# NUTRIENT RELEASE FROM GREEN MANURE UNDER DIFFERENT SUN-EXPOSED FACES

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**ABSTRACT:** The evaluation of the decomposition of plant residues added to the soil for green manures allows better understanding of the nutrient supply for coffee. The aim of this study was to determine the decomposition constant (κ), the half-lifetime ($t_{1/2}$) and the nutrient release from legumes and spontaneous plant under two environmental conditions of sun-exposure in the Zona da Mata of Minas Gerais state. The experimental unit located in Araponga has northwest sun-exposure face and the experimental unit located in Pedra Dourada has the south sun-exposure face. The experimental design was a randomized block in a 2 x 8 x 6 factorial (two environments facing sun-exposure, 8 green manures and 6 residue decomposition assessment times), with four replicates. The results showed that κ and $t_{1/2}$ of the evaluated green manures did not differ between the northwestern face (highest altitude, temperature and incident light) and the south face (lower altitude, temperature and incident light). The κ difference obtained between all green manures was due to its chemical and biochemical composition. At the end of the evaluation period of 240 days an average of 62,3 and 63,1% N; 99,4 and 99,5% P and 92,8 and 93,3% K were released from the green manures of the northwest and south faces respectively. The most promising legume in the total nutrients release on the northwest face was *D. lablab* with 74,6; 10,9 and 69,0 kg $ha^{-1}$ of N, P and K, respectively. To the south face the most promising legume was *C. spectabilis* with 69,1; 10,4 and 47,9 kg $ha^{-1}$ of N, P and K, respectively.

**Index Term:** Nutrient cycling, plant residues, polyphenols, ratio C/N, plant coffee.

# LIBERAÇÃO DE NUTRIENTES DE ADUBOS VERDES SOBRE DIFERENTES FACES DE EXPOSIÇÃO SOLAR

**RESUMO:** A avaliação da decomposição dos resíduos vegetais adicionados ao solo por adubos verdes permite melhor compreensão do fornecimento de nutrientes para o cafeeiro. O objetivo foi determinar a constante de decomposição (κ), o tempo de meia vida ($t_{1/2}$) e a liberação de nutrientes de leguminosas sob duas condições ambientais de face de exposição solar na Zona da Mata de Minas Gerais. A unidade experimental localizada em Araponga possui face de exposição solar noroeste, já a unidade experimental localizada em Pedra Dourada possui face de exposição solar sul. O delineamento experimental foi em blocos casualizados, em fatorial 2 x 8 x 6 (dois ambientes sob face de exposição solar, 8 adubos verdes e 6 tempos de avaliações da decomposição dos resíduos), com 4 repetições. Os resultados mostraram que a κ e $t_{1/2}$ dos adubos verdes não diferiram entre a face noroeste (maior altitude, temperatura e incidência de luz) e a face sul (menor altitude, temperatura e incidência de luz). A diferença obtida na κ entre os adubos verdes deve-se a sua composição química e bioquímica.Ao final de 240 dias de decomposição foi liberado em média para o cafeeiro 62,3 e 63,1% do N; 99,4 e 99,5 % do P e 92,8 e 93,3% do K no ambiente sob face noroeste e sob face sul, respectivamente. A leguminosa mais promissora na liberação total de nutrientes sob face noroeste foi a *D. lablab* com 74,6; 10,9 e 69,0 kg $ha^{-1}$ de N, P e K, respectivamente. Sob face sul, a leguminosa mais promissora na liberação total de nutrientes foi a *C. spectabilis* com 69,1; 10,4 e 47,9 kg $ha^{-1}$ de N, P e K, respectivamente.

**Termos para indexação:** Ciclagem de nutrientes, resíduo de plantas, polifenois, relação C/N, cafeeiro.

## 1 INTRODUCTION

The soils in the Zona da Mata region of Minas Gerais are characterized by being highly weathered and acid, with low fertility and low concentration of nutrients available to plants (Matos et al., 2008; Coelho et al., 2013; Guimarães et al., 2016). For family coffee growers in the region, the use of chemical fertilizer to replenish the nutrients is not feasible due to the low level of available funds, making integrated management of nutrients and water necessary in these areas. Such management focuses on organic matter and crop species able to use local resources in the most efficient manner (Matos et al., 2011; Coelho et al., 2013).

The majority of the coffee plantations in the region are installed on relief ranging from wavy to strongly wavy (Guimarães et al., 2016). This relief situation and coffee cultivation without soil cover are conditions favorable for erosion and with it, high soil, water, organic matter and nutrient losses, making coffee an agricultural activity with low environmental sustainability (Matos et al., 2008).

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One way to achieve agricultural sustainability is focused on the protection of the soil by legumes. In addition to erosion control, legumes improve the soil chemical, physical and biological attributes (Mafongoya and Jiri, 2016; Mendonça et al., 2016). Other advantages of legumes are: having an aggressive root system exploiting deeper soil layers, a symbiotic association with $N_2$-fixing bacteria contributing to the N nutrition of cash crops, a low C/N ratio which favors their decomposition and mineralization by soil microorganisms, among others (Coelho et al., 2013; Mendonça et al., 2016).

The decomposition and mineralization of crop residues depends on their chemical and biochemical quality and soil characteristics, such as temperature, moisture, clay fraction mineralogy, acidity, biological activity and nutrient availability (Matos et al., 2008). Thus, the sun exposure face on which the plot is located and its environmental characteristics may interfere with the decomposition and mineralization of plant residues on the soil (Matos et al., 2008; Matos et al., 2011; Coelho et al., 2013).

