PERSISTENCE AND RELEASE OF MACRONUTRIENTS AND SILICON OF PIGEONPEA AS A FUNCTION OF FRAGMENTATION

Jayme Ferrari Neto[1], Carlos Alexandre Costa Crusciol[2], Rogerio Peres Soratto, Claudio Hideo Martins da Costa[3], Gustavo Spadotti Amaral Castro[4]

Universidade Católica Dom Bosco, Campo Grande, MS.[1], Universidade Estadual Paulista, Faculdade de Ciências Agronômicas, Departamento de Produção e Melhoramento Vegetal, Botucatu, SP.[2], Universidade Federal de Goiás, Regional Jataí, Unidade Acadêmica Especial de Ciências Agrárias, Jataí, GO.[3], Embrapa Monitoramento por Satélite, Campinas, SP.[4]

ABSTRACT

The objective of this work was to evaluate the persistence and macronutrient and silicon release of pigeonpea phytomass, with and without mechanical fragmentation. The experiment was design in randomized blocks, with four replications, arranged as 2x6 factorial combination, 2 managements (with and without fragmentation) and 6 times of phytomass harvest (0, 18, 32, 46, 74 and 91 days after management). The fragmentation of the phytomass did not alter decomposition and release of N, P, Ca, Mg and S, and the maximum daily release of these occurred between 0 and 18 DAM. Potassium was released faster, especially with the fragmentation of the phytomass. At the last evaluation, at least 85% of all macronutrients were released to the soil. Silicon release from the phytomass was negligible and there is an increase of the element level over time, mainly, with mechanical fragmentation.

Keywords: *Cajanus cajan*; cover crop; decomposition rate; nutrients recycling; phytomass management.

PERSISTÊNCIA E LIBERAÇÃO DE MACRONUTRIENTES E SILÍCIO DA FITOMASSA DO GUANDU-ANÃO EM FUNÇÃO DA FRAGMENTAÇÃO

RESUMO

Objetivou-se avaliar a persistência e a liberação de macronutrientes e Si da fitomassa do guandu-anão (*Cajanus cajan*) submetida ou não à fragmentação mecânica. O delineamento experimental foi em blocos casualizados, com quatro repetições, em esquema fatorial constituído por dois manejos (sem e com fragmentação mecânica) e seis épocas de coleta da fitomassa (0, 18, 32, 46, 74 e 91 dias após o manejo (DAM)). A fragmentação mecânica da fitomassa do guandu-anão não alterou a decomposição e a liberação de N, P, Ca, Mg e S, e as máximas taxas de liberação diária ocorreram de 0 a 18 DAM. O K foi o nutriente mais rapidamente liberado, principalmente com a fragmentação da fitomassa. Aos 91 DAM pelo menos 85% de todos os macronutrientes foram liberados ao solo. A liberação de Si foi baixa, sendo, proporcionalmente menor que a taxa de degradação da fitomassa o que acarretou em aumento do teor do elemento com o passar do tempo, principalmente com a fragmentação mecânica.

Palavras-chave: *Cajanus cajan;* cobertura vegetal; reciclagem de nutrientes; manejo da fitomassa; taxa de decomposição.

INTRODUCTION

The cover crops species to be included into a crop rotation and succession in no-till system (NT) must produce enough biomass that promotes soil protection against erosive agents and also accumulate, and subsequently, provide nutrients to the soil during decomposition. In this context, Doneda et al. (2012) reported the importance of understanding the dynamics of decomposition and nutrients release from cover crops, and select species that have greater potential to produce biomass and to accumulate nutrients.

The pigeonpea (*Cajanus cajan*) is a legume commonly used in tropical and subtropical region. Adapted for wide range of precipitation, is drought tolerant and develops better at high temperatures (CALEGARI, 2000), and produces shoot dry matter (SDM) up to 6.000 kg ha^{-1} (TORRES et al., 2008). In general, compared to grasses, pigeonpea has higher decomposition rate because it is a legume with lower C/N ratio (TEIXEIRA et al., 2009). However, is able to add great amounts of N to the soil through symbiotic fixation atmospheric N_2 (SALMI et al., 2006) and to recycle nutrients. Thus, the pigeonpea is a good alternative to compose crop rotation in NT, since the release of nutrients during decomposition may occur quickly, providing short-term benefits to the next crop (SALMI et al., 2006; TORRES et al., 2008).

With regard to the durability of SDM, the indicators more commonly used to express the resistance to decomposition are the C/N, C/P and C/S ratios. Another indicator that has been researched is the C/Si ratio, because the Si absorbed by the plants and present in the cell wall can work as a physical barrier, reducing the loss and, or, the access to the cellular material during decomposition of biomass on soil (SILVA; BOHNEN, 2001).

Regarding the SDM management, there are negative reports in the literature concerning the use of horizontal crusher straw, especially with regard to the increased cost of production and soil compaction (DENARDIN; KOCHHAN, 1993), but there are also positive outcomes related to greater nutrient cycling (PARIZ et al., 2011).

More information related to cover crops management in different soil and climatic conditions are needed, so that we can understand the dynamics of degradation and nutrient release from the species due to management in each region (PEGADO et al., 2008).

