

# EUCALIPYTUS LITTER CONTRIBUTION TO THE INTEGRATED CROP-LIVESTOCK SYSTEM

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## Resumo

*Contribuição da serapilheira de eucalipto ao sistema de integração lavoura e pecuária.* O objetivo do estudo foi avaliar a deposição mensal de serapilheira e nutrientes de eucalipto depositado dos 47 aos 58 meses em consórcio do eucalipto com cultivo agrícola (ILF), eucalipto com pastagem (IPF), e em monocultivo de eucalipto (F). Os dados foram comparados entre os sistemas de integração pelo teste t e entre esses com o monocultivo por meio da ANOVA e o teste de Duncan, ao nível de 5% de probabilidade. A deposição anual total acumulada de serapilheira foi de 0,63 t ha<sup>-1</sup> ano no ILF, de 0,43 t ha<sup>-1</sup> ano no IPF e de 6,34 t ha<sup>-1</sup> ano no monocultivo. A deposição de serapilheira total e compartimentalizada nos sistemas de integração (0,19 a 0,26 kg.m<sup>-2</sup>) diferiram significativamente do monocultivo (0,63 kg.m<sup>-2</sup>) ao nível de área de coletor, no entanto, ao nível de hectare, os sistemas de integração não diferem entre si. Essa mesma tendência foi observada para o estoque de nutrientes nos diferentes compartimentos da serapilheira. Independentemente do sistema de produção, a fração folhas foi a mais representativa na composição da serapilheira, seguida por galhos e casca. O teor de nutrientes foi similar entre os tratamentos avaliados. Por fim, o estoque de nutrientes foi superior no monocultivo e entre os sistemas de integração, a maior contribuição nutricional ocorreu no ILF.

*Palavras-chave:* *Eucalyptus grandis* x *E. urophylla* (clone H13), sistema de ILPF, ciclagem de nutrientes.

## Abstract

The aim of this study is to assess eucalyptus litter and nutrient deposition on a monthly basis, at the age 47 to 58 years, in integrated eucalyptus with crop system (ICF), eucalyptus with livestock (ILF) and eucalyptus monoculture (F). Integration system data were compared through t test and compared to eucalyptus monoculture through ANOVA and Duncan test, at 5% probability level. Annual litter deposition reached 0.63 t ha<sup>-1</sup> year in CFI, 0.43 t ha<sup>-1</sup> year in LFI and 6.34 t ha<sup>-1</sup> year in the monoculture system. The total and fractioned litter deposition in integration systems (0.19 to 0.26 kg.m<sup>-2</sup>) was significantly different from the monoculture system (0.63 kg.m<sup>-2</sup>) at collector area level, however, integration systems did not differ from one another at hectare level. The same trend was observed for nutrient stock in different compartments of the assessed litter. Regardless of the production system, the leaf fraction was the most representative factor in litter composition, which was followed by branches and bark. Nutrient content was similar among the tested treatments. Finally, nutrient stock was higher in the monoculture system; the highest nutritional contribution was observed in CFI between the assessed integration systems.

*Keywords:* *Eucalyptus grandis* x *E. urophylla* (clone H13), CLF integration system, nutrient cycling.

## INTRODUCTION

Integrated Crop-livestock-forestry system (ICLF) consists in the agriculture, livestock and forest consortium in the same land in order to assure sustainable land-use and production expansion (BALBINO *et al.*, 2011) in Brazil in the years to come.

Production cost reduction and income diversification are among the benefits from this system (ALVARENGA *et al.*, 2010), as well as water, soil and climate resource conservation, recovery of degraded areas, natural pest and disease control, greenhouse gas emission reduction (BALBINO *et al.*, 2011), changes in microclimate such as temperature and humidity (GUIMARÃES; CALIL, 2017), light, wind, pH and C and N stock (BENAVIDES *et al.*, 2009), and soil quality changes naturally motivated by nutrient cycling due to tree-component presence.

Cycling is the main way to circulate nutrients in soil-plant-atmosphere systems composed of litter deposition fractions like leaves, branches, wood, bark and roots. Trees contribute to nutrient availability in soil

profile due to this natural mechanism and to root stratification. This process allows nutrient mobility, since roots absorb nutrients at deep soil layers and give them back to soil surface through litter deposition and decomposition. According to Notaro *et al.* (2014), this process adds to organic matter content, which is the source of nutrients for plant reabsorption.

Despite the several scientific publications reporting such deposition, accumulation and decomposition in native and planted forests in tropical and temperate regions, recent research address litter dynamics in integrated production systems (GUIMARÃES; CALIL, 2017; FREITAS *et al.*, 2013).

Litter quantitative and qualitative regulation is determined by different factors such as altitude, latitude, rainfall, temperature, relief, water availability, soil type, evaluation time (CALDEIRA *et al.*, 2008) and wind (PIETRO-SOUZA, 2012). These factors are closely related to vegetation and cultivation type and diversity, in other words, to community heterogeneity (GUIMARÃES; CALIL, 2017), which, consequently, affects nutrient devolution to forests, cultures or systems.