In the South Hemisphere, the path of the sun undergoes declination to the north, resulting in less radiation in the fields facing toward the south, which causes a temperature decrease and an increase in the soil moisture of that face (Ferreira et al., 2005). In the South Hemisphere, Coelho et al. (2013) concluded that the southern facing environment has humic substances that are structurally more resistant to degradation. In the North Hemisphere, where the opposite occurs, Egli et al. (2009) verified higher soil organic matter content in the face with north exposure, indicating that locations that have lower temperature and higher humidity stock more carbon, as well as verifying differences in microbial activity and the cycling dynamics of the contributed material.

When there is no limitation in the environmental conditions and they are influenced by sun-exposed face, the factor that may limit the decomposition kinetics and nutrient release from green manure and therefore, the microbial community activity is the green manure chemical and biochemical quality (Mendonça and Stott, 2003). Over the short term, the decomposition and N mineralization can be influenced by the C/N ratio, polyphenols content and polifenol/N ratio (Fan et al., 2017). Over the long term, the mineralization of C and N can be affected by recalcitrant components, such as cellulose, lignin and the lignin/N ratio (Matos et al., 2008).

Matos et al. (2011) reported the importance of the legumes *Arachis pintoi* Krapov. & W.C.Greg., *Calopogonium mucunoides* Desv., *Stylozanthes guyanensis* (Aubl.) Sw. and *Stizolobium aterrimum* Piper & Tracy as a source of nutrients in coffee present in the mountainous region due to low amounts of lignin/N, lignin/polyphenol and (lignin+ polyphenol)/N ratios, however, differences in the decomposition constant were found on different sun-exposed faces. Thus, for the choice of legumes to be used by the farmer, in addition to considering the amount of mass and nutritional accumulations, the amount of nutrients released over a specific period of time should also be observed (Matos et al., 2011). Some annual (crotalaria, lablab, mucuna and pigeon pea) and perennial legumes (forage peanut, calopo and stylo) have been used by farmers in the region, however, without diagnosing the amount of nutrients released over a given time.

Studies of decomposition and nutrient release of cover crops in no-tillage system of annual crops are present in many studies such as in Teixeira et al. (2009) and Leite et al. (2010). However, there are few reports emphasizing the role of legumes as to decomposition and release of nutrients in the soil for coffee. The aim of this study was to determine the decomposition constant, the half-life and total release of nutrients from legumes and spontaneous plants under two sun exposure environmental conditions in the Zona da Mata of Minas Gerais.

## 2 MATERIAL AND METHODS

### Characterization of study areas

The experiment was carried out on two experimental units (agricultural land) installed in family farm areas. The experimental unit in Araponga is located at 20° 41'S and 42° 33'W and has an altitude of 950 m, average annual maximum monthly temperature of 34,2ºC and an average annual minimum monthly temperature of 12,1ºC, with an average annual temperature of 18,0°C and an average of 1320 mm of rainfall. The land receives sun exposure on the northwest and there is an average daily sun exposure time of 9,1 h (measured in field). The experimental unit in Pedra Dourada is located at 20° 50'S and 42° 08'W, has altitude of 690 m, annual maximum monthly temperature of 32,0°C and an average annual minimum monthly temperature of 10,4°C, with an average annual temperature of 14,0°C and rainfall of 1277 mm. This land receives sun exposure on the south face and has an average daily sun exposure time of 6,8 h (measured in field). Thus, the environment facing the south (Pedra Dourada) has a lower altitude, lower temperature and lower light incidence compared to the northwest facing environment (Coelho et al., 2013).

The landscape of the experimental units is rugged with a nearly 40% slope; the soils are well drained, porous and deep; however, acidic and low nutrients availability. The soils of the two study areas were an Oxisols (Soil Survey Staff, 2014), corresponding to a *Latossolo Vermelho-Amarelo* by the Brazilian classification system (EMBRAPA, 2013). The chemical and physical characterization, in the 0-0,2 m depth at the time of experiment set-up is shown in Table 1.

The coffee plantations were conducted in an organic system since the formation of the seedlings. Before coffee planting, soil amelioration was conducted with limestone and thermophosphate and potassium sulfate were applied according to soil analyses and recommendations of Soil Fertility Commission for the State of Minas Gerais (V. Alvarez et al., 1999). In Araponga 260 kg $ha^{-1}$ of limestone, 64 kg $ha^{-1}$ of gypsum, 125 kg $ha^{-1}$ of potassium sulfate and 800 kg $ha^{-1}$ thermophosphate were applied; in Pedra Dourada, 1200 kg $ha^{-1}$ limestone, 300 kg $ha^{-1}$ of gypsum, 125 kg $ha^{-1}$ of potassium sulfate and 800 kg $ha^{-1}$ thermophosphate were used. In each location the *Coffea arabica* L. coffee plants were grown at a spacing of 2,8 x 0,5 m.

## Study design

The experimental design was a randomized complete block design with four replicates in a factorial 2 x 8 x 6 with: two environments with sun-exposed faces (one with northwestern face exposure and one with southern face exposure), 8 green manure that were evaluated in the coffee plant interrows: forage peanut (*A. pintoi*), calopo (*C. mucunoides*), crotalaria (*Crotalaria spectabilis* Röth), (*Stylozanthes guyanensis* (Aubl.) Sw.), pigeon pea (*Cajanus cajan* (L.) Huth), (*Dolichus purpureus* (L.) Sweet), mucuna (*Stizolobium deeringianum* Bort.) and the control consisting of spontaneous plants being predominant *Amaranthus viridis* L., *Bidens pilosa* L., *Emilia fosbergii* Nicolson, and *Eleusine indica (L.) Gaertn.*, and evaluation times (0, 15, 30, 60, 120 and 240 days).

