Floresta e Ambiente 2017; 24: e20160028
http://dx.doi.org/10.1590/2179-8087.002816
ISSN 2179-8087 (online)

Original Article

Litterfall and Nutrient Input in a Degraded Area

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ABSTRACT

This study aimed to test the effects of fertilization with organic compost from industrial production of pulp on the litterfall and nutrient input of monospecific plantations in a loan area. The treatments consisted of three doses of the organic compost D_{10}, D_{15} and D_{20} (10, 15 and 20 Mg ha^{-1}, respectively), mineral conventional fertilization (D_{AM}) and no fertilization (D_0) in land plots (N = 4/treatment/species; 15 x 12 m). Litterfall was monthly collected by two traps (0.72 m^2/plot) and sorted out into leaves, twigs, seeds, flowers, fruits and others. We determined the input of nitrogen, phosphorous and potassium. There were no differences among the treatments and between species in terms of total annual litterfall. The higher nutrient input was obtained by $D_{AM,}$ followed by D_{10}, in both plantations. The annual nutrient input was higher for the litterfall on the *E. urograndis* plantation.

Keywords: *Eucalyptus urograndis*, *Mabea fistulifera*, nutrient cycling.

1. INTRODUCTION

Removal of vegetation and topsoil in loan areas inhibits natural regeneration as it eliminates the seed bank, seedlings, seed rain, and thus the possibility of regrowth (Alves & Souza, 2011). In these cases, recovery of the ecosystem can be extremely slow or may not even occur spontaneously. Thus, planting forest species allows for the recovery of the soil's physical, chemical and biological attributes in degraded areas (Valcarcel & Silva, 2000). This is due to the fact that the tree canopy provides mechanical protection against erosive agents and favors soil restructuring, as does deciduous material, which also contributes to nutrient cycling (Heaney & Proctor, 1989; Parrotta, 1995; Li et al., 2014).

The return of mineral elements through litter decomposition and mineralization is particularly relevant where soils are chemically poor, like most tropical forest ecosystems (Vitousek & Sanford, 1986; Martius et al., 2004). As a result, litter influences the plant community structure in these ecosystems (Facelli & Pickett, 1991; Molofsky & Augspurger, 1992). Litter is still considered a bio-indicator of ecosystem functioning, as environmental changes influence litterfall (Martins & Rodrigues, 1999; Klumpp, 2001). This is based on the fact that even within the same type of vegetation, litterfall responds to the degree of environmental degradation, successional stage, latitude, altitude, temperature, rainfall, winds, herbivores, soil water and nutrient availability (Portes et al., 1996; Martins & Rodrigues, 1999; Figueiredo et al., 2003).

Likewise, the litter nutrient content also depends on the edaphic and climatic conditions, as well as on plant species, plant tissue and the mineral element (Ferraz, 2009). Thus, studies focused on litterfall and nutrients input contribute to the knowledge of its potential for the recovery of soil attributes in degraded areas (Souza & Davide, 2001). In these areas, certain types of industrial waste can also improve the chemical attributes of the soil in forest plantations, such as the ones obtained from the production of pulp and paper (Bellote et al., 1998). However, depending on the applied dose, this practice can also produce negative effects, such as higher availability of sodium in the soil (Maciel et al., 2015).

As a result, it is important to investigate the suitability of pulp residue doses in forest plantations for land recovery. This study aimed to test the effect of soil fertilization with organic compost from industrial pulp production on litterfall and nutrient input in monospecific plantations established on degraded soil. We hypothesized that fertilization with this organic compound increases litter production and nutrient input compared to the control and mineral fertilization in monospecific plantations of *Mabea fistulifera* Mart. and *Eucalyptus urograndis* at a loan area in Selvíria, Mato Grosso do Sul, Brazil.