As previously observed, the *Zea mays-E. grandis x E. urophylla-Acacia mangium-Brachiaria decumbens* and *Zea mays-E. grandis x E. urophylla* agroforestry systems produce more litter than *Brachiaria decumbens* monoculture (FREITAS *et al.*, 2013). However, when one compares deposition in secondary forests (SOUZA *et al.*, 2016) or in native forests, such larger litter production is not often observed. This outcome suggests that native environments present higher litter yield values than consortium systems. Therefore, litter yield can be influenced by the species integrated to the tree component due to matters intrinsic to growth and ecophysiology, mainly the ones related to competition degree (BENAVIDES *et al.*, 2009).

However, with respect to quality, litter does not show differences due to changes in culture type, it keeps the prevailing prevalence of higher leaf input rate, which is the most representative fraction of litter composition (FREITAS *et al.*, 2013). Nevertheless, other compartments such as branches, bark and miscellany recorded different leaf input rates due to soil type, climate and cultivation type (LIMA *et al.*, 2010).

Litter nutrition content can be mainly influenced by the diversity (LIMA *et al.*, 2010) and composition of the integrated crop-forestry system (SOUZA *et al.*, 2016), as well as by vegetation structure and by abiotic factors such as light, temperature and rainfall, since all these factors can influence the biochemical and physiological processes (HOLANDA *et al.*, 2017) due to differences in plants' anatomical features; soil humidity and temperature also influence the aforementioned variations (GUIMARÃES; CALIL, 2017). *Eucalyptus globulus* leaves have higher N, P, S, B and Mn content; fractions "thin branches" and "miscellany" recorded increased Fe and Mg content. Thick and thin branches, in their turn, present higher Ca content, similar to leaves. This element is accumulated in its crystal form in the leaves; however, K, Cu and Zn content does not differ between litter compartments (VIERA *et al.*, 2014). Other variations can be observed, such as higher Mg content in the leaves, because this element is also found in chlorophyll (LIMA *et al.*, 2010). Contents change in litter compartments due to nutrient displacement from senescent organs to the growth regions; these variations depend on plant species, environment or site, and on management practices (VIERA *et al.*, 2014). These contents change due to alterations in factors such as management, climate and physiological features of the plant species. These changes highlight litter's influence on the nutritional dynamics of the systems (LIMA *et al.*, 2010).

Accordingly, assessing the seasonality of litter deposition, compartment contributions, content and accumulation is essential to better understand fertility dynamics and trees' contribution when they are integrated to other cultures. Similar to natural "fertilization" mechanisms, knowing the contribution degree of litter from the tree component to the crop/livestock system is relevant; individuals can benefit from right planning and management throughout the production cycle. Trees in CLI can benefit from the fertilization of cultivated crops or from the nutrition provided by post-crop waste. The LFI system, in its turn, likely benefits from nutrients provided by the presence of animals, mainly by the devolution of nutrients by fecal matter, which is translocated and absorbed by tree roots.

Therefore, understanding such process helps decision-making about implantation, which mainly involves choosing the right spacing and species for a consortium, as well as forest intervention practices such as fertilization. Knowing and describing these differences due to species, cultivation type and site is essential, since the chemical composition of this material is closely related to decomposition speed and, consequently, to the return to the geochemical cycle and to the influence on the export of nutrients from these fractions at culture exploration time. Applying generalizations to studies about integrated production systems can be risky, since litter input is an ecological and dynamic process regulated by the features of the species involved in the consortium, by soil and climate characteristics and by planning parameters such as spacing and post-culture interventions, for instance, management practices, mainly pruning, which have straight influence on this dynamics.

Given the aforementioned considerations, the aim of this study was to assess the contribution from the deposition of eucalyptus trees litter and nutrients to integrated crop and livestock systems.

## MATERIALS AND METHODS

The study was applied to Integrated Crop-Forestry (ICF) and Integrated Livestock-Forestry (ILF) systems, and to eucalyptus monoculture (F), at the age of 47 and 58 months, in the experimental field of Embrapa Agrossilvipastoral (11° 51' 43" S and 55° 35' 27" W- altitude 384m), Sinop County – Mato Grosso State.

Local climate is tropical, warm and humid. It is classified as Am based on Köppen's classification. Mean temperature in the region is 25.6°C and mean rainfall ranges from 1,800mm to 1,900mm. The dry season goes from April to October (SOUZA *et al.*, 2013). Soil was classified as Red-yellow Latosol (VIANA *et al.*, 2015).

The production systems were implemented in November 2011. Implementation demanded subsoiling and the application of 350 kg.ha<sup>-1</sup> of simple superphosphate in the furrows, as well as the cultivation of *Eucalyptus urophylla* x *E. grandis* (clone H13) in triple rows heading from East to West, spaced 3.5x3m from each other. Implementation integrated tree rows, every 30m (270 trees ha<sup>-1</sup>), to *Brachiaria brizantha* (ILF) pasture and soy and maize crops (ICF), as well as to monoculture at the same spacing (952 trees.ha<sup>-1</sup>). Fertilization was carried out 30 days after implementation, it consisted in the coverage of 100 g plant<sup>-1</sup> with NPK 20-00-20; one year later the site was covered with 40 g meter<sup>-1</sup> linear of NPK 20-05-20.