## Characterization of legumes

Legumes were implemented during the years 2004-2007, always at the beginning of the rainy season and harvest every 150 days after planting and the residue spread under the canopy of the trees. Sowing occurred in the coffee interrow at a spacing of 0,4 m, totaling 5 planting lines of legumes for each coffee inter row. After germination, 5 plants were allowed per linear meter, corresponding 89.286 plants per hectare.

For the characterization of the green manure, the C and N contents were obtained by dry combustion in a Perkin Elmer CHNS/O 2400 analyzer. The elementary P was determined after nitropercloric digestion. In the same digestion K content was determined by flame photometry; and Ca and Mg by atomic absorption spectrophotometry. The soluble polyphenols were extracted with methanol (50%) and determined by colorimetric method, using the Folin-Denis reagent (Anderson and Ingram, 1996). The cell wall components were obtained via serial method (van Soest et al., 1991), using 2 mL of a 1% amylase solution per sample, in the determination of neutral detergent fiber (NDF) and acid detergent fiber (ADF). The values of hemicellulose in the analyzed material, as a percentage of dry matter, were determined by difference by subtracting the ADF from the NDF. Cellulose contents were also obtained by difference, by subtracting the lignin from the ADF. The average of the chemical and biochemical composition characterization of the evaluated materials is exhibited in Table 2.

## Decomposition plant residues and nutrient release rate

To evaluate of the decomposition plant residues and nutrient release rate, conducted only for legumes and spontaneous plants in 2007, 100 grams of fresh plant material were placed in nylon decomposition bags (20x20 cm). The decomposition bags (litterbags) were placed on the soil surface under the coffee canopy. At 0, 15, 30, 60, 120 and 240 days the materials were collected and dried in a forced air circulation oven at 70°C for 72 hours and then ground to pass through a 2 mm sieve. The total N, P and K contents were determined (same method described in the characterization of green manure). From these data, we determined the dry mass (DM), N, P and K percentages remaining in relation to the quantities added initially; and then calculated the amounts of nutrients released to the coffee plants after 240 days.

**TABLE 1** - Chemical and physical characteristics of the soil at a depth of 0-0,2 m.

| Chemical analysis | Araponga (northwest exposed face) | Pedra Dourada (south exposed face) |
|---|---|---|
| Water pH (1:2,5)* | 5,24 | 5,04 |
| [1]Phosphorus (mg/ $dm^3$) | 1,00 | 2,92 |
| [1]Potassium (mg/ $dm^3$) | 59,80 | 53,50 |
| [2]Aluminum (cmolc / $dm^3$) | 0,47 | 0,59 |
| [2]Calcium (cmolc / $dm^3$) | 1,74 | 0,99 |
| [2]Magnesium (cmolc / $dm^3$) | 0,74 | 0,47 |
| [3]Organic Carbon (g / kg) | 29,04 | 36,80 |
| [1]Zinc ( mg / $dm^3$) | 1,17 | 1,56 |
| [1]Iron (mg / $dm^3$) | 40,7 | 14,70 |
| [1]Manganese (mg / $dm^3$) | 10,4 | 20,20 |
| [1]Copper (mg $dm^{-3}$) | 0,50 | 0,38 |
| Granulometric analysis | | |
| Sand (g / kg) | 39 | 36 |
| Chay (g / kg) | 52 | 45 |
| Textural class | Chayey | Chayey |

*In table: pH (hydrogen potential); 1-extractor Mehlich$^{-1}$; 2-extractor KCl 1mol $L^{-1}$; 3-method Walkley Black.

Models were used to estimate the decomposition and release of nutrients from the legumes and spontaneous plants. The model that provided the best fit for all species was first order exponential $y = a\ exp^{(-kt)}$ (Olson, 1963), where y is dry weight or nutrient remaining at a given time (days) at a constant decomposition (k). The parameter (a) corresponds to the maximum point, i.e. the initial amount of dry weight or nutrient added by the green manure. Reorganizing the terms of this equation (linearization) it is possible to calculate the decomposition constant, or κ value, by the equation: $\kappa = \ln(a/y)/t$. With the κ value, we calculated the half-life ($t_{1/2}$), i.e., the time required for half of the plant material to decompose, as follows: $t_{1/2} = \ln(2)/\kappa$.

### Statistical analysis

The equation coefficients were tested (t-test) at 1, 5 and 15% significance. Pearson correlations between the $t_{1/2}$ and the chemical and biochemical composition of green manure were carried out. Data on dry mass and the amounts of total nutrients released from green manure after 240 days were subjected to analysis of variance and Scott-Knott averages tests. To run the analysis, we used the Sisvar statistical program (Ferreira, 2007).

## 3 RESULT AND DISCUSSION

There are differences in κ values between legumes and spontaneous plants for each environmental condition exposure (Table 3). Spontaneous plants and *S. deeringianum* obtained the lowest dry matter (DM) κ. The lowest N release κ was observed for *S. guyanensis* and spontaneous plants. Similarly, the *C. mucunoides* and spontaneous plants presented the lowest κ for P and K.

