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No-tillage in organic production system: production parameters and biomass decomposition

Lucas Vasconcelos Rocha, Dérique Biassi, Júlio César Ribeiro, Marcos Gervasio Pereira*, Everaldo Zonta

Federal Rural University of Rio de Janeiro, Seropédica, Brazil
*Corresponding author, e-mail: gervasio@ufrrj.br

Abstract

Soils with sandy texture in the first layers are of wide occurrence throughout Brazil. Because of their fragility, it is essential to use crop practices, such as the adoption of a no-tillage system, to promote benefits to these soils. The objective of this study was to evaluate biomass production, nutrient content and accumulation, decomposition rates, half-life time ($T^{1/2}$) and dynamics of the N, P and K release from residues of cover crops in organic cropping of vegetables in Seropédica Rio de Janeiro state, Brazil. The experiment was conducted using a randomized block design with multiple replicates and six treatments: sunn hemp (*Crotalaria juncea*), palisade forage peanuts (*Arachis pintoi*), Brachiaria (*Brachiaria brizantha*), millet (*Pennisetum americanum*), a cocktail of seeds, and an area of spontaneous vegetation. Dry matter decomposition and nutrient release were evaluated at 15, 30, 60, 90 and 120 days by the litter-bag method. Sunn hemp had higher dry matter production (15.48 Mg ha^{-1}) and accumulation of N, P and K (426, 40 and 325 kg ha^{-1}, respectively). As for dry matter decomposition, millet and forage peanut plants had the longest (98 days) and shortest (23 days) half-life, respectively. Millet was the cover crop with the longest half-life in terms of P and K release, while for N, the longest half-life was verified in the cocktail of seeds (sunn hemp, millet and brachiaria).

Keywords: *Crotalaria juncea*, nutrient accumulation, nutrient availability, sandy soils, half-life time

Introduction

Organic agriculture recommends the association of food production with environmental preservation and sustainability in the use of natural resources, in addition to promoting greater well-being and health to rural workers. However, the production of vegetables, including those grown organically, is characterized by intense soil turning, which unbalances the soil-water-plant system, mainly by reducing the quantity and changes in the quality of soil organic matter (Marouelli et al., 2010).

The no-tillage system (NTS) can be applied as a strategy to minimize the impacts caused by conventional agriculture. NTS is based on a technique of maintenance and recovery of the production capacity of the soils, recommending minimum turning, maintenance of crop residues and rotation of economic crops with cover crops, hence protecting the soil from variations in temperature, humidity and also reducing the decomposition of organic matter in the off-season (Adami et al., 2020). This promotes improvement in the physical, chemical and biological characteristics of soils compared to conventional cultivation.

The effectiveness of NTS, even more significant in soils with sandy texture in surface, is related to the quantity and quality of residues produced by the cover crops, which minimize water losses by evaporation and the consequent water deficit, contributing to a better cycling of nutrients and reduction in their leaching (Castro et al., 2017; Pereira et al., 2017; Silva et al., 2017). Studies such as Loss et al. (2014), Kappes et al. (2015) and Vendruscolo et al. (2017) show the beneficial effects of the use of this system on soil attributes and yield of subsequent crops, resulting from dry matter production, mobilization and recycling of nutrients by the decomposition of straw and soil protection against climatic agents.

Thus, the search for sustainability of natural

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resources in production systems has guided research studies related to the no-tillage planting of vegetables in the straw of cover crops, as well as the evaluation of parameters of decomposition and release of nutrients. These studies have demonstrated the NTS as a viable alternative for the agricultural cultivation of vegetables, also considering the economic aspects (Kappes et al., 2015; Vendruscolo et al., 2017).

In this context, the objective was to evaluate the biomass production, the contents and accumulations of N, P and K, the decomposition rates, half-life time and dynamics of the release of these nutrients from the residues of different cover crops under no-tillage for cultivation of organic vegetables in Seropédica-RJ, Brazil.

Material and Methods

The experiment was conducted during the period from 2016 to 2017, in an organic production unit (Sítio do Sol), affiliated to ABIO (Association of Organic Farmers of Rio de Janeiro State), located at coordinates 22° 49' 19.79" S and 43° 44' 16.43" W with an average altitude of 26 m. The production unit has been certified as organic since 2000, when liming was applied in total area. From this moment on, in the area, only inputs permitted for organic production were used, especially bovine manure, composts and thermophosphate.

