is intended to estimate their potential

478 for decomposition and nutrient release. RBQI, in turn, incorporates experimental data on N  
479 release and biomass persistence in relation to a reference standard. From this perspective, PRQI  
480 may be more applicable to preliminary assessments before field application, while RBQI seems  
481 more appropriate for retrospective analyses grounded in empirical data.

482         Ultimately, the adoption of PRQI and RBQI presents a promising strategy for selecting  
483 CC species according to specific agronomic goals, with potential benefits for soil conservation  
484 and nutrient management in tropical systems (Souza et al., 2025; Rigon, Franzluebbbers &  
485 Calonego, 2020). Despite that, the present study was limited to a single cropping season, one  
486 geographical location, and focused solely on CC species, without including field measurements  
487 of soil nutrient dynamics or cash crop responses. Additionally, the use of the litter bag method  
488 may not fully represent natural decomposition processes due to microenvironmental alterations.  
489 Therefore, future research should evaluate these indices under a wider range of edaphoclimatic  
490 conditions, across multiple years, and integrate direct assessments of soil fertility and cash crop  
491 productivity to improve the robustness and practical applicability of our findings.

#### 492 **4. CONCLUSIONS**

493         The residue quality indices effectively differentiated summer CC in terms of their  
494 decomposition and N release potential. PRQI showed a strong correlation with kinetic  
495 parameters ( $K$  and  $K_N$ ), indicating its utility in predicting nutrient cycling efficiency. RBQI  
496 highlighted species with balanced N accumulation and biomass production, such as *Pennisetum*  
497 *glaucum* and *Urochloa ruziziensis*. These indices are valuable tools for selecting CC in tropical  
498 no-till systems, aiming to improve N cycling and promote long-term soil conservation.

#### 499 **5. AUTHORS CONTRIBUTION**

500         Conceptual idea: Dias, V.O.; Favarin, J.L.; Khatounian, C.A.; Methodology design:  
501 Dias, V.O.; Favarin, J.L.; Souza, M.E.A.; Santana, D.M.; Ribas, G.G.; Data collection: Dias,

502 V.O.; Souza, M.E.A.; Santana, D.M.; Data analysis and interpretation: Dias, V.O.; Souza,  
503 M.E.A.; Khatounian, C.A.; Piero, J.A.R.; Writing and editing: Dias, V.O.; Favarin, J.L.;  
504 Khatounian, C.A.; Piero, J.A.R.; Ribas, G.G.

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## 512 **7. CONFLICT OF INTEREST**

513 The authors declare no competing financial or personal interests that could have  
514 influenced the work reported in this manuscript.

## 515 **8. DATA AVAILABILITY**

516 The data that support the findings of this study are not publicly available but can be  
517 obtained from the corresponding author upon request ([victordeoliveiradias@usp.br](mailto:victordeoliveiradias@usp.br)).

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