2. MATERIAL AND METHODS

The study area belongs to Universidade Estadual Paulista (UNESP) and it is located at coordinates 20°22'S and 51°22'W, in Selvíria, state of Mato Grosso do Sul, Brazil, at an altitude of 327 m above sea level (Colodro, 2005). The climate type is Aw (tropical humid climate, with rainy season in the summer and dry in winter), according to Köppen (1948). According to the meteorological data obtained for the period between January 2011 and January 2012 from the website of São Paulo State University (UNESP, 2016), the total annual precipitation is 1,695.6 mm, the average monthly temperature is 24.7°C and the relative monthly humidity ranges from 70% to 80%. The rainy season extends from October to April and the wettest months are January, February and March (Figure 1). The dry season extends from May to September, and the driest months are July, August and September. The relief is plain or flat, and the soil is Oxisoil (EMBRAPA, 2006). The original vegetation is Cerrado (savanna).

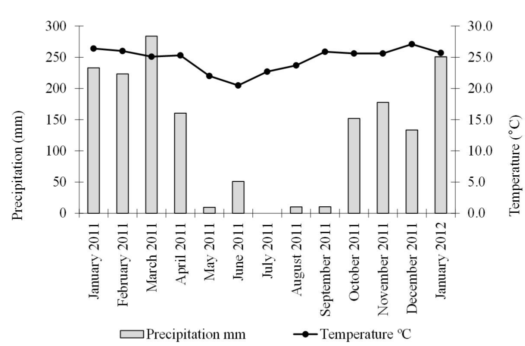

Figure 1. Monthly average precipitation and temperature in Ilha Solteira, approximately 11 Km away from Selvíria, MS. Source: UNESP (2016).

A loan area was selected for the experiment, in which a soil layer with 8.60 m average thickness was removed in 1969 for earthmoving and foundation of the Hydroelectric Plant of Ilha Solteira, in the state of São Paulo (Alves & Souza, 2011). The remaining B horizon is still exposed, and its physical and chemical characteristics were obtained by Giácomo (2013) before the experiment was performed. According to this author, the results were (0-0.40 m): pH ($CaCl_2$) = 5.6; P = 3 mg dm^{-3}; K = 1.2 mg dm^{-3}; Ca^{2+} = 8 $mmol_c$ dm^{-3}; Mg^{2+} = 7 $mmol_c$ dm^{-3}; H^+ + Al^{3+} = 14 $mmol_c$ dm^{-3}; organic matter = 10 g dm^{-3}; sandy clay loam texture; bulk density = 1.63 kg dm^{-3}. Due to the high bulk density of the soil, it was necessary to perform soil unpacking in the whole area, in December 2009 (in the depth of 0.40 m), and in the row, in February 2010 (until 0.50 m).

After soil unpacking, we established monospecific plantations of *Eucalyptus urograndis* and the native Cerrado species *Mabea fistulifera* in four plots of 15 m x 60 m each per forest species, in February 2010. The experimental design was a completely randomized block, in a split-plot arrangement, with four replicates (plots). We planted 200 seedlings of *Eucalyptus urograndis* or *Mabea fistulifera* per plot in rows. Spacing was 3.0 m between rows and 1.5 m between trees in each row. The plots were spaced 2.0 m apart from one another, and the blocks, 3.0 m from one another.

We considered as useful three central rows (18 plants each) in each treatment, avoiding the edges. The plots were divided into subplots (15 m x 12 m), where we considered five treatments: (1) D_0 (control or no fertilization); (2) D_{AM} (mineral fertilization according to the crop's needs); (3) D_{10} (organic fertilization with 10 Mg ha^{-1} of the industrial residue from pulp production, according to the crop's needs); (4) D_{15} (15 Mg ha^{-1} of industrial residue); (5) D_{20} (20 Mg ha^{-1} of industrial residue). These treatments were selected according to the results of the chemical soil analyses performed by Giácomo (2013).