As reported by Doneda et al. (2012), it is necessary to intensify the studies related to decomposition and release of nutrients from cover crops, especially under NT. Therefore, the objective of this study was to evaluate the persistence and release of macronutrients and Si from pigeonpea as a function of mechanical fragmentation, under NT.

MATERIAL AND METHODS

This study was carried out at field conditions, from November 2004 to April 2005, in Botucatu, São Paulo, Brazil (22°58'S, 48°23'W, 765 m above sea level). Soil at the location is a Red Nitisol (EMBRAPA, 2013) and the chemical characteristics of the soil (0-20 cm) were: 25.0 g dm^{-3} of organic matter, pH ($CaCl_2$) 5.0, 17.0 mg dm^{-3} de P (resin); 1.6, 33.3, 17.6, 34.1 mmolc dm^{-3} of K, Ca, Mg and H+Al, respectively, and 61% of base saturation. In regard to textural classification, the soil has a clayey texture with 512 g kg^{-1} of clay, 381 g kg^{-1} of sand and 107 g kg^{-1} of silt.

According to the Köppen climate classification, the predominant climate in the region is the is Cwa, i.e., a higher altitude tropical climate with dry winters and hot, wet summers. Reference data for average monthly temperature and total monthly rainfall throughout the experimental period are shown in figure 1.

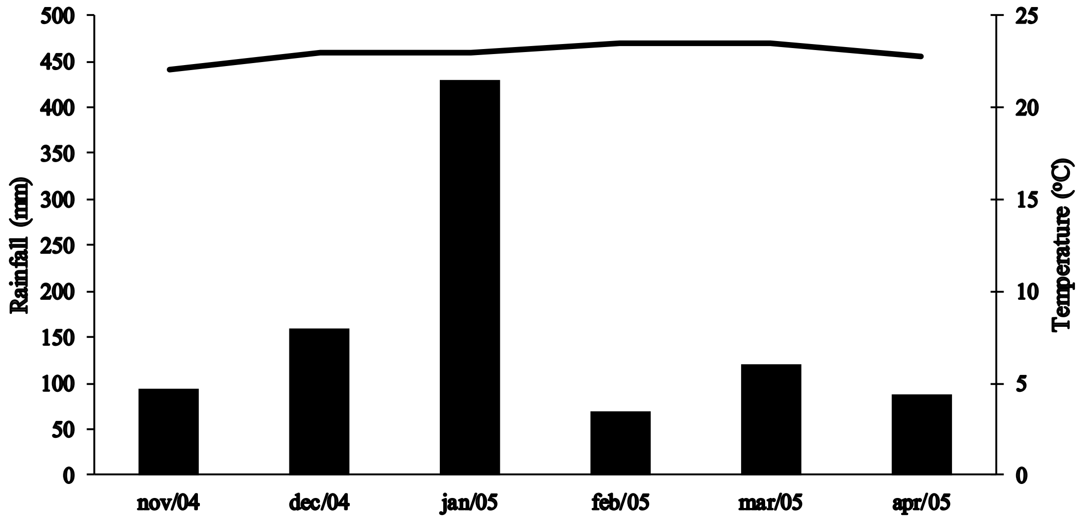

Figure 1. Total monthly rainfall (▮) and average monthly temperature (—) in the period of conducting the experiment.

The experiment was design in randomized blocks, with four replications, arranged as 2x6 factorial combination, two managements (with and without fragmentation) and six samplings of SDM (0, 18, 32, 46, 74 and 91 days after management (DAM)). The dimension of the plots was 5 m width and 15 m length, for a total of 75 m^2.

Sowing of the pigeonpea was performed on 10/21/2004, emergence of which occurred nine days afterward (10/30/2004). A quantity of 40 kg ha^{-1} of seeds was used in a spacing of 0.17 m between rows and approximately 0.05 m depth. No fertilizer was applied, as well as cultural practices (pest and diseases control).

At 75 days after emergence (DAE), at time of flowering (01/14/2005), desiccation was carried out using glyphosate herbicide (1.920 g a.i. ha^{-1}). After desiccation the mechanical management was performed by horizontal crusher straw (Triton) in predetermined plots.

Samplings of the SDM were made on the day of desiccation (0 DAM), on 02/01/2005 (18 DAM), on 02/15/2005 (32 DAM), on 03/01/2005 (46 DAM), on 03/29/2005 (74 DAM) and on 04/15/2005 (91 DAM). Three plots were sampled on each time period, with 0.25 m^2 of internal area (simple samples), which constituted one compound sample per plot. The topographic profiling of the sample within the experimental units was performed in a crosswise direction, with random samplings points, excluding the 0.50 m at each end as a border.

The plant residues were subjected to a pre-cleaning for removal of larger soil particles. Then they were washed according to the methodology of Malavolta et al. (1997), although modified, i.e., without the use of detergent. Thus, the samples were shaken for a few seconds in deionized water in three successive portions, and then placed on paper toweling. It should be noted that not using detergent reduced exposure time to shaking in water and the number of successive portions, which reduced probable K losses from the SDM as much as possible (ROSOLEM et al., 2003). The samples were placed in paper bags and dried in a forced air circulation oven at 65ºC until reaching constant weight, and then weighed for determination of SDM. The material was ground in a Wiley mill for determination of macronutrient (MALAVOLTA et al., 1997), carbon (TEDESCO, 1995) and silicon concentration (KORNDÖRFER et al., 2004).

