

Decomposition and nutrients released from forest and perennial crops associated with organic coffee

João Batista Silva Araujo¹, Matheus Wandermurem da Silva¹, Wallace Luís de Lima², Ana Claudia Hertel Pereira³,
Denise Coutinho Endringer³, Jacimar Luís de Souza¹

¹Instituto Capixaba de Pesquisa Assistência Técnica e Extensão Rural/Incaper, Vitória, ES, Brasil

²Instituto Federal de Educação Ciência e Tecnologia do Espírito Santo/IFES, Alegre, ES, Brasil

³Universidade Vila Velha/UVV, Vila Velha, ES, Brasil

Contact authors: joaoaraujovni@gmail.com; matheus_wandermurem@hotmail.com; wallace@ifes.edu.br; anahertel@gmail.com; endringe@gmail.com; jacimar6@gmail.com

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ABSTRACT

Agroforestry consortia increase organic matter and nutrient cycling in agricultural systems. For this reason, the objective of this work was to study the release rate of nutrients and the decomposition of different organic residues, two times of the year, obtained from four cultures intercropped with conilon coffee, aiming to relate the released nutrients to the coffee needs. The decomposition of organic matter residues and the release of nutrients from *Inga edulis*, *Musa* spp, *Gliricidia sepium*, and *Bactris gasipaes* were evaluated in two different periods. *I. edulis* residues with a higher amount of polyphenols, and those of *Musa* spp, with a higher C/N ratio, showed slow decomposition. The decomposition rates were lower in experiments started in March and higher in August. Inga and banana have high residual values of nutrients at 270 days in the decomposition started in March.

Key words: Agroforestry system; Organic coffee; SAF synchrony; Consortium; Low input.

1 INTRODUCTION

Agroforestry systems (SAFs) and consortia of perennial crops are important in the agroecological context, as they increase biodiversity and sustainability (Zapata Arango, 2019). Trees promote the increase of organic matter in SAFs and greater nutrient cycling, bringing nutrients from deeper levels to the soil surface, making them available for the crop of commercial interest (Isaac; Borden, 2019).

Among the species used in SAFs, legumes (Fabaceae), that fix nitrogen biologically (N-BNF), are important. The N of these fixing species can be transferred to the receiving plants by decomposition and mineralizing organic residues (Munroe; Isaac, 2014). The management of these shade trees is done, traditionally by coffee growers from Costa Rica, through pruning according to the coffee phenology. They prune at the end of the dry season to promote flowering and complete pruning before harvest to promote fruit ripening (Nygren et al., 2012).

There must be synchronization with the input of organic residues and the nutrients released to meet the coffee needs and their nutritional demands. For this reason, it is necessary to know the composition of residues and its decomposition rates (Duarte et al., 2013; Munroe; Isaac, 2014; Petit-Aldana et al., 2019). As the coffee demand for nutrients is highest during fruiting (DaMatta, 2007; Partelli et al., 2014), fertilization should occur between October and March (Partelli et al., 2014).

Decomposition can be evaluated with litterbags (Petit-Aldana et al., 2019) and covered litter (Ribas et al., 2010), aiming to facilitate soil fauna access to organic residues. The

results obtained generate mathematical models, including the single and double exponential (Petit-Aldana et al., 2019), generating decomposition and nutrient release curves.

Some species have a rapid decomposition, such as *Gliricidia sepium* (Kaba et al., 2019; Paula et al., 2015; Pérez-Marin; De Arruda Sarmento; Vendruscolo, 2018). Other species tend to be more recalcitrant and slow to decompose, such as *Inga edulis* (Leblanc; Nygren; Mcgraw, 2006), *Inga semialata* (Silva et al., 2008) and *Inga subnuda* (Duarte et al., 2013). So, if nutrient release is too fast, nutrients can be lost to leaching or volatilization, and if it is slow, they can be made available in insufficient quantities (Petit-Aldana et al., 2019).

The chemical composition of the residues, the community of decomposers and environmental factors such as soil, humidity and temperature influence the decomposition rate (Petit-Aldana et al., 2019). In the chemical composition, the C/N ratio and N, hemicellulose, cellulose, lignin and polyphenols content is important (Aita; Giacomini, 2003; Duarte et al., 2013; Handayanto; Cadish; Giller, 1994; Petit-Aldana et al., 2019; Silva et al., 2008). Higher levels of lignin and polyphenols provide recalcitrant behavior and higher levels of hemicellulose and cellulose labile behavior. Muchecheti and Madadze (2016), for example, observed rates of N release with *L. leucocephala* > *A. angustissima* > *C. calothyrsus* > *A. karoo*, being negatively correlated with lignin levels, soluble condensed tannins and lignin/N ratio. Duarte et al. (2013) observed Lignin/N and (Lignin + polyphenol)/N ratios negatively correlated with CO₂ flow, indicating less decomposition with higher lignin levels and polyphenols.

Therefore, it's necessary to know the dynamics of the input of organic residues in the system, on which the productive response of the coffee will depend. The synchrony between coffee nutrition, the moment of application of organic residues and the decomposition rates can determine the best crop response. For this reason, the objective of this work was to study the decomposition and nutrients release from four different organic residues, at two times of the year, obtained from cultures intercropped with the conilon coffee tree, aiming to know the release of nutrients and relate to the coffee needs.