The soil of the area was classified as *Argissolo Vermelho-Amarelo* (Ultisol), with the following characteristics in the 0-0.3 m layer: sand = 890 g kg^{-1}, silt = 60 g kg^{-1}, clay = 50 g kg^{-1}, pH in H_2O (1:2.5) = 5.1; Al^{+3} = 0.17 $cmol_c$ dm^{-3}; Ca^{+2} = 1.92 $cmol_c$ dm^{-3}; Mg^{+2} = 1.21 $cmol_c$ dm^{-3}; H+Al = 4.11 $cmol_c$ dm^{-3}; exchangeable K^+ = 5.86 mg dm^{-3} and available P = 1.23 mg dm^{-3}.

The climate of the region, according to the classification of Köppen (1928) is type Aw or Tropical of Central Brazil, with rainfall concentrated in the period from November to March, average annual precipitation of 1213 mm and average annual temperature of 24.5 °C.

The experimental design was in randomized blocks, with six treatments and four replicates. The treatments consisted in the planting of the following cover crops: sunn hemp (*Crotalaria juncea*), forage peanut (*Arachis pintoi*), brachiaria (*Urochloa brizantha*), millet (*Pennisetum americanum*), cocktail of seeds (brown hemp, millet and palisade grass), and spontaneous vegetation. The plots comprised an area of 4 m² (2x2 m), with seven rows spaced by 0.3 m, with a density of 40 thousand plants ha^{-1}.

Irrigation was performed through a drip system at a flow rate of 0.5 L h^{-1}. During the experimental period, there was an attack of pests and diseases, so phytosanitary control was carried out with products recommended for organic agriculture (Azadirachtin, D-limonene and *Bacillus subtilis*). Weeds were manually removed from the treatments.

In order to increase Ca and Mg contents and pH, 3000 kg ha^{-1} of dolomite limestone (RNV 75%) were applied 60 days before planting the cover crops.

All cover crops were manually sown broadcast, except forage peanut, for which transplantation was carried out with rooted seedlings, all in November 2016, beginning of the rainy season in the region (Figure 1). The cover crops were cultivated until the moment when 50% of them reached the maximum flowering point (163 days after planting), when, theoretically, there is the greatest accumulation of nutrients in the aerial part.

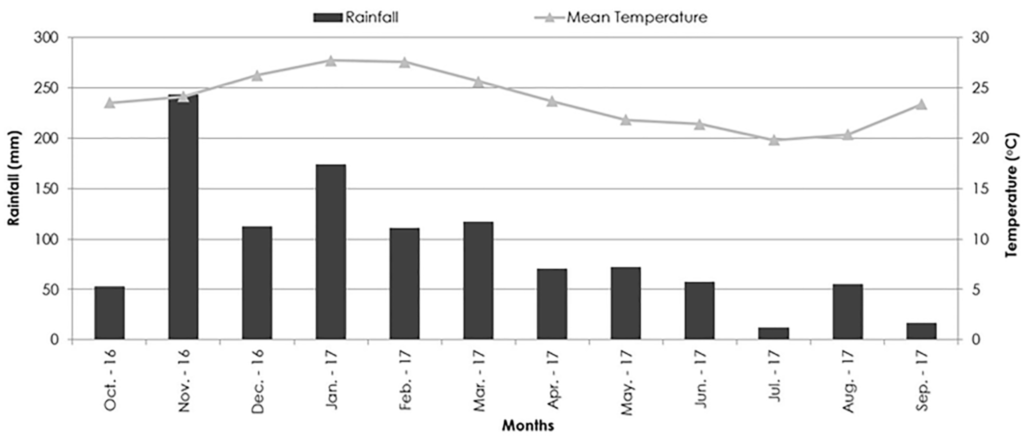

Figure 1. Climatic data of mean temperature and rainfall during experimental period (October/2016 to September/2017), extracted from the Ecology Meteorological Station, located in the municipality of Seropédica-RJ.

The sampling for biomass evaluation was carried out using a quadrat with dimensions of 0.20 x 0.20 m, totaling 0.04 m², randomly thrown in each plot.

Subsequently, the collected material was dried in a forced circulation oven at 65 °C until it reached constant weight. After drying, the samples were weighed and crushed in a Wiley-type mill, and then the N, P and K contents were determined (Tedesco et al., 1995). N contents were determined by Kjeldahl method, P by colorimetry and K by flame photometry (Tedesco et al., 1995). Nutrient accumulation was obtained by the product of dry matter multiplied by nutrient content.