The content of macronutrients, C and Si in the SDM were determined by the product of the amount of SDM and the concentration of the elements of the plant residue in each sampling. With these values, the degradation of SDM and the content of elements contained in it were calculated, and the data were expressed in kg ha^{-1}. This result was also expressed in percentage (%) through the calculation: content remaining of SDM or of each nutrient from the initial content in each time period, multiplied by 100.

To describe SDM decomposition and the remaining content of the elements (N, P, K, Ca, Mg, S, C and Si) in it, both in kg ha^{-1} and in %, the exponential mathematical model described by Thomas e Asakawa (1993) was used of the $X = X_o e^{-kt}$ type, in which X is the content of SDM or of elements remaining after a period of time t, in days; Xo is the initial quantity of SDM or of elements; and k is the constant of residue decomposition or release of elements. With the k value, the half-life time was calculated (t½ = 0.693/k) (PAUL; CLARK, 1989), which expresses the period of time necessary for half of the plant residue to decompose or for half of the elements contained in the SDM to be released. Applying the derivative first to the functions fitted to the data on SDM and content release of the elements, the daily rates of SDM decomposition and release of elements after management of the cover crops were calculated (ROSOLEM et al., 2003; KLIEMANN et al., 2006).

The data were initially tested in regard to the normality of distribution of the error (Lilliefors test / SAEG 5.0) and the homogeneity of their variances (Cochran and Bartlett tests / SAEG 5.0), thus verifying if they met the requirements for use of analysis of variance (Table 1). The mean values of the treatments of the type of plant cover factor were compared by the t test (LSD) at 5% probability and the other data from the SDM collection period factor were fitted to mathematical functions at 5% probability.

Table 1. Analysis of variance for variables related to shoot dry matter (SDM), ratios between carbon, nutrients and Si concentration, content and percentage in the pigeonpea shoot dry matter (SDM) according to management (M) and days after management (DAM).

Variable	F Value			CV (%)
	Management (M)	DAM (D)	M x D	
SDM (kg ha^{-1})	39,105**	103,028**	1,865ns	14,2
SDM (%)	50,906**	137,146**	2,508ns	12,1
C/N Ratio	0,074ns	6,011**	0,535ns	19,8
C/P Ratio	0,849ns	4,188**	0,360ns	17,9
C/S Ratio	0,073ns	39,148**	3,140ns	20,9
C/Si Ratio	12,979**	53,015**	1,093ns	18,8
N (g kg^{-1})	2,906ns	26,880**	0,390ns	16,8
P (g kg^{-1})	7,318*	10,845**	0,499ns	16,7
K (g kg^{-1})	96,090**	217,885**	8,743**	11,9
Ca (g kg^{-1})	1,719ns	13,554ns	1,030ns	13,3
Mg (g kg^{-1})	0,249ns	24,711**	0,769ns	12,8
S (g kg^{-1})	5,501*	38,199**	1,262ns	16,0
C (g kg^{-1})	48,524**	8,403**	1,089ns	8,0
Si (g kg^{-1})	10,165**	81,772**	9,639**	14,1
N (kg ha^{-1})	27,354**	63,448**	0,519ns	28,9
P (kg ha^{-1})	37,059**	71,554**	1,531ns	21,9
K (kg ha^{-1})	37,059**	158,810**	4,244**	21,9
Ca (kg ha^{-1})	15,713**	99,330**	1,092ns	18,1
Mg (kg ha^{-1})	29,819**	122,500**	2,094ns	18,0
S (kg ha^{-1})	5,480*	61,610**	0,254ns	27,0
C (kg ha^{-1})	26,726**	80,550**	1,684ns	18,4
Si (kg ha^{-1})	5,143*	2,558*	0,219ns	19,8
N (%)	33,806**	200,626**	1,932ns	15,7
P (%)	29,069**	83,088**	1,568ns	20,3
K (%)	144,859**	601,121**	16,918**	11,3
Ca (%)	13,884**	111,889**	1,346ns	16,9
Mg (%)	36,861**	161,872**	2,723ns	15,6
S (%)	10,120**	94,183**	0,624ns	21,3
C (%)	45,081**	141,980**	2,594ns	13,5
Si (%)	4,025*	2,048*	0,189ns	20,5

ns: not significant; *p < 0,05; **p < 0,01.

RESULTS AND DISCUSSION

The SDM of pigeonpea after 75 DAE was 4.720 kg ha^{-1} (Figure 1A). SALMI et al. (2006) and CAVALCANTE et al. (2012), in Seropédica (RJ) with planting in October and Arapiraca (AL) in May, respectively, verified SDM during the flowering stage between 4.670-5.950 kg ha^{-1} in Seropédica and 4.000 kg ha^{-1} in Arapiraca. Seropédica (RJ) has a tropical climate with rainy summer and dry winters and Arapiraca (AL) has dry summer with rains in the fall/winter period. Therefore, it is important to know the biomass production of plants used as cover crops in the different climatic conditions in agricultural regions, considering, among other factors, such as sowing time.