All of the fertilizers were manually distributed in the row, with its subsequent incorporation into the soil by means of light harrowing. The seedlings of *Eucalyptus urograndis* and *Mabea fistulifera* were produced from seeds and donated by the Fibria company and Companhia Energética de São Paulo (CESP), respectively. The industrial residue was obtained by the Kraft method and donated by the Central de Compostagem of Grupo Ambitec. This material consisted of a mixture of dregs (dark-colored sediment), grits (yellowish granules), lime mud, ash and other waste, which underwent a process of composting for 30 days. During this process, the organic compound was exposed in windrows and periodically revolved mechanically. According to Giácomo (2013), the organic compound presented: pH ($CaCl_2$) = 9.5; organic carbon = 186 g kg^{-1}; N = 6.3 g kg^{-1}; C/N = 6.3; P = 2.4 g kg^{-1}; K = 5.9 g kg^{-1}; Ca = 86.9 g kg^{-1}; Mg = 3.8 g kg^{-1}; S = 1.8 g kg^{-1}; Na = 1.35 g kg^{-1}; B = 30.3 mg kg^{-1}; Cu = 14.3 mg kg^{-1}; Fe = 5458 mg kg^{-1}; Mn = 845 mg kg^{-1}; Zn = 27.9 mg kg^{-1}.

The litterfall was evaluated by means of two traps installed in the central row of each treatment. The litter traps were constructed with 1.0 mm nylon mesh measuring 0.80 m x 0.80 m mounted on a frame of four PVC tubes suspended 0.20 m above the soil surface and attached to wooden stakes. Litter samples were collected monthly from February 2011 to January 2012, placed in paper, and transported to the laboratory. The material was manually separated into 1) leaves, 2) branches, 3) flowers, 4) fruits, 5) seeds and 6) unidentified material (others). Each sample was oven-dried at 65 °C for 72 hours and subsequently weighed. Litterfall biomass was estimated according to the equation $AL = \frac{(\Sigma ML\ x10,000)}{TA}$ (Lopes et al., 2002), where: AL = annual average of litterfall (kg ha^{-1} $year^{-1}$); ML = monthly litterfall (kg ha^{-1} $month^{-1}$); TA = trap area (m^2).

The litter samples were ground using a Wiley mill with a 1mm mesh screen and subjected to sulfuric acid digestion in order to determine nutrient concentration (Tedesco et al., 1995). The nitrogen (N) concentration was determined by means of steam distillation; phosphorus (P), by colorimetry; and potassium (K), by flame photometry. Thereafter, the contents of N, P and K were determined by multiplying the biomass by the appropriate nutrient concentration.

The data were subjected to analysis of variance, assuming the existence of homogeneity of variance and normality of residuals. When averages were significant, they were compared by means of the Scott-Knott test with a level of significance of 5%. For these analyses, the original data of litterfall and nutrient content was transformed by $\sqrt{x}$, and we used SISVAR 5.1 software version (Ferreira, 2008). The Pearson correlation analysis was performed with the aim of identifying the influence of meteorological factors (precipitation, temperature) on total annual litterfall. A cluster analysis was also performed in order to identify possible correlations between fertilization treatments and annual litterfall (total and fractions) by using version 2.17c of the PAST software (Hammer et al., 2001). Thus, we obtained a dendrogram of distances by means of the complete linkage method and Euclidean distance. In the case of *Eucalyptus urograndis* planting, we only considered the results obtained from total annual litterfall, leaves, twigs and the fractions "other", since there was no production of reproductive structures (flowers, fruits and seeds) in this area.

3. RESULTS AND DISCUSSION

In the area, total annual litterfall ranged from 1.1 Mg ha^{-1} yr^{-1} (D_{20}) to 2.6 Mg ha^{-1} yr^{-1} (D_{AM}) in the *Mabea fistulifera* plantation, and from 0.9 Mg ha^{-1} yr^{-1} (D_0) to 2.6 Mg ha^{-1} yr^{-1} (D_{AM}) in the *Eucalyptus grandis* plantation (Table 1). The coefficient of variation values for total annual litterfall for comparison among fertilization treatments in the same species were considered medium (between 10% and 20%), and between species in the same fertilization treatment were considered high (between 20% and 30%), according to Pimentel-Gomes (1990). This fact probably contributed to the absence of significant differences in both comparisons. In contrast, fertilization with residue from industrial pulp production in the planting row resulted in higher litterfall for an *Eucalyptus grandis* plantation, compared to the mineral fertilizer in Mogi Guaçu, São Paulo (Ferreira et al., 2001).