Litter deposition was assessed on a monthly basis, from October/2015 to September/2016, with 20 collectors in an 1m<sup>2</sup> site covered by nylon net (0.2mm, 0.5m high). Four (4) collectors were distributed in the monoculture eucalyptus: 2 in the row and 2 between rows; the remaining collectors were divided between the ICF and ILF systems. These systems were located on the line and the other ones between tree rows. The remaining ones were placed 3.5m, 7.5m and 15m away from each other, between tree rows – North and South exposure was taken into account. The deposited material was stored in paper bags, labeled and subjected to drying in oven at 55°C until reaching constant weight. Subsequently, samples were subjected to leaves, branches, bark and miscellany (flowers, fruits and seeds) separation; next, they were weighed on scale at precision 0.01g. Each litter compartment, in each treatment, was separated into composed samples, which were subjected to the dry (April to September) and rainy periods (October to March) in order to determine nutrient contents (N, P, K, Ca, Mg, S, Na, Cu, Fe, Mn, Zn). The content of N and S was assessed in CHNS-analyzer; the remaining elements were assessed through standard chemical analysis.

Litter weight per hectare was determined based on the ratio between collector site and site covered with trees per hectare, which, in this case, corresponded to 24.3% of the hectare in the integration systems (ICF and ILF). Nutrient stock per hectare was calculated by multiplying the litter weight (ha) by the respective nutrient content. Finally, the accumulated input during the assessed period, litter weight, and total nutrient stock and nutrient stock per compartment, were calculated.

Data normality was assessed through Shapiro-Wilk test and variance homogeneity was calculated through Bartlett and Levene tests. The first homogeneity test assessed data presenting normal distribution and the second one evaluated data that did not present normality trend. The accumulated input of litter deposition in litter's different compartments and nutrient stocks were assessed based on collector area (m<sup>2</sup>) by comparing the integration systems to the homogeneous culture through ANAVA, and means were compared through Duncan Test at 5% probability level. The accumulated deposition per hectare, in its turn, was only compared between integration systems through t test, at 5% probability level.

## RESULTS

The stock of N, P, K and Mg presented normal distribution and litter weight, the content and stock of all nutrients presented homogeneous variance, a fact that allowed using parametric statistics for data evaluation. Compartment 'miscellany' was not taken into consideration in input assessments, because the recorded values were almost null.

The mean annual total litter deposition per collector (Figure 1A) was 0.26 kg.m<sup>-2</sup> in ICF, 0.19 kg.m<sup>-2</sup> in ILF, and these numbers correspond to 40.7% and 30.7% of 0.63 kg.m<sup>-2</sup> of the input deposited in the eucalyptus monoculture (F), respectively. With respect to compartments (Figure 1A), it was possible observing that input rate in leaves was 51.9% in ICF and 39.1% in ILF; this rate in the branches was 24.5% in ICF and 19% in ILF; and in the bark, it was 28% in ICF and 20% in ILF in comparison to the input (100%) of these compartments recorded for F.

Significant differences in litter input (kg m<sup>-2</sup>) between systems were recorded for leaves, branches, bark and total; comparison between systems showed higher litter input in F. There were no significant differences between litter compartments in ICF and ILF (Figure 1B).

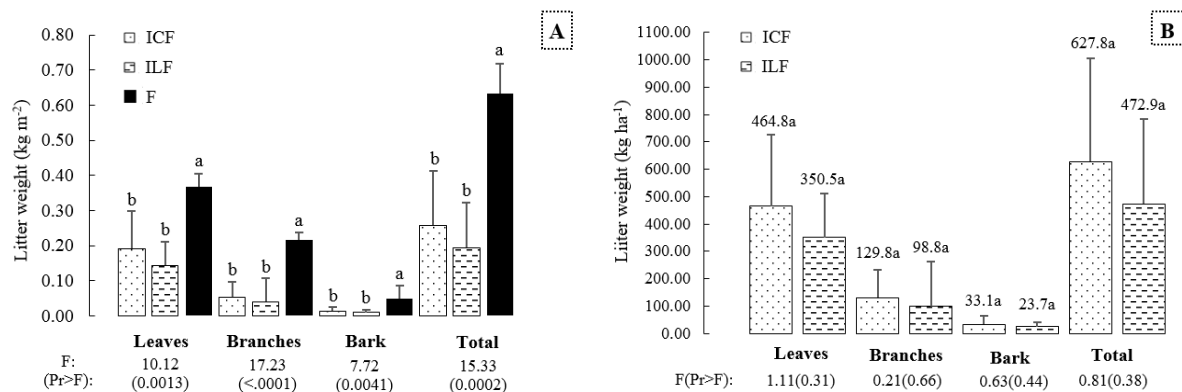


Figure 1. Total accumulated litter deposition (A in kg m<sup>-2</sup>; B in kg ha<sup>-1</sup>) and accumulated litter deposition per compartment in the integrated crop-forestry (ICF), livestock-forestry (ILF) systems and eucalyptus monoculture (F) in Sinop, MT. Means followed by the same letter do not statistically differ between treatments in the Duncan Test (A) and between integrated systems in the t test(B), both at 5% error probability.