2 MATERIAL AND METHODS

This work was carried out at the Agroforestry System Observation Unit, implanted in January 2013 at the Experimental Farm of Bananal do Norte (FEBN), with latitude 20°45'15.16" S, longitude 41°17'04.98" W and altitude of 96 m, in the municipality of Cachoeiro de Itapemirim, ES, Brazil. The local climate is tropical, with dry winter, of the Aw type in the Köppen-Geiger climate classification (Alvares et al., 2013). It has 18.0 °C of minimum temperature in the coldest month and 31 °C in the warmest, average annual precipitation of 1,046 mm (Agrometeorologia, Incaper). During the study, precipitation was obtained using a pluviometer, already installed at the experimental farm (Figure 1).

The total area, 6,170 m², was divided into five plots, with 15 sample points per plot, containing five coffee trees. One plot was planted with coffee in monoculture (CMON) and the other four in consortia with: inga (*Inga edulis* Mart) (CING); gliricidia (*Gliricidia sepium* Jacq. Steud) (CGLI);

banana (*Musa* spp. cv. Japira) (CBAN) and peach palm (*Bactris gasipaes* Kunth) (CPP). The variety of *Coffea canephora* Emcaper 8151 (Robusta Tropical), with maturation in May-June (Ferrão et al., 2017), was planted. The coffee tree was planted at 3.0 x 1.0 m (3,333 plants ha⁻¹); banana and peach palm were 3.0 x 6.0 m (556 plants ha⁻¹); for gliricidia and inga it was 6.0 x 6.0 m (278 plants ha⁻¹), replacing coffee trees in planting lines.

The fertilization was 80 m³ ha⁻¹ year⁻¹ of organic compost, divided into November and February, providing, on average, in kg ha⁻¹ year⁻¹: 147.1 N; 29.4 P; 98.0 K; 77.2 Ca and 58.8 Mg. The compost was made with chicken manure, coffee husk, bovine manure, and *Panicum maximum* (Jacq.) grass. Chemical analyzes of soils were carried out in June 2017 (Table 1). Soil samples were collected with a manual post hole digger (1.5 dm³), in the coffee canopy projection, 0.00-0.20 m deep, in 12 sampling points per plot, with three sub-samples per sample. The calculation for fertilization was made according to Prezotti (2020) for the productivity of 39.5 sc ha⁻¹ (Ferrão et al., 2017).

The coffee tree was performed with four stems per plant. Peach palm was managed without pruning. The banana tree was conducted with three pseudostems per plant (Costa et al., 2006). Inga and gliricidia were pruned in March and August of each year, starting in March 2014, aiming at 35% shade (Farfán; Baute, 2010). Gliricidia receiving drastic pruning (100%) in August.

Biomass production was measured at six sample points with one plant per point. The total production of green matter at each point was weighed and samples

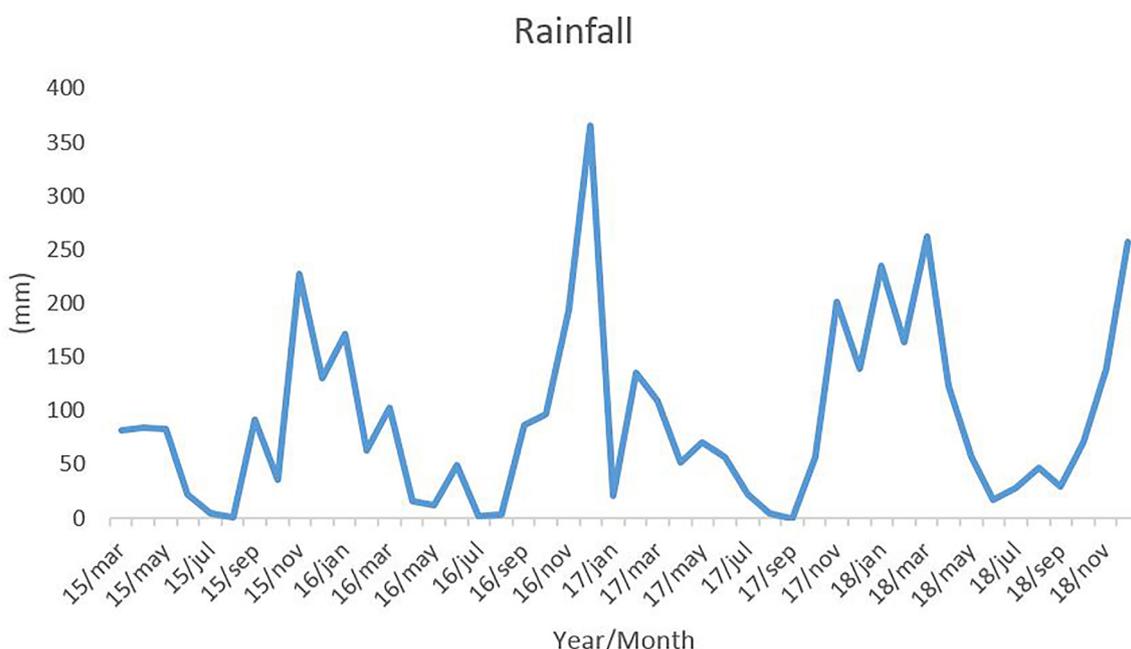


Figure 1: Monthly rainfall from March/2015 to December/2018, at FEBN, Cachoeiro de Itapemirim, ES. Source: Experimental Farm of Bananal do Norte, INCAPER.