Nutrient decomposition and release rates were evaluated after mowing the plants, using the method of litter bags with 2-mm-opening mesh, with dimensions of 0.20 x 0.20 m, as described by Santos and Whilford (1981). In each litter bag, 10 g of dry material from the cover crops were placed. Fifteen bags were distributed on the surface of each block, and three bags were collected in each sampling at 15, 30, 60, 90 and 120 days after distribution. After sampling, the plant residue of each bag was manually cleaned and dried in a forced circulation oven at 65 °C until it reached constant weight to determine the remaining dry matter. This fraction was crushed in a Wiley-type mill, and the contents of N, P and K were also determined (Tedesco et al., 1995). The contents and remaining dry matter were then used to calculate the remaining amounts of N, P and K, expressed in mg g^{-1}.

To describe the decomposition of plant residues and nutrient release, the exponential mathematical model described by Thomas and Asakawa (1993) (Equation 1) was applied:

$$X = X0.\ e^{-k.t}$$

Where X is the amount of dry matter or nutrients remaining after a period of time t (days); X0 is the amount of dry matter or nutrients at the beginning of decomposition (g), and K is the decomposition constant of the residue. Reorganizing the terms leads to the following equation (Equation 2):

$$K = \ln (X / Xo) / t$$

The half-life time ($T^{1/2}$) refers to the period necessary for the decomposition of 50% of the biomass and was calculated from the values of the constant (k) according to the mathematical model proposed by Paul and Clark (1996) (Equation 3):

$$T_{1/2} = 0.693/k$$

The equations of dry matter decomposition and mineralization of nutrients were fitted using SgmaPlot software, version 12.0 (Systat Software Inc, 2006).

The results were analyzed for normality and homogeneity through the Lilliefors and Cochran and Bartlett tests, respectively. The results were then subjected to analysis of variance in the statistical program R (Core Team, 2014), applying the F test for significance and comparing the means by the Tukey test, at 5% probability level.

Results and Discussion

Table 1 shows the values of dry matter production and days of vegetative growth after sowing until the mowing of the different cover crops.

Table 1. Dry matter production, constant of decomposition and half-life time of plants used for soil cover: sunn hemp (*Crotalaria juncea*), forage peanut (*Arachis pintoi*), brachiaria (*Urochloa brizantha*), millet (*Pennisetum americanum*), cocktail of seeds (brown hemp, millet and palisade grass), and spontaneous vegetation. Seropédica-RJ, 2017.

Cover crops	Dry matter	DAS	k	$T^{1/2}$	R^2
	Mg ha^{-1}		g g^{-1}	Days	
Sunnhemp	15.48 a	120	0.0109	63	0.70 *
Millet	5.33 b	66	0.0071	98	0.68 *
Spontaneous	4.03 b	120	0.0085	82	0.78 *
Forage peanut	3.66 b	120	0.0304	23	0.78 *
Cocktail	3.93 b	63	0.0085	82	0.70 *
Brachiaria	4.35 b	69	0.0101	69	0.81 *
CV (%)	15.28				

Means followed by the same letter in the column do not differ from each other at 5% probability level (p<0.05) by Tukey test. CV: Coefficient of variation; DAS: Days of vegetative growth after sowing until mowing; k: Constant of decomposition; $T^{1/2}$: Half-life time; R^2: Coefficient of determination.

It is observed that only sunn hemp differed significantly from the others, with an average production of 15.48 Mg ha^{-1} (Table 1). According to Darolt (1998), dry matter production values greater than 6.0 Mg ha^{-1} are sufficient to provide adequate soil cover in no-tillage systems for providing at least 50% of soil surface cover. The other evaluated species showed production below this value, but were statistically equal to each other.

The lowest values of dry matter verified for the other cover crops may be related to the lower adaptability of these plants to the edaphoclimatic conditions of the region, besides not having been grown in their optimal seasonal period, to the availability of nutrients and water in the soil, and to the incidence of pests and diseases, which, despite being controlled, may have compromised the proper development of these plants.