Figura 1. Deposição de serapilheira (A em kg m<sup>-2</sup>; B em kg ha<sup>-1</sup>) acumulado total e por compartimento nos sistemas de integração lavoura-floresta (ILF), pecuária-floresta (IPF) e monocultivo de eucalipto (F), em Sinop, MT. Médias seguidas por mesma letra não diferem estatisticamente entre os tratamentos pelo Teste de Duncan (A) e entre os sistemas de integração pelo teste t (B), ambos ao nível de 5% de probabilidade de erro.

Variation coefficient of accumulated total weight and its nutrient stock was lower in the monoculture (from 10.5% to 15.7%) than in ICF (from 55.5% to 61.6%) and ILF (from 50.4% to 73.6%). The value recorded for the monoculture (from 7.7% to 13.0%) was observed in all compartments, except for the bark (from 62.4 to 92.5%). Systems ICF (from 52.9% to 91.0%) and ILF (from 43.7 to 171.7%) presented variation coefficient higher than 50% in nutrient weight and stock in all litter compartments. It is important emphasizing that the highest variation coefficient in ICF was recorded for the bark; as for LFI, such variation was observed for branches. The lowest variation coefficients in both systems were recorded for compartment “leaves”.

Comparisons between integrated systems (Figure 1B) showed input of 0.63 t ha<sup>-1</sup> in ICF and of 0.47 t ha<sup>-1</sup> in ILF. Although the ICF system showed higher litter input values in all compartments, except for the branches, which presented values similar to those observed for ILF, the t test did not show significant differences in input deposition of different compartments and of total litter.

Accumulated litter deposition trend (kg m<sup>-2</sup> and t ha<sup>-1</sup>) was leaves>braches>bark, regardless of the culture system; however, there were variations in the contribution rates of each compartment, mainly in F, when only the input per collector site was taken into account. Leaves represented 74% in ICF and ILF, on average, when deposition per collector site (m<sup>2</sup>) and per hectare were taken into account in the integrated systems. They were followed by branches, 20.6% in ICF and from 20.8% to 21% in ILF; bark recorded approximately 5.28% to 5.4% in ICF and 5% in ILF. The F system (kg m<sup>-2</sup>) showed that leaves accounted for 58% of the total of these compartments in litter composition; they were followed by the branches (34.1%) and the bark (7.9%).

There were differences in nutrient contents in litter compartments between integrated systems and eucalyptus monoculture (Table 1).

Table 1. Mean content of macronutrients (g kg<sup>-1</sup>) and micronutrients (mg kg<sup>-1</sup>) in litter compartments of eucalyptus cultivated in integrated crop-forestry (ICF), livestock-forestry (ILF) systems and eucalyptus monoculture (F) in Sinop County, Mato Grosso State.

Tabela 1. Teor médio de macro (g kg<sup>-1</sup>) e micronutrientes (mg kg<sup>-1</sup>) dos compartimentos da serapilheira nos sistemas de produção avaliados em em Sinop, MT.

Compartment	Treatment	Macronutrients (g kg <sup>-1</sup> )						Micronutrients (mg kg <sup>-1</sup> )				
		N	P	K	Ca	Mg	S	Na	Cu	Fe	Mn	Zn
Leaves	ICF	9.49	1.13	3.61	6.98	1.95	1.04	265.83	9.63	205.09	67.39	19.00
	ILF	8.22	0.70	3.81	6.97	2.15	1.56	246.03	6.60	208.09	78.08	15.98
	F	10.46	1.07	4.42	6.77	2.07	2.87	210.95	5.66	156.97	112.51	15.05
Branches	ICF	1.76	0.83	2.02	8.18	1.30	0.89	196.28	3.62	40.51	26.29	18.43
	ILF	1.82	0.78	2.61	8.18	1.47	1.12	190.28	4.84	45.02	31.16	19.20
	F	2.29	0.51	2.61	7.27	0.97	1.56	136.26	4.09	35.43	40.47	19.56
Bark	ICF	2.44	0.24	0.00	1.67	1.88	0.80	126.97	6.42	57.69	22.63	8.60
	ILF	3.00	0.21	0.15	2.50	1.91	1.09	116.41	11.36	68.81	26.77	8.13
	F	3.99	0.28	0.37	2.64	1.94	0.87	72.60	6.01	115.47	28.45	8.29

N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; Na: sodium; Cu: copper; Fe: iron; Mn: manganese; Zn: Zinc.

In numeric terms, N, P, K, Na, Fe, and Mn content was higher in the leaves, and Cu content was higher in the leaves in ICF than in the other treatments, as well as in the bark compartment in ILF than in ICF and in the monoculture. The highest Ca content was observed in branches and the lowest Zn contents were observed in the bark in the assessed treatments.

The leaves compartment presented the highest N, Ca, K and Mg content and the lowest amount of P and S. The branches compartment had the trend to show the highest contents of Ca, K, N and Mg and the lowest amount of P and S. Finally, the bark compartment tended to have higher N, Ca or Mg and S contents and lower P and K amounts. With regard to micronutrients, the leaves compartment, regardless of the treatment, presented content trend Na>Fe>Mn>Zn and Cu, and this very trend was observed in the branches and bark, in the integrated systems. The eucalyptus monoculture (F) presented variations in this trend, mainly between Fe and Mn in branches and between Na and Fe in the bark.