were collected. Weighing leaves and banana pseudostem were separate, collecting samples from one leaf and four pseudostem discs at points equidistant from the base to the top. The discs were 0.05 m high. The peach palm sample was from a medium leaf, collected after the palm heart was harvested. One branch per tree was collected to sample gliricidia and inga. At four equidistant points, between the tip and base of the branch, 0.10 m pieces were cut, including the leaves present in each part. The samples were dried at 65 °C in a forced air circulation oven and then weighed, ground in a Willey mill and analyzed to determine the nutrient content (Table 2). The biomass productivity was calculated by multiplying the average of the sample points by the number of plants per hectare (Table 3). The samples of gliricidia and inga were collected at the time of pruning and those of banana and peach palm were estimated in the harvests throughout 2017.

The neutral fiber analysis was performed according to the methodology described by Souza et al. (1999).

The equation obtains the fiber calculation in neutral detergent: $NDF (\%) = ((CB) \times 100)A^{-1}$, where A is the mass of the sample, B refers to the weight of the empty and dry crucible and C is the weight of the crucible with the residue at the end of the procedure. The analysis of acidic fiber (cellulose, lignin) was also performed as described by Souza et al. (1999). The same equation obtains the calculation of fiber in acid detergent as the neutral fiber.

The quantification of cellulose and lignin was adapted from the description by Gresser (Graça; Barlocher; Gressner, 2005). Briefly, to the crucible contents, 75% sulfuric acid was added and homogenized to break up the existing lumps, and the process was repeated three times. The calculation consists of $\%lignin = ((DB)-(EB)) \times 100A^{-1}$, where A is the mass of the sample, B refers to the weight of the empty and dry crucible and C is the weight of the crucible with the residue after adding the acid and E as the weight of the crucible with residue after incineration.

Table 1: Chemical attributes of the soil in monoculture conilon coffee (CMON) and intercropped with inga (CING), banana (CBAN), gliricidia (CGLI) and peach palm (CPP).

Consortium	pH	P	K	Ca	Mg	H+ Al	SB and t	T	V	SOM
CMON	7.06	100.5	329.4	4.00	0.973	1.30	5.83	7.15	81.5	14.0
CING	6.93	99.8	259.7	3.63	0.700	1.11	5.00	6.11	81.5	13.4
CBAN	6.77	105.8	191.8	3.97	1.100	1.33	5.56	6.88	80.6	11.9
CGLI	6.95	101.6	311.7	4.66	1.230	1.18	6.72	7.90	85.0	19.9
CPP	6.89	78.9	347.5	4.13	0.818	1.32	5.84	7.16	81.4	18.5

pH, in H₂O; P e K: extractor Mehlich 1; H+AL: potential acidity, extractor SMP; SB: sum of bases; (t): effective cation-exchange capacity; T: potential cation-exchange capacity; BS, base saturation; SOM, soil organic matter (Oxidation – Na₂Cr₂O₇ + H₂SO₄ 10N).

Table 2: Nutrient content in residues of species intercropped with conilon coffee. Cachoeiro de Itapemirim, ES.

Date	Species	C/N	N	P	K	Ca	Mg
27/Mar/2015	Inga	35.2	15.17	1.44	9.07	7.21	1.23
	Gliricidia	18.2	27.83	1.28	8.96	11.40	3.44
	Banana	68.8	8.17	1.56	8.13	9.39	5.44
	Peach palm	33.4	18.73	2.25	10.32	5.10	2.66
03/Aug/2016	Inga	26.5	22.68	1.20	5.63	10.79	1.06
	Gliricidia	25.7	22.03	1.12	7.09	10.57	2.73
	Banana	48.2	11.62	0.91	12.29	12.29	2.75
	Peach palm	33.1	13.79	2.21	12.71	6.43	1.77
29/Mar/2017	Inga	40.6	14.21	0.92	8.34	5.96	0.40
	Gliricidia	39.9	13.84	0.93	11.46	6.57	2.34
	Banana	91.1	6.09	0.70	22.29	6.57	2.27
	Peach palm	26.9	20.53	2.06	14.59	2.75	1.88

N: sulfuric digestion with titrometric determination; P, K, Ca and Mg: Nitro-perchloric digestion. C: muffle combustion at 550 °C.

Table 3: Green matter (GM), dry matter (DM) and total nutrients of compost (COMP) and inga (ING), banana (BAN), gliricidia (GLI) and peach palm (PP). Cachoeiro de Itapemirim, ES.

Source	GM (t ha ⁻¹)	DM (t ha ⁻¹)	N	P	K (kg ha ⁻¹)	Ca	Mg
Compost	20.90	12.26	147.12	29.40	98.00	77.20	58.80
ING (a)	13.50	5.34	121.11	6.41	30.06	57.62	5.66
ING (b)	6.16	3.17	45.01	2.85	26.31	19.02	1.27
GLI (a)	15.70	7.34	161.70	8.22	52.04	77.58	20.04
GLI (b)	13.77	4.70	64.86	4.23	54.05	31.02	10.81
BAN	9.72	1.46	12.92	1.17	25.22	13.77	3.68
PP	3.26	0.96	13.20	2.11	12.16	6.15	1.69
Amount							
COMP + ING	40.57	20.77	313.24	38.66	154.37	153.84	65.73
COMP + GLI	50.38	24.30	373.68	41.85	204.09	185.80	89.65
COMP + BAN	30.63	13.72	160.04	30.57	123.22	90.97	62.48
COMP + PP	24.17	13.22	160.32	31.51	110.16	83.35	60.49

Compost applied in the agricultural year 2016/17. Banana and peach palm residues measured throughout 2017, and inga and gliricidia at the time of pruning on 08/Mar/2016 (a) and 29/Aug/2017 (b).