The SDM decomposition rates were similar between the managements adopted, with and without mechanical fragmentation, being the half-life after 46 DAM (Figure 2A). This half-life value indicates rapid mineralization (NASCENTE et al., 2014) and, in the last sampling (91 DAM), there were remained only 26% of the initial amount, evidencing the accelerated decomposition (Figure 2B). The decomposition was more intense in the period 0-18 DAM, with decomposition rate of 62 kg ha^{-1} day^{-1}, reducing the intensity over time, thus in the period 75-91 DAM was 21 kg ha^{-1} day^{-1} (Table 2). In the literature, there are several reports about the higher decomposition rate at an early stage, with subsequent decrease (GIACOMINI et al., 2003; CRUSCIOL et al., 2005; SORATTO et al., 2012, DONEDA et al., 2012).

The C/N, C/P, C/S and C/Si ratios are indicative of the durability of the plant residue. At the desiccation moment the values were 18, 204, 350 and 45, for C/N, C/P, C/S and C/Si, respectively (Figures 2C, 2D, 2E and 2F). However, over time, due to the release of N, P and S from the SDM, the C/N, C/P and C/S increased, but the C/Si decreased, reaching at the last sampling average values, respectively, 32, 284, 927 and 13. Si is a component of compounds which are difficult to degrade because when absorbed by the plant is polymerized in the form of silica, strongly linked to cellulose and this can only be separated when mineralized (LEWIN; REIMANN, 1969). Thus, as the biomass degrades, the concentration of silicon increases in the plant residue, until this high concentration decreases the decomposition rate (Figure 2). It can be inferred that as the others ratios, the C/Si is an important tool in the analysis of the degradation of biomass cover crops.