Torres et al. (2014b) quantified values of 2.10 Mg ha^{-1} for the biomass production of sunn hemp in the Triângulo Mineiro region. The cover crop was sown in March and desiccated in June, in the dry season, which may be a possible explanation for the low values of biomass produced. However, Padovan et al. (2014) verified results similar to those observed in this study, quantifying values of 12.89 and 11.66 Mg ha^{-1} of sunn hemp biomass at 104 and 108 days after sowing in Dourados and Itaquiraí-MS, respectively, in a *Latossolo Vermelho* (Oxisol).

The results obtained for sunn hemp show good adaptability of the species to the edaphoclimatic conditions of the region, enabling rapid development and establishment, which possibly caused a reduction in the incidence of weeds, in addition to the biological fixation of nitrogen by the legume crop, giving sunn hemp a dry matter production about three times higher compared to the other cover crops studied, so it can be considered a potential species for the cultivation of cover crops under conditions similar to those evaluated.

For the dry matter of millet, the value was low compared to those of the other cover crops (5.3 Mg ha^{-1}), but with no significant difference from the others (Table 1). This low dry matter production by millet may be associated with the planting period, which did not correspond to its optimal photoperiod (September and October), with short vegetative development up to the cutting point under the conditions of this study up to 66 DAS. According to Queiroz et al. (2012), the optimal photoperiod occurs in August, but the planting season issue should be viewed with reservation, as it may vary depending on the region and climate variations between years. The results observed for millet were similar to those found in the municipality of Sete Lagoas-MG by Simão et al. (2015) (6.1 Mg ha^{-1}), who sowed several millet cultivars at different times after corn cultivation and found that low dry matter yield occurred due to the planting outside the optimal photoperiod.

The low dry matter value of brachiaria (4.35 Mg ha^{-1}) (Table 1), compared to those found in other experiments such as that conducted by Kliemann, Braz and Silveira (2006), who found dry matter production of brachiaria greater than 12.42 Mg ha^{-1} in *Latossolo Vermelho* (Oxisol) under no-tillage system in the municipality of Santo Antônio de Goiás (GO), may possibly be related to the climatic conditions of the period. Conditions such as higher water availability and higher temperature may have favored its early flowering, a factor that was determinant for its mowing at 69 DAS and consequently a lower dry matter production. According to Tonato et al. (2010) and Carvalho et al. (2012), the climatological parameters have great influence on the establishment and yield of forage plants, as well as on their flowering cycle and nutrient accumulation, and these authors pointed to the time when the plants reach about 50% of flowering as an optimal cutting point.

Forage peanuts had the lowest dry matter production (3.66 Mg ha^{-1}) among the cover crops, not differing statistically from millet, spontaneous vegetation, cocktail of seeds and palisade grass (Table 1). This lower production was possibly due to its slow development and early flowering, a factor that was determinant for its early cutting at 120 DAS, in order to ensure the greatest accumulation of nutrients in its straw, which however led to a lower soil cover. According to Guerra and Teixeira (1997), the period required for the complete soil cover by forage peanuts is about 190 DAS, that is, the 120-day period used in the present study was possibly not sufficient to promote complete soil cover and consequently a higher dry matter production by forage peanut plants.

For spontaneous vegetation (4.03 Mg ha^{-1}) and cocktail of species (sunn hemp, millet and brachiaria) (3.93 Mg ha^{-1}), low values of production were also observed (Table 1). The low dry matter production by these plants is possibly due to the low natural development of the local spontaneous species, with predominance of short grasses, such as nutsedge (*Cyperus rotundus L.)* and colonião grass (*Panicum maximum*), and the shorter period of development until the flowering shown by the cocktail (63 DAS,) since there was early flowering of the palisade grass and millet plants forming the stand.

Regarding the nutrient contents in the cover crops, in general, millet, cocktail and brachiaria had higher K contents, while sunn hemp and forage peanut showed the highest N contents. Regarding P contents, the cover crops did not differ significantly from one another (Table 2).

Regarding the accumulation of the nutrients analyzed, sunn hemp showed a significant difference from the other cover crops evaluated, with accumulation of N, P and K on the order of 426, 40 and 325 kg ha^{-1}, respectively (Table 2).

The higher N accumulation in sunn hemp plants (426 kg ha^{-1}) when compared to the values quantified by Padovan et al. (2014) (267 kg ha^{-1}), in an experiment carried out in a *Latossolo Vermelho* (Oxisol) with sowing between October and November in Mato Grosso do Sul, is possibly related to the higher N content and dry matter observed in the present study. Thus, it is possible to predict that the capacity for N accumulation in a short period of time, as well as for P and K, makes brown hemp a plant species with potential for use as soil cover.