The determination of polyphenols was performed according to Krepesky et al. (2012), with adaptations. The analyzes were performed in a microplate with a reading at 715 nm of the reaction product between the solution of the plant material with the Folin-Ciocalteu reagent and sodium carbonate. As a standard, gallic acid was used, the results being expressed in gallic acid equivalent 100g⁻¹.

The biomass loss of dry matter and nutrients of inga (DM-ING), banana (DM-BAN), gliricidia (DM-GLI) and peach palm (DM-PP) were evaluated. Fresh matter samples of 0.20 kg of each species were placed on the ground (covered litter), under the coffee canopy, covered with 0.30 x 0.30 m screens and 0.004 x 0.004 m mesh (Ribas et al., 2014). Three decomposition evaluations were made with the first one started on 27/Mar/2015, with collection at 0, 7, 15, 25, 40, 60, 90, 120 and 150 days, and three replications arranged in randomized block design. In the second and third evaluations, started on 03/Aug/2016 and 29/Mar/2017, the period for DM-ING and DM-BAN was extended with collections at 0, 7, 30, 60, 90, 120, 150, 190, 230 and 270 days, because the half-life (t1/2) was not reached in the first evaluation. The remaining biomass samples were cleaned to remove the adhered soil, dried at 65 °C in a forced air circulation oven, crushed in a Willey mill and analyzed to determine the levels of N, P, K, Ca and Mg.

Decomposition rates of dry matter and mineralization of nutrients from green manures were determined by non-linear regression models, described by Wieder and Lang (1982) as cited by Aita and Giacomini (2003). The asymptotic model has the following mathematical equation: DMR or NR = A e^{-kat}, where: DMR and NR correspond to the percentage of dry matter and nutrient remaining at time t; t is the sampling time

from 0 to 150 or 270 days; ka is the constant rate of dry matter decomposition and nutrient mineralization. DMR and NR were calculated relative to DM and nutrients at time zero for each sampling time. From the decomposition constants of the DMR or NR, it was calculated the half-life time (t1/2) required for 50% to be mineralized to the soil, using the equation (t1/2) = ln 0.5k⁻¹, according to Paul and Clark (1996).

The organic matter composition data were submitted to variance analysis and the Tukey test's averages at 5% probability. The decomposition variables were analyzed using regression analysis, and the parameters of the mathematical equations were tested for significance level using the t test, using the Genes program (Cruz, 2013).

3 RESULTS

The chemical compositions of dry matter residues are shown in Table 4. In the second collection (03/August/2016) the DM-ING presented higher levels of cellulose (22.36%), LG (21.55%) and PPs (3.824%), as well as a higher LG/N (1.033) and (LG+PPs)/N (1.210) ratio than the other residues. The DM-BAN presented higher levels of hemicellulose (19.99%) and C/N ratio (48.2). The DM-GLI presented lower levels of hemicellulose (4.62%), intermediates of cellulose (12.38%) and lignin (13.56%). The DM-PP presented higher levels of hemicellulose (12.38%) and lower levels of cellulose (9.09%) and LG (7.72%).

In the third collection (29/March/2017), the DM-PP showed higher levels of hemicellulose (21.10%) concerning to the other sources (6.31% to 10.60%) (Table 4). The DM-BAN presented higher C/N ratio (91.0) and lower levels of PPs (0.425%). DM-ING showed higher polyphenols levels (2.134%) compared to other sources (0.425% to 1.081%).

Table 4: Chemical composition of inga, gliricidia, banana and peach palm collected on 03/August/2016 and 29/March/2017.

Plant	C/N	Hemic. (%)	Cellulose (%)	LG (%)	PPs (%)	LG/N	(LG+PP)/N
Inga	26.5 b	4.06 c	22.36 a	21.55 a	3.697 a	1.034 a	1.211 a
Banana	48.2 a	19.99 a	7.28 c	7.16 c	0.897 b	0.621 b	0.699 b
Gliricidia	25.7 b	6.05 bc	12.38 b	13.56 b	0.847 b	0.640 b	0.682 b
Peach palm	33.1 b	12.38 ab	9.09 bc	7.72 c	0.707 b	0.465 b	0.507 b
Inga	40.6 b	6.31 b	23.60	23.57	2.134 a	1.686	1.825
Banana	91.0 a	10.60 b	8.48	8.74	0.425 b	1.420	1.491
Gliricidia	39.9 b	8.78 b	26.82	26.53	0.432 b	1.901	1.939
Peach palm	26.9 b	21.10 a	10.64	11.86	1.081 ab	0.579	0.633

Means followed by the different letter in the columns differ by Tukey's test ($p \leq 0.05$). Hemic.: Hemicellulose; PP: polyphenols; LG/N: lignin/nitrogen (LG+PP)/N: (lignin+polyphenol)/nitrogen.