No difference was observed in the κ values for each green manure between the two sun-exposed environments. Comparing the average κ values between the environments with sun-exposed faces (Table 3), P was the most quickly released nutrient in the decomposition process, with an average value of 0.0267 $d^{-1}$ in Araponga and 0.0264$d^{-1}$ in Pedra Dourada. The rapid release of P in the residues is related to the low C/P ratio. C/P ratio lower than 200 in plant residues contributes to the rapid P release (Chacón et al., 2011) that is dependent on the decomposition process by soil microorganisms. Residues with C/P ratio greater than 300 will prevail P immobilization (Dossa et al., 2009).The P released from legumes may be temporarily fixed, primarily in fungal structures and made available to the coffee plant in a gradual way instead of undergoing rapid mineralization and becoming strongly adsorbed on Fe and Al oxyhydroxides which, together with kaolinite, dominates the clay fraction of Oxisols (Silva and Mendonça, 2007).

**TABLE 2-** Average of the chemical and biochemical characterization of green manure and spontaneous plants of the year 2007on two experimental units in Araponga and Pedra Dourada.

| Green Manure | C | N | P | K | HM | CL | LG | PP | C/P | C/N | LG/N | LG/PP | PP/N | (LG+PP)/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | .................................dag Kg$^{-1}$........................................... | | | | | | | | | | | | | |
| Araponga (northwest exposed face) | | | | | | | | | | | | | | |
| *A. pintoi* | 41,5 | 2,9 | 0,30 | 2,5 | 12,6 | 30,2 | 7,3 | 1,8 | 138,3 | 14,3 | 2,5 | 4,0 | 0,62 | 3,1 |
| *C. mucunoides* | 44,0 | 3,5 | 0,32 | 2,4 | 14,9 | 26,7 | 8,9 | 1,4 | 137,5 | 12,5 | 2,5 | 6,3 | 0,40 | 2,9 |
| *C. spectabilis* | 51,4 | 3,3 | 0,28 | 1,9 | 12,6 | 33,5 | 7,6 | 1,2 | 183,5 | 15,5 | 2,3 | 6,3 | 0,36 | 2,6 |
| *C. cajan* | 42,4 | 3,5 | 0,27 | 1,6 | 17,9 | 28,1 | 9,7 | 1,5 | 157,0 | 12,1 | 2,7 | 6,4 | 0,42 | 3,2 |
| *D. lablab* | 43,7 | 3,4 | 0,38 | 2,1 | 18,1 | 27,5 | 7,6 | 1,5 | 115,0 | 12,8 | 2,2 | 5,0 | 0,44 | 2,8 |
| *S. guyanensis* | 42,5 | 3,2 | 0,29 | 1,7 | 14,7 | 28,6 | 5,8 | 1,7 | 146,5 | 13,2 | 1,8 | 3,4 | 0,53 | 2,3 |
| *S. deeringianum* | 48,5 | 3,3 | 0,25 | 1,8 | 16,7 | 31,3 | 7,8 | 1,9 | 194,0 | 14,6 | 2,3 | 4,1 | 0,57 | 2,9 |
| Spontaneous | 64,1 | 2,2 | 0,27 | 3,2 | 21,4 | 30,5 | 9,7 | 1,2 | 237,4 | 29,1 | 4,4 | 8,0 | 0,54 | 4,9 |
| Pedra Dourada (south exposed face) | | | | | | | | | | | | | | |
| *A. pintoi* | 43,4 | 2,9 | 0,28 | 2,2 | 13,0 | 30,7 | 7,9 | 1,7 | 155,0 | 14,9 | 2,7 | 4,6 | 0,58 | 3,3 |
| *C. mucunoides* | 45,2 | 3,4 | 0,27 | 2,1 | 15,6 | 24,9 | 8,6 | 1,3 | 167,4 | 13,3 | 2,5 | 6,6 | 0,38 | 2,9 |
| *C. spectabilis* | 48,7 | 3,0 | 0,31 | 1,9 | 12,3 | 33,0 | 7,7 | 1,1 | 157,0 | 16,2 | 2,5 | 7,0 | 0,36 | 2,9 |
| *C. cajan* | 41,8 | 3,2 | 0,28 | 1,5 | 17,9 | 27,7 | 9,0 | 1,4 | 149,2 | 13,0 | 2,8 | 6,4 | 0,43 | 3,2 |
| *D. lablab* | 47,9 | 3,3 | 0,36 | 2,3 | 18,4 | 26,7 | 7,5 | 1,5 | 133,0 | 14,5 | 2,2 | 5,0 | 0,45 | 2,7 |
| *S. guyanensis* | 45,6 | 3,2 | 0,29 | 1,8 | 13,6 | 29,8 | 5,9 | 1,7 | 157,2 | 14,2 | 1,8 | 3,4 | 0,53 | 2,3 |
| *S. deeringianum* | 44,7 | 3,5 | 0,26 | 1,8 | 15,3 | 30,7 | 8,0 | 1,9 | 171,9 | 12,7 | 2,2 | 4,2 | 0,54 | 2,8 |
| Spontaneous | 66,5 | 2,1 | 0,26 | 3,1 | 19,9 | 28,8 | 9,8 | 1,1 | 255,7 | 31,6 | 4,6 | 8,9 | 0,52 | 5,1 |

C = carbon; N = nitrogen; P = phosphorus; K = potassium; HM = hemicellulose; CL = cellulose; LG = lignin; PP = total soluble polyphenols; LG/N= rationlignin/ nitrogen; LG/PP= ratio lignin/polyphenols; PP/N= ratio polyphenols/nitrogen; (LG+PP)/N= ratio (lignin+polyphenols) nitrogen.