Although the other plants evaluated in the present study produced less dry matter (Table 2), they accumulated statistically similar amounts of P, and in general in a smaller amount when compared to N and K accumulations, probably because this nutrient is available at low concentrations in the soil and its accumulation is naturally reduced in plant tissues (Machado et al., 2011). forage peanut and spontaneous plants had the lowest K accumulations (27.0 and 39.0 kg ha^{-1}, respectively), which is directly related to their low dry matter production.

Table 2. Content and accumulation of N, P and K in the aerial part of soil cover crops: sunn hemp (*Crotalaria juncea*), forage peanut (*Arachis pintoi*), brachiaria (*Urochloa brizantha*), millet (*Pennisetum americanum*), cocktail of seeds (sunn hemp, millet and brachiaria), and spontaneous vegetation. Seropédica-RJ, 2017.

Cover crops	N		P		K	
	Content (g kg^{-1})	Accumulation (kg ha^{-1})	Content (g kg^{-1})	Accumulation (kg ha^{-1})	Content (g kg^{-1})	Accumulation (kg ha^{-1})
Sunnhemp	27.6 a	426 a	2.6 a	40 a	20.9 b	325 a
Millet	15.0 bc	80 b	3.5 a	19 b	27.9 a	149 ab
Spontaneous	10.2 c	41 b	2.7 a	11 b	9.6 c	39 b
Forage peanut	28.0 a	102 b	3.1 a	11 b	7.4 c	27 b
Cocktail	19.4 ab	76 b	3.1 a	12 b	24.4 ab	96 ab
Brachiaria	13.4 c	58 b	3.1 a	14 b	23.6 ab	103 ab
CV (%)	28.87	35.05	27.42	27.12	51.81	60.37

Means followed by the same letter in the column do not differ from each other at 5% probability level (p<0.05) by Tukey test. CV: Coefficient of variation.

Regarding the rate of decomposition of the residues of the cover crops, a similarity of the process was observed in all treatments, with an exponential decrease in higher rates with the legume species, followed by the grass species (Figure 2). This pattern has also been observed in other studies (Acosta et al., 2014; Torres et al., 2014b). Marangoni et al. (2017), evaluating the production and decomposition of biomass of legume plants (pigeon pea (*Cajanus cajan*)) and grass plants (millet (*Pennisetum americanum*)), found similar values at different evaluation times. It was verified that, at 20 days of evaluation of decomposition in the field, 78% of the initial dry matter of the legume plants (pigeon pea) still remained on the soil surface, against 86% of the grass plants (millet), a pattern that was repeated at all the evaluated times, corroborating the results verified in the present study.

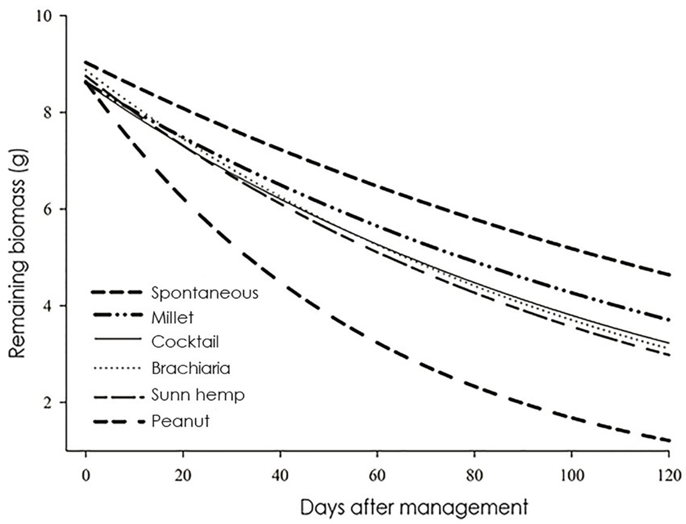

Figure 2. Remaining dry matter (g) from residues of soil cover crops: sunn hemp (*Crotalaria juncea*), forage peanut (*Arachis pintoi*), brachiaria (*Urochloa brizantha*), millet (*Pennisetum americanum*), cocktail of seeds (sunn hemp, millet and brachiaria), and spontaneous vegetation in the period of 120 days. Seropédica-RJ, 2017.

