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Decomposition and nutrients cycling of residual biomass from integrated crop-livestock system

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Abstract

The objective was to evaluate the decomposition and nutrient release of biomass from maintenance of fallow or oat crop (IPR 126), managed in integrated crop-livestock, during the soybean crop cycle (85 days) in no tillage system in two years (2014 and 2015). The design was a randomized complete block in a subdivided plot scheme, with the parcel consisting of four plots (four straws, from fallow or oat cultivation) and the subplots (evaluation periods 0, 10, 35, 60 and 85 DAS) with the evaluation times throughout the crop cultivation soybean. The amount of biomass and the content of C, N, P, K, Ca, Mg and Zn were calculated. The amount of biomass and nutrients presents a similar pattern of decrease in their values; however, the climatic conditions and the C/N ratio play an important role in the decomposition and mineralization of nutrients. The mineralized amount of N, K, P, Ca, Mg and Zn is directly proportional to their initial content in the biomass, and K nutrient is quickly released from crop residues. Most of the nutrients studied were released during the soybean crop development cycle, favoring its development; this can provide a reduction of external inputs in the property.

Keywords: *Avena sativa*, Management system, Mineralization of nutrients, Nutrient accumulation, Plant biomass.
Abbreviations: days after sowing (DAS), half-life (t½), integrated crop-livestock system (ICLS).

Introduction

The integrated crop-livestock system (ICLS) is used by many small and medium-sized farms in south Brazil, which is characterized mainly by the cultivation of annual winter pasture and, in the summer, by the production of grain (corn, soybeans or beans) or silage (maize or sorghum) (Veiga et al., 2014). However, the ICLS requires adequate management, since the use of the grazing area can cause soil compaction problems due to animal trampling, as well as the reduction of the soil cover by the straw, which may compromise the no-tillage system (Veiga et al., 2012).

The presence of animals into the agricultural production system can modify the rates and flows, that is, the nutrient dynamics between the compartments of the system (Anghinoni et al., 2013). The heights pasture management determine the total amount of dry matter produced by the aerial part and root system, the magnitude of the impact of the animal trampling and the amount of dry matter recycled in the system (Aguinaga et al., 2008). Excessive grazing pressures may reduce pasture growth due to low leaf area index and the amount of remaining straw for posterior crops (Balbinot Júnior et al., 2009). It is recommended that the remaining amount of residues is greater than 2 t ha^{-1} (Flores et al., 2007), so there are no changes in the system.

The conservation of organic matter is crucial for the chemical, biological and physical properties of the soil in temperate and tropical environments (Batista et al., 2014), as well as being an important constituent of the nutrient reserve, whose availability can be rapid and intense (Rosolem et al., 2007), or slow and gradual, depending on the quantity, type of material and climatic conditions. The knowledge of nutrient cycling is important for the efficient use of soil nutrients, residues and fertilizers in the ICLS, because losses and additions of carbon and nutrients modify soil dynamics (Hentz et al., 2014).

The objective was to evaluate the decomposition and nutrient release of straw from fallow or oat cultivation, managed in integrated crop-livestock system, during the winter period, in a soybean crop, with no-tillage system for two years.

Results and Discussion

In this study, due to the experimental design used, it was not possible to do the joint analysis of data therefore, the results are presented separately for each year. A significant interaction among the residues (oats 1 grazing, oats 2 grazing, oats without grazing and fallow) and the time of decomposition (0, 10, 35, 60 and 85 days) for the remaining biomass (2014 and 2015) and total carbon (2014 and 2015) were observed. There was also a significant interaction, for the amount of remaining nutrients, nitrogen (2014 and 2015), potassium (2014 and 2015), phosphorus (2014) and magnesium (2014). The amount of remaining nutrients, which were calcium, zinc and magnesium, was the measure of the influence of the decomposition time (only in 2015).