**TABLE 3** - Decomposition constant (κ) and DM (dry matter), N (nitrogen), P (phosphorus) and K (potassium) release estimated by the equation $y = a\ exp^{(-kt)}$ and the half-life ($t_{1/2}$) of green manure and spontaneous plants under two sun-exposure conditions.

| Green manure | DM | N | P | K | DM | N | P | K |
|---|---|---|---|---|---|---|---|---|
| | κ($d^{-1}$) | | | | | | | |
| | Araponga (northwest exposed face) | | | | Pedra Dourada (southexposed face) | | | |
| *A. pintoi* | 0,0022A | 0,0045A | 0,0286B | 0,0143A | 0,0022A | 0,0047A | 0,0283B | 0,0141A |
| *C. mucunoides* | 0,0026A | 0,0044A | 0,0161C | 0,0088C | 0,0025A | 0,0045A | 0,0159C | 0,0083C |
| *C. spectabilis* | 0,0024A | 0,0043A | 0,0294B | 0,0126B | 0,0023A | 0,0044A | 0,0287B | 0,0124B |
| *C. cajan* | 0,0025A | 0,0041A | 0,0278B | 0,0135A | 0,0021A | 0,0042A | 0,0275B | 0,0133A |
| *D. lablab* | 0,0023A | 0,0046A | 0,0271B | 0,0140A | 0,0022A | 0,0048A | 0,0268B | 0,0138A |
| *S. guyanensis* | 0,0021A | 0,0034B | 0,0354A | 0,0137A | 0,0021A | 0,0035B | 0,0351A | 0,0136A |
| *S. deeringianum* | 0,0018B | 0,0040A | 0,0342A | 0,0116B | 0,0017B | 0,0041A | 0,0338A | 0,0119B |
| Spontaneous | 0,0019B | 0,0031B | 0,0152C | 0,0072C | 0,0019B | 0,0033B | 0,0149C | 0,0077C |
| **Mean** | **0,0022** | **0,0041** | **0,0267** | **0,0120** | **0,0021** | **0,0042** | **0,0264** | **0,0119** |
| | $t_{1/2}$ (d) | | | | | | | |
| | Araponga (northwest exposed face) | | | | Pedra Dourada (south exposed face) | | | |
| *A. pintoi* | 313 | 154 | 25 | 49 | 314 | 146 | 24 | 49 |
| *C. mucunoides* | 268 | 157 | 43 | 78 | 276 | 154 | 44 | 82 |
| *C. spectabilis* | 290 | 162 | 25 | 56 | 302 | 157 | 25 | 57 |
| *C. cajan* | 278 | 168 | 26 | 52 | 329 | 166 | 26 | 53 |
| *D. lablab* | 300 | 151 | 26 | 48 | 314 | 144 | 26 | 51 |
| *S. guyanensis* | 329 | 203 | 20 | 52 | 331 | 197 | 20 | 52 |
| *S. deeringianum* | 384 | 173 | 21 | 59 | 405 | 169 | 21 | 57 |
| Spontaneous | 345 | 223 | 46 | 95 | 364 | 211 | 48 | 89 |
| **Mean** | **313** | **174** | **29** | **61** | **329** | **168** | **29** | **61** |

Means followed by same letter between green manure on each condition exposed face belong to the same cluster at 5% probability by means of Scott-Knott test.

The second most quickly released nutrient was K (0.0120 and 0.0119 $d^{-1}$ for Araponga and Pedra Dourada, respectively). Unlike P, K is found in nonstructural components and in ionic form in the vacuole of plant cells (Leite et al., 2010), having low dependence on microbial processes for its release (Crusciol et al., 2008). According to the authors, after the management of the phytomass, with the dry material on the soil, there is the initial wetting process of the rainfall, with significant diffusion of K, mainly, of the cells of the surface of the residue.After the saturation of the material by rain, there is a reduction of diffusion K, which happens to be from dead cells of the plant residue. As legumes are less lignified than grasses, hydration of the material is facilitated. In legumes the release of K is considered fast.In a field experiment, Leite et al (2010) also reported fast release of K compared to N and P.

The N κ presented average values of 0.0041 and 0.0042$d^{-1}$ for Araponga and Pedra Dourada, respectively. The lower N decomposition is due to the high soluble polyphenol content, since they have the capacity to complex proteins and thereby reduce the N availability to the soil microorganisms (Matos et al., 2008, Chacón et al., 2011).

The average DM κ values were 0.0021 $d^{-1}$ for Araponga and 0.0022 $d^{-1}$ for Pedra Dourada. Low DM κ values may be related to high concentration of recalcitrant components, such as lignin, cellulose and hemicellulose that prolong the DM decomposition (Stott and Mendonca, 2003). Another factor related to low DM κ values is related to the low P availability for microorganisms, since the P contents of the Oxisols studied were classified as very low (Alvarez V. et al., 1999).

The similarity between the DM decomposition and N, P and K release κ values show no differences between the two sun-exposed environmental conditions for the decomposition period of 240 days. However, working with four legumes, Matos et al. (2011) found average DM κ values of $0.0052d^{-1}$ for a crop facing south and $0.0026\ d^{-1}$ for a crop facing west in an evaluation period of 360 days. The authors verified a 50.7% reduction in the residue decomposition rate on the western face compared to the southern, i.e., in the environment with less sunlight (south facing) the residue was decomposed more rapidly.