The stock of nutrients ( $m^{-2}$ ) accumulated in litter presented significant differences between integration systems and monoculture in ANOVA. Eucalyptus monoculture (F) in all assessments recorded higher nutrient stock means; this outcome was different from that of integration systems (ICF and ILF), which were different from each other. However, exceptions to such outcome were recorded for P stock in the leaves, branches and total, as well as for Na stock in the leaves. The P stock in the leaves (F: 17.92; Pr>F: <.0001) and in total (F: 16.52; Pr>F:0.0001) were different from each other in all systems; the eucalyptus monoculture (F) presented the highest mean, which was followed by ICF and, finally, by ILF. The P stock in the branches (F:2.32; Pr>F: 0.1288) and the Na stock in the leaves only differed from the eucalyptus monoculture (F) in ILF, which was different from ICF (Table 2).

Table 2. Macronutrients ( $kg m^{-2}$ ) and micronutrients ( $g m^{-2}$ ) stocks accumulated in the litter compartments of eucalyptus cultivated in integrated crop-forestry (ICF), livestock-forestry (ILF) systems and eucalyptus monoculture (F) in Sinop County, Mato Grosso State.

Tabela 2. Estoque de macro ( $kg m^{-2}$ ) e micronutrientes ( $g m^{-2}$ ) acumulado nos compartimentos da serapilheira de eucalipto cultivado nos sistemas de integração lavoura-floresta (ILF), pecuária-floresta (IPF) e em monocultivo em Sinop, MT.

Fraction	Treat.	Macronutrients ( $kg m^{-2}$ )					Micronutrients ( $g m^{-2}$ )					
		N	P	K	Ca	Mg	S	Na	Cu	Fe	Mn	Zn
Leaves	ICF	0.0016a	0.0002b	0.0009b	0.0013b	0.0004b	0.0002b	0.0562ab	0.0014b	0.0364b	0.0126b	0.0028b
	ILF	0.0011b	0.0001c	0.0007b	0.0010b	0.0003b	0.0002b	0.0394b	0.0010b	0.0278b	0.0117b	0.0020b
	F	0.0034a	0.0004a	0.0020a	0.0024a	0.0007a	0.0012a	0.0774a	0.0022a	0.0559 <sup>a</sup>	0.0408a	0.0053a
Branches	ICF	0.0001b	0.0001ab	0.0001b	0.0004b	0.0001b	0.0001b	0.0107b	0.0002b	0.0022b	0.0014b	0.0010b
	ILF	0.0001b	0.0000b	0.0001b	0.0003b	0.0001b	0.0000b	0.0074b	0.0002b	0.0018b	0.0012b	0.0008b
	F	0.0005a	0.0001a	0.0005a	0.0016a	0.0002a	0.0003a	0.0286a	0.0009a	0.0078 <sup>a</sup>	0.0087a	0.0042a
Bark	ICF	0.0000b	0.0000b	0.0000b	0.0000b	0.0000b	0.0000b	0.0014b	0.0001b	0.0007b	0.0003b	0.0001b
	ILF	0.0000b	0.0000b	0.0000b	0.0000b	0.0000b	0.0000b	0.0012b	0.0001b	0.0007b	0.0003b	0.0001b
	F	0.0002a	0.0000a	0.0000a	0.0001a	0.0001a	0.0000a	0.0036a	0.0003a	0.0060 <sup>a</sup>	0.0014a	0.0004a
Total	ICF	0.0018b	0.0003b	0.0010b	0.0017b	0.0005b	0.0003b	0.0683b	0.0017b	0.0393b	0.0143b	0.0039b
	ILF	0.0011b	0.0001c	0.0008b	0.0013b	0.0004b	0.0003b	0.0479b	0.0013b	0.0303b	0.0131b	0.0028b
	F	0.0042a	0.0005a	0.0025a	0.0041a	0.0010a	0.0015a	0.1097a	0.0033a	0.0697 <sup>a</sup>	0.0509a	0.0099a

N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; Na: sodium; Cu: copper; Fe: iron; Mn: manganese; Zn: Zinc; means of each nutrient followed by the same letter do not statistically differ between systems in each litter fraction or compartment.

The stock of S ( $m^{-2}$ ) in the leaves, bark and total, Cu stock in the branches and in the bark, as well as the K and Ca stock in the bark were higher in ILF than in ICF, although these stocks did not significantly differ at 5% probability level in the comparison of means test.

The leaves compartment in ICF provided nutrient contribution ( $kg m^{-2}$  and  $g m^{-2}$ ) from 16.7% to 72.60% in integration systems in comparison to the eucalyptus monoculture one (F); Branches contribution ranged from 5% to 208.3%, bark's ranged from 0% to 38.4% and the percentage of total stocks ranged from 28.1% to 62.3%. As for the ILF system, leaves compartment presented nutrition contribution from 16.7% to 50.9%, branches reached from 2% to 222.2%, and bark ranged from 0% to 38.7%; the percentage of total stock of different nutrients ranged from 17% to 43.4% in comparison to eucalyptus monoculture (F). Values higher than 100%, mainly in Cu stock in the branches, in both integration systems (ICF: 0.0019  $kg m^{-2}$  and ILF: 0.0020  $kg m^{-2}$ ) evidenced that they were higher than the stock observed for eucalyptus monoculture (F: 0.0009  $kg m^{-2}$ ).