Biomass

Among the cultural residues, the decomposition kinetics of the biomass and the amount of nutrients presented a similar pattern, with exponential decay, with the progressive decrease of dry mass. The highest biomass loss observed for the oat crop without grazing in both years is due to the greater amount of initial residues (Fig 1). This residue also showed larger amounts of remaining dry mass in all evaluated epochs in 2014 and the first three in 2015 (Fig 1). It is possible to observe that the animal presence provided smaller amounts of remaining biomass, with different behavior. However, only fallow in both years had initial residual residues of less than 2 t ha^{-1}, favoring the existence of negative changes in the system (Flores et al., 2007).
The highest half-life (t ½) of the remaining biomass was verified for fallow, with 98 days in 2014 and 76 days in 2015 (Fig 1). This is mainly due to the higher C/N ratio of the material (Table 1). The high C/N ratio of fallow is due to the fact that the fallow did not receive any type of nitrogen fertilization, base or cover, when compared to oats, besides having Poácea, in the spontaneous vegetation, component of the fallow treatment. Among the predominant spontaneous species that sprouted in the fallow area are turnip (*Brassica napus* L.) and ryegrass (*Lolium multiflorum*).
Different patterns of decomposition and mineralization of nutrients of cultivate residues are observed in field experiments, depending on the type of residue and the initial amount. In addition, the climatic factors, wich are mainly frequency and intensity of rains, as reported for *Brachiaria* residues (Pacheco et al., 2011), are associated with the existence of high temperatures.
Teixeira et al. (2011) evaluated the decomposition and release of nutrients from the aerial part of millet and sorghum plants, found half-life (t½), 98 days for millet, and 96 days for sorghum. However, Gao et al. (2016) evaluated the decomposition of wheat straw in anaerobic and aerobic conditions, found a longer half-life (t ½), 122 days, under anaerobic conditions, when compared to aerobic conditions, 73 days.
In 2015, the remaining biomass was lower, which also had a shorter half-life (t ½). This fact can be explained by the high volume of precipitation (November and December) (Fig 3), inducing the increase of the microbial activity and the decomposition of the biomass.

Carbon

The total carbon kinetics followed the pattern of the remaining biomass because the amount of carbon is proportional to the biomass content in the area. The highest half-life (t ½) of total carbon was verified for fallow, with 100 days in 2014 and 54 days in 2015 (Fig 1). Evaluating the values of the C/N ratio of the crop residues (Table 1), we can see that they are close to or above 25, a value that is considered as a reference between Fabaceae (rapid decomposition) and Poaceae (slower decomposition) (Costa et al., 2015), which were the predominant residues in the area. Thus, even the small amount of residues from the fallow, providing a straw with slow decomposition, will remain longer on the surface of the soil.

Nitrogen

In this work the N was the first nutrient extracted by the forages and, therefore, with greater accumulation in the phytomass. In spite of the non-fertilization of nitrogen, it also managed to absorb and accumulate N in the biomass. The highest half-life (t½) of the remaining nitrogen was verified for the two grazing oats, with 75 days in 2014 and for the 120 days fallow in 2015 (Fig 1), which is due to a higher C/N ratio of the material. For Torres et al. (2005), evaluating the nitrogen decomposition and release of cultivate residues of cover crops in a closed ground, where N mineralization was evaluated, it was found t ½ of 100 days for the millet, 141 days for the sorghum and 47 days for the fallow.
To Perin et al. (2010) the release rate of N is closely related to the release of C because the amount of N follows the same behavior of the remaining biomass, reinforcing the concept that the C/N ratio has a great contribution in the regulation of the decomposition process of the vegetal biomass. Assmann et al. (2014) evaluating the decomposition and nutrient release of dual-purpose wheat residues, in an ICLS with soybean in succession, found that the total N released was influenced by the initial level of residues and the quantity of plant residues.
Mendonça et al. (2015) evaluating the nutrient release of straw from intercropped forages with corn with soybean crop in succession, found that the N release was more intense up to 30 days, tending to stabilize from that period. In this sense, an amount of N of the total portion absorbed by the plants in succession comes from the crop residues, even in the soybean crop (Costa et al., 2012).