It is observed that the values obtained for the half-life time varied between the cover crops, being lower for legumes (forage peanut and sunn hemp) when compared to grasses (Table 1). These results can be attributed to lower C:N ratio (Laroca et al., 2018) and to high precipitation in the period (Figure 1) (which favors decomposition), as well as to the ability of legumes to fix atmospheric N, which favors the activity of microorganisms and consequently increases the speed of decomposition (Alcantara et al., 2014). Similar behavior was also observed by Torres et al. (2014a) when evaluating the decomposition rates of legumes and grasses in Cerrado soil in the Triângulo Mineiro region.

The cocktail of the cover crops (sunn hemp, millet and brachiaria) had the same half-life time (82 days) as spontaneous plants (Table 1). Despite having similar values, the decomposition curve of spontaneous plants decreased more gradually when compared to that of the cocktail (Figure 2), pattern that occurred probably because the latter is composed of a mixture of grasses and legumes, which possibly reduced the C:N ratio.

During the period of decomposition and release of nutrients, there was a rapid initial phase followed by a slower one (Figure 3), a pattern also observed by Marangoni et al. (2017). This pattern is possibly related to the soil moisture maintained by drip irrigation and rainfall during the experiment (Figure 1), which accelerates the initial stages of decomposition (Costa et al., 2015). Similar results were reported by Rossi et al. (2013), when evaluating the rates of decomposition and release of nutrients from palisade grass, sorghum and soybean straw in no-tillage areas in the Cerrado region of Goiás.

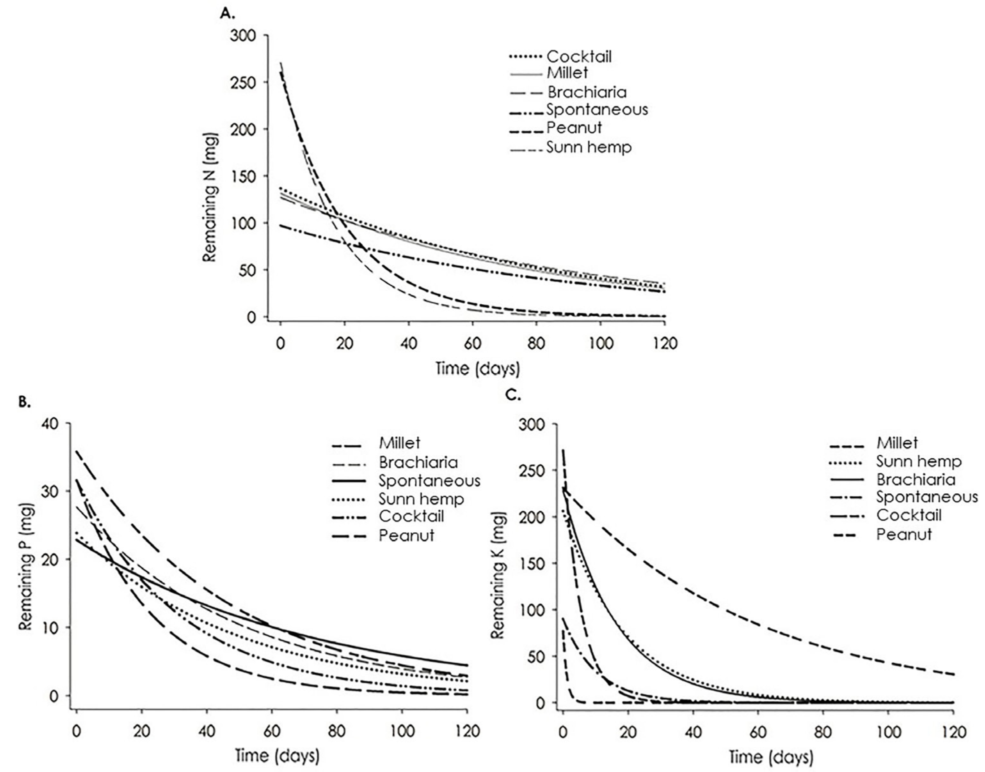

Figure 3. Curves of release (g) of N (A) P (B) and K (C) of soil cover crops: sunn hemp (*Crotalaria juncea*), forage peanut (*Arachis pintoi*), brachiaria (*Urochloa brizantha*), millet (*Pennisetum americanum*), cocktail of seeds (sunn hemp, millet and brachiaria), and spontaneous vegetation in the period of 120 days. Seropédica-RJ, 2017.