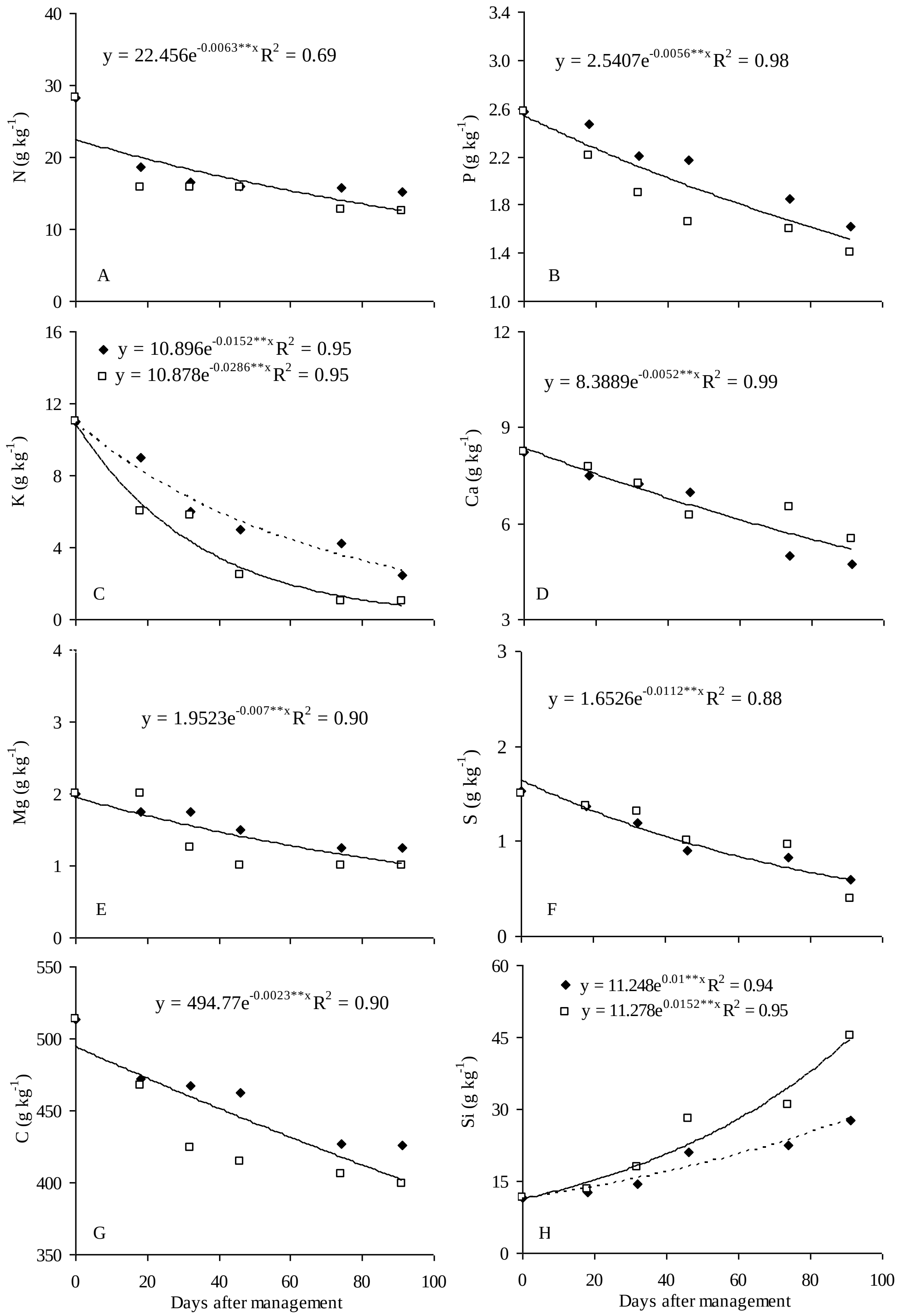

Figure 2. Shoot dry matter - SDM (A), percentage of plant shoot dry matter (B), C/N (C), C/P (D), C/S (E) and C/Si (F) ration of pigeonpea according to time after management, without (◆) e with (□) mechanical fragmentation. **Significant at 1% by test F. The equations were adjusted based on the average management treatments. $T_{1/2}$ refers to the half-life time in DAM.

Table 2. Rates of decomposition and daily releases of N, P, K, Ca, Mg, S, C e Si of pigeonpea shoot dry matter according to days after management (DAM), with or without mechanical fragmentation.

Mechanical fragmentation	Interval				
	0-18 DAM	19-32 DAM	33-46 DAM	47-74 DAM	75-91 DAM
			SDM (kg ha^{-1} day^{-1})		
Average	62	49	40	29	21
			N (kg ha^{-1} day^{-1})		
Average	3.0	1.9	1.2	0.7	0.3
			P (kg ha^{-1} day^{-1})		
Average	0.2	0.1	0.1	0.1	0.0
			K (kg ha^{-1} day^{-1})		
Without	1.1	0.7	0.5	0.3	0.2
With	1.5	0.7	0.4	0.1	0.0
			Ca (kg ha^{-1} day^{-1})		
Average	0.8	0.5	0.4	0.2	0.2
			Mg (kg ha^{-1} day^{-1})		
Average	0.2	0.1	0.1	0.1	0.0
			S (kg ha^{-1} day^{-1})		
Average	0.2	0.1	0.1	0.0	0.0
			C (kg ha^{-1} day^{-1})		
Average	35	26	21	15	10
			Si (kg ha^{-1} day^{-1})		
Average	0.2	0.2	0.1	0.1	0.1

At the moment of management, the concentrations of N, P, K, Ca, Mg, S, C and Si were, respectively, 28, 2.6, 11, 8.3, 2.0, 1.5, 514 and 11.5 g kg^{-1} (Figure 3). Teixeira et al. (2005), in comparison with this study, observed lower concentrations of N, P, K, Ca, Mg and S in the shoot dry matter of pigeonpea at the beginning of flowering.

The macronutrients concentration was reduced over time, following the SDM decomposition (Figure 2). However, the management x time interaction was observed only for the K (Table 1). The fragmentation of the biomass have increased the K release to the soil because the K concentration in the SDM without fragmentation were 11.0, 9.0, 6.0, 5.0, 4.3 and 2.5 g kg^{-1}, and with fragmentation were 11.0, 6 0, 5.8, 2.5, 1.0 and 1.0 g kg^{-1}, respectively, 0, 18, 32, 46, 74 and DAM 91 (Figure 3).

The accelerated release of K from biomass was also observed by Crusciol et al. (2005, 2008), in oilseed radish and oats. This occurs because K is not associated with any structural component of plant tissue and is not metabolized in the plant and forms bonds with easily reversible organic complexes (MARSCHNER, 2012). Thus, as the shoot of the plants begins the drying process and degrades, the concentration of this nutrient in the tissue decreases drastically because it is easily carried away by rainwater (KHATOUNIAN, 1999) after rupture of the plasmatic membrane (MALAVOLTA et al., 1997).