Potassium

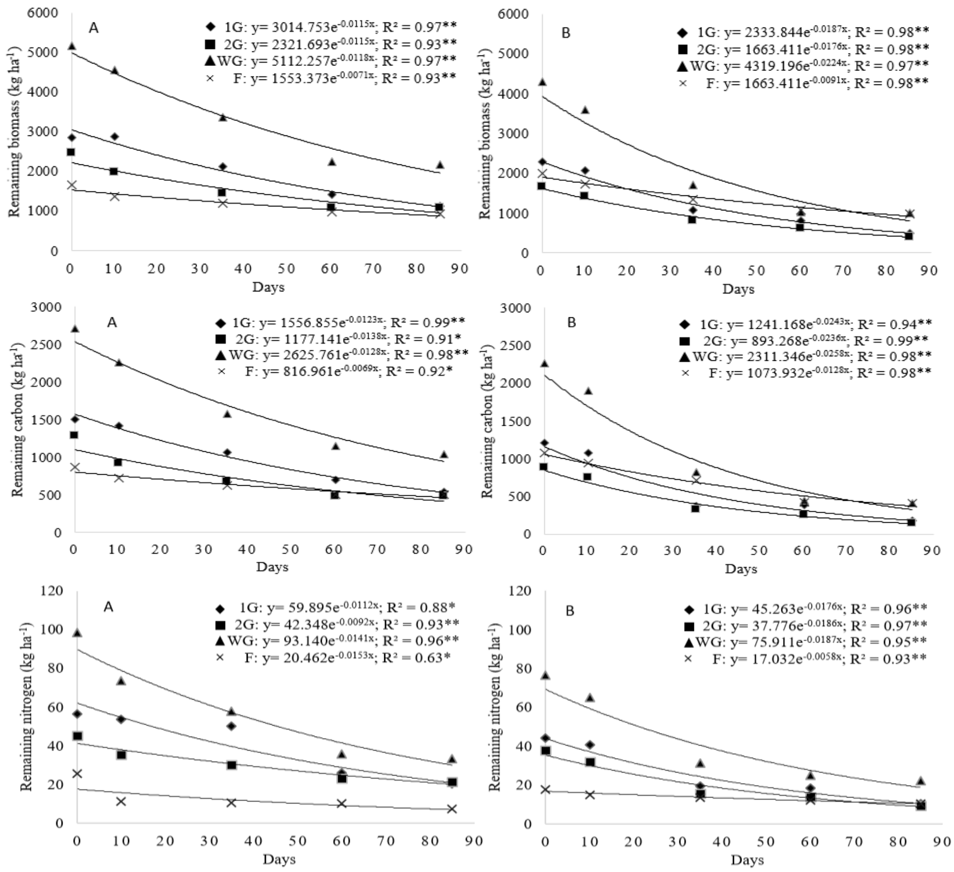
The K was the second nutrient most extracted by the forages, presenting a longer half-life (t½), of 7 days, for residues from oats with grazing and oats without grazing in 2015 and 16 days for Oats with 1 grazing (Fig 2). Assmann et al. (2014) working with dual-purpose wheat, found an initial K concentration of 17 ± 2 g kg^{-1}, a value similar to this study. However, the accumulation of K in forages obtained by several researchers (Pariz et al., 2011; Assmann et al., 2014) showed that the macronutrient with the highest accumulation was K, followed by nitrogen N.
Although K is the most abundant cation in the cytoplasm of plant cells and does not have structural function, in order to form connections with organic complexes of easy reversibility and, therefore, of easy release of the vegetal remains, the decomposition of K liberates it totally and quickly (Mendonça et al., 2015), as proven by the low half-life (t ½). Moreover, the rapid release of K from straw and animal residues is independent of grazing (Assmann et al., 2014), as well as the action of rainwater, regardless of the mineralization of organic matter, may be an important

factor in the leaching of plant remains (Calonego et al., 2012).

Table 1. Chemical characteristics of the cultivated straw and amount contributed in each experimental unit.

Straw	N ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	Ca ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	C ($g\ kg^{-1}$)	C/N Ratio	MS g
2014									
Oat 1G	20.89	2.41	15.58	5.65	2.63	29.14	524.56	25.18	27.87
Oat 2G	18.49	2.20	15.06	11.47	2.15	19.92	522.00	28.28	18.49
Oat WG	19.23	2.29	13.13	9.35	3.52	23.50	525.16	27.34	38.66
Fallow	14.81	1.29	13.95	20.00	3.30	46.63	526.93	36.38	12.34
2015									
Oat 1G	21.19	2.20	18.48	14.52	3.20	26.87	528.19	24.93	20.62
Oat 2G	23.03	2.28	19.03	18.43	4.68	45.45	527.74	22.93	12.51
Oat WG	17.79	2.45	18.90	9.21	2.18	31.41	526.03	29.58	32.24
Fallow	8.85	1.81	14.88	11.29	1.61	30.95	539.27	61.59	14.98

Note. 1G: one grazing; 2G: 2 grazing; WG: Without grazing; F: Fallow.