Nevertheless, the cluster analysis indicated differences in the effect of the treatments on both forest plantations. In the case of *Mabea fistulifera*, we basically obtained two groups: group 1 (D_0, D_{15} and D_{20}) and group 2 (D_{10} and D_{AM}) (Figure 2). Treatments D_{15} and D_{20} showed high similarity because they correlated to each other at a distance of about 10%. Both of them presented a distance of correlation of about 20% with D_0. The D_{10} and D_{AM} correlated to each other at a distance of more than 36%. The correlation distance between group 1 and group 2 was about 60%, which indicated low similarity between them.

Table 1. Total anual litterfall in *Mabea fistulifera* and *Eucalyptus urograndis* plantations, Selvíria, MS. D_0: control; D_{AM}: mineral fertilizer; D_{10}, D_{15} and D_{20}: 10, 15 and 20 Mg ha^{-1} of industrial residue from pulp production, respectively.

Treatment	*Mabea fistulifera*	*Eucalyptus urograndis*
	Mg ha^{-1} yr^{-1}	
D_0	1.3	0.9
D_{AM}	2.6	2.6
D_{10}	1.5	1.9
D_{15}	1.2	1.2
D_{20}	1.1	1.5
CV[1] (%)	18.3	
CV[2] (%)	27.8	

CV[1]: Coefficient of variation among treatments; CV[2]: Coefficient of variation between species.

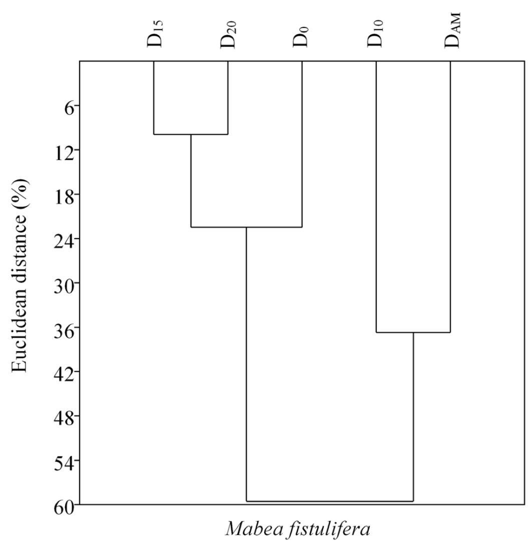

Figure 2. Distance dendrogram obtained by the mean of total annual litterfall and fractions in the *Mabea fistulifera* plantation, Selvíria, MS. D_0: control; D_{AM}: mineral fertilizer; D_{10}, D_{15} and D_{20}: 10, 15 and 20 Mg ha^{-1} of industrial residue from pulp production, respectively.

In the *Eucalyptus urograndis* plantation, we found that group 1 was formed by D_0 and $D_{10,}$ and group 2 formed by D_{15}, D_{20} and D_{AM} (Figure 3). The D_{20} and D_{AM} presented higher similarity (the distance of correlation between them was approximately 20%). These treatments were correlated to D_{15} with a distance higher than 25%. This distance of correlation was the same between D_0 and D_{10}. The low similarity between group 1 and group 2 was indicated by a correlation distance of about 80%.

In the *Mabea fistulifera* plantation, the descending order of the fractions' relative participation in total litterfall was: leaves > flowers > fruits > others > branches > seeds. The relative participation of leaves ranged from 77% (D_{20}) to 82% (D_{AM}) in this plantation, with an average of 79% across all treatments. In the *Eucalyptus grandis* plantation, relative participation of the fractions followed the order: leaves > branches > others, and there was no participation of flowers, fruits and seeds. The relative participation of leaves in this plantation ranged from 81% (D_{20}) to 87% (D_{10}), with an average of 84% considering all the treatments.

The order of relative participation of litter fractions for the forest species were the same in all treatments. The high contribution of leaves, which commonly reaches 60% or more of total litter, was also observed in different tropical forest ecosystems (Cianciaruso et al., 2006; Giácomo et al., 2012; Schumacher et al., 2004, 2013). In the *Mabea fistulifera* plantation, the higher total litterfall occurred in the dry season (mainly between July and September) in all fertilization treatments (Figure 4). This pattern corroborated the results observed in an Amazon-Cerrado Transition Forest in Mato Grosso (Silva et al., 2009) and in different physiognomies of Cerrado (Cianciaruso et al., 2006; Giácomo et al., 2012). Higher litterfall influenced by higher leaf fall during the dry season occurs for many tree species as a strategy to overcome water deficit (Silva et al., 2014).