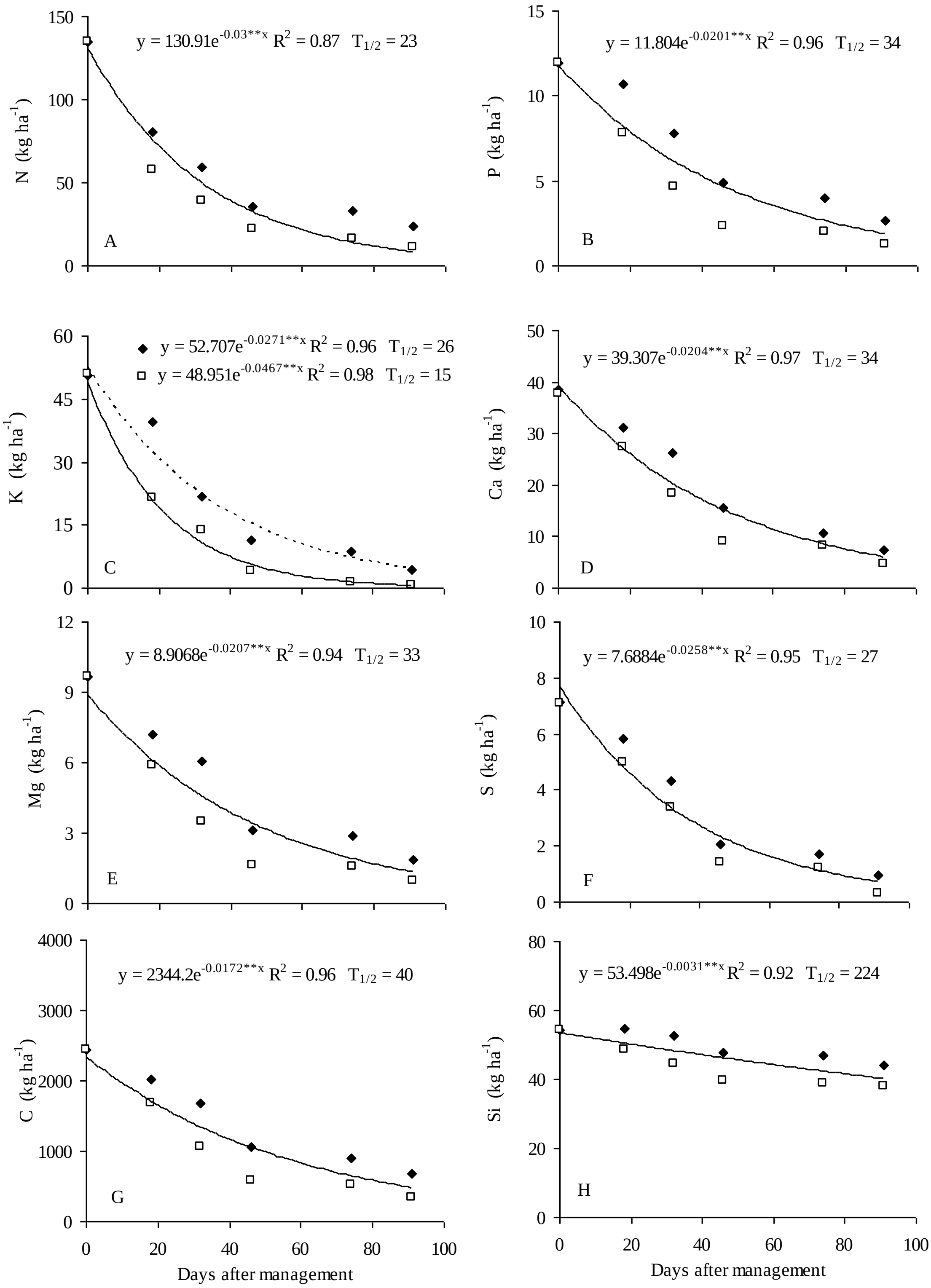

Figure 3. N (A), P (B), K (C), Ca (D), Mg (E), S (F), C (G) e Si (H) concentration of pigeonpea shoot dry matter according to time after management, without (◆) e with (□) mechanical fragmentation. **Significant at 1% by test F. The equations relating the concentrations of N, P, Ca, Mg, S, Si and C were adjusted based on the average management treatments.

In contrast to other nutrients the Si concentration increased over sampling, and after 91 DAM, 140% and 293% higher than the initial values, respectively, with and without fragmentation (Figure 3H).

At the time of desiccation, the contents of N, P, K, Ca, Mg, S, C and Si in the SDM of pigeonpea were approximately 135, 12, 51, 38, 10, 7, 2,434 and 54 kg ha^{-1} (Figure 4). These values correspond to the quantities that can be recycled by pigeonpea.

Calvo et al. (2010) observed lower N contents than this study. They sowed the pigeonpea on March on an Ultisol, in Presidente Prudente-SP, the region has hot summer and dry winter, and 90 days after sowing it was observed a content of 64 kg ha^{-1} N. The climatic conditions of each study for growing pigeonpea have directly influenced the contents of N.

Compared with other species such as oilseed radish and black oat, the pigeonpea accumulated higher amounts of N and Ca (CRUSCIOL et al., 2005; 2008). However, the difference was significant only for N, higher in 78 and 65 kg ha^{-1} compared to values observed in SDM oilseed radish and oats, respectively.

The nutrients release from SDM over time was significant, regardless of the adopted management (Figure 4). Thus, at 91 DAM remained 9, 2, 3, 6, 1, 1 and 490 kg ha^{-1}, respectively, N, P, K, Ca, Mg, S and C, and providing about 122, 10, 49, 33, 8, 7 and 1854 kg ha^{-1}, respectively. In terms of NPK were released to the soil the equivalent to 125, 23,5 and 61 kg ha^{-1} of N, P_2O_5 and K_2O, respectively.

Regarding the K, the initial release was more pronounced with the fragmentation of SDM. The fragmentation increases the contact surface with the soil, facilitating its release, so the time to released 50% into the soil was 15 days, whereas without fragmentation occurred at 26 days (Figure 4C). It is noteworthy that, at 91 DAM, the amount of K released to the soil were similar. Similar results have been observed by several authors for this nutrient in differents cover crops species (CRUSCIOL et al., 2008; PACHECO et al., 2011).