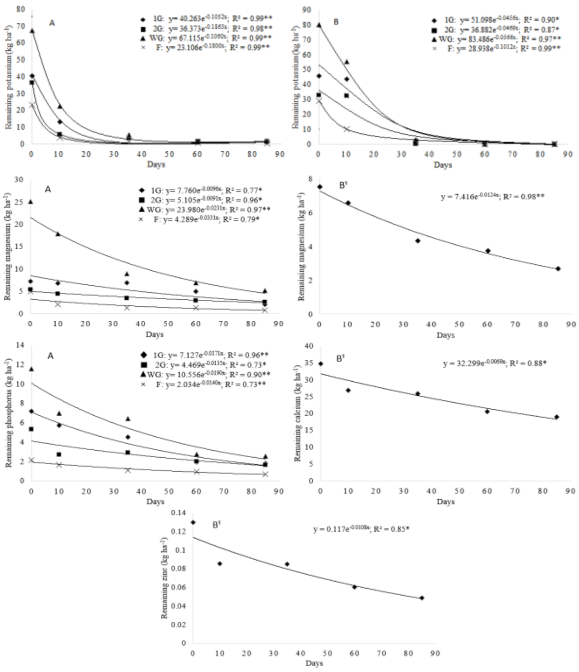
Note: * significant at 5% probability by the F test; ** significant at 1% probability by the F test; A – year of 2014; B – year of 2015.

Fig 1. Remaining biomass, carbon and nitrogen from cover crops in assessments carried out over time in pockets of soil surface decomposition. 1G: one grazing; 2G: 2 grazing; WG: Without grazing; F: Fallow.

Table 2. Soil chemical and textural characteristics, before the implantation of the winter crop of 2014.

Depth	P	pH	$H^{+}Al$	Al^{3+}	K^{+}	Ca^{2+}	Mg^{2+}	SB	CTC	V	Clay	Silt	Sand
m	mg dm^{-3}	$CaCl_2$	------------$cmol_c$ dm^{-3}--------------------							%	---------g kg^{-1}----------		
0.0-0.1	30.3	4.4	6.6	0.4	0.5	3.0	1.8	5.3	12.0	44.7	681.0	266.5	52.5
0.1-0.2	20.2	4.4	6.8	0.3	0.5	2.7	1.4	4.6	11.4	40.1	751.5	199.1	49.4

Note. P and K - obtained by MEHLICH-1; Al, Ca and Mg - obtained by KCl 1 mol L^{-1}; $H^{+}Al^{-}$ obtained by pH SMP (7.5).



Note: * significant at 5% probability by the F test; ** significant at 1% probability by the F test; A – year of 2014; B – year of 2015; B¹ - year 2015 - there was significant for the release time, regardless of treatment.

Fig 2. Remaining potassium, phosphor, magnesium, calcium and zinc from cover crops in assessments carried out over time in pockets of soil surface decomposition. 1G: one grazing; 2G: 2 grazing; WG: Without grazing; F: Fallow.

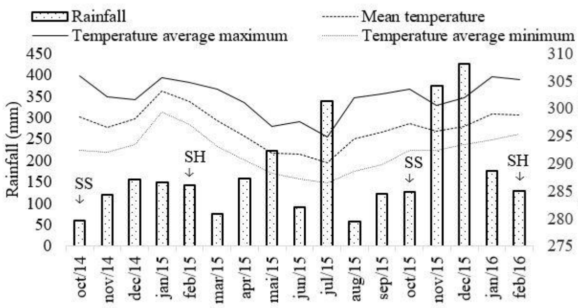


Fig 3. Monthly average of the maximum, minimum and average temperatures (K) and accumulated rainfall (mm) during the months of the experimental period. Soybean Seeding (SS) and soybean harvest (SH).

Phosphorus

The initial levels of P in oat residues in both years were higher compared to fallow, which is due to mineral fertilization performed in the crop. Also, the animal presence tends to affect the amount of residues remaining on the soil, and therefore the amount of P and the period of release in the later cultivation, evidenced by the different half-lives (t½), 41, 51 and 37 days respectively for oats with grazing, two grazing and no grazing (Fig 2).

The choice of plant species that present high P accumulation capacity in the aerial part of the plants and subsequent release to the soil via mineralization, is an important strategy to increase the availability of P to the plants. The process of P mineralization is regulated by the C/P ratio, where a value greater than or equal to 300 tends to immobilize and less than 200 favors mineralization (Maluf et al., 2015). However, the P to be released from the organic tissues can be made available both for absorption of the root system of the crop in succession and for immobilization in mineral compounds of difficult solubility (Mendonça et al., 2015), as well as non-labile forms of fixation (Calonego et al., 2012).