When it comes to deposition per hectare, it was possible observing that the ICF system presented higher values than ILF; however, these values were not statistically different from each other (Figure 2), except for the P stock in the leaves, which had higher (0.55  $kg ha^{-1} year$ ) and more significant means (Pr>F: 0.0177) in the ICF system than in ILF (0.21  $kg ha^{-1} year$ ).

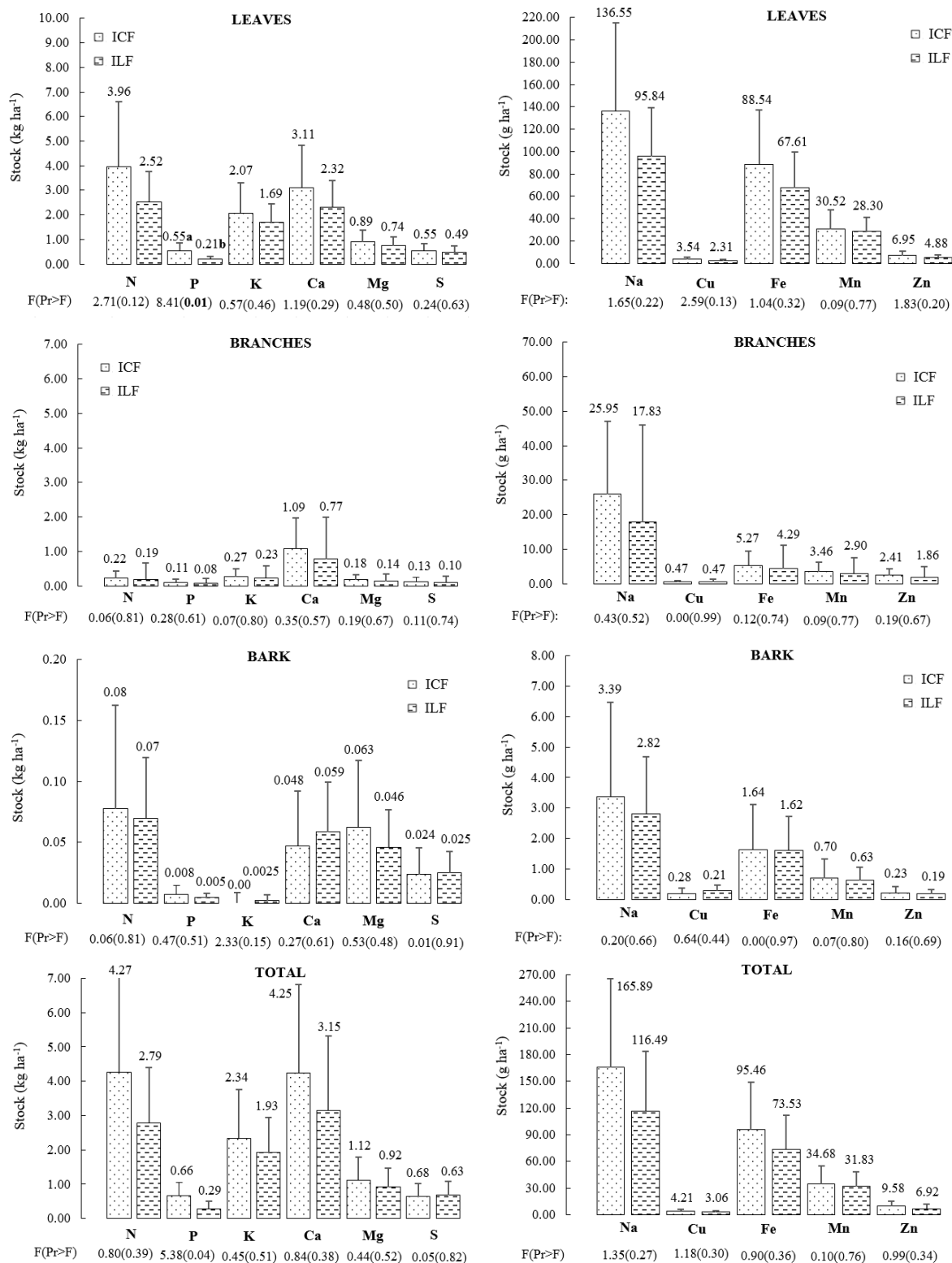


Figure 2. Macro (kg ha<sup>-1</sup>) and micro (g ha<sup>-1</sup>) stocks in the compartments of the eucalyptus litter cultivated in forest-forest integration (ILF) and forest-livestock (IPF) systems in Sinop, MT.

Figura 2. Estoque de macro (kg ha<sup>-1</sup>) e micro (g ha<sup>-1</sup>) nos compartimentos da serapilheira de eucalipto cultivado nos sistemas de integração lavoura-floresta (ILF) e pecuária-floresta (IPF) em Sinop, MT.