Due to differences in κ values, there was variation among legumes regarding the half-life ($t_{1/2}$) for the DM decomposition rate, and N, P and K release in each location. On average, the time taken for half of the green manure constituents to decompose and be released was 313, 174, 61 and 29 days for DM, N, K and P, respectively, in the location with a northwest-exposed face. In the location with a southern-exposed face, the $t_{1/2}$ of DM, N, K and P was 329, 168, 61 and 29 days, respectively. Matos et al. (2011) also observed that the $t_{1/2}$ for MD> N> K> P, however, the $t_{1/2}$ was 57% shorter for *A. pintoi*, *S. guyanensis* and *S. aterrimum* on southern-exposed face compared to the western exposure.

Due to lower decomposition constant values in spontaneous plants, they presented a $t_{1/2}$ of 345 and 364 days for DM in Araponga and Pedra Dourada, respectively. In these same locations, the shortest DM $t_{1/2}$ was for *C. mucunoides*, being 268 and 276 days, respectively. Longer DM $t_{1/2}$ in mountain environments is positive because one of the functions of green manure is soil protection against hidric erosion (Mendonça and Stott, 2003). Thus, the quick release of P, K and N and the longer DM permanence on the soil benefit coffee nutrition and soil conservation.

According to Mendonca and Scott (2003) the concentration of compounds such as lignin, cellulose and hemicelluloses, as well as the C/P, C/N, lignin/polyphenol, lignin/N and polyphenols/N ratios interfere with the decomposition of residue. Correlations of $t_{1/2}$ with the C/N, C/P, lignin/N, polyphenols/N and (lignin+polyphenol)/N in the present study explain the differences in the decomposition of green manure studied (Table 4).

Unlike the present study, Matos et al. (2011) and Matos et al. (2008) found no correlation between the $t_{1/2}$ and the chemical and biochemical composition of green manure. The authors pointed out that differences in κ and $t_{1/2}$ of the green manure studied occurred because of edaphoclimatic factors of the locations assessed.

After 240 days of decomposition an average of 41.6 and 39.9% DM was decomposed and 62.3 and 63.1% N; 99.4 and 99.5% P and 92.8 and 93.3% K was released for Araponga and Pedra Dourada, respectively (Figure 1).

**TABLE 4** - Pearson correlation between the chemical and biochemical constituents and the half-life ($t_{1/2}$) for DM, N, P and K of the green manure.

| Half-Life | C | N | P | K | HM | CL | LG | PP | C/P | C/N | LG/N | LG / PP | PP / N | (LG+PP)/ N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Araponga (northwest exposed face) | | | | | | | | | | | | | | |
| MS ($t_{1/2}$) | 0,31 | 0,23 | -0,33 | 0,37 | 0,38 | 0,20 | 0,37 | 0,68# | -0,18 | 0,24 | 0,18 | -0,49 | 0,73* | 0,28 |
| N ($t_{1/2}$) | 0,66* | -0,47 | -0,50 | 0,43 | 0,31 | -0,33 | 0,28 | 0,36 | -0,60# | 0,68# | 0,50 | -0,08 | 0,56# | 0,54# |
| P ($t_{1/2}$) | 0,59# | -0,38 | -0,23 | 0,67# | 0,52 | -0,03 | 0,50 | -0,49 | -0,79* | 0,60# | 0,76* | 0,62# | 0,13 | 0,71* |
| K ($t_{1/2}$) | 0,76* | -0,35 | -0,27 | 0,70* | 0,50 | -0,12 | 0,58# | -0,35 | -0,78* | 0,70* | 0,80* | 0,50 | 0,31 | 0,78* |
| Pedra Dourada (south exposed face) | | | | | | | | | | | | | | |
| MS ($t_{1/2}$) | 0,27 | 0,22 | -0,38 | 0,21 | 0,35 | 0,18 | 0,13 | 0,61# | -0,18 | 0,22 | 0,23 | -0,25 | 0,57# | 0,31 |
| N ($t_{1/2}$) | 0,61# | -0,44 | -0,55# | 0,39 | 0,31 | -0,32 | 0,23 | 0,39 | -0,54# | 0,62# | 0,45 | -0,09 | 0,49 | 0,48 |
| P ($t_{1/2}$) | 0,61# | -0,37 | -0,24 | 0,67# | 0,54 | -0,31 | 0,50 | -0,49 | -0,80* | 0,61# | 0,76* | 0,61# | 0,14 | 0,71* |
| K ($t_{1/2}$) | 0,68# | -0,26 | -0,18 | 0,65# | 0,49 | -0,18 | 0,57# | -0,41 | -0,74* | 0,61# | 0,73* | 0,54 | 0,19 | 0,70* |

*; # Significantat 5 and 15%, respectively.