However, in the *Eucalyptus grandis* plantation, the higher total litterfall was observed during the rainy season until the beginning of the dry season (the period between December and April) (Figure 4). This same pattern occurred in a plantation of *Eucalyptus urophylla* x *Eucalyptus globulus maidenii* in Eldorado do Sul, Rio Grande do Sul (Schumacher et al., 2013). This fact is probably due to the mechanical action of heavy precipitation and winds of higher speed, which usually occur during the rainy season (Scheer et al., 2009). According to Guedes (2005), the production of leaf litter by eucalyptus would not be subject to a mechanism to minimize evapotranspiration during the dry season (winter), but to a higher internal retranslocation of nutrients from older to younger tissue, which influences higher litter production during the rainy season.

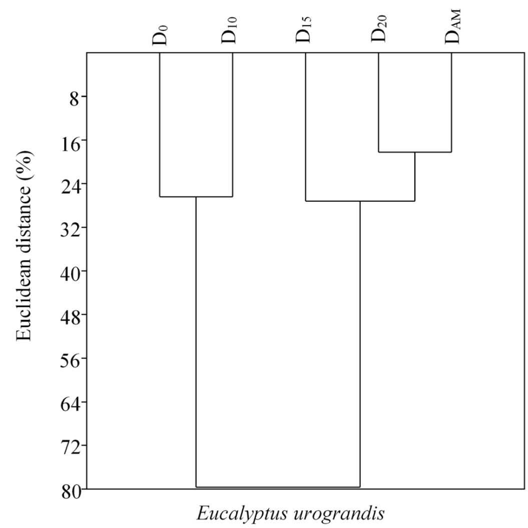

Figure 3. Distance dendrogram obtained by the mean of total annual litterfall and fractions in the *Eucalyptus urograndis* plantation, Selvíria, MS. D_0: control; D_{AM}: mineral fertilizer; D_{10}, D_{15} and D_{20}: 10, 15 and 20 Mg ha^{-1} of industrial residue from pulp production, respectively.

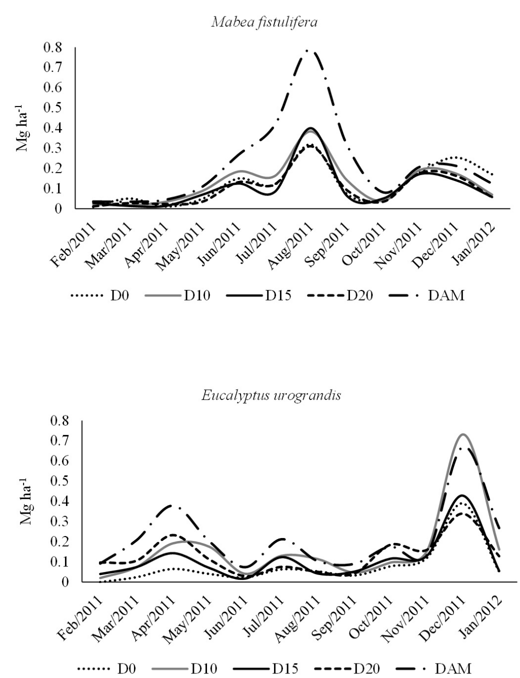

Figure 4. Monthly mean values of total litterfall in *Mabea fistulifera* and *Eucalyptus urograndis* plantations, Selvíria, MS. D_0: control; D_{AM}: mineral fertilizer; D_{10}, D_{15} and D_{20}: 10, 15 and 20 Mg ha^{-1} of industrial residue from pulp production, respectively.

The Pearson correlation did not present significant values between total annual litterfall and precipitation, nor between total annual litterfall and temperature in both of the plantations and in all treatments (Table 2). The absence of significant correlation between litter production and meteorological factors, such as precipitation and temperature, was also observed in mesophytic forest and savanna (Cianciaruso et al., 2006; Giácomo et al., 2012). According to Scoriza & Piña-Rodrigues (2014), the correlation between litterfall (total and its fractions) in tropical forest ecosystems and meteorological factors (precipitation and temperature) may not be significant in considering evaluation of litterfall during the same month.