The first evaluation, between 27/Mar to 23/Aug/2015, was in the dry season (Table 1) of autumn-winter, without adjusting the equations of DM-ING and DM-BAN (Table 5), indicating accumulation on the soil. DM-GLI and DM-PP had $t_{1/2}$, respectively, at 109.1 and 82.9 days. In the second evaluation, started on 03/Aug/2016, the $t_{1/2}$ of the DM was between 87.9 days (DM-PP) and 207.1 days (DM-ING) (Table 6). In the third assessment, started in 29/Mar/2017, $t_{1/2}$ was reached only at DM-PP at 108.0 days (Table 7).

In the first evaluation, the $t_{1/2}$ of the nutrients from DM-GLI was between 39.5 days (K) and 63.5 days (N), and from DM-PP between 40.3 days (K) and 79.1 days (N) (Table 5). The $t_{1/2}$ of the DM-ING was reached with K at 101.9 days, with immobilization of Ca (119.5%) and Mg (115.8%), without adjustment for N and P. With DM-BAN $t_{1/2}$ was not achieved with all nutrients. In the second evaluation, which started on 03/Aug/2016, the $t_{1/2}$ of the nutrients ranged from 62.3 days (K) to 135.2 days (Ca) in the DM-BAN; 60.5 days (K) to 90.0 days (Ca) on DM-GLI; 47.5 days (K) to 107.9 (Ca) of DM-PP; and 137.8 days (P) to 263.2 days (Mg) on DM-ING, and not reached with Ca in DM-ING (Table 6).

In the evaluation started on 29/Mar/2017 the nutrients $t_{1/2}$ was reached between 55.1 days (K) and 136.3 days (Ca) in the DM-PP; between 46.8 days (K) and 135.1 days (S) on DM-GLI, without adjustment in the Ca equation (Table 7). With DM-BAN, only $t_{1/2}$ of K was reached at 92.3 days and with DM-ING the $t_{1/2}$ of the studied nutrients was not reached.

4 DISCUSSION

The decomposition rate shows a negative correlation with the levels of lignin and polyphenols, the C/N, LG/N and (LG+PPs)/N ratios and positive with hemicellulose and cellulose levels (Petit-Aldana et al., 2019). Silva et al. (2008) observed a higher decomposition rate of *G. sepium* than *I. semialata*, with respective values of 31.9 and 72.7 g kg⁻¹ of

PPs, 74.5 and 237.4 g kg⁻¹ of LG, 0,83 e 3,08 de PPs/N, 1,93 e 10,06 de LG/N, 2,76 e 13,14 de (LG+PPs)/N. Also, Duarte et al. (2013) observed a low decomposition rate of *I. subnuda* with a higher ratio (LG+PPs)/N (10.1). For this reason, the higher levels of LG (21.55%) and PPs (3.697%) in 2016 and PPs 2,134) in the 2017 collection, with higher LG/N (1,034) and (LG + PPs)/N (1,211) ratios, give DM-ING a recalcitrant character.

Despite not containing high levels of LG and PPs, the banana residues showed low decomposition rate. However, higher C/N ratios lead to a lower decomposition rate, and ratios below 40 are recommended for composting (Acosta et al., 2014) so that there is no immobilization of nutrients (Giacomini et al., 2015). For this reason, the high C/N ratio of the DM-BAN, between 48.0 and 91.0, induces greater recalcitrance and immobilization of nutrients.

The DM-GLI presents rapid decomposition, with $t_{1/2}$ of the oxidizable carbon of leaves at 30 days (Nyamai, 1992), loss of 69% of the dry matter after 70 days (Zaharah; Bah, 1999), $t_{1/2}$ of the dry matter after 21 days (Silva et al., 2008) and $t_{1/2}$ of 21 days in the dry season and 13 days in the rainy season (Paula et al., 2015). The observed decomposition was slower with $t_{1/2}$ of the DM-GLI at 109.1 and 132.3 days in the first and second evaluations and not reached in the third. This result is certainly due to the use of whole branches and not just leaves. The evaluation of whole branches is justified because the ratio of branches/leaves of gliricidia is 7/1, with 30% of N in the leaves (Kaba et al., 2019) and, therefore, evaluating only leaves would underestimate 70% of N contained in 87.5% of the biomass.

Unlike gliricidia, species of the genus *Inga* tend to slowly decompose the leaves with $t_{1/2}$ of 269 days of *I. semialata*, 69% of dry matter remaining after 150 days for *I. subnuda* (Duarte et al., 2013) and 67 % of dry matter remaining of *I. edulis* after 20 weeks (Leblanc et al., 2006). In this study, the decomposition rates were lower with the $t_{1/2}$ of the DM-

ING reached in 207.1 days only in the second evaluation. This resulted from the use of whole branches and not just leaves, giving a more recalcitrant character. As the pruning residue is made up of whole branches, the leaf decomposition rates estimate will tend to overestimate the decomposition and the nutrients released.