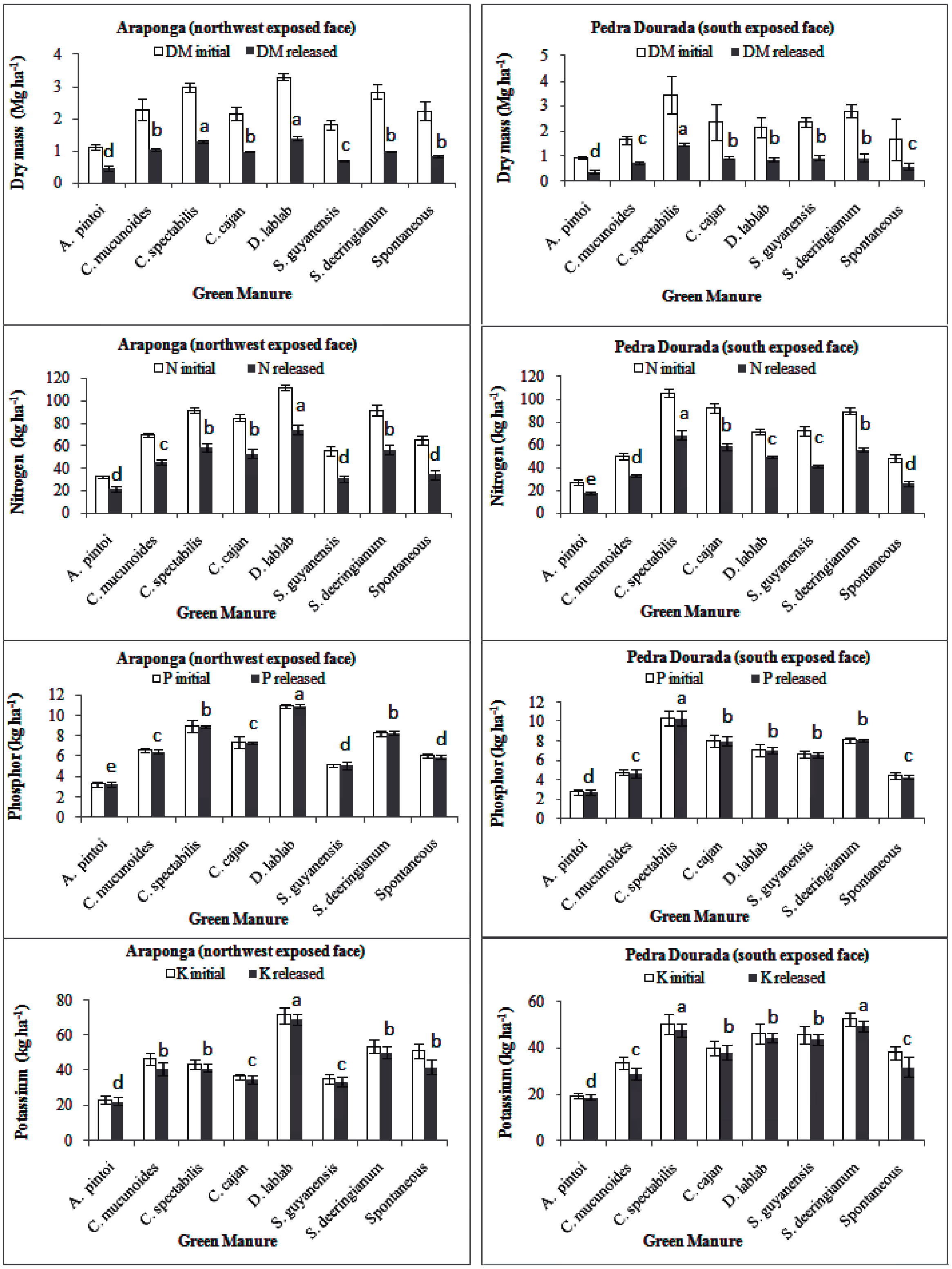


**FIGURE 1** - DM decomposition and of N, P and K released from green fertilizers and spontaneous plants after 240 days. Means followed by same letter in the amount of nutrient released do not differ at 5% probability by means of Scott-Knott test. Bars indicate the standard deviation.

There was no difference in the average amount of N, P and K released between the two locations. The N release trend similar to that of the present study was verified by Matos et al. (2011), who obtained 83.5% N released after 360 days.

Differences in nutrient release between the legumes and spontaneous plants were verified at each location. Besides the difference in the decomposition constant and half-life, there are differences in DM, N, P and K initial accumulation for each green manure (Figure 1), which reflected in the amount of the nutrient released. *A. pintoi* was the legume which released the least amount of nutrients, as follows: 21,6; 3,3 and 22,5 kg ha$^{-1}$ N, P and K in Araponga, respectively and 18,4; 2,7 and 18,4 kg ha$^{-1}$ of N, P and K in Pedra Dourada, respectively. The most promising legumes for nutrient release in Araponga was *D. lablab* with 74,6; 10,9 and 69,0 kg ha$^{-1}$ of N, P and K, respectively; and in Pedra Dourada it was *C. spectabilis* with 69,1; 10,4 and 47,9 kg ha$^{-1}$ of N, P and K, respectively.

In Matos et al. (2011), after 360 days *S. guianensis* released, 86,2; 7,1 and 50,4 kg ha$^{-1}$ of N, P and K, respectively; *S. aterrimum* released 93,0; 7,8 and 63,6 kg ha$^{-1}$ of N, P and K, respectively. This study considered only the aerial part decomposition of legumes and spontaneous plants. Thus, legume roots also have a great contribution in the supply of nutrients to coffee plants.

## 4 CONCLUSIONS

The decomposition constant and nutrient release of legumes and spontaneous plants increased in the order $DM<N<K<P$.

There was no influence between the northwestern-exposed face and southern-exposed face on the decomposition and nutrient release of the residue.

Under field conditions, the difference in decomposition constant and nutrient release from the green manure residue were dependent on the residue chemical and biochemical composition, since the half-life of the plant residues correlated with the C/N, C/P lignin/N, polyphenols/N and (lignin+polyphenol)/N ratios.

After 240 days of decomposition 62,3 and 63,1% N; 99,4 and 99,5% P and 92,8 and 93,3% K was released to the coffee plants in Araponga and Pedra Dourada, respectively.

The ground cover was prolonged by the low dry matter decomposition (41,6 and 39,9% for Araponga and Pedra Dourada, respectively).