Magnesium

The initial contents, as well as the Mg release, were very variable, depending on the type of biomass. The highest half-life (t ½) of Mg, 76 days in 2014, was found for oats that underwent two grazing, however, in 2015, the mean half-life (t ½) of the biomass was 56 days (Fig 2). The difference between the half-life times, if due, the initial amount of biomass and the climatic conditions of 2015, which favored the mineralization of the materials. Teixeira et al. (2011) found that, at 90 days almost all the Mg was released from the vegetable residues.

Calcium

Although the behavior of Ca is influenced only by weather conditions, it is a nutrient that plants extract in smaller quantities when compared to N and K. Ca is an element that is part of the structural composition of cells (such as wall cell), besides being a cofactor of some enzymes involved in the hydrolysis of ATP and phospholipids and secondary messenger in the metabolic regulation (Taiz et al., 2017). In addition, it present greater difficulty to be mineralized and released to the soil. The half-life (t½) is 100 days (Fig 2). However, when released from cultivate residues, it favors the successor crop that can absorb considerable amounts of this element (Mendonça et al., 2015). Crusciol et al. (2008), evaluating the decomposition and macronutrient release rates of black oat straw in no-tillage, found that for Ca and Mg in the phytomass decomposition, the points of maximum accumulated release were reached at 53 and 50 days after the process of mineralization, respectively.

Zinc

In this study, the fallow presented high levels of Zn in both evaluation years (Table 1), however, there was no difference between the residues, because only in 2015, it was significant for the release time. However, despite Zn being a micronutrient, in 2015 it had a half-life of (t ½) of 64 days, which favors the release of the nutrient and consequently a better utilization by the crop that would be planted later. Although micronutrient mineralization studies are still scarce, it is important to maintain the cultural residues on the soil, because, over time, the mineralization of micronutrients becomes important, especially in relation to Zn (Maluf et al., 2015).
The speed of nutrient release of the cultural residues during the decomposition process depends on numerous factors, such as the location and form of these residues in the plant tissue (Mendonça et al., 2015), the species used, soil fertility, the amount deposited on the soil surface, the C/N ratio, the sowing time, and the climatic conditions of each study (Pariz et al., 2011). However, depending on the mineralization rate of each nutrient of the evaluated plants, it is possible to adapt the sowing of the subsequent cultivation, according to their needs for each nutrient, thus reducing the costs with mineral fertilization (Teixeira et al., 2011).

Materials and Methods

Location, climate and soil of the study area

The work was developed at the experimental station "Professor Antônio Carlos dos Santos Pessoa" (24º31'58''S and 54º01'10''W, with an approximate elevation of 400 m), belonging to the Universidade Estadual do Oeste do Paraná - Campus Marechal Cândido Rondon, in a clayey Red Latosol (Santos et al., 2013). The area was being managed under integrated crop-livestock system (summer soybean and double purpose cereals in the winter) for two years, and had the following physicochemical characteristics described in table 2. Due to the saturation by bases, present values are below to 50%, so we made a surface liming with 3 t ha^{-1} of calcite limestone that was performed 30 days before seeding the 2014 oat crop. The objective was to increase the base saturation to 70% (Table 2).
The climate of the region, according to Koeppen's classification, is subtropical humid mesothermal type Cfa, with well-distributed rainfall during the year and hot summers. The average temperatures of the coldest quarter vary between 290.15 and 291.15 K (Kelvin), between 301.15 and 302.15 K (Kelvin) for the warmest quarter and between 295.15 and 296.15 K (Kelvin) for the annual temperature. The climatic data regarding the experimental period were obtained from an automatic weather station distant about 50 m from the experimental area (Fig 3).

Experimental design

The experimental design was a randomized complete block design, with two replications, in a subdivided plot scheme. The plots (with dimensions of 10 x 5 m) were composed of four straws, and the subplots, by the evaluation periods throughout the cultivation of the soybean crop (0, 10, 35, 60 and 85 days after sowing (DAS), of soybeans).