In the three evaluations analyzed, the DM-PP showed remnants of 24.1%, 23.8% and 35.2% at 150 days. Pereira et al. (2015) observed that faster decomposition with 99.7% of the DM-PP decomposed at 112 days, due to the material crushed and buried at a depth of 10 cm, facilitating the decomposition. This higher rate of decomposition of peach palm is due to the composition of the residue with a higher hemicellulose content and a tendency to lower levels of cellulose, lignin and polyphenols in comparison with the ingá

residue. Hemicellulose gives it a labile character and, mainly, lignin and polyphenols recalcitrant character (Petit-Aldana et al., 2019).

Unlike peach palm, the banana tree had a slow decomposition. Brito et al. (2017) observed a slow decomposition of Japira banana litter, with a t1/2 of 236 days in an irrigated system, corroborating the results of the first and third evaluations, with strong recalcitrance and without adjustment of the equations. However, it was slower than in the second evaluation of the present study with t1/2 at 108 days, a fact explained by the lower C/N ratio (48/1). In addition, the higher speed released of nutrients from the second evaluation, for all plants studied, coincides with the rainiest period and more humid that favors decomposition (Bona et al., 2006; Paula et al., 2015).

Table 5: Parameters of the equation $X = X_0 e^{-kt}$ adjusted to the values of dry matter (DM), N, P, K, Ca, Mg and S, half-life times, and dry matter and nutrients remaining at 150 days, of inga, banana, gliricidia and peach palm, between 27/Mar and 23/Aug/2015.

Variable	Source	X ₀ (day) (%)	K	t _(1/2) (day)	X ₁₅₀ (day) (%)	r ²
DM	Inga	90.74180	0.000114 ^{ns}	---	---	0.9
	Banana	99.77271	-0.000343 ^{ns}	---	---	3.4
	Gliricidia	88.34810	-0.006351 ^{**}	109.1	34.1	87.7
	Peach palm	83.47488	-0.008360 ^{**}	82.9	24.1	89.9
N	Inga	77.88238	-0.000553 ^{ns}	---	---	2.7
	Banana	78.44304	-0.001844 ^{ns}	---	---	9.5
	Gliricidia	70.48606	-0.010912 ^{**}	63.5	13.7	76.1
	Peach palm	76.65099	-0.008758 ^{**}	79.1	20.6	86.9
P	Inga	85.46083	-0.002484 ^{ns}	---	---	39.7
	Banana	83.53100	-0.002692 ^{ns}	---	---	37.0
	Gliricidia	96.90686	-0.012716 ^{**}	54.5	14.4	91.5
	Peach palm	88.32134	-0.009282 ^{**}	74.7	21.9	93.3
K	Inga	87.79091	-0.006804 ^{**}	101.9	31.6	81.2
	Banana	87.58088	-0.003340 ^{ns}	---	---	31.4
	Gliricidia	96.15311	-0.017545 ^{**}	39.5	6.9	93.6
	Peach palm	95.86467	-0.017206 ^{**}	40.3	7.3	88.1
Ca	Inga	79.05066	0.002755 [*]	---	119.5	56.1
	Banana	10.99765	0.000680 ^{ns}	---	---	12.5
	Gliricidia	10.06754	-0.010938 ^{**}	63.4	20.8	81.7
	Peach palm	85.35707	-0.004991 ^{**}	138.9	40.4	75.2
Mg	Inga	90.62417	0.001637 ^{**}	---	115.8	65.5
	Banana	86.04277	-0.003494 [*]	---	50.9	46.2
	Gliricidia	10.77418	-0.013017 ^{**}	53.2	15.3	82.6
	Peach palm	93.44513	-0.009625 ^{**}	72.0	22.1	86.3

* and **: Significant, respectively, at 5% and 1%.

Table 6: Parameters of the equation $X = X_0 e^{-kt}$, adjusted to the values of dry matter (DM), N, P, K, Ca, Mg and S, half-life time ($t_{1/2}$), DM and remaining nutrients at 150 and 270 days, from inga, banana, gliricidia and peach palm, between 03/Aug/2016 and 28/Apr2017.

Variable	Species	X_0	K	$t_{(1/2)}$	X_{150}	X_{270}	r^2
		(day)			(day)	(day)	
		(%)		(day)	(%)	(%)	
DM	Inga	101.04152	-0.003347**	207.1	61.2	40.9	92.0
	Banana	102.66986	-0.006383**	108.6	39.4	18.3	93.9
	Gliricidia	94.09034	-0.005239**	132.3	42.9	--	94.4
	Peach palm	101.51833	-0.007886**	87.9	31.1	--	98.6
N	Inga	92.22597	-0.004154**	166.9	49.5	30.0	94.9
	Banana	104.64953	-0.005959**	116.3	42.8	20.9	80.3
	Gliricidia	81.13838	-0.010566**	65.6	16.8	--	94.4
	Peach palm	94.82329	-0.009209**	75.3	23.8	--	97.9
P	Inga	108.47588	-0.005029**	137.8	51.0	27.9	89.1
	Banana	98.30920	-0.006337**	109.4	38.0	17.8	93.5
	Gliricidia	78.66487	-0.009333**	74.3	19.4	--	93.7
	Peach palm	116.66510	-0.011810**	58.7	19.8	--	96.9
K	Inga	132.80198	-0.004905**	141.3	63.6	35.3	85.7
	Banana	97.01592	-0.011131**	62.3	18.3	4.8	74.1
	Gliricidia	121.24075	-0.011457**	60.5	21.7	--	96.3
	Peach palm	169.62197	-0.014599**	47.5	19.0	--	86.6
Ca	Inga	105.08267	-0.002203**	---	75.5	58.0	79.5
	Banana	106.18003	-0.005126**	135.2	49.2	26.6	76.4
	Gliricidia	108.75110	-0.007698**	90.0	34.3	--	88.2
	Peach palm	105.56862	-0.006422**	107.9	40.3	--	94.2
Mg	Inga	80.75891	-0.002634**	26.2	54.4	39.7	74.8
	Banana	127.35682	-0.007217**	96.0	43.1	18.1	90.4
	Gliricidia	117.65303	-0.010263**	67.5	25.2	--	94.4
	Peach palm	94.03476	-0.009205**	75.3	23.6	--	93.6

* and **: Significant, respectively, at 5% and 1%.