Regarding the release of N, the legumes tended to accumulate higher contents of this nutrient and to release it faster than grasses (Figure 3A). Regarding the half-life time ($T^{1/2}$) for N release, it was verified that half of this nutrient present in sunn hemp and forage peanut plants had been released at 41 and 38 days, respectively (Table 3). A pattern opposite to that observed in this experiment was verified by Pereira et al. (2016), who found $T^{1/2}$ of 86 days for brown hemp plants under conditions of low precipitation (0.0 and 11.4 mm) between the months of June and December in Jaguaribe-CE. This is due to the variation in the rate of biomass decomposition shown by these legumes in relation to temperature balance and average precipitation.

Table 3. Mineralization parameters of N, P and K contents of soil cover crops: sunn hemp (*Crotalaria juncea*), forage peanut (*Arachis pintoi*), brachiaria (*Urochloa brizantha*), millet (*Pennisetum americanum*), cocktail of seeds (sunn hemp, millet and brachiaria), and spontaneous vegetation. Seropédica-RJ, 2017.

Cover crops	N			P			K		
	k	$T^{1/2}$	R^2	k	$T^{1/2}$	R^2	k	$T^{1/2}$	R^2
	$g\ g^{-1}$	days		$g\ g^{-1}$	days		$g\ g^{-1}$	days	
Sunn hemp	0.0168	41	0.75 *	0.0128	54	0.67 *	0.0224	31	0.68 *
Millet	0.0096	72	0.72 *	0.0122	57	0.75 *	0.0213	33	0.44 *
Spontaneous	0.0092	75	0.53 *	0.0129	54	0.76 *	0.0222	31	0.80 *
Forage peanut	0.0183	38	0.78 *	0.02	35	0.90 *	0.027	26	0.65 *
Cocktail	0.0077	90	0.31 *	0.0131	53	0.65 *	0.0398	17	0.94 *
Brachiaria	0.0094	74	0.70 *	0.0131	53	0.74 *	0.0257	27	0.69 *

*Significant at 5% probability level ($p<0.05$) by Tukey test. k: Constant of decomposition; $T^{1/2}$: Half-life time; R^2: Coefficient of determination.

For P release, the pattern was similar between treatments and to that of N, with a rapid release in the first days of evaluation (Figure 3B). This rapid release is possibly related to the dynamics of P, which is associated with the organic components of the plant tissue, and its mineralization can occur in an accelerated manner due to the decomposition by soil organisms (Mendonça et al., 2015).

Only spontaneous cover crops showed a more gradual release of P over time (Figure 3B). This result is possibly associated with the longer $T^{1/2}$ (82 days) of decomposition of their straw, in addition to the characteristic of greater adaptability of local spontaneous plants, predominantly grasses, which favored a slower decomposition due to a higher C:N ratio, thus leading to a gradual release of P.

Among the nutrients evaluated, K had a faster release, with $T^{1/2}$ of 17, 26, 27, 31, 31 and 33 days for the cocktail, forage peanut, brachiaria, sunn hemp, spontaneous plants and millet, respectively (Table 3). The faster release of this nutrient compared to the others can be attributed to the fact that K, besides being required in large quantities, does not have structural function, which makes it easily released and/or lost (Santos et al., 2014).

Among the cover crops, millet stands out for having a less accentuated curve of straw decomposition (Figure 2), which can be justified by the fact that it is a grass with low C:N ratio (Silveira et al., 2011) and, consequently, lower rate of decomposition and more gradual release of K (Figure 3C). A similar pattern was observed by Perin et al. (2010) when evaluating the $T^{1/2}$ of K release with spontaneous, sunn hemp and millet cover crops, finding values of 09, 10 and 12 days, respectively.

Conclusions

Sun hemp was the cover crop that had the highest dry matter production and accumulation of N, P and K compared to the others in the evaluated period.

Forage peanut and millet plants had the lowest (23 days) and the highest (98 days) half-life times, respectively.

Forage peanut and sunn hemp showed a higher N release when compared to other cover crops. Only spontaneous plants showed a more gradual release of P over time.

Millet was the cover crop with the longest half-life time for the release of P and K, while for N, the longest half-life time was verified in the cocktail of seeds (brown hemp, millet and brachiaria).

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