## DISCUSSION

As for the present study, the lower deposition of litter produced in ICF and ILF systems in comparison to eucalyptus monoculture (F) was also lower than the other crop-forestry systems with the same tree species (CORRÊA *et al.*, 2013; FREITAS *et al.*, 2016; FREITAS *et al.*, 2013). However, the quantified deposition was similar to, or even higher than, the input shown in the literature (SALVADOR *et al.*, 2016; VIERA *et al.*, 2014; LEITE *et al.*, 2011; BELLOTE *et al.*, 2008). Differences in litter amount in comparison to references in the literature can be associated with the composition of species in the consortium, with individuals' diversity and density, with cultivation age, as well as with variations in sites' features (NETO *et al.*, 2015; CALDEIRA *et al.*, 2008). According to Souza *et al.* (2016), secondary forests present higher deposition (7.47 t.ha<sup>-1</sup>.year<sup>-1</sup>) in multi-stratified crop-forestry systems (2.69 t.ha<sup>-1</sup>.year<sup>-1</sup>). However, the lowest litter deposition in integrated systems was also observed in the coffee consortium with *Musa paradisiaca*, *Anacardium occidentale*, *Leucaena leucocephala* and *Mimosa tenuifl* in comparison to the accumulated deposition in native forests and in homogeneous coffee cultures (NOTARO *et al.*, 2014). On the other hand, Freitas *et al.* (2016) stated that litter and nutrient stock in crop-forestry systems correspond to that recorded for native sites.

Differences in litter deposition in ICF and ILF systems in comparison to monoculture are associated with the area covered by trees, given the spacing and width of the rows that, consequently, reflect on plant density, as well as, physiologically, on the interaction degree. Moreover, the intraspecific competition level is higher in the monoculture than in the integration systems, i.e., integration systems have higher interspecific interaction. Therefore, the higher the density of the individuals, the greater the contribution to deposition, since there is less influence from other factors. Similar to the literature, litter deposition has positive correlation to biomass (BELLOTE *et al.*, 2008); thus, the larger the number of trees, the greater the biomass production and, consequently, the greater the export of nutrients (LEITE *et al.*, 2011) due to the greater overlap of canopies, and, consequently, to the greater litter deposition (PINTO *et al.*, 2008). Shorter, closer and denser spacing leads to natural pruning and, consequently, to great litter input (VILLA *et al.*, 2016).

Litter input associated with tree growth and biomass accumulation can be influenced by the extension of the tree-culture interface, due to the magnitude of the edge effect, which is closely related to the type of competition for resources. Thus, the longer the length of the tree-culture interface, the lower the litter input, likely because of lower growth caused by lower intraspecific and greater interspecific competition, mainly when individuals in the consortium present different light demands.

The eucalyptus monoculture (F) may potentiate the intraspecific competition, without edge effect, and it reflects higher biomass accumulation and litter input. The same outcome can be observed for trees in the central rows of the integrated systems, they spend physiological energy for biomass accumulation and litter deposition due to greater intraspecific competition and to the lower interspecific competition shown by the tree-culture interface. However, different from this process, trees located in the rows in the consortium lines – which have longer tree-culture interfaces – reflect greater interspecific competition and, consequently, lower biomass accumulation and litter deposition.

The central lines for tree cultivation in consortium systems show more litter deposition, and such accumulation diminishes on the edges (FREITAS *et al.*, 2013), but other studies have shown no differences in litter input between collector positions and greater deposition trend in tree lines (RADOMSKI; RIBASKI, 2012). Moreover, findings in the literature help justifying the variation coefficient values recorded for integration systems in comparison to monocultures. They presented collectors either in the tree-culture lines or between rows, in other words, they were placed in the tree-culture interface.

However, the amount of eucalyptus litter deposited by different tree compartments between integration systems was not influenced by culture type (agriculture or pasture) at the age of 60 months. By taking into account that litter deposition is associated with biomass accumulation due to tree growth, Azevedo *et al.* (2009) stated the significant effect of pasture type on tree height and volume - Pasture growth compartment influences the degree of aggressiveness and tree competitiveness. This statement is proven by the fact that *Brachiaria brizantha* was less competitive and had better association with the trees than *Panicum maximum* and *B. humidicola* given its straight-upwards position. *B. humidicola* had negative effect on tree growth given its greater nutritional demand in consortium with *Schizolobium amazonicum*, *Eucalyptus tereticornis* and *Bagassa guianensis* in different pastures in Yellow Latosol in Pará State. Therefore, according to Benavides *et al.* (2009), the association between pasture species and tree cultivation can have effect on tree growth, mainly at the initial establishment stage, due to different competition skills.

In terms of litter quality, one can observe that leaves represent the highest amount of litter, which is followed by branches and roots. Neto *et al.* (2015) also found that leaves were the most representative litter fraction, which was followed by branches, miscellany and bark. Variations in percentages between compartments can take place depending on the assessment time.

The proportion of compartments composing the litter is influenced by plant density because of greater canopy interaction between individuals belonging to the same species. Competition in cultures presenting greater coverage density become more expressive between canopies as cultures grow; this process diminishes leaf yield and, consequently, decreases or stabilizes such yield in litter contribution, a fact that leads to relative increase in the deposition of other compartments such as branches (SALVADOR *et al.*, 2016). This process may take place due to physiological displacement caused by photoassimilate translocation in the production of different vegetative fractions throughout the growth cycle, given the function of different plant features and demands.