Thus, a significant correlation is observed when the meteorological factors from the previous months are considered, and the influence of precipitation and temperature on litterfall may not be immediate (Scoriza & Piña-Rodrigues, 2014). Besides meteorological factors, the phenological aspect of the tree species also influences litterfall seasonality (Souza & Davide, 2001), which may account for the different patterns observed in relation to the forest species studied under the same climatic conditions.

In both plantations, the annual return of nutrients from total litterfall to the soil followed the order N > K > P (Table 3). This pattern corroborated the results obtained in monospecific plantations of *Eucalyptus grandis* Hill ex Maiden, *Eucalyptus camaldulensis* Dehn., and *Eucalyptus pellita* F. Muell in Campos dos Goytacazes, Rio de Janeiro (Zaia & Gama-Rodrigues, 2004), mesophytic forest and savanna in the Ecological Station of Pirapitinga, Minas Gerais (Giácomo et al., 2012).

The input of N, P and K ranged from 9.25 (D_{20}) to 20.30 (D_{AM}), from 0.69 (D_0) to 1.40 (D_{AM}) and from 5.35 (D_{20}) to 14.69 (D_{AM}) kg ha^{-1} yr^{-1}, respectively, in the plantation of *Mabea fistulifera* (Table 3). In the

Table 2. Pearson correlation coefficients (r) between total annual litterfall and meteorological factors (precipitation and temperature) in *Mabea fistulifera* and *Eucalyptus urograndis* plantations, Selvíria, MS. D_0: control; D_{AM}: mineral fertilizer; D_{10}, D_{15} and D_{20}: 10, 15 and 20 Mg ha^{-1} of industrial residue from pulp production, respectively.

Treatment	*Mabea fistulifera*		*Eucalyptus urograndis*	
	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Temperature (°C)
D_0	r = -0.25^{ns}	r = -0.03^{ns}	r = 0.03^{ns}	r = 0.43^{ns}
D_{AM}	r = -0.66^{ns}	r = -0.30^{ns}	r = 0.19^{ns}	r = 0.43^{ns}
D_{10}	r = -0.60^{ns}	r = -0.29^{ns}	r = 0.03^{ns}	r = 0.38^{ns}
D_{15}	r = -0.43^{ns}	r = -0.18^{ns}	r = 0.08^{ns}	r = 0.47^{ns}
D_{20}	r = -0.46^{ns}	r = -0.15^{ns}	r = 0.36^{ns}	r = 0.59^{ns}

ns = no significant coefficient (p<0.05).

Table 3. Annual input of N, P and K via total litterfall in *Mabea fistulifera* and *Eucalyptus urograndis* plantations, Selvíria, MS. D_0: control; D_{AM}: mineral fertilizer; D_{10}, D_{15} and D_{20}: 10, 15 and 20 Mg ha^{-1} of industrial residue from pulp production, respectively.

Treatment	*Mabea fistulifera*			*Eucalyptus urograndis*		
	N	P	K	N	P	K
	kg ha^{-1} yr^{-1}					
D_{AM}	20.30 Ba	1.40 Aa	14.69 Aa	17.09 Aa	1.40 Aa	16.60 Aa
D_0	10.55 Ac	0.69 Ab	6.80 Ab	10.21 Ab	0.62 Ab	6.01 Ac
D_{10}	12.96 Ab	0.86 Bb	7.08 Bb	15.13 Aa	1.58 Aa	13.50 Aa
D_{15}	9.57 Bc	0.78 Ab	5.57 Bb	12.65 Ab	0.81 Ab	9.06 Ab
D_{20}	9.25 Bc	1.28 Aa	5.35 Bb	14.82 Aa	1.04 Ab	9.95 Ab
CV[1] (%)	5.99	17.43	14.22	5.99	17.43	14.22
CV[2] (%)	7.95	16.36	10.43	7.95	16.36	10.43

Means followed by the same capital letter in the lines and lower-case letter in the columns do not differ by Scott-Knott test (P <0.05). CV[1]: Coefficient of variation among treatments; CV[2]: Coefficient of variation between species.