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## 6 REFERENCES

ALVAREZ, V. H. et al. Interpretação dos resultados das análises de solos. In: RIBEIRO, A. C.; GONTIJO, P. T. G.; ALVAREZ, V. H. **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais – 5ª aproximação**, Comissão de Fertilidade do Solo do Estado de Minas Gerais, Viçosa- MG, 1999, p. 289-302.

ANDERSON, J. D.; INGRAM, J. S. I. **Tropical soil biology and fertility: A handbook of methods**. 2.ed. Wallingford, UK CAB International. 1996, 171p.

CHACÓN, E. A. V. et al.Decomposição de fontes orgânicas e mineralização de formas de nitrogênio e fósforo. **Revista Ceres**, Viçosa, v. 58, n. 3, p. 373-383, maio/jun. 2011.

COELHO, M. S. et al.Qualidade da matéria orgânica de solos sob cultivo de café consorciado com adubos verdes. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 37, n.6, p. 1576-1586, nov/dez. 2013.

CRUSCIOL, C. A. C. et al. Taxas de decomposição e de liberação de macronutrientes da palhada de aveia preta em plantio direto. **Bragantia**, Campinas, v.67, n.2, p.481-489, abr/jun. 2008.

DOSSA, E. L. et al. Carbon, nitrogen and phosphorus mineralization potential of semiarid Sahelian soils amended with native shrub residues. **Geoderma**, Amsterdam, v. 148, n.3-4, p. 251-260, Jan. 2009.

EGLI, M.et al. Effect of North and South exposure on organic matter in high Alpine soils. **Geoderma**, Amsterdam, v.149, n.1-2, p. 124-136, Feb. 2009.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Sistema brasileiro de classificação de solos**. 3. ed. Brasília, 2013, 353 p.

FAN, D. et al. Tea polyphenols dominate the short-term tea (*Camellia sinensis*) leaf litter decomposition. **Biomedicine & Biotechnology**,Zhejiang, v.18, n. 2, p. 99-108, 2017.

FERREIRA, F. P. et al. Exposição solar e propriedades do solo em Santa Maria-RS. **Revista Brasileira de Agrociência**, Pelotas, v. 11, n.3, p. 377-381,jul/set. 2005.

FERREIRA, D. F. **SISVAR software: versão 4.6**. Lavras: UFLA/DEX, 2007.

GUIMARÃES, G. P. et al. Productivity of coffee and legumes intercropped under different sun exposure face. **Australian Journal of Crop Science**, Australia, v.10, n.4, p. 513-519, Apr. 2016.

LEITE, L. F. C. et al.Decomposição e liberação de nutrientes de resíduos vegetais depositados sobre Latossolo Amarelo no Cerrado Maranhense. **Revista Ciências Agronômicas**, Fortaleza,v. 1, n. 1, p. 29-35, jan/mar. 2010.

MAFONGOYA, P. L.; JIRI, O. Soil nitrogen and physical properties and maize yields after mixed planted fallows of tree and herbaceous legumes. **Nutrient Cycling in Agroecosystems,** Netherlands,v. 105, n. 1, p. 75-84, 2016.

MATOS, E. S. et al. Decomposition and nutrient release of leguminous plants in coffee agroforestry systems. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 35, n. 1, p. 141-149, jan/fev. 2011.

MATOS, E. S. et al. Green manure in coffee systems in the region of Zona da Mata, Minas Gerais: Characteristics and kinetics of carbon and nitrogen mineralization. **Revista Brasileira de Ciência do Solo**, Viçosa,v. 32, n. 5, p.2027-2035, set/out. 2008.

MENDONÇA, E. S.; STOTT, D. E. Characteristics and decomposition rates of pruning residues from a shaded coffee system in Southeastern Brazil. **Agroforestry Systems**, Amsterdã,v. 57, n. 2, p. 117-125, Nov. 2003.

MENDONÇA, E. S. et al. Biological Nitrogen Fixation by Legumes and N Uptake by Coffee Plants. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 41, p.1-10, jan. 2017.

NUNES, L. A. P. L.; DIAS, L. E.; JUCKSCH, I.; BARROS, N. F. Atributos físicos do solo em área de monocultivo de cafeeiro na zona da mata de minas gerais. **Bioscienc Journal**, Uberlândia, v. 26, n. 1, p. 71-78, jan/fev. 2010.

OLSON, J.S. Energy storage and the balance of producers and decomposers in ecological systems. **Ecological Society of America**, Washington, v. 44, n. 2, p. 322-331,Apr. 1963.

SILVA, I. R.; MENDONÇA, E. S. Matéria Orgânica do Solo. In: NOVAIS, R. F.; et al. **Fertilidade do Solo**. 1ª ed. Viçosa, MG, 2007, p.275-374.

Soil Survey Staff. **Keys to soil taxonomy**. United States Department of Agriculture. Natural Resources Conservation Service, 12th ed. Washington, 2014, 372p.

TEIXEIRA, C. M. et al. Decomposição e liberação de nutrientes das palhadas de milheto e milheto+crotalária no plantio direto do feijoeiro milheto+ crotalária no plantio direto do feijoeiro. **ActaScientiarum Agronomy**, Maringá, v. 31, n. 4, p. 647-53, out/dez. 2009.

VANSOEST, P. J.; ROBERTSON, J. B.; LEWIS, B. A. Methods for dietary fiber, neutral-detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. **Journal DairyScience**, Champaign, v. 74, n, 10, p.3583-3597, Oct. 1991.