Regarding the content of nutrients in litter compartments, there were no expressive numeric variations between different consortium types or monocultures; however, the same was stated by Viera *et al.* (2014), according to whom, litter fractions present chemical composition different from each other. The content observed in the present study was similar to that recorded by Vieira *et al.* (2014) in the culture of hybrid clones of *Eucalyptus urophylla* × *E. globulus*, which showed higher Ca content, followed by N, K, Mg, S and P – leaves accounted for the greatest contribution. Moreover, contents recorded for integration systems and for monocultures were lower than that recorded by Villa *et al.* (2016) in forest re-composition culture of native species in Fluvic Cambisol. Leite *et al.* (2011) overall observed that leaves have higher N, P, K and Mg content than other components; bark presented the highest Ca content in *E. grandis* at the age of 4.5 years under different cultivation densities. However, these results point towards a trend different from that recorded by Holanda *et al.* (2017), who assessed litter and nutrient input in *Caatinga*. According to these authors, variations in nutrient content in different litter compartments can be observed in the same species, given site and plants' features, and features of the element itself. Based on Leite *et al.* (2011), variations in the same element can happen within the same forest species, although Guimarães; Calil (2017) stated that nutrient concentration in each compartment is related to its function.

Significant variations in nutrient stocks in monoculture in comparison to ICF and ILF and the non-significant ones in the integration systems are explained by the same reasons, which justify variations in litter input, because content variations in each nutrient in the different compartments were minimal in the assessed systems. However, Villa *et al.* (2016) stated the existence of high stock variability, mainly of litter macronutrients, due to plant species, climate, and soil physical and chemical conditions.

Systems present trend  $N > Ca > K > S > Mg > P$ , which is similar to the trend observed for eucalyptus monoculture (VIERA *et al.*, 2014; CORRÊA *et al.*, 2013). However, Notaro *et al.* (2014) found variations in the accumulated litter nutrient stock depending on coverage type. The coffee consortium with other species presented higher Ca, K and P stocks; native forests showed high N, Ca and Mg stocks. Variation in nutrient stocks depends on the amount of waste input in the system (FREITAS *et al.*, 2016) and on nutrient content. Such content is affected by environmental factors such as soil humidity and temperature, as well as on the plant species; competition also leads to variations in the amount of demanded nutrients (GUIMARÃES; CALIL, 2017).

Nutrient stocks mainly decrease in the leaves compartment, which is followed by branches and bark. According to Viera *et al.* (2014), the greatest amount of nutrients is in the leaves, since they are the most representative fraction of the total litter. As for Salvador *et al.* (2016), nutrient stocks are observed in leaves > bark > branches > wood; however, if contents are taken into consideration, Ca is the most abundant element in the bark.

Leaves are the organs better representing plants' nutritional condition since they have the highest nutrient contents, mainly of N (SALVADOR *et al.*, 2016). Nitrogen is one of the constituents or activators of many compounds such as proteins, amino acids and enzymes, mainly of chlorophyll molecules; consequently, they act in different processes such as respiration and photosynthesis (MALAVOLTA, 2006). Based on Viera *et al.* (2014), Ca is also important, since it is a moving element that stays inside the leaves, in its crystal form, even when leaves fall. Moreover, Ca contributes to biochemical cycling; according to Malavolta (2006), its accumulation mostly happens in the bark and the smallest part of it is observed in the wood, since Ca is essential to keep cell wall structure and function.

Results recorded for P in the compartments, except for the branches, were low in comparison to results in other studies (FREITAS *et al.*, 2013). According to Malavolta (2006), this behavior can be justified due to P, which is considered a moving element that can be easily taken from old organs to newer plant organs. It is essential for Mg assimilation; therefore, Mg presence is related to P. However, Mg results in the present study were lower than those recorded for P.

K is an essential element for photosynthesis; K concentration acts in stomata opening and closing processes (MALAVOLTA, 2006). S, in its turn, is a chlorophyll and immobile constituent, i.e., it has small redistribution and is hard to be taken from an old plant organ to a new one (MALAVOLTA, 2006).

Leaves recorded the largest micronutrient stock in the following decreasing order:  $Fe > Mn > Zn > Cu$ ; it was followed by branches and bark. On the other hand, Viera *et al.* (2014) recorded the highest Mn content and stock values in eucalyptus monoculture; other micronutrients were found in the following decreasing magnitude:  $Mn > Fe > Zn > B > Cu$ .



When it comes to micronutrients, their highest stock was observed in the leaves; litter weight in each system is the main factor regulating such stocks. This aspect was confirmed by Villa *et al.* (2016), who clarified that even if litter input was similar in different publications, nutrient contents are different due to spacing, species, age, seasonality and location, given the higher or lower litter production.

## CONCLUSION

- Leaves are the compartment mostly participating in litter composition, regardless of the system, it is followed by branches and bark. There was difference in the contribution by branches and bark in the monoculture (F).
- The Integrated Crop-Forestry (ICF) and Livestock-Forestry (ILF) systems are less effective in litter nutrient deposition and stock than the eucalyptus monoculture (F) per site unit. With respect to integrated systems (ICF and ILF), there was no influence from consortium type on eucalyptus' litter contribution.
- The nutritional content of compartments composing the litter in integrated systems (ICF and ILF) and in the eucalyptus monoculture (F) did not present specific variation in influence on consortium development.

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