Eucalyptus urograndis plantation, the input of N, P and K ranged from 10.21 (D_0) to 17.09 (D_{AM}), from 0.62 (D_0) to 1.58 (D_{10}) and from 6.01 (D_0) to 16.60 (D_{AM}) kg ha^{-1} yr^{-1}, respectively. Thus, the average annual input of N, P and K were 12.53, 1.00 and 7.89 kg ha^{-1} yr^{-1}, respectively, in the *Mabea fistulifera* plantation. On the other hand, the average annual input of N, P and K were 13.98, 1.09 and 11.02 ha^{-1} yr^{-1}, respectively, in the plantation of *Eucalyptus urograndis*.

In both plantations, the average annual input of P was relatively higher than that observed in plantations of *Eucalyptus camaldulensis* and *Eucalyptus pellita* (0.89 and 0.86 ha^{-1} yr^{-1}, respectively), but lower than in the *Eucalyptus urograndis* plantation (1.33 ha^{-1} yr^{-1}) in Campos dos Goytacazes, Rio de Janeiro (Zaia & Gama-Rodrigues, 2004). In general, the input of nutrients by the total litterfall in *Eucalyptus urograndis* was higher compared to the litterfall of *Mabea fistulifera*, considering the average values in the fertilization treatments (Table 3).

In general, D_{AM} provided higher annual input of N, P and K via total litterfall in the *Mabea fistulifera* plantation, and there were no significant differences among D_0, D_{10}, D_{15} and D_{20} (Table 3). Although D_{AM} had also influenced higher input of nutrients in the plantation of *Eucalyptus urograndis*, there was no significant difference between this treatment and D_{10}, which were both higher than D_0, D_{15} and D_{20}.

The present study indicated that there was no difference among all of the fertilization treatments with respect to the influence on total annual litterfall. On the other hand, the D_{AM} treatment resulted in significant increases in the annual input of nutrients via total litterfall in the case of both tree species, when compared to D_0 and the three different doses of industrial residue (D_{10}, D_{15} and D_{20}). In addition, comparing the different doses of the industrial residue to each other (D_{10}, D_{15} and D_{20}), the D_{10} influenced higher input of N via total litterfall in the *Mabea fistulifera* plantation, as it did in terms of the input of N, P and K in the *Eucalyptus urograndis* plantation.

Therefore, the application of 10 Mg ha^{-1} of industrial residue from pulp production in the row of both *Mabea fistulifera* and *Eucalyptus urograndis* plantations was the most promising dose for recovery of the degraded areas studied. This result is consistent with a previous work that indicated that the application of this dose in the row of *Eucalyptus urograndis* plantation presented a total cost of R$ 4,267.86 ha^{-1} (Arruda et al., 2011). According to these authors, this cost included the purchase of residue, manual and mechanized operations, which was lower when compared to the doses of 15 and 20 Mg ha^{-1}, whose costs were R$ 4,879.90 ha^{-1} and R$ 5,472.33 ha^{-1}, respectively.

In addition, the forest species showed different patterns of annual input of nutrients, which was higher in the *Eucalyptus urograndis* plantation. In terms of total litterfall seasonality, *Mabea fistulifera* (higher litter production in the dry season) and *Eucalyptus urograndis* (higher in the rainy season) can be considered complementary. Thus, the plantation of the two forest species in consortium could provide well distributed litterfall throughout the year.

4. CONCLUSIONS

There was no difference among the fertilization treatments and between forest species with respect to the total annual litterfall.

The mineral fertilizer provided higher litter input of nutrients, followed by the dose of 10 Mg ha^{-1} of industrial residue from pulp production for both *Mabea fistulifera* and *Eucalyptus urograndis*.

The annual input of nutrients via total litterfall of *Eucalyptus urograndis* was higher in comparison to the litter of *Mabea fistulifera*.

SUBMISSION STATUS

Received: 23 aug., 2016
Accepted: 28 aug., 2016

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