However, considering the Si average values after 91 DAM only 13 kg ha^{-1} were released, and the estimated time to release 50% was 224 days. Within this context, the last evaluation still remained in the SDM 75% of the accumulated Si (Figure 4H). So there was a great accumulation of Si in pigeonpea SDM, with subsequent slow release of this element in the soil.

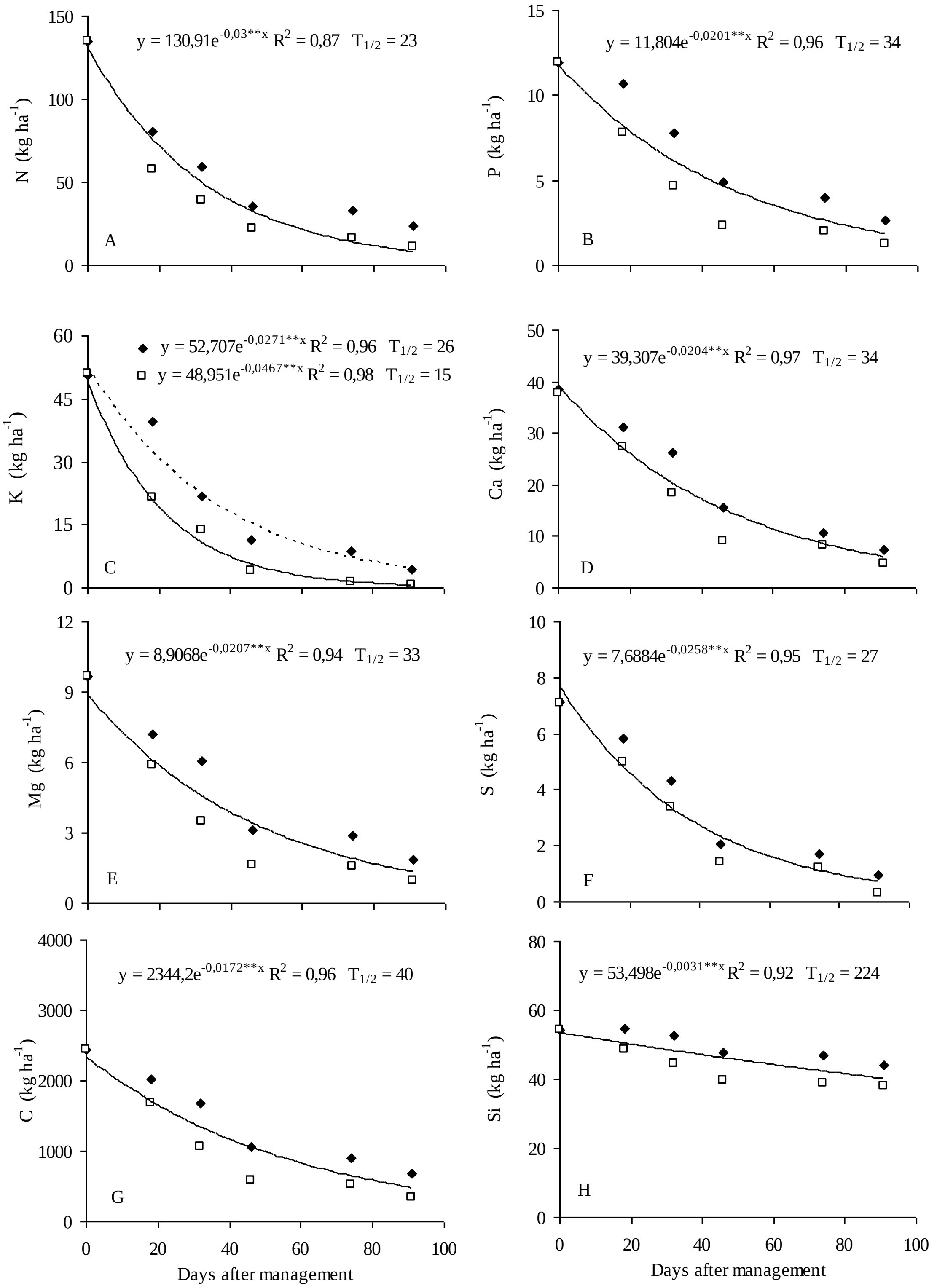

Figure 4. Content remaining of N (A), P (B), K (C), Ca (D), Mg (E), S (F), C (G) e Si (H) in pigeonpea shoot dry matter according to time after management, without (◆) e with (☐) mechanical fragmentation. **Significant at 1% by test F. The equations relating the contents of N, P, Ca, Mg, S, Si and C were adjusted based on the average management treatments.

At 91 DAM It had already been released 90, 84, 96, 87, 88, 94, 76 and 25% of N, P, K, Ca, Mg, S, C and Si, respectively (Figure 5). In addition, substantial portions of nutrients were released, which could supply the needs of the next crop. Because 50% of the total quantity of N, P, K, Ca, Mg, S and C in the SDM had been released, respectively, 23, 34, 21, 34, 33, 27 and 40 DAM (Figure 4). It is evident that recycling and nutrient retention by cover crops always minimize the risk of leaching losses (AITA et al., 1994).