Implantation and management of crops

In April of 2014 and 2015, it was carried out the direct seeding of oat (60 kg ha^{-1} IPR 126) using 250 kg ha^{-1} of a formulation 10-15-15 (N, P_2O_5 and K_2O) for base fertilization, and 120 kg ha^{-1} of N in the form of urea for cover fertilization. Oat was managed in integrated crop-livestock system (one grazing with 0.15-0.20 m height of residue, second cropping with 0.15-0.20 m residue height and third party no grazing area), as well as maintenance of fallow. For grazing, Dutch cows were used during lactation, with an average weight of 650 kg ± 50 kg.
The residual straw was collected one week before seeding the soybean crop, at 143 DAS in 2014 and at 138 DAS in 2015, with the aid of a metallic square with a known area (0.25 m²). It was launched randomly twice in each plot and the entire straw above the soil surface that was contained inside was collected. After the collection, the material was

identified and submitted to oven drying with forced air ventilation at 328.15 K (Kelvin) for 72 hours.

To evaluate the decomposition and nutrients release, it was used the litter bags method decomposition, made with nylon with a 4 mm opening mesh, with dimensions of 0.30 x 0.25 m and an internal area of 0.075 m^2. In each litter-bag the dry residues of the winter crops were conditioned, being this amount the proportion of the aerial part of each evaluated material, according to Table 1. The litter-bags were evenly distributed on the soil surface of each plot, above the remaining straw of the plants, and four litter-bags were arranged in each plot, soon after sowing the soybean crop. The evaluation of nutrient decomposition and release was monitored by a sequence of four samplings, the first one being at 10 DAS, the other at 35, 60, and 85 DAS, respectively.

The soybean crop seeding was carried out on 10/09/2014 and 10/16/15, using the cultivars V-TOP 1059 RR (2014) and NIDEIRA 5909 RR (2015), with 17 and 15 seeds per linear meter, respectively, with spacing between the rows of 50 cm, in no-tillage on the remaining straw. The soybean base fertilization was 270 (2014) and 290 (2015) kg ha^{-1} of fertilizer 02-20-18 (N, P_2O_5 and K_2O). The seeds were treated with Carbendazim + Thiram fungicides, Fipronil insecticide and inoculated with *Bradyrhizobium japonicum*. During the development of the soybean crop, cultivation treatments were carried out as it was necessary, following an agronomic recommendation.

Performed analyzes

At each sampling period, the straw contained in the litter-bags were oven dried at 328.15 K until constant weight was reached to determine the remaining dry matter. After weighing, the material was ground in Willey mill to determine the concentrations of C, N, P, K, Ca, Mg and Zn, including time zero. The C was obtained from the determination of the organic matter in muffle as described by Silva and Queiroz (2006). For the estimation of the concentration of C in the samples, the organic matter concentration was divided by 1.72 as recommended by Peixoto et al. (2007). N was determined by sulfuric digestion and distillation in a semi-micro Kjeldahl system, while for the determination of macro and micronutrients the nitroperchloric solution was carried out, with subsequent reading in an atomic absorption spectrophotometer (Donagema et al., 2011). It was also determined the C/N ratio and the accumulation of the nutrients under study in the aerial part of the cover plants until the 85 days after the seeding, being this one obtained by the product of the dry mass with the content of the nutrients.

To describe the decomposition of plant straw and the release of macronutrients, the exponential mathematical model of type $Y = Yoe^{(-kx)}$ was applied, where Y is the amount of dry mass remaining after a period of time x, in days, Yo is the initial amount of dry mass or nutrient, and k is the residue decomposition constant (Thomas and Asakawa, 1993). With the value of k, the half-life ($t½ = 0.693/k$) was calculate, which expresses the time required for half of the straw to decompose or half of the nutrients contained in the residues to be released (Paul and Clark, 1989).

Statistical analysis

The obtained data were submitted to analysis of variance with application of Test F between the treatments. Statistical analyzes were performed using the SISVAR computer program (Ferreira, 2011). When they had significance the regression equation was adjusted using Sigma Plot 12.0 software.

Conclusion

The biomass and nutrient content present a similar pattern, with exponential decay, with the progressive decrease of the dry mass, the climatic conditions, as well as the C/N ratio, play an important role in the decomposition and mineralization of the nutrients.

The mineralized amount of N, K, P, Ca, Mg and Zn is directly proportional to their respective initial contents in the straw.

The K is the nutrient most quickly released from cultural straw.

Most of the studied nutrients were released during the development cycle of the soybean crop, favoring its development.

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