As the decomposition rate is different among the residues, they can meet the needs of the coffee at different times. Tree pruning occurs before flowering and before coffee harvest (Nygren et al., 2012), meeting the need to reduce shade in crucial phenological stages, favoring the formation of flowers and fruit maturation. The flowering of Conilon coffee takes place from July to November (DaMatta, 2007), with more than 90% of flowers opened in early September, in non-irrigated condition (Marsetti et al., 2013).

The stages of fruit development coffee, in weeks after flowering, are: *pinhead* (up to 6th or 10th); *rapid swelling* (from 6th and 17th); *suspended and slow growth* (two weeks); *endosperm filling* (between 17th to 28th); and *ripe* (between the 24th to the 34th) (DaMatta, 2007). The highest fruit accumulation rates are found between the rapid swelling stage and endosperm filling, with 100%, 96%, 52% and 38%

of the total N accumulated in early, intermediate, late and very late varieties, respectively, on 12 March (Partelli et al., 2014). In this case, for intermediate varieties, fertilization must take place before March 12 for fruit formation, being a parameter to evaluate the efficiency of nutrients released by organic residues.

Gliricidia results demonstrate fast nutrients release, with 79% of P, 99% of K, 91% of Ca and 82% of Mg released of leaves after 70 days of incubation (Zaharah; Bah, 1999) and 74%, 87% and 94% of N, P and K released from fragmented thin branches after 15 days of decomposition, respectively (Pérez-Marin et al., 2018). In the present study, the release rates were slower, possibly because whole branches were used. The $t_{1/2}$ occurred between 39.5 days (K) and 63.5 days (N) in the first evaluation; between 60.5 days (K) to 90.0 days (Ca) in the first evaluation; between 46.8 days (K) and 135.1 days (S) in DM-GLI, without adjustment in the Ca equation in the third evaluation.

Table 7: Parameters of the equation $X = X_0 e^{-kt}$, adjusted to the values of dry matter (DM), N, P, K, Ca, Mg and S, half-life time ($t_{1/2}$), DM and remaining nutrients at 150 and 270 days, from inga, banana, gliricidia and peach palm, between 29/Mar and 23/Dec/2017.

Variable	Species	X_0 (day) (%)	K	$t_{(1/2)}$ (day)	X_{150} (day) (%)	X_{270} (day) (%)	r^2
DM	Inga	93.96059	-0.000843 ^{ns}	---	---	---	32.3
	Bananeira	104.80921	-0.000060 ^{ns}	---	---	---	00,1
	Gliricidia	96.71204	-0.003370 ^{**}	---	58.3	---	79.8
	Peach palm	92.13614	-0.006419 ^{**}	108.0	35.2	---	81.7
N	Inga	100.25174	-0.001348 [*]	--	81.9	69.7	60.7
	Bananeira	137.76177	0.002242 ^{ns}	--	---	---	34.7
	Gliricidia	94.35499	-0.005395 ^{**}	128.5	42.0	---	75.0
	Peach palm	86.81135	-0.009289 ^{**}	74.6	21.5	---	79.6
P	Inga	101.83421	-0.001255 [*]	---	84.4	72.6	52.0
	Bananeira	118.30578	0.002530 ^{ns}	---	---	---	33.0
	Gliricidia	112.82335	-0.005624 ^{**}	123.2	48.5	---	84.1
	Peach palm	100.48715	0.006397 ^{**}	110.1	39.1	---	85.4
K	Inga	98.08809	-0.001848 ^{**}	---	74.3	59.6	80.9
	Bananeira	84.44094	-0.007512 ^{**}	92.3	27.4	11.1	87.7
	Gliricidia	117.28988	-0.014818 ^{**}	46.8	12.7	---	90.2
	Peach palm	102.84535	-0.012579 ^{**}	55.1	15.6	---	83.0
Ca	Inga	111.73582	-0.000038 ^{ns}	---	---	---	0.1
	Bananeira	135.64112	0.002476 [*]	---	196.6	264.7	45.7
	Gliricidia	123.01469	-0.003427 ^{ns}	---	---	---	28.2
	Peach palm	119.18469	-0.005083 ^{**}	136.3	55.6	---	70.2
Mg	Inga	118.89176	0.000512 ^{ns}	---	---	---	3.3
	Bananeira	131.63323	0.001222 ^{ns}	---	---	---	20.7
	Gliricidia	117.93262	-0.005600 [*]	123.8	50.9	---	63.2
	Peach palm	109.89944	-0.005757 ^{**}	120.3	46.3	---	74.5

* and **: Significant, respectively, at 5% and 1%.

DM-GLI, from August pruning, presented $t_{1/2}$ between 60.5 days of K and 74.3 days of P (01 to 15 October) during flowering and pinhead stages, with less demand of nutrients for fruiting.

Therefore, in August pruning, the $t_{1/2}$ of nutrients from the DM-GLI, between 60.5 days of K and 74.3 days of P (01 to 15 October), coincided with the flowering and pinhead stages, of lower nutrient demand for fruiting. In March pruning, during ripe stage, DM-GLI presented $t_{1/2}$ between 46.8 days from K to 128.5 days from N (14 May to 04 August), coinciding with stages of low nutrient accumulation in fruits (Partelli et al., 2014) and the dormancy stage after harvest (Marsetti et al., 2013). Therefore, in this period, there is a great availability of nutrients from DM-GLI, with low potential to contribute to coffee nutrition.

With DM-ING, in August pruning (second evaluation), there was a rapid release of K with $t_{1/2}$ at 63.6 days (04 October), coinciding with the pinhead stage. The other macronutrients showed a gradual release between 137.8 days of P (17 December) and 263.2 days of Mg (22 April), between the beginning of fruit grown at the end of ripening, concerning with higher demand. At the end of ripe stage, in the March pruning (third evaluation), the $t_{1/2}$ of the macronutrients was not reached, indicating immobilization and accumulation on the soil. This is due to the greater recalcitrance of the genus *Inga*. *I. edulis* leaf presents 24 weeks of N half-life (Leblanc et al., 2006) and *I. subnuda* presents a slow decomposition with 35% of N, 50% of P and 82% of K released at 150 days, and without adjustments for Ca and Mg (Duarte et al., 2013). In the present study, with whole branches, greater recalcitrance was observed.

The behavior of DM-BAN was similar to DM-ING. In the second evaluation, initiated in August, the $t_{1/2}$ of the nutrients varied from 62.3 days (K) to 135.2 days (Ca) in the DM-BAN. However, it is not possible to establish a relationship with the phenological stages of coffee, because the harvest is not concentrated on a date. In the evaluation started in March, DM-BAN $t_{1/2}$ was only reached from K at 92.3 days, indicating a slow decomposition according to (Brito et al., 2017). Unlike banana residues, in the three evaluations of the DM-PP, the remaining N at 150 days were 20.6%, 23.8% and 21.5%, indicating fast decomposition, although slower than that observed by Pereira et al. (2015) with 99.4% of the N released at 112 days with crushed and buried leaves. This rapid release of nutrients after each harvest, points to a favorable effect of DM-PP.

The fertilization for CMON, CING, CBAN, CGLI and CPP was 279, 279, 281, 274 and 274 kg ha⁻¹ of N, respectively (Prezotti, 2020). The recommended K was only for CING and CBAN, 10 and 66 kg ha⁻¹, and no application of liming and P in all treatments. The compost provided 98.00 kg ha⁻¹ of K, being sufficient to meet the recommendations. N-compost supply was 147.12 kg ha⁻¹ year⁻¹, between 52.4% and 52.7% of the recommendation. The sum of the N of the compost plus the N released from the pruning of Aug/2016 and Mar/2017 (Tables 3, 6 and 7) was 319.27 kg ha⁻¹ in CGLI (13.6% above the recommendation) and 245.54 kg ha⁻¹ in CING (12.0% below the recommendation).

Part of the N, added by pruning, comes from biological fixation derived from the atmosphere (%Ndfa), and part of the N of the soil. In *I. edulis*, Leblanc et al. (2006) observed 57% of Ndfa and Kurppa, Leblanc and Nygren (2010), 74% to 81%. In gliricidia there are observations of 85% (Kurppa; Leblanc; Nygren, 2010) and 55% (Apolinário et al., 2016), with Nygren et al. (2012) reporting between 50% and 92% of Ndfa in five field experiments with different pruning intervals. Considering 60% Ndfa of legumes added to N-compost, the deficit in N input would be 10.9% in CGLI and 26.1% in CING, indicating less than necessary contributions, which may limit coffee productivity.

According to the results, the N release of the DM-ING (August pruning) is slow and gradual, reaching all the fruiting stages. The N released of DM-GLI is, predominantly, in stages of low nutrients demand, at flowering and pinhead stages in August pruning, and at the end of ripeness in March pruning. Possibly, an intermediate pruning of gliricidia, coinciding with the rapid swelling stage, could improve the synchrony with the coffee tree. Another option would be the consortium of gliricidia and inga, considering that the mixture of pruning, with labile and recalcitrant materials is favorable, reducing the capacity of binding of polyphenols to proteins (Handayanto; Cadish; Giller, 1994), which can guarantee greater release of N.

5 CONCLUSIONS

Gliricidia and peach palm tend to have higher rates of decomposition and lower inga and banana.

The decomposition rates were lower in experiments started in March and higher in August.

The release of nutrients from the dry matter of gliricidia, after the March pruning, occurs in a period of low nutritional demand for coffee and in August, it occurs in a period of low demand for the formation of coffee fruits.

The decomposition of the dry matter of inga starting in August is slow, with release of nutrients in the various stages of fruiting of the coffee tree.

Inga and banana have high residual values of nutrients at 270 days in the decomposition started in March.

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