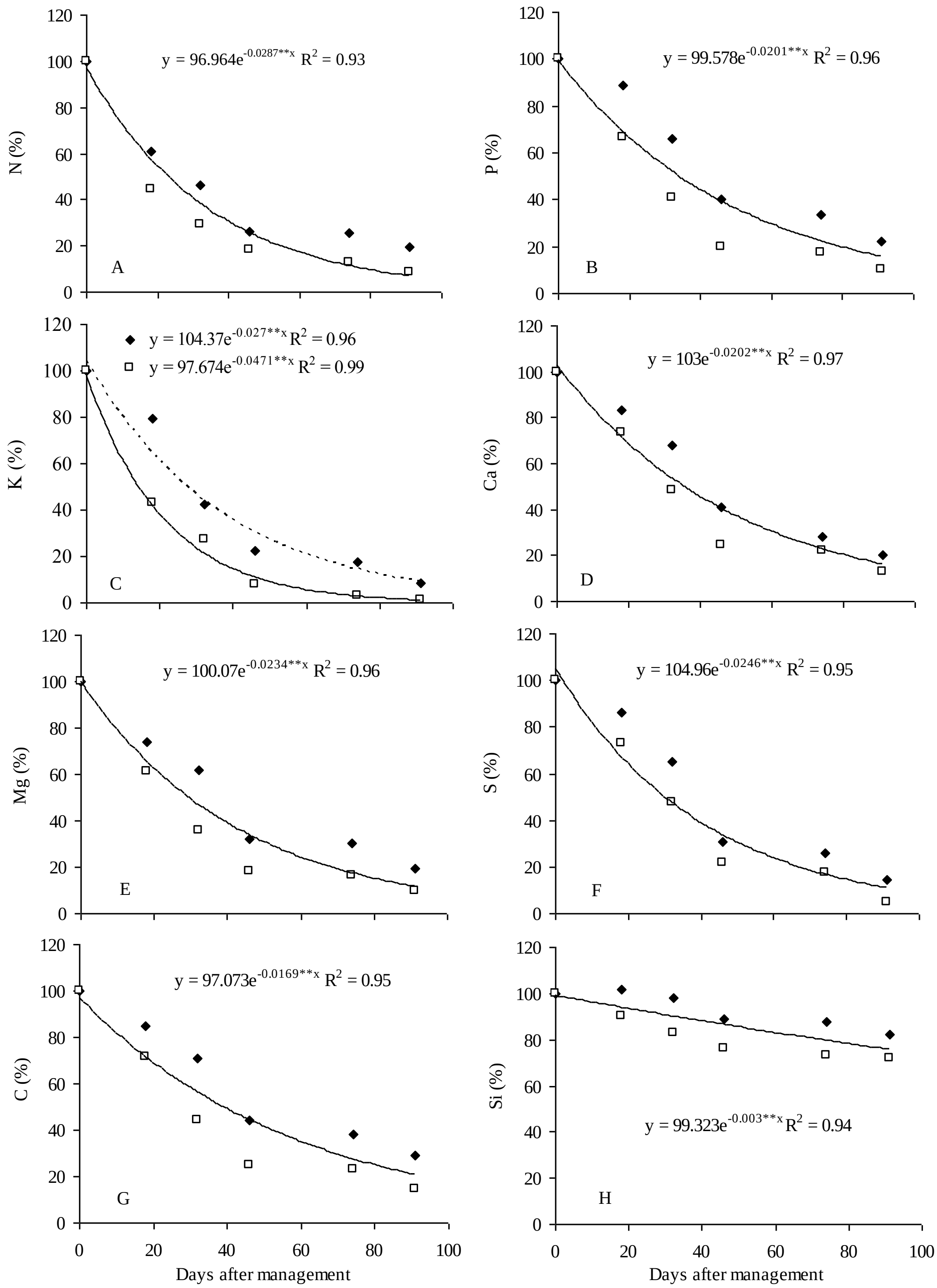

Figure 5. Percentages of N (A), P (B), K (C), Ca (D), Mg (E), S (F), C (G) e Si (H) in pigeonpea shoot dry matter according to time after management, without (◆) and with (□) mechanical fragmentation. **Significant at 1% by test F. The equations relating the percentage of N, P, Ca, Mg, S, Si and C were adjusted based on the average management treatments.

CONCLUSIONS

The mechanical fragmentation of pigeonpea shoot dry matter did not alter the decomposition and the release of N, P, Ca, Mg and S, and the maximum daily release rates occurred between 0-18 DAM. The K was the most quickly released nutrient, especially with the fragmentation of shoot dry matter. After 91 DAM at least 85% of all macronutrients were released to the soil. The release of Si was low being proportionally less than the degradation rate, which resulted in, increased the concentration over time, especially with mechanical fragmentation.

ACKNOWLEDGEMENTS

The authors would like to thank the São Paulo Research Foundation (FAPESP) for financial support (Registry numbers: 2004/10361-1) and the National Council for Scientific and Technological Development (CNPq) for an award for excellence in research to the second and third author.

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Recebido para publicação em 16/12/2016
Revisado em 16/02/2017
Aceito em